# A MIXED METHOD STUDY EXPLORING THE EFFICACY OF PERSONALISED DIGITAL PREHABILITATION PROGRAMME, FIT4SURGERY (F4S), FOR PATIENTS UNDERGOING MAJOR SURGERY IN DECREASING THE ANAESTHESIA AND SURGICAL COMPLICATIONS

By

**MATAR SAEED M. ALZAHRANI**




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School of Infection, Inflammation & Immunology
College of Medicine and Health
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# Abstract

**Background:** Patients undergoing major thoracic surgeries such as lung cancer resection and lung volume reduction surgery are at high risk of postoperative complications, reduced functional capacity, and prolonged recovery. Prehabilitation has emerged as a promising strategy to enhance patients' physical and psychological readiness for surgery. However, traditional prehabilitation services face limitations in accessibility and scalability. This thesis aimed to evaluate the feasibility, acceptability, and clinical impact of a novel digital prehabilitation intervention, the Fit4Surgery (F4S) app.

**Methods:** A mixed-methods design was adopted across five integrated studies. A matched case-control analysis using propensity score matching compared patients who underwent pulmonary rehabilitation (PR) to those who did not, assessing outcomes including postoperative pulmonary complications (PPC), hospital length of stay (LOS), and quality of life (QoL). Concurrently, the F4S app was developed using the Double Diamond design framework, underpinned by Self-Determination Theory. Its feasibility, usability, and impact were evaluated through physical performance measures, validated QoL instruments, and patient engagement metrics. Qualitative interviews explored patient experiences and barriers to engagement.

**Results:** Participation in PR was associated with a 60% reduction in PPC and a LOS reduction of up to 1.8 days. The F4S app demonstrated high levels of feasibility and acceptability, with strong patient satisfaction and engagement. Statistically and clinically significant improvements were observed in exercise capacity and QoL domains, with sustained gains up to 6 months post-surgery. Positive correlations were found between app engagement and functional outcomes. Qualitative findings highlighted the app's usability, its role in enhancing patient autonomy, and its psychological benefits.

**Conclusion:** This thesis provides robust evidence supporting the role of digital prehabilitation in optimising surgical outcomes. The F4S app, developed through a user-centred, theory-driven process, represents a scalable and accessible solution to conventional rehabilitation barriers. Its implementation could enhance perioperative care, improve clinical outcomes, and support patient-centred recovery. Future research should focus on large-scale randomised controlled trials and explore long-term cost-effectiveness, digital equity, and broader applicability across surgical populations.

# LIST OF PUBLICATIONS

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# List of Abbreviations

| Abbreviation | Meaning |
|---|---|
| PR | Pulmonary Rehabilitation |
| NG | Non-intervention or Control Group |
| LOS | Length of Stay |
| PPC | Postoperative Pulmonary Complications |
| QoL | Quality of Life |
| PSA | Propensity Score Analysis |
| COPD | Chronic Obstructive Pulmonary Disease |
| MRC | Medical Research Council |
| FEV1 | Forced Expiratory Volume in 1 second |
| DLCO | Diffusing Capacity for Carbon Monoxide |
| PpoFEV1 | Predicted Postoperative Forced Expiratory Volume in 1 second |
| PpoDLCO | Predicted Postoperative Diffusing Capacity for Carbon Monoxide |
| VATS | Video-Assisted Thoracic Surgery |
| MGS | Melbourne Group Scale |
| EORTC QLQ-C30 | European Organisation for Research and Treatment of Cancer Quality of Life Questionnaire (version C30) |
| EE | Effect Estimate |
| SE | Standard Error |
| CI | Confidence Interval |
| BMI | Body Mass Index |
| VATS | Video-Assisted Thoracic Surgery |
| MCID | Minimal Clinically Important Difference |
| FC | Functional Capacity |
| HADS | Hospital Anxiety Depression Syndrome |
| EQ5D5L | EuroQol 5-Dimension 5-Level questionnaire |
| EORTC | European Organisation for the Research and Treatment of Cancer |
| SVS | Subjective Vitality Scale |
| PA | Physical Activity |
| POC | Postoperative Complication |
| SDT | Self-Determination Theory |
| 6MWT | Six Minute Walk Test |
| ISWT | Incremental Shuttle Walk Test |
| STS | Sit To Stand |
| RCT | Randomised Clinical Trial |
| CR | Cardiac Rehabilitation |
| F4S | Fit4Surgery |
| PPI | Public and Patients Involvement |
| HCPs | Healthcare Professionals |
| UHB | University Hospitals Birmingham NHS Foundation Trust |
| UoB | University of Birmingham |

| | |
|---|---|
| EE | Effect Estimate |
| MDT | MultiDisciplinary Team |
| CNS | Clinical Nurse Specialist |
| LC | Lung Cancer |
| LVRS | Lung Volume Reduction Surgery |
| UGI | Upper Gastrointestinal |
| PROMs | Patient-Reported Outcome Measures |
| TAM | Technology Acceptance Model |
| RPE | Rate of Perceived Exertion |
| CROMs | Clinician-Reported Outcome Measures |
| FYI | For Your Information |
| SIM | Subscriber Identity Module |
| QE | Queen Elizabeth Hospital |
| PIC | Participant Identification Centre |
| HRA | Health Research Authority |
| AAC | Assess, Arrange, & Confirm |
| REC | Research Ethics Committee |
| PIS | Participant Information Sheet |
| PG-SGA | Patient-Generated Subjective Global Assessment |
| SD | Standard Deviation |

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# Chapter 1

# Introduction

## 1. 1 BACKGROUND

### 1.1.1 Problem

Over 50,000 patients annually in the UK undergo major chest and abdominal operations. However, it is common for major complications to follow on from these operations giving rise to a higher risk of admission into an intensive care unit, a longer stay in hospital, or even death [1,2,3]. These complications pose a dual challenge: first, they have a negative impact on patient recovery, and second, they place additional strain on healthcare resources. Either mitigating these complications or preventing them entirely could result in significant benefits not only for patients but also for healthcare providers and the NHS.

There is a growing body of evidence that emphasises the importance of physical fitness in successful surgical outcomes. A systematic review and a meta-analysis of preoperative exercise training/rehabilitation programmes indicate that those who have undertaken some form of exercise training for between 2 to 6 weeks prior to chest or abdominal surgery have a better chance of surgery being successful [4,5]. Nonetheless, for these interventions to have any benefit, patients need immediate access to face-to-face rehabilitation programmes, but such programmes are expensive and over-stretched, with the result that, currently, the NHS is hampered in its adoption of such strategies. This issue is further exacerbated by restrictions imposed by pre- and post-surgery self-isolation in order to prevent COVID infection.

### 1.1.2 Importance

Recently, the James Lind Alliance Priority Sharing Partnership identified the following as a major research priority for perioperative care and anaesthesia (2015) [6]: “Does pre-operative exercise or fitness training improve outcomes after surgery?” Up to 20% of patients who are undergoing all types of major chest or abdominal surgery suffer from major complications. For example, with regard to lung complications and cancer surgery, 7,000 patients annually in the

UK have surgery for curative lung cancer resection or removal. Of these, 13% go on to develop post-operative pulmonary or lung complications (PPC), resulting in a 1% to 12% increase in mortality, a 1.9 to 28% increase in the ITU admission rate, an increase in hospital length of stay (LOS) from 6 to 13 days, and a 12 to 21% increase in 30-day hospital readmission with complications. PPC also occurs frequently after major abdominal, cardiac, and vascular surgery; therefore, the benefits can be extrapolated [2,3,4]. Even slight improvements in the rate of PPC due to conventional rehabilitation following lung surgery are estimated to result in huge cost savings through the lower incidence of ITU and a reduction in the number of ward hospital bed days [7].

Given that, increasingly, surgery is offered to patients who are older and less fit, there could be a significant cost saving to the NHS should rehabilitation result in preventing a significant proportion of all major complications following major surgery [8]. One potential solution to this problem could be offered by a digital-based programme of prehabilitation and rehabilitation involving, for example, exercise training, which could be adopted across the NHS. In addition, such a programme could be beneficial in reaching the targets established in the NHS outcomes framework; these include rapid recovery from episodes of ill health, and making sure that patients have an excellent experience of care and long-term quality of life (QoL) [9]. Furthermore, such a programme would allow patients to have control over their own rehabilitation/exercise programme, and this aspect of their care could be conducted at a time and in a manner convenient to them, rather than being obliged to schedule time in the run-up to surgery to visit the local hospital for the exercise programme.

Prehabilitation refers to the process of enhancing a patient's functional capacity before surgery in order to improve postoperative outcomes, particularly in reducing postoperative pulmonary complications (PPCs), which are known to significantly impact recovery and long-term outcomes following major surgery such as lung resection [1]. While traditionally associated with cardiothoracic and major abdominal procedures, prehabilitation has evolved into a multidisciplinary, multimodal approach that typically includes physical exercise training, respiratory muscle conditioning, nutritional optimisation, and psychological support. Evidence from cardiac and abdominal surgery demonstrates that targeted interventions, such as preoperative inspiratory muscle training, can reduce the incidence of PPCs and support improved postoperative recovery [4]. In thoracic surgery, structured pulmonary rehabilitation and exercise-based programmes have been shown to improve baseline function and support

patients preparing for curative lung cancer surgery [5,7] More broadly, perioperative exercise interventions have been explored across diverse surgical pathways—including gastrointestinal, vascular, colorectal, and transplant surgery—although considerable variation exists in implementation, referral pathways, timing, and programme components [2,3] Some programmes are centre-based and supervised, while others incorporate home-based or remote support models, leading to significant heterogeneity in delivery. International and national research priorities, including the James Lind Alliance top 10 for perioperative care, emphasise the growing need for evidence-based, standardised prehabilitation pathways to optimise surgical outcomes across specialties [6]. Additionally, with increasing surgical demand, such as high rates of bowel cancer requiring major resection procedures, prehabilitation is increasingly recognised as a key component of improving population-level postoperative outcomes as reflected within broader NHS performance frameworks [8,9]. Collectively, the literature highlights that while prehabilitation consistently aims to enhance functional reserve, its structure and application vary widely across surgical specialties, healthcare settings, and patient populations, including those undergoing complex surgeries such as vascular reconstruction and organ transplantation.

Prehabilitation has emerged as an important component of modern perioperative care, driven by convincing evidence that improving patients' physical and respiratory reserve before surgery can reduce postoperative complications, enhance functional recovery, and improve longer-term outcomes, particularly following major procedures such as thoracic, abdominal, and vascular surgery [1,4,5,7]. Given the well-established association between postoperative pulmonary complications and increased morbidity, prolonged hospital stay, and long-term adverse outcomes, the case for prehabilitation is clinically compelling rather than optional [1]. However, despite its demonstrated benefits, conventional face-to-face prehabilitation programmes are limited by poor attendance, restricted access, geographical and transport barriers, and variability in patient engagement and service provision [5,7]. These challenges constrain scalability and equity of delivery, particularly within resource-pressured healthcare systems. Consequently, digital prehabilitation platforms offer a pragmatic solution by enabling wider access, flexible participation, and more efficient use of healthcare resources, while preserving the core evidence-based components of prehabilitation that underpin improved surgical outcomes [6,9].

The use of a digital-based programme of exercise to improve recovery post-surgery could lead to a reduction in health and social resource usage for the NHS. Evidence from perioperative and rehabilitation literature indicates that structured exercise-based interventions, whether delivered face-to-face or remotely, are clinically effective in improving functional capacity and reducing postoperative pulmonary complications, while digital delivery offers additional advantages in accessibility, scalability, and reduced dependence on hospital-based resources [1,4,5,7]. Consequently, digital programmes may enhance acceptability and usability for patients who face barriers to attending in-person sessions, with potential downstream benefits including improved patient experience and QoL and a more efficient recovery pathway; this may also reduce disruption to the wider family unit, through decreased travel requirements, fewer hospital visits, and an earlier return to work.

### 1.1.3 Study aim and research question

The main goal of this research is to test whether the Fit 4 Surgery app (F4S), tailored for a specific type of surgery, can be used before and after surgery to improve the recovery of physical function after major elective surgery. The research will also examine whether the F4S app is acceptable to patients and if a larger trial to assess the app's effectiveness in improving individual outcomes would be feasible.

The primary research question for this study is: Is it feasible to use a personalised digital prehabilitation programme, Fit4Surgery (F4S), before and after surgery to improve the recovery of physical function following major elective surgery?

## 1.2 LITERATURE REVIEW

### 1.2.1 Search strategy:

Using Google Scholar, a preliminary scoping exercise was conducted to assess the extent and range of the literature supporting the goal of the study and to identify any gaps in the literature [10]. Additionally, to facilitate a comprehensive search strategy, a grey literature database was examined [11]. The term "grey literature" is used to refer to any information created at various levels that is not controlled by commercial publishers; this includes government and academic studies [11]. Paez (2017) states that grey literature can help provide a more balanced view of the evidence by reducing publication bias, as it is characterised by offering neutral and negative

studies as well as positive commercially published papers [11]. Backward chaining was also used to ensure that all relevant articles were identified [12]. Backward chaining is a search strategy that involves identifying relevant literature by tracking references cited in key articles to uncover earlier foundational works on a topic [12]. Hence, seminal texts were found that were used to refine the search terms in-depth; this helped facilitate systematic searches using the following suggested databases: EMBASE and MEDLINE via Ovid and Scopus, CINAHL and ERIC via EBSCO. Bramer et al. (2018) stated that using these electronic databases to carry out a systematic search helps in formulating a large number of high-quality studies that are relevant to the research query and the study aim [13]. Initially, the selection process was informed by the titles and the abstracts of the related papers [14]. Next, the Critical Appraisal Skills Programme (CASP) was applied to the relevant studies to facilitate a critical appraisal of the literature [15]. According to Williamson (2017), it is essential to use a critical evaluation approach like CASP in order to analyse the strengths and weaknesses of studies and to assess both the reliability and the quality of their findings [16].

Following the analysis of the literature and the identification of the most relevant studies, certain conclusions could be drawn from the research findings. Cronin et al. (2008) commented that to develop a conceptual framework, it is important to first organise the literature review into themes [14]. This framework is crucial for this project as it assists in incorporating varied types of literature linked to the trial. As a result, the author was able to identify four themes to explore further in the literature review: prehabilitation compared to postoperative rehabilitation, remote rehabilitation compared to outpatients' rehabilitation, app/website rehabilitation compared to conventional rehabilitation, and the feasibility and acceptability of digital prehabilitation programmes.

### 1.2.2 Existing evidence:

#### 1.2.2.1 Prehabilitation compared to postoperative rehabilitation:

Patients who are recovering from major surgery are often given a structured physical activity (PA) programme and are offered guidance on how they can make adjustments to their lifestyle, such as advice on nutrition, and psychological health interventions that focus on their mood and their well-being [17]. Research has shown that when this package of care is delivered following major surgery, it serves to help minimise mortality, enhance QoL, and avoid

hospitalisation [17,18]. The evidence regarding the success of these programmes has led to an increasing interest in whether it is viable to offer prehabilitation as both a preventive and a corrective approach to rehabilitation therapies [17,18]. Prehabilitation programmes are also of benefit when patients are placed on the waiting list for elective major surgery, with an average wait of at least 1 month [18]. While this waiting system is moderately safe, previous research has demonstrated that patients on surgical waitlists tend to participate in only limited PA out of fear [18]. However, for patients who are already deconditioned, weak, and elderly, such inactivity is prejudicial to their health [17,18]. Given this increasing need to enhance outcomes, prehabilitation may be particularly important for frail and elderly adults who are on the waiting list for an elective major operation [18]. Nonetheless, currently, there is no established pathway that can encourage these patients to improve their health as they wait for their major surgical interventions. [18]. Therefore, there is a need for research to evaluate the need for and efficacy of prehabilitation before major surgery; this comprises giving a range of prevention strategies to patients who are on the wait list for major surgery with the aim of reducing the incidence or the severity of postoperative complications [17,18]. This theme will include three recent studies that explored the effectiveness of prehabilitation in comparison with postoperative rehabilitation [19,20,21].

A systemic review by Drudi et al. (2019) assessed how preoperative exercise training (prehabilitation) affected perioperative clinical outcomes in individuals who had undergone vascular and cardiac procedures [19]. Nine studies that met the final inclusion criteria were analysed in the systemic review as follows: vascular ($n$ = 2) and cardiac ($n$ = 7) [19]. Drudi et al. (2019) demonstrated that there was a link between prehabilitation, decreased LOS and postoperative complications (POC), and improved QoL and PA in patients undergoing vascular and cardiac procedures [19]. One of the strengths of Drudi et al.'s (2019) study is that their systematic review drew on the highest-quality available evidence, as defined by the inclusion of methodologically rigorous primary studies identified through a transparent, reproducible search strategy, explicit eligibility criteria, and critical appraisal of study quality in line with established systematic review principles [22]. Moreover, because systemic interviews provide a complete, unbiased summarisation of several relevant studies in a single document, this approach gives Drudi et al.'s (2019) findings increased validity [19,21]. However, one of the limitations that might undermine the strength of their findings is that the included studies demonstrated heterogeneity in many aspects such as the study design and patient populations, and this could limit the generalisation of the findings to other populations [19,10]. Nonetheless,

Drudi et al.'s (2019) findings emphasise the need to carry out robust experimental studies exploring the impacts of prehabilitation on perioperative clinical outcomes.

Another systemic review with meta-anaysis was conducted by Gravier et al. (2021); they compared prehabilitation to postoperative rehabilitation in non-small lung cancer before lung resection [20]. Their final analysis involved 14 studies with a total of 791 participants [20]. Like Drudi et al. (2019), Gravier et al. (2021) showed that compared with normal care, the exercise training in prehabilitation led to a reduction in the total POC (10 studies, 617 participants, RR 0.58, 95% CI 0.45 to 0.75) [19,20]. This study also demonstrated a reduction in clinically relevant POC compared to postoperative rehabilitation (4 studies, 302 participants, Clavien-Dindo score ≥2 RR 0.42, 95% CI 0.25 to 0.69) [20]. According to Gravier et al. (2021), prehabilitation improved exercise capacity, functional capacity (FC), QoL, and depression compared with usual care [20]. Gravier et al. (2021) conducted a systematic review with meta-analysis, quantitatively pooling results across eligible studies, which strengthens the level of evidence by increasing statistical power, improving precision of effect estimates, and reducing random error. In contrast, Drudi et al. (2019) undertook a systematic review without meta-analysis, synthesising evidence narratively due to heterogeneity in interventions, outcomes, and study designs; therefore, while methodologically rigorous, it does not provide pooled effect estimates [19,20,22]. Nonetheless, the heterogeneity of the included studies is a limitation that might undermine the strength of their findings; the training programmes explored in the included studies were varied with regard to frequency, duration, and composition, and this may restrict the generalisation of the findings to other populations [20,10].

Ferreira et al. (2021) compared the prehabilitation programme with a postoperative rehabilitation programme in patients who were scheduled for non-small cell lung cancer resection [21]. The patients were randomised into two groups; patients in the PREHAB (n=52) group were told to begin the programme 4 weeks before surgery and continue with it for 8 weeks post-surgery, while patients in the REHAB (n=43) group were told to begin the programme immediately after surgery and continue with it for the next 8 weeks [21]. In contrast to Gravier et al.'s (2021) study, Ferreira et al. (2021) concluded that there were no significant differences in functional capacity (FC) between the two groups during the perioperative period [20,21]. In addition, there was no significant difference between groups in the mean change in the 6-minute walk test (6MWT) at any point in time or with regard to the proportion of patients who returned to or even exceeded their baseline FC [21]. Both groups returned to baseline FC

by 8 weeks following surgery, and a similar percentage of patients (>75%) in both groups had recovered to their baseline [21]. However, like the studies by Drudi et al. (2019) and Gravier et al. (2021), Ferreira et al. (2021) demonstrated that 4 weeks post-surgery, patients in the PREHAB group had significantly better scores in mental health (P = 0.044) and general health (P = 0.007), and had better scores in PA but did not reach statistical significance (P = 0.065), and in social function (P = 0.091) than the REHAB group, although this was not the case regarding the change in FC [19, 20, 21]. Interestingly, no significant difference was found between the two groups in mean postoperative complication rates and hospital LOS; however, more than 40% of individuals in the PREHAB group were released home by postoperative day 2 [21]. In the previous study, the patients were randomised into two groups; this had the benefit of reducing the chance of the Hawthorne effect from occurring. The Hawthorne effect is also commonly known as the observer effect, as the patients' behaviour changes because they are aware that they are being examined or watched [21,23]. The Hawthorne effect could eventually lead to queries being raised regarding the validity of the findings in any study and may limit the generalisability of the findings. In the study by Ferreira et al. (2021), the reduction in the Hawthorne effect could increase the strength and validity of their findings [23]. However, the difficulty in identifying a statistically significant difference in such a small and imbalanced sample size could explain why no statistically significant difference was found between the two groups regarding the FC and 6MWT [24]. Furthermore, in contrast to the previous two reviews, Ferreira et al.'s (2021) study uniquely used a randomised controlled trial (RCT) design to compare multimodal prehabilitation to rehabilitation in lung cancer surgery within an enhanced recovery pathway [21]. While the previous systematic review by Gravier et al. (2021) evaluated the benefits of prehabilitation in lung cancer patients, there was no direct comparison with post-operative rehabilitation, and the greater width of Drudi et al.'s (2019) study, which covers prehabilitation in cardiac and vascular surgeries, makes it less directly comparable [19, 20]. Moreover, in contrast to Ferreira et al.'s (2021) study, which evaluates functional recovery over multiple time points, the reviews by Drudi et al. (2019) and Gravier et al. (2021) focused mainly on postoperative complications and LOS [19, 20, 21]. Hence, the divergence in findings can be explained by these methodological differences and distinct outcome priorities [19, 20, 21].

The limitations and heterogeneity in study design and patient populations mean no conclusions can be drawn regarding whether the prehabilitation programme had an impact on perioperative care compared to the usual postoperative rehabilitation programme. Hence, further rigorous

methodological clinical trials need to be conducted to explore the impact of prehabilitation on perioperative clinical outcomes compared to postoperative rehabilitation in major surgeries.

#### 1.2.2.2 Remote rehabilitation compared to outpatients' rehabilitation:

There has been increasing interest in remote rehabilitation since the beginning of the Covid-19 pandemic due to the lifestyle changes enforced by the pandemic, such as practising social distancing and self-isolation [25, 26]. The lack of PA is linked to prolonged home isolation in the general population, and the drawbacks of physical inactivity are greater in vulnerable individuals, such as those with cardiac illness [25]. Furthermore, to mitigate the threat of Covid-19 infection, many hospitals might not offer outpatient rehabilitation pathways; this leads to rehabilitation services to vulnerable patients being interrupted [25]. In these circumstances, remote rehabilitation could provide a solution to overcome this interruption of rehabilitation services since patients would be able to continue with rehabilitation exercises in their own homes [25,26].

Two studies conducted by Nakayama et al. (2020) and Vernon-Platt et al. (2021) explored the effectiveness of remote rehabilitation in comparison to outpatient rehabilitation [25,26]. Both studies were conducted on patients with cardiac diseases, and the aim was to assess the effectiveness of home-based cardiac rehabilitation (CR) with outpatient CR centres. Nakayama et al.'s (2020) study was conducted in Japan; they divided their CR patients into two groups: outpatient CR (n=69) and remote CR (n=30). Vernon-Platt et al.'s (2021) study was conducted in the United States and included 42 patients who undertook CR in their homes. Nakayama et al. (2020) found that remote CR is as effective as outpatient CR. Interestingly, the QoL score in Nakayama et al.'s (2020) study is significantly higher in the remote CR group than in the outpatient CR group ($P = 0.03$). Similarly, Vernon-Platt et al. (2021) concluded that remote CR is as safe as outpatient CR. However, unfortunately, both investigations had major flaws that could jeopardise the validity of their conclusions, such as the use of a single-site design and the probability of gender bias, which could limit the applicability of the study findings in other settings [27].

The findings of both studies are similar with regard to the effectiveness of remote CR compared to outpatient CR. However, since both studies have many limitations that could indicate non-

conclusive outcomes, no conclusions can be drawn about the effectiveness of remote CR compared to outpatient CR, and therefore, there is a need for more rigorous research.

#### 1.2.2.3 App/website rehabilitation compared to usual care rehabilitation:

Medical interventions offered via smartphone apps represent an opportunity to manage or overcome such healthcare challenges. Evidence shows that apps are successful in disease self-management, in monitoring patients remotely, and in patient education [28,29]. Systemic reviews and meta-analyses provide evidence on how apps have been used successfully as behaviour change tools to promote PA [29,30]. A review of smartphone apps for promoting PA highlighted their efficacy, and in particular, their ability to monitor PA/exercise behaviour, track progress toward PA goals, and include options to undertake different types of PA [30,31]. This theme will include three recent studies that explored rehabilitation using an app/website and compared it to conventional forms of rehabilitation [32,34,36].

Houchen-Wolloff et al. (2018) conducted an RCT from two centres in the UK to evaluate the efficacy of web-based CR compared to conventional CR [32]. Houchen-Wolloff et al. (2018) recruited and randomised 60 patients in the study into two groups: the web group (n=37) and the control (n=23). Their results showed that in the web group, QoL improved by a significant clinical amount (0.5±1.1 units vs 0.2±0.7 units: control), while capacity for exercise increased in both groups [32]. However, in both groups, the mood remained the same; this could be due to the participants' low levels of depression and anxiety and their high scores for self-efficacy at the beginning of the programme, meaning there was only a small window for change [32]. The findings of Houchen-Wolloff et al.'s (2018) study were reflected in Patterson et al.'s (2021) recent systematic review; the aim of their review was to examine the effectiveness of app/website rehabilitation in CR, which may support Houchen-Wolloff et al.'s (2018) conclusions [32,33]. Furthermore, because the participants in Houchen-Wolloff et al.'s (2018) study were randomised, the Hawthorne effect could be minimised, and this enhances the validity of their results [23]. However, it is important to note that there was an imbalanced sample size, with participants in the web group (n=37) outnumbering those in the control group (n=23), which could have influenced Houchen-Wolloff et al.'s (2018) findings [32].

Wijnen et al. (2020) conducted a non-randomised observational study in the Netherlands to compare the effectiveness of app rehabilitation with that of usual rehabilitation in total hip arthroplasty [34]. This included 15 patients in the intervention group (app rehabilitation) and 27 patients in the control group (conventional rehabilitation). The results show that the intervention group performed functional tests significantly more rapidly than the control group did at 12 weeks and 6 months postoperatively [34]. In addition, they demonstrated that the intervention group had significantly higher scores on the following sub-scales: PA and recreational activities, QoL, and physical role limitations at 12 weeks and 6 months at the postoperative period [34]. They therefore concluded that more significant effects were observed in the intervention group, indicating that an app rehabilitation programme after total hip arthroplasty can be more beneficial and effective than usual care [33]. Nonetheless, the small sample size of this study could be a major limitation for generalising the results while the single-centre design could result in a limited external validity [27,34,35].

Y. Sui, et al. (2020), using an RCT, compared the effectiveness of app rehabilitation with that of usual care in patients undergoing lung resection surgery [36]. Their study was conducted in China in a single hospital with 200 participants equally divided between the intervention (app) group (n=100), and the control group (n=100); however, 80% of the entire sample size were males [36]. After 12 months from the intervention, Y. Sui, et al. (2020) indicated that the hospital anxiety and depression scale (HADS) score ($P = 0.001$) and the anxiety rate ($P = 0.001$) were all significantly minimised in the intervention group compared to the control group [36]. Furthermore, the QoL score was significantly higher in the intervention group than in the control group ($P = 0.049$) [36]; they therefore concluded that the use of an app in rehabilitation for lung resection surgery patients was an effective way to reduce the loss of follow-up, improve patients' QoL, and decrease the amount of anxiety and depression in the intervention group in comparison to the control group [36]. Nevertheless, Y. Sui, et al.'s (2020) study had various limitations, such as it being a single-centre study and the possibility of gender bias, both of which could limit the generalisability of their findings in other settings. [27,36].

All the studies included in this theme have limitations that could affect both the validity and the reliability of their findings [32,34,36]. Therefore, further exploration using a rigorous research methodology is necessary to assess the effectiveness of app/website rehabilitation in comparison to conventional rehabilitation. In our feasibility study, a prehabilitation programme was delivered via the Fit4Surgery (F4S) app, and the participants were patients awaiting lung

surgery [37]. The benefits of the F4S app include home use, options for higher intensity exercises, patient convenience, and integrated biofeedback for both the patient and the clinician. Feedback from patients and clinicians following the pilot indicated that to encourage participation in exercise and PA, there is a need for F4S to be further refined for individual patients in a way that facilitates their engagement with app. Guided by self-determination theory (SDT), one way that patient engagement with the app can be optimised is by fostering patients' autonomous motivation to adopt and maintain exercise and PA. In version 2 of F4S, a range of behavioural change techniques (e.g., goal setting), underpinned by SDT, have been incorporated to address these issues. It is posited that an individual's sense of autonomy (voice and choice), competence (meets demands placed upon them), and connection (to others in a caring and supportive manner) in their attempts at exercise/PA will promote greater autonomous motivation and not only encourage the uptake of exercise/PA but will help individuals sustain this in the long-term [38,39].

#### 1.2.2.4 Feasibility and Acceptability of Digital Prehabilitation Programmes:

Digital prehabilitation programmes are gaining attention as innovative tools to improve patient readiness for surgery by offering flexible, accessible, and patient-centred support. These programmes leverage digital platforms, including mobile health (mHealth) apps and web-based tools, to deliver interventions such as exercise training, patient education, and psychological support. Evidence suggests that digital approaches address barriers like time, geographical distance, and resource limitations, providing an alternative to traditional rehabilitation methods [40 - 43]. However, understanding their feasibility, usability, and acceptability is crucial for integrating them effectively into clinical practice. This theme will review the findings from recent studies investigating the implementation and outcomes of digital prehabilitation programmes [40 - 43].

Powell et al. (2023) conducted a multi-perspective qualitative study to assess the impact of a prehabilitation and recovery programme, including digital elements, on the emotional well-being of cancer surgery patients. The study highlighted that participants appreciated the structured support, which provided psychological and emotional benefits during the challenging perioperative period. Participants reported feeling more prepared for surgery and better able to manage emotional distress. However, the study also noted challenges such as

varying patient engagement levels and the need for personalised support to maximise the programme's effectiveness. These findings underline the importance of tailoring digital interventions to meet patients' individual needs and preferences [40].

Similarly, Buch et al. (2024) conducted a qualitative process evaluation of the *RehaPro-SERVE* digital rehabilitation care planning platform aimed at improving care access for patients with work disabilities. The study identified significant benefits, such as enhanced accessibility and care coordination. However, implementation challenges emerged, including usability issues and the need for proper integration into healthcare systems. The authors highlighted that for digital platforms to be widely adopted, they must be user-friendly and seamlessly incorporated into existing clinical workflows. Despite these barriers, the platform demonstrated its potential to address care inequities and improve rehabilitation outcomes [41].

Machado et al. (2023) explored the feasibility of a home-based preoperative exercise training programme for lung cancer patients undergoing surgery. The study demonstrated that digital tools could successfully deliver exercise interventions in a home-based setting, improving adherence and patient readiness for surgery. Participants reported positive outcomes, including increased physical activity and better preparation for surgery. However, barriers such as limited technological access, patient motivation, and varying levels of digital literacy were identified as potential limitations to wider implementation. These findings emphasise the need for adequate support to ensure all patients can engage with digital interventions effectively [42].

In a pilot randomised controlled trial, Van der Velde et al. (2021) assessed the usability and preliminary effectiveness of a preoperative mHealth app for patients undergoing major surgery. The study revealed that patients found the app acceptable and easy to use, with promising results for improving patient engagement and surgical readiness. Importantly, the authors highlighted the role of co-design and user feedback in enhancing the app's usability and effectiveness. The involvement of patients in the development process contributed to higher satisfaction and adoption rates. Nonetheless, the study acknowledged its preliminary nature and called for larger trials to validate its findings and further refine the app [43].

In summary, the feasibility and acceptability of digital prehabilitation programmes have been supported across recent studies [40 - 43]. These programmes offer significant advantages, including improved accessibility, flexibility, and patient engagement, while addressing

common barriers in traditional rehabilitation delivery. However, challenges such as usability issues, varying patient motivation, and technological limitations remain. Future research should focus on addressing these barriers through user-centred design, personalised interventions, and robust clinical integration. In our feasibility study, F4S app demonstrated strong patient acceptability and usability, offering home-based prehabilitation with personalised support. Feedback suggested the importance of behavioural change techniques and user autonomy to enhance patient engagement, and these issues have been addressed in the app's second version. By fostering autonomous motivation and addressing individual needs, digital prehabilitation tools like F4S have the potential to improve long-term adoption and pre-surgical outcomes.

### 1.2.5 Summary:

Major surgeries remain a high-priority area due to the significant risks of postoperative complications and the lack of tested digital prehabilitation and rehabilitation programmes in this cohort of patients, as evident in the literature. This chapter so far has reviewed the existing evidence on prehabilitation, structured around four key themes, highlighting its potential to improve patient outcomes, particularly through digital and remote delivery models.

The first theme explored the effectiveness of prehabilitation compared to postoperative rehabilitation, demonstrating that prehabilitation can improve postoperative complications, physical function, and quality of life, especially in frail or high-risk patients awaiting major surgery. The second theme examined remote rehabilitation compared to outpatient rehabilitation, where evidence suggested that remote programmes are as effective and safe as outpatient options, offering practical solutions for maintaining care access during challenging periods such as the COVID-19 pandemic. The third theme focused on app/website rehabilitation compared to usual care rehabilitation, showcasing the role of digital tools in enhancing physical activity, reducing anxiety, and improving quality of life through tracking, biofeedback, and personalised goal-setting features. Finally, the fourth theme addressed the feasibility and acceptability of digital prehabilitation programmes, underlining their potential to deliver accessible, flexible, and patient-centred interventions while highlighting challenges such as usability, patient motivation, and technological access.

Based on these findings, we proposed the development and testing of a bespoke digital rehabilitation programme, the Fit4Surgery (F4S) app, designed specifically to address the limitations of conventional prehabilitation and rehabilitation delivery identified above, including access, attendance, and scalability within routine NHS practice. The F4S app offers unique benefits, including home-use, options for higher intensity exercises, patient convenience, and integrated biofeedback to both patients and clinicians. Patient and clinician feedback following the pilot suggested the need for further refinement of the app to facilitate greater patient engagement with exercise and PA. Guided by SDT, version 2 of the F4S app incorporates behavioural change techniques, such as goal setting, to foster patients' autonomous motivation by supporting their sense of autonomy, competence, and connection. A detailed description of the F4S app is written in section 4.3.9 titled F4S intervention that can be found in page 93. These refinements aim to optimise patient engagement and ensure the adoption and maintenance of exercise and PA, ultimately enhancing recovery and long-term surgical outcomes.

In summary, this chapter highlights the evidence supporting prehabilitation, particularly digital and remote models, while identifying the gaps and challenges that remain. These findings establish the rationale for the current study, which aims to evaluate the feasibility, usability, and clinical impact of the F4S app as a personalised digital prehabilitation solution.

## 1.3 RESEARCH AIMS, OBJECTIVES, AND HYPOTHESIS

### 1.3.1 Study aim

The overarching aim of this research is to investigate whether the F4S, refined for a specific type of surgery, can be used both before and after surgery to enhance physical function recovery after major elective surgery. The research will also examine whether the F4S app is acceptable to patients and if a larger trial to assess the app's effectiveness in improving individual outcomes would be feasible.

Feasibility studies are crucial for assessing the viability of a large and costly full-scale study [44]. Therefore, we designed this multi-centre feasibility study to evaluate the efficacy of a personalised digital prehabilitation programme, F4S, for patients undergoing major surgery.

### 1.3.2 Objectives of the study

The goals of the feasibility study are to evaluate various aspects of the study design and management, and to determine whether a larger trial to assess the app's effectiveness in improving individual outcomes would be feasible.

#### 1.3.2.1 Primary objective

To test whether it is acceptable to patients to deliver a digital prehabilitation programme and if it is feasible to do so before and after major surgery.

#### 1.3.2.2 Secondary objective

1. To investigate whether the 'real world' prehabilitation programme, which is a referral to pulmonary rehabilitation classes, had an impact on perioperative care compared to the usual care, no prehabilitation, on patients who underwent lung cancer surgery
2. To demonstrate the application of the Double Diamond method in developing a digital-based prehabilitation and rehabilitation programme within the pathway of elective major surgery through the examination of several case studies
3. To assess variation in the use of F4S and so adherence/compliance rates
4. To evaluate the variation and delivery of other prehabilitation measures administered as part of usual care
5. To define a set of refinements to the programme based on structured feedback from patients and healthcare professionals

### 1.3.2 Study hypothesis

The F4S digital prehabilitation programme, refined for a specific type of surgery, can be used before and after surgery to enhance the recovery of physical function after major elective surgery.

# Chapter 2

# Effect of Pulmonary Rehabilitation on Lung Cancer Surgery Outcomes: A Matched-Case Analysis

This chapter was published in full in the Journal of Perioperative Medicine under the title "**Effect of pulmonary rehabilitation on lung cancer surgery outcomes: a matched-case analysis**" (see appendix 8.1). The paper is shown in full below, and author contributions, as published, are listed.

Matar Alzahrani, [1,2,3] Rajnikant Mehta,[4] Salma Kadiri,[5] Saffana Algaeed,[6] Aya Osman,[5] Mohammed Alsanad,[1,3,7] Joan Duda,[8] Fang Gao,[2] Babu Naidu[2,5]

**Names of the authors:**
1. College of Applied Medical Sciences, King Saud bin Abdulaziz University for Health Sciences, Jeddah, Saudi Arabia.
2. Institution of Inflammation and Aging, University of Birmingham, Birmingham, UK.
3. King Abdullah International Medical Research Center, Jeddah, Saudi Arabia.
4. Wolfson Institute of Population Health, Queen Mary, University of London
5. Thoracic Surgery, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK.
6. King Saud University, Riyadh, Saudi Arabia
7. Warwick Clinical Trials Unit, University of Warwick, Coventry, UK.
8. School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, Birmingham, UK.

**- Authors' contributions**

Conception: BN, MA, RM

Data extraction & cleaning: MA, SK, SA, HS, AO

Analysis and interpretation of data: MA, RM

Draft the work: MA

Draft revision: BN, FG, JD, HF, RM, MS

Approval of the version: MA, BN, RM, MS, SK, SA, HS, AO, FG, JD, HF

## Abstract

Pulmonary rehabilitation programs for COPD patients are extensively accessible throughout the UK and have demonstrated efficacy in enhancing outcomes, including recovery from exacerbations. Numerous lung cancer surgery patients possess COPD, and the surgery may be regarded as a definitive aggravation of COPD. It is ambiguous in practical application whether referral to pulmonary rehabilitation programs enhances surgical and patient-reported results. We want to address this topic by conducting a propensity-score analysis (PSA) of participants in an enriched cohort trial.

**Methods:** An enriched cohort research was conducted, providing rehabilitation both pre- and post-surgery pragmatically through local pulmonary rehabilitation providers for patients undergoing lung cancer resection, and compared to a contemporaneous control group receiving standard treatment. The study enrolled 873 participants (Pulmonary Rehabilitation (PR) n=135, non-intervention or control (NG) n=738). Regression analyses for exposed and unexposed matching, effect estimation, and standard error estimations were conducted.

**Results:** 114 participants were matched PR (n=57) NG (n=57). The multivariate-linear regression indicated a reduction in length of stay (LOS) of 0.2 days of LOS compared to the usual care group (EE = -0.20), and that reduction could potentially go up to 1.8 days (95% CI = -1.8 – 1.6). The multivariate log-binomial regression revealed that PR had a reduction of 60% postoperative pulmonary complications (PPC) rate (EE = -0.60, 95% CI = -1.8 – 0.5). Lastly, the multivariate-linear regression showed an improvement in quality of life 6 weeks and 6 months after surgery (QoL) in patients in PR, especially in the physical functioning score in which an improvement of 6.6% was noted for the PR group compared to the NG group following surgery (EE = 6.6).

**Conclusion:** Participation in 'real world' pulmonary rehabilitation prior to and following surgery seems to yield improved patient and clinical results post-lung cancer surgery. Nonetheless, prompt access to pulmonary rehabilitation may be a significant challenge following COVID.

## 2.1 Introduction

Major complications occur in up to 20% of patients undergoing chest or abdominal surgery, with up to 13% of patients developing postoperative pulmonary complications (PPC) following curative lung cancer surgery, which is often exacerbated by underlying COPD [45–47]. PPC significantly increases mortality, intensive therapy unit (ITU) admissions, length of hospital stay, and 30-day hospital readmissions, and its occurrence across various surgeries highlights the potential for cost savings through improved rehabilitation [3, 4, 7, 48, 2].

As surgery is increasingly performed on older and less-fit patients, structured post-surgical programmes, including physical activity, nutritional guidance, and psychological interventions, have shown effectiveness in reducing mortality, improving quality of life (QoL), and preventing hospital readmissions [8,17,18]. These successes have sparked interest in prehabilitation as a proactive strategy to enhance surgical outcomes and further reduce complications [17,18].

Prehabilitation before surgery has been recognised as a critical step to improve postoperative outcomes. It enhances an individual's functional capacity to withstand the stress of major surgery [49]. Prehabilitation can lead to significant improvements in patients' physical fitness, mental well-being, and overall readiness for surgery [50]. The American College of Surgeons highlights that prehabilitation helps enhance the functional capacity of patients before surgery, making them more resilient to postoperative inactivity and decline [51]. This multimodal approach includes exercise training, nutritional support, and psychological interventions, which collectively help in reducing perioperative complications and improving recovery times [49].

Access to prehabilitation services in the UK and globally remains limited despite its recognised benefits in improving surgical outcomes. In the UK, a significant proportion of patients are not offered prehabilitation due to inconsistent implementation across health services [52]. For example, a study revealed that while the need for prehabilitation is widely acknowledged, only a small percentage of patients actually receive these services [52]. This gap is often attributed

to a lack of resources, standardised protocols, and sufficient training for healthcare providers [48]. Globally, the situation is similar. For instance, a survey of thoracic surgeons in Australia found that although there is a high perceived need for prehabilitation, only a small fraction of patients had access to these services [53]. This disparity highlights the broader issue of unequal access to prehabilitation across different countries and healthcare systems [53].

In response to this rising need to enhance outcomes, prehabilitation may have significant relevance for frail and elderly populations awaiting an elective major operation [8]. There is currently no established pathway for engaging these patients in improving their health as they wait for their major surgical interventions [18]. Furthermore, in real-world practice, it is uncertain whether referral to pulmonary prehabilitation classes improves surgical and patient-reported outcomes. Using real-world data improves generalisability by including diverse patient populations often excluded from randomised controlled trials (RCTs) and better reflects routine clinical practice, capturing real-world treatment effectiveness, adherence, and patient behaviours [54,55]. Recent studies have demonstrated that pulmonary rehabilitation significantly reduces postoperative complications, particularly pulmonary complications, and improves recovery in lung cancer surgery patients, supporting its potential role in this context [56,57]. Therefore, whether referral to pulmonary rehabilitation classes could be an alternative for patients who are waiting for lung cancer surgery to reduce the incidence or severity of postoperative complications should be investigated [17,18]. By performing a propensity-score analysis (PSA), we aim to investigate whether the prehabilitation programme, which is a referral to pulmonary rehabilitation classes, had an impact on perioperative care compared to the usual care, no prehabilitation, on patients who underwent lung cancer surgery.

## 2.2 Methods

### 2.2.1 Study Design

This study is a retrospective, longitudinal, single-centre study. The Institutional Review Board approved the study (REC number: 10/H1208/41).

**Participants and Procedures**

This enriched cohort study involved consecutive recruitment of patients undergoing lung cancer resection at University Hospital Birmingham NHS Foundation Trust from 2010 to 2020 by offering rehabilitation pre and post-surgery pragmatically by local providers compared to a contemporaneous control group who just had usual care. Informed consent was obtained from all participants, and quality of life (QoL) measures were self-reported by all participants following lung surgery. Data was collected prospectively from patients' medical records including length of stay (LOS) and postoperative pulmonary complications (PPC) using the Melbourne group scale (MGS) [1].

The study recruited 873 participants who underwent lung cancer surgery from 2010 until 2020. Participants were allocated to two groups: Pulmonary Rehabilitation (PR) (n=135) and non-intervention or control (NG) (n=738). Participants in the PR offered rehabilitation pre and post-surgery pragmatically by local providers, and participants in the NG received usual care. The inclusion criteria were above the age of 18 years, undergoing lung cancer curative resection, able to provide written informed consent, and before surgery at the time of consent. The exclusion criteria were unable to provide written informed consent. Participants were recruited at least two weeks prior to surgery and were followed up to five months after surgery in both groups.

### 2.2.2 PR Programme

The participants were recruited from 11 hospitals across the UK, of which only three—Walsall Manor, Heartlands, and Worcester—had pulmonary rehabilitation programmes in place [58]. Patients in the PR group were enrolled in a 12-week pulmonary rehabilitation programme at these three hospitals, commencing before their lung cancer surgery. Each patient attended at least two sessions prior to their surgery. Worcester offered a community-based programme, while Heartlands and Walsall Manor hospitals provided in-hospital, class-based programmes. These programmes aligned with the British Thoracic Society's guidelines, which recommend a minimum six-week PR programme with twice-weekly supervised sessions, incorporating tailored aerobic and resistance exercise training, structured education, and a multidisciplinary team approach to improve functional capacity, symptom management, and quality of life for patients with chronic respiratory conditions [58].

### 2.2.3 Outcome Measures

The primary outcome measures were hospital length of stay (LOS), postoperative pulmonary complications (PPC) defined using the MGS [1], and quality of life (QoL). The LOS and PPC were extracted from the medical records. The QoL for the participants was measured in baseline before surgery, 6 weeks after surgery, and 6 months after surgery. The EORTC QLQ-C30 is a standardised questionnaire designed to measure the quality of life in cancer patients. It evaluates three main domains: **functional** (physical, role, emotional, cognitive, and social aspects), **symptom** (issues such as fatigue, pain, nausea, and financial difficulties), and **global health**, which provides an overall perspective on health and quality of life [59]. Scores are derived using a 0-100 scale for clarity, with raw scores averaged for each domain and linearly transformed for final interpretation. The tool consists of 30 items organised into multi-item and single-item scales. The QoL domains' scores were interpreted based on the clinically meaningful difference defined as a change of 10 units.

For functional scales and the global health status/QoL scale, higher scores indicate better functioning and quality of life [59]. Conversely, for symptom scales, higher scores indicate greater symptom severity or more problems [59]. These standardised scores facilitate comparison across different studies and patient populations, allowing clinicians and researchers to assess and monitor patients' quality of life effectively [60].

### 2.2.4 Matching, Covariates, and Statistical Analysis

To create a comprehensive and current database, it was essential to clean the existing data and collect new data prospectively from patients' electronic medical records. To address this challenge, research fellows have been gathering data and building multiple databases over the last decade. Matching was then performed using Propensity Score Analysis (PSA). PSA is a statistical technique used to estimate the effect of a treatment, policy, or intervention by accounting for covariates that predict receiving the treatment [61]. This method is particularly useful in observational studies where random assignment is not feasible [61]. By using PSA, researchers aim to reduce selection bias and simulate a randomised controlled trial. The key concept is the propensity score, which is the probability of a unit (e.g., a person) receiving the treatment given their observed characteristics. PSA is widely used in fields such as

epidemiology, economics, and social sciences to draw causal inferences from non-experimental data.

Due to the missing values within the data set, as presented in Figure 1, imputation techniques were applied using RStudio version 2024.04.2+764 before moving to univariate regression for the outcomes. The data imputation approach that was used is the MICE package installed in R [62]. The package creates multiple imputations (replacement values) for multivariate missing data. The approach relies on Fully Conditional Specification, wherein each incomplete variable is imputed using an individual model. The MICE algorithm can impute combinations of continuous, binary, unordered categorical, and ordered categorical data. Furthermore, MICE is capable of imputing continuous two-level data while ensuring consistency among imputations by passive imputation. Numerous diagnostic plots are utilised to evaluate the quality of the imputations.

Figure 2.1 summarises the Propensity Score Analysis (PSA) steps. After carrying out the regression analysis for the outcomes, the following covariates were included in the matching: COPD, gender, age, incision, side, resection, MRC dyspnoea, DLCO, and packyears. After deciding on the variables to include and performing the regression for each outcome, the next steps in PSA are to match exposed and unexposed subjects, then check the balance of covariates in the exposed and unexposed groups after matching, and finally calculate the effect estimate and standard errors with this match population. After matching, it is essential to check the balance of covariates between the treated and control groups. This step ensures that the matching process successfully creates comparable groups (Figure 2.2). Figure 2.2 shows the standardised mean differences for covariates before (red) and after (blue) adjustment in PSA. The two vertical dashed lines represent the thresholds for acceptable balance, typically set at ±0.1, indicating covariates with differences within these lines are considered well-balanced (Figure 2.2).

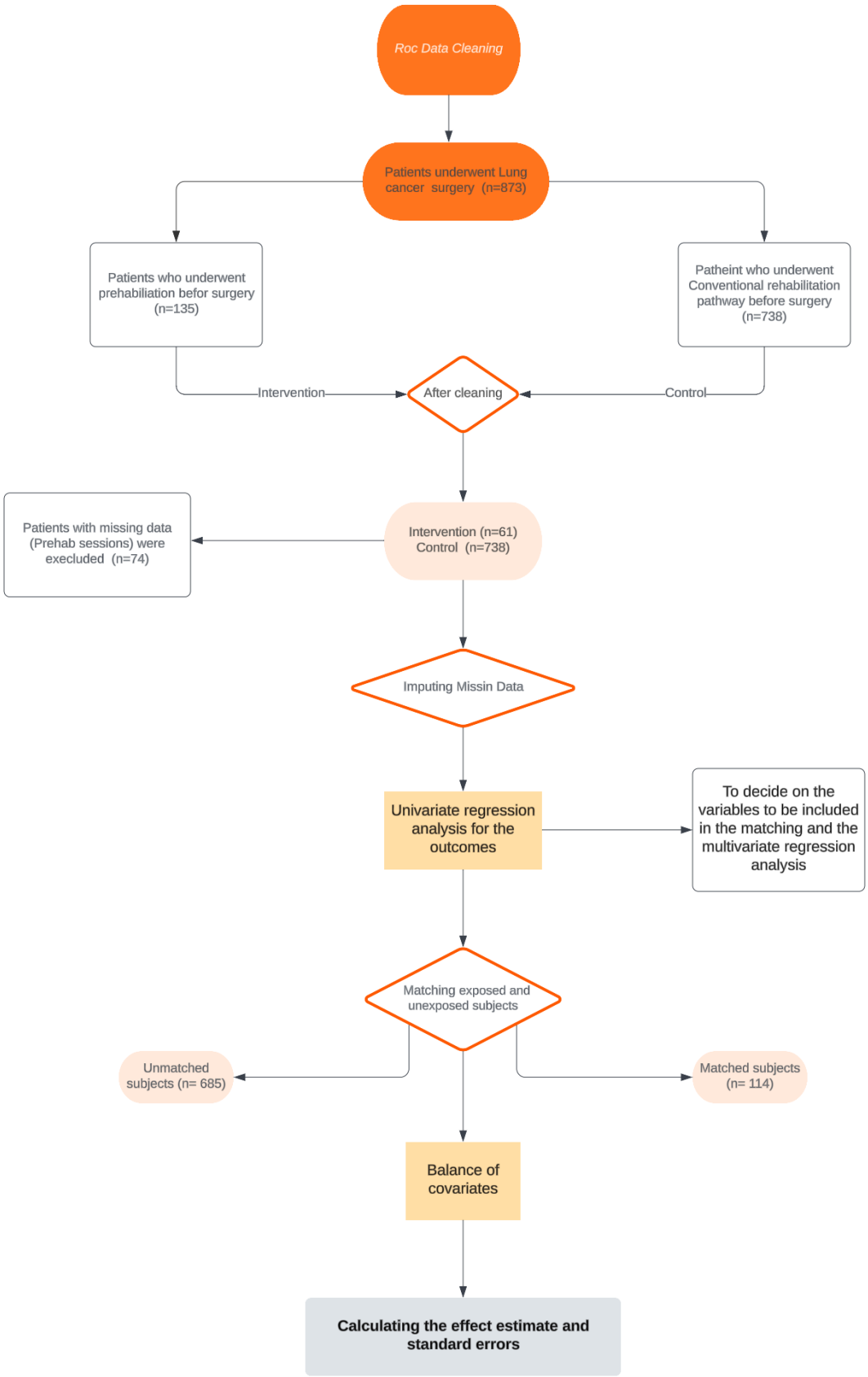



***Figure 0.1: PSA steps flowchart for evaluating pulmonary rehabilitation impact on lung cancer surgery patients***

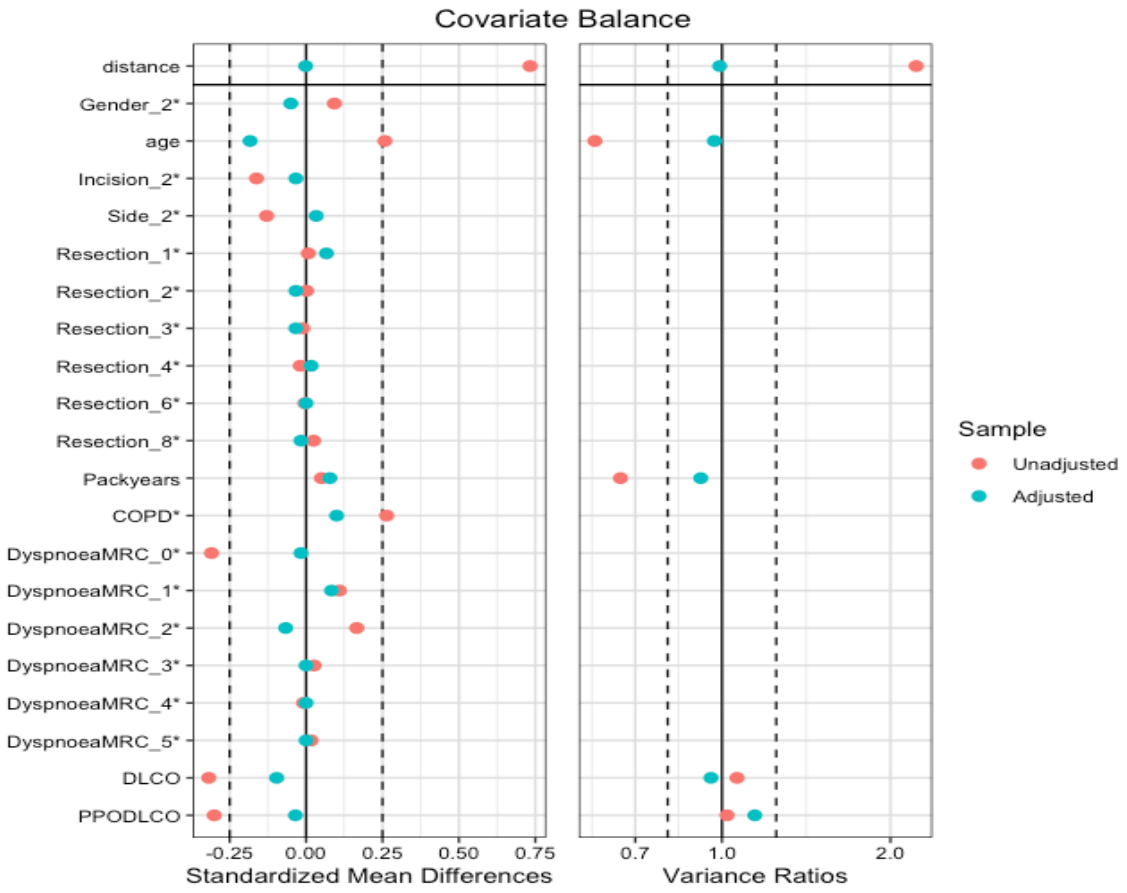



***Figure 0.2: covariates balance assessment before and after propensity score matching***

### 2.2.5 Propensity Score Model

After selecting covariates and performing regression for each subject, the Propensity Score Analysis (PSA) proceeded with matching exposed and unexposed subjects, checking covariate balance post-matching, and calculating effect estimates and standard errors. The matching process was conducted in R using the MATCHiT version 4.6.0 package, with nearest neighbour matching within a calliper of 0.02 to ensure that the propensity scores (PS) of matched pairs were close enough for comparability [63]. A calliper of 0.02 was chosen to balance precision and confidence in match quality, as values too small or large could compromise matching effectiveness. A 1:1 matching ratio without replacement was used, meaning each unexposed subject was matched to only one exposed subject, enhancing precision by maximising the use of available subjects.

## 2.3 Results

### 2.3.1 General Patient Characteristics

A total of 873 patients were recruited from 2010 until 2020 who underwent lung cancer surgery and were included in the statistical analysis (Figure 4.1). After data cleaning, 74 patients were excluded from the intervention arm since there was no information about how many prehabilitation sessions they had (Figure 2.1). The participants' baseline characteristics and clinical data are shown in Table 2.1.

***Table 0.1: Baseline characteristics of 799 patients included in the study***

| Characteristic | Pulmonary rehabilitation (PR) (n = 61) | Non-intervention or control (NG) (n = 738) |
|---|---|---|
| **Patient demographics** | | |
| Age | 71 (66, 75) | 70 (63, 75) |
| Gender (male) | 26 (43%) | 383 (52%) |
| BMI | 25.2 (22.8, 28.5) | 26.9 (24.0, 30.3) |
| **BMI Classification** | | |
| Healthy Weight | 26 (43%) | 212 (29%) |
| Obese | 9 (15%) | 180 (24%) |
| Overweight | 21 (34%) | 296 (40%) |
| Severely Obese | 1 (1.6%) | 16 (2.2%) |
| Underweight | 4 (6.6%) | 34 (4.6%) |
| **Smoking Status** | | |
| Current | 9 (15%) | 76 (10%) |
| Ex-smoker | 42 (69%) | 512 (70%) |
| Never smoker | 10 (16%) | 142 (19%) |
| Pack years | 40 (15, 50) | 28 (5, 45) |
| Unknown pack years | 9 | 46 |
| **Lung Function** | | |
| $FEV_1$ (L) | 2.14 (1.70, 2.55) | 2.02 (1.56, 2.30) |
| % $FEV_1$ | 87 (74, 100) | 81 (66, 99) |
| %DLCO | 77 (65, 91) | 71 (58, 84) |
| $PpoFEV_1$ | 69 (56, 81) | 62 (46, 81) |
| PpoDLCO | 61 (51, 73) | 57 (48, 66) |
| **Surgical incision** | | |
| Open | 37 (61%) | 327 (44%) |
| VATS | 24 (39%) | 409 (56%) |
| **Surgery side** | | |
| Right | 43 (70%) | 425 (58%) |

| | | |
|---|---|---|
| **Lobe** | | |
| Upper | 37 (63%) | 402 (56%) |
| Middle | 2 (3.4%) | 44 (6.1%) |
| Lower | 15 (25%) | 227 (31%) |
| Upper Bilobe | 4 (6.8%) | 10 (1.4%) |
| Lower Bilobe | 0 | 5 (0.7%) |
| Entire lung | 1 (1.7%) | 26 (3.6%) |
| **Lung resection** | | |
| Wedge | 10 (16%) | 129 (17%) |
| Segmentectomy | 2 (3.3%) | 23 (3.1%) |
| Lobectomy | 45 (74%) | 539 (73%) |
| Bilobectomy | 3 (4.9%) | 18 (2.4%) |
| Sleeve | 0 | 3 (0.4%) |
| Pneumonectomy | 1 (1.6%) | 26 (3.5%) |
| **Comorbidity** | | |
| COPD | 27 (44%) | 132 (18%) |
| Hypertension | 20 (34%) | 316 (46%) |
| | | |
| **Other measures** | | |
| MRC dyspnoea score > 2 | 4 (6.6 %) | 21 (3 %) |
| **Rehabilitation sessions** | | |
| Pre-Surgery | 2 (1, 5) | |
| Post-Surgery | 0 (0, 2) | |
| **Perioperative Outcomes** | | |
| Postoperative pulmonary complications | 7 (11%) | 46 (6.2%) |
| Hospital length of stay (days) | 5.0 (4.0, 7.0) | 4.00 (3.00, 6.00) |

Data are presented as mean (median), standard deviation (interquartile range), or numbers and percentages for categorical data. $FEV_1$; forced expiratory volume for 1 second, DLCO; diffusing capacity for carbon monoxide, $PpoFEV_1$ or PpoDLCO; predicted postoperative $FEV_1$ or DLCO, VATS; video-assisted thoracic surgery, COPD; chronic obstructive pulmonary disease.

Table 2.1 represents baseline demographic and smoking data for 799 patients. The median age is 70 years old, and it can be noticed that around half of the patients are male. It can be seen that the mean BMI for the no prehab group is 26.9. The majority of the patients reported they had quit smoking before their surgery, while almost a third of the patients in both groups were never smokers. It is apparent that 45% of the patients suffered from hypertension, and 20% had chronic obstructive pulmonary disease (COPD). Regarding postoperative outcomes, only 7%

of patients had postoperative pulmonary complications (PPC), and the median length of hospital stay (LOS) was four days (Table 2.1).

### 2.3.2 Quality of life scores

Table 2.2 shows the difference in functional or global health domains at different time points (Figure 2.3). Clinically, global health has deteriorated from baseline to six weeks, generally indicating lower quality of life. Similarly, physical functioning has clinically declined between preoperative six-week and five-month scores. Also, emotional functioning has clinically declined between preoperative and six-week scores; however, there has been a marginal improvement, but not to the point of clinical difference. Regarding the dyspnoea symptom domain clinically, the patients' scores declined significantly post-surgery at six weeks and six months compared to that before surgery.

***Table 0.2: Comparison between EORTC QLQ-C30 functioning and global health domains, and dyspnoea symptom domain***

| QoL domain | baseline | 6 weeks | 6 months |
|---|---|---|---|
| Global health | 75 (67, 92) | 67 (50, 83) | 67 (50, 83) |
| Physical functioning | 93 (80, 100) | **80 (60, 87)** | **80 (60, 93)** |
| Role functioning | 85 (60, 87) | **63 (50, 83)** | **70 (67, 92)** |
| Emotional functioning | 83 (67, 100) | 76.6 (67, 92) | 83 (67, 100) |
| Cognitive functioning | 85 (60, 87) | 80 (60, 87) | 83 (67, 100) |
| Social functioning | 85 (60, 87) | 83 (67, 100) | 85 (60, 87) |
| Dyspnoea | 20.5 ± (25.4) | **41.9 ± (29.6)** | **39.2 ± (29.4)** |

Data are presented as mean (median) and standard deviation (interquartile range). Highlighted numbers indicate clinically meaningful differences of 10 units or more,

Following propensity score matching, table 2.3 shows the difference in functional and global health domains at different time points after matching. Clinically, global health and physical functioning declined from baseline to six weeks, indicating a reduction in overall quality of life postoperatively, with a slightly greater decline in the NG group. Role functioning also showed a decrease at six weeks, with some recovery at six months, though scores remained lower than baseline. Emotional and cognitive functioning showed minor fluctuations over time, with no clinically significant differences between groups. Dyspnoea scores worsened significantly

postoperatively in both groups at six weeks and remained elevated at six months, with NG patients experiencing a greater impact compared to PR patients.

***Table 0.3: Comparison between EORTC QLQ-C30 functioning and global health domains, and dyspnoea symptom domain after matching***

| QoL domain | baseline | | 6 weeks | | 6 months | |
|---|---|---|---|---|---|---|
| | PR | NG | PR | NG | PR | NG |
| Global health | 75.42 | 66.81 | 62.92 | 58.06 | 66.81 | 61.81 |
| | (20.84) | (20.61) | (15.83) | (20.87) | (21.89) | (23.13) |
| Physical functioning | 85.89 | 78.78 | 72.22 | 66.44 | 74.33 | 66.56 |
| | (16.56) | (21.06) | (17.79) | (23.19) | (20.68) | (25.26) |
| Role functioning | 87.50 | 79.72 | 65.28 | 58.61 | 68.06 | 63.33 |
| | (21.18) | (27.97) | (28.67) | (28.87) | (30.73) | (34.00) |
| Emotional functioning | 80.00 | 72.36 | 75.83 | 70.51 | 77.78 | 75.42 |
| | (18.04) | (22.21) | (22.27) | (24.79) | (21.19) | (25.28) |
| Cognitive functioning | 88.33 | 84.72 | 80.56 | 78.61 | 84.17 | 78.89 |
| | (17.71) | (16.89) | (24.39) | (20.83) | (21.13) | (19.13) |
| Social functioning | 90.28 | 85.28 | 73.06 | 70.56 | 74.72 | 76.39 |
| | (18.49) | (23.59) | (27.46) | (29.17) | (29.67) | (28.17) |
| Dyspnoea | 21.1 | 26.6 | 47.20 | 51.07 | 42.7 (29.2) | 51.6 (31.2) |
| | (27.2) | (27.7) | (28.07) | (30.71) | | |

Data are presented as mean and standard deviation.

### 2.3.3 Other Analyses

Table 2.5 shows the baseline characteristics of 114 patients included in the study after matching. Once the balance of the matched population is ensured, as indicated in Figure 2.2, the final step of the PSA is to calculate the effect estimate (EE) and standard errors (SE) for the outcomes, which are the length of stay (LOS), postoperative pulmonary compilations (PPC), 6 weeks postoperative physical functioning (PF 6W) domain, 6 weeks postoperative dyspnoea

(DY 6W), 6 weeks postoperative global health (QoL 6W) and 6 months postoperative global health (QoL 6M) as indicated in table 2.4. Figure 2.4 points out the forest plot of key outcomes.

***Table 0.4: Multivariate regression results for the outcomes in the PR group after matching***

| **Outcomes** / **Values** | PPC | LOS | PF 6W | DY 6W | QoL 6W | QoL 6M |
|---|---|---|---|---|---|---|
| EE | -0.60 | -0.20 | 6.6 | -0.44 | 5.1 | 4.7 |
| SE | 0.59 | 0.82 | 3.71 | 0.38 | 3.34 | 3.35 |
| Antilog | 1.8 | - | - | 0.64 | - | - |
| 95 % CI | -1.8 – 0.5 | -1.8 – 1.6 | -0.80 – 14 | -1.1 – 0.24 | -1.5 – 12 | -3.5 – 13 |

[1] CI = Confidence Interval, [2]EE = Effect Estimate, [3]SE = Standard Error.

In Table 2.4, it can be noted that the PR group had a reduction of 0.2 days in LOS compared to the usual care group (EE = -0.20), with the potential reduction extending up to 1.8 days, though the confidence interval also includes the possibility of an increase of 1.6 days (95% CI = -1.8 to 1.6). In regard to the PPC, the PR group had a reduction of 60% (EE = -0.60, 95% CI = -1.8 – 0.5). There was an indication of a 6.6 % improvement in the physical functioning score for the PR group compared to the usual care group following surgery (EE = 6.6). Although it is only 6.6 %, the 95%CI indicated that the maximum could be 14 units, which is considered a clinically significant improvement. Also, there was a slight reduction of -0.4 in the dyspnoea score for the PR group 6 weeks following surgery.

In regard to the QoL global health score 6 weeks following surgery, there was an improvement of 5.1% for the PR group. Furthermore, there was an indication of a 4.7 % improvement in the QoL global health score for the PR group compared to the usual care group 6 months following surgery (EE = 4.7). Although it is only 4.7 %, the 95%CI indicated that the maximum could be 13 units, which is considered a clinically significant improvement.

## 2.4 Discussion

The comparative effectiveness of research evaluating the impact of 'real world' pulmonary rehabilitation on surgical outcomes is not extensively documented. Randomised controlled trials (RCTs) have strict patient inclusion and exclusion criteria that might restrict the generalisability of the study results. Overall, in this case, matched analysis, the participants in the PR group were matched to the NR group in their demographic characteristics, BMI classification, smoking status, lung function, surgery incision, surgery side, lobe, lung resection technique, comorbidities, other measures as presented in table 2.1. The PPC and LOS showed a trend of being higher in the PR group compared to the NG group, which could be attributed to the PR group having a trend toward a higher prevalence of COPD and greater pack-year histories. Furthermore, this study revealed that the PR group had a reduction of 0.2 days of LOS compared to the usual care group (EE = -0.20) and that reduction can potentially go up to 1.8 days (95%CI = -1.8 – 1.6). Also, in the PPC, the PR group had a reduction of 60% (EE = -0.60). In the PR group, the QoL domains, including physical functioning, dyspnoea score, and global health score, all improved 6 weeks following surgery, with a maximum improvement of more than 10 units in physical functioning and global health scores 6 weeks and 6 months following surgery, which is considered a clinically significant improvement. Patient participation in the PR programme was higher before surgery than after, demonstrating that the intervention is both feasible and acceptable to patients. This increased preoperative engagement highlights the programme's ability to complement patients' needs effectively during the pre-surgical period.

A preoperative exercise rehabilitation programme, pulmonary rehabilitation, has been shown to reduce LOS and PPC and is associated with better QoL. Pulmonary rehabilitation focuses on improving respiratory function and overall health in patients with chronic lung conditions through exercise, education, and support [64]. Similarly, prehabilitation, a preparatory intervention aimed at enhancing a patient's physical and mental fitness before surgery, has demonstrated the potential to improve outcomes and recovery [19,20,21]. Furthermore, pulmonary rehabilitation reduces LOS by enhancing recovery as patients become fitter, and it reduces PPC by improving mobility, enabling more effective coughing, decreasing the likelihood of atelectasis, and enhancing overall breathing [64,19,20]. However, due to study heterogeneity, no firm recommendations can be made regarding the optimal exercise modality, delivery method, frequency, or preoperative duration of these interventions. Nonetheless, a

preoperative exercise rehabilitation programme should be considered, particularly for patients with borderline lung function or limited exercise capacity, to optimise surgical readiness and recovery.

The latter findings correlate with findings from a systemic review that showed prehabilitation was associated with decreased LOS, postoperative complications, improved objective physical functioning, and improved QoL measures in patients undergoing cardiac and vascular procedures [19]. Similarly, evidence from another systemic review has shown that prehabilitation improves PPC, exercise capacity, and QoL compared to usual care in patients undergoing non-small lung cancer resection [20]. The findings of this study and of those studies presented in the literature suggest that prehabilitation could improve surgical outcomes, including LOS, PPC, and QoL, in patients undergoing cardiac, vascular, and lung cancer procedures [19,20].

Interestingly, this study's findings contradict findings from an RCT, which showed that prehabilitation had no effect on PPC and LOS in patients scheduled for non-small cell lung cancer resection [21]. However, the same study concurred with this study's findings in showing the impact of prehabilitation and its association with better QoL, including physical functioning following lung cancer surgery [21]. Nonetheless, it should be noted that this RCT had a short follow-up period, a weakness that may have limited the ability to demonstrate the long-term impact of prehabilitation on QoL [21].

In addition, this study's findings oppose those of a recent systemic review that examined prehabilitation for cancer patients and concluded that while some prehabilitation programs showed benefits, many did not significantly improve postoperative outcomes, including postoperative complications, LOS, and QoL compared to usual care [65]. However, it should be mentioned that the results of this systemic review could be limited by the heterogeneous tools for outcome measurement for the study included in the review [65].

Our analyses faced certain limitations typical of observational studies; the results may not be applicable to other major surgeries, different populations, or various settings. Additionally, the uneven availability of PR across sites could introduce site-related bias, as the outcomes observed in patients receiving PR might not be generalisable to those from non-PR sites or to

the broader patient population. This limited accessibility could also affect the representativeness of the study sample. Furthermore, the widespread implementation of PR faces multiple barriers, including resource constraints such as funding, infrastructure, and trained personnel, particularly in rural areas, as well as patient adherence challenges such as logistical difficulties, low motivation, and competing medical priorities [64]. Inadequate referral pathways, sociocultural factors, and the absence of long-term follow-up further limit accessibility and effectiveness, highlighting the need for targeted interventions to improve enrolment and adherence [64].

While propensity score analysis (PSA) was employed to minimise confounding and improve the comparability of groups, the potential for unmeasured confounding remains a limitation. Certain variables, such as patient motivation, informal caregiver support, or individual clinician practices, may not have been fully accounted for, which could influence both engagement in PR and postoperative outcomes. Despite the use of robust analytical methods, residual confounding cannot be entirely ruled out, and future studies with additional adjustments for such factors may provide further insights into the true impact of PR.

## 2.5 Conclusion

In summary, engagement in ‘real-world’ pulmonary rehabilitation before surgery appears to result in better patient and clinical outcomes after lung cancer surgery. However, due to the limitations and heterogeneity in study design and patient populations in the literature, the impact of pulmonary rehabilitation before major surgery could not be conclusively determined. Hence, we suggest the need for further rigorous methodological clinical trials to investigate the impact of rehabilitation on perioperative clinical outcomes compared to usual care in major surgeries. Additionally, the public health importance of integrating PR into standard perioperative care should be recognised, including the implementation of a tariff system to promote uptake and accessibility. Future research should also explore what the optimal PR programme should be to maximise benefits for patients undergoing major surgery.

## Supplementary tables and figures

***Table 0.1: Baseline characteristics of 114 patients included in the study after matching***

| Characteristic | Pulmonary rehabilitation (PR) (n = 57) | Non-intervention or control (NG) (n = 57) |
|---|---|---|
| **Patient demographics** | | |
| Age | 70.48 (7.25) | 71.80 (7.36) |
| Gender (male) | 32 (56.7%) | 35 (61.7%) |
| **Smoking Status** | | |
| Pack years | 32.67 (23.58) | 30.82 (24.63) |
| **Lung Function** | | |
| %DLCO | 71.38 (18.70) | 73.19 (19.13) |
| PpoDLCO | 57.22 (15.41) | 57.76 (14.40) |
| **Surgical incision** | | |
| Open | 35 (60%) | 33 (56.7%) |
| VATS | 22 (40%) | 24 (43.3%) |
| **Surgery side** | | |
| Right | 16 (30 %) | 14 (26.7%) |
| **Lung resection** | | |
| Wedge | 10 (17.5%) | 12 (21.1%) |
| Segmentectomy | 2 (3.5%) | 4 (7%) |
| Lobectomy | 41 (71.9%) | 37 (64.9%) |
| Bilobectomy | 3 (5.3%) | 4 (7%) |
| Sleeve | 0 | 0 |
| Pneumonectomy | 1 (1.8%) | 0 |
| **Comorbidity** | | |
| COPD | 25 (45%) | 19 (34.2%) |
| **Other measures** | | |
| MRC dyspnoea score > 2 | 3 (5.3%) | 3 (5.3%) |

Data are presented as mean (median), standard deviation (interquartile range), or numbers and percentages for categorical data. DLCO; diffusing capacity for carbon monoxide, PpoDLCO; predicted postoperative DLCO, VATS; video-assisted thoracic surgery, COPD; chronic obstructive pulmonary disease.

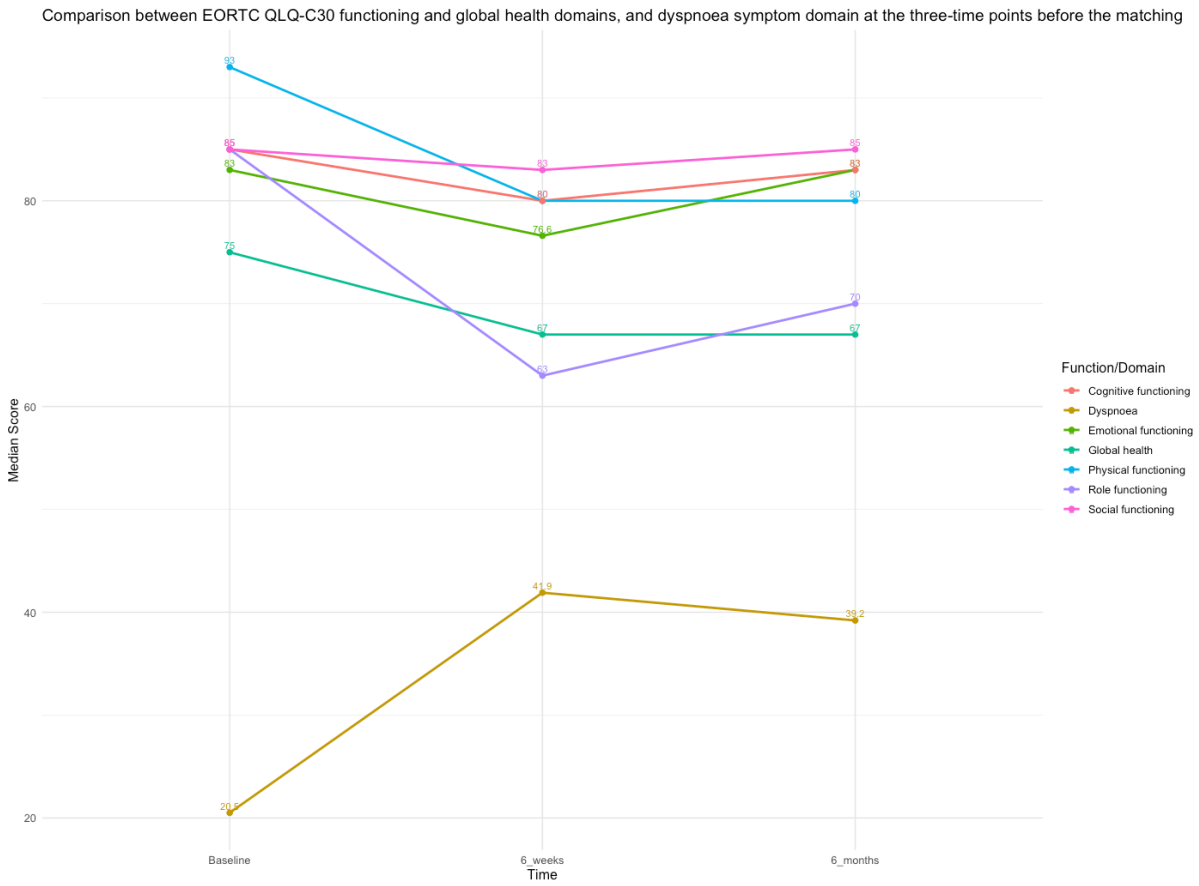



***Figure 0.1: Comparison between EORTC QLQ-C30 functioning and global health domains, and dyspnoea symptom domain.***

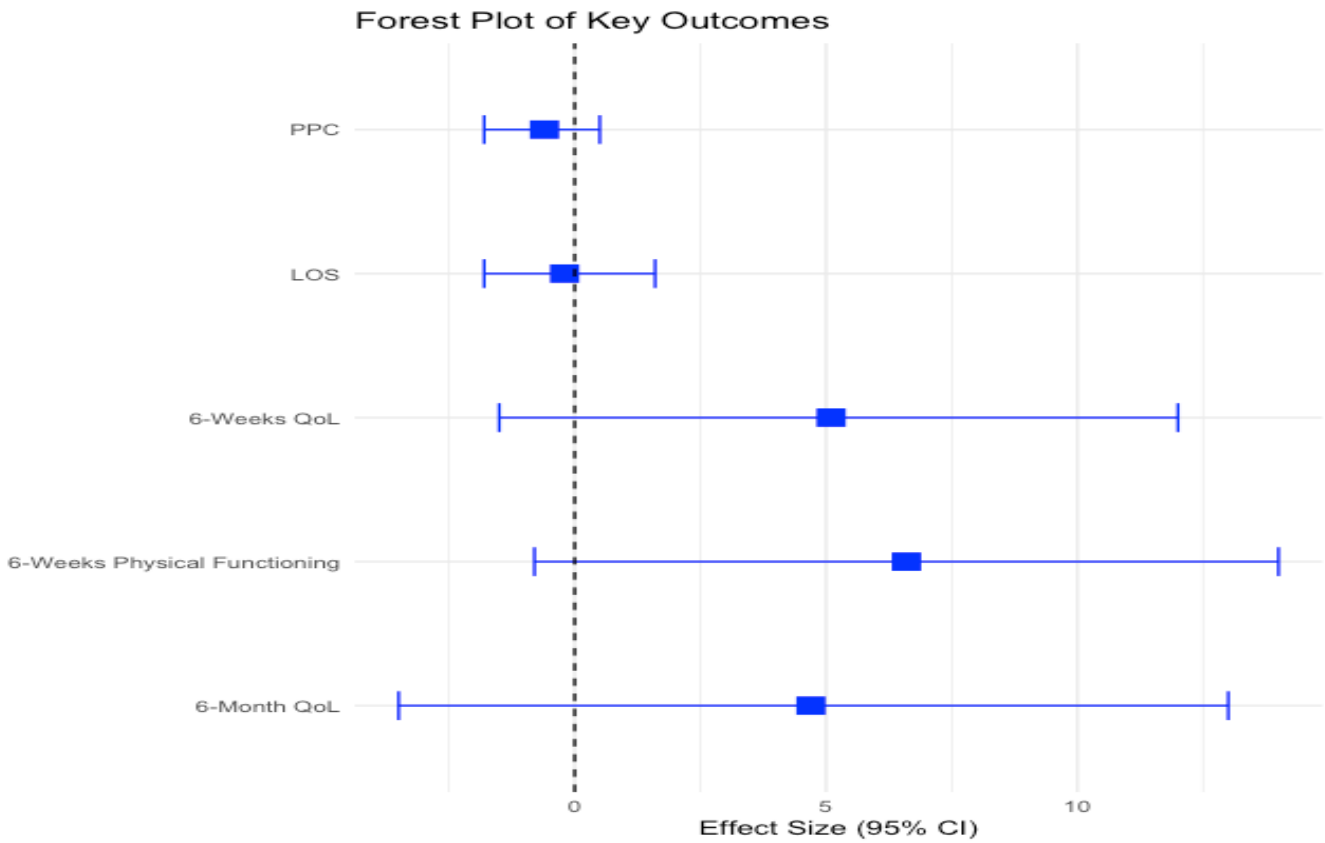



*Figure 0.2: Forest plot of key outcomes*

# Chapter 3

# Successful Agile Co-redesign of a personalised digital prehabilitation programme, Fit4Surgery app (F4S)

Parts of this chapter have been presented as abstracts forms in the British Thoracic Oncology Group conference 2023 under the title "**Successful agile co-redesign of a personalised digital prehabilitation programme: Fit4Surgery app**" (see appendix 8.2), and in the European Respiratory Society International Congress 2024 under the title "**User-centered design of an integrated, hybrid personalised digital prehabilitation intervention in the lung volume reduction surgical pathway ('Fit4Surgery'): A case study of the double diamond method**" (see appendix 8.3).

Matar Alzahrani,[1] Babu Naidu,[1] Salma Kadiri,[2] Joan Duda,[3] Sally Fenton, [3] Louisa Stonehewer,[4]

1. Birmingham Acute Care Research Group, Institute of Inflammation and Ageing, College of Medical and Dental Sciences, University of Birmingham, Birmingham, UK.
2. Department of Thoracic Surgery, Queen Elizabeth Hospital, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK.
3. School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, UK.
4. Atruim Health, Birmingham, UK

**- Authors' contributions of the 1st abstract**

Conception: BN, MA,

Data extraction & cleaning: MA, SK,

Analysis and interpretation of data: MA,

Draft the work: MA

Draft revision: BN, JD, SF, LS, MS

Approval of the version: MA, BN, JD, SF, LS, SK

Matar Alzahrani,[1] Salma Kadiri,[2] Joan Duda,[3] Sally Fenton, [3] Louisa Stonehewer,[4] Hazem Fallouh, [2] Babu Naidu,[1]

1. Birmingham Acute Care Research Group, Institute of Inflammation and Ageing, College of Medical and Dental Sciences, University of Birmingham, Birmingham, UK.
2. Department of Thoracic Surgery, Queen Elizabeth Hospital, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK.

3. School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, UK.
4. Atruim Health, Birmingham, UK

**- Authors' contributions of the 2nd abstract**

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## Abstract

### Introduction

The Fit4Surgery (F4S) app is a digital prehabilitation programme designed to enhance patient readiness for major surgeries. With over 50,000 patients undergoing major chest and abdominal surgeries annually in the UK, complications remain a significant challenge. To address these issues, the app leverages tailored exercise regimens, nutritional guidance, and behaviour-change techniques to support patients remotely, thus bridging gaps in access to prehabilitation programmes. This chapter outlines the development of F4S using the Double Diamond design framework, a user-centred approach that integrates insights from healthcare professionals (HCPs) and patients.

### Methods

The Double Diamond methodology was employed across four phases: Discover, Define, Develop, and Deliver. A series of workshops involving patients, HCPs, and the research team were conducted to identify barriers to prehabilitation and to refine solutions. Insights from the Discover phase informed the design brief in the Define phase, prioritising key app features. During the Develop phase, prototypes were iteratively tested and refined using Agile methodologies, incorporating user feedback. The Deliver phase produced a final prototype ready for feasibility testing, including features like tailored exercise plans, nutritional support, and outcome-tracking tools.

### Results

Workshops revealed critical barriers, including the need for personalized interventions, simplified technology access, and integrated feedback mechanisms for patients and HCPs. The iterative development process addressed these needs by creating a hybrid app accessible on multiple devices, promoting engagement through evidence-based behavioural techniques. Usability testing with patients and HCPs validated the app's features and design, highlighting its relevance and ease of use. Limitations such as small sample sizes and digital literacy challenges were identified but did not hinder the app's development.

### Conclusion

The F4S app represents an innovative approach to digital prehabilitation, combining user-centred design and Agile development principles. It addresses critical gaps in prehabilitation accessibility while enhancing patient engagement and outcomes. Future studies, including a

multi-centre feasibility trial, will evaluate its effectiveness and scalability across different surgical pathways. This project demonstrates the potential of co-designed digital tools to transform prehabilitation and improve surgical care delivery.

## 3.1Introduction

Over 50,000 patients/year in the UK undergo major chest and abdominal surgery. Major complications following these operations are common and are linked to an increased risk of death, admission into an intensive care unit, and a longer stay in hospital [1,2,3]. Avoidance of these complications would offer significant benefits both to patients and the NHS. A systematic review and a meta-analysis of preoperative exercise training/rehabilitation programmes suggest that fitness for surgery is better in those who undergo exercise training for between 2 to 6 weeks prior to the chest or abdominal surgery [4,5]. However, these 'face-to-face' interventions require immediate access to expensive and over-stretched rehabilitation programmes, which is hampering NHS adoption of these strategies at present. This is further compounded by restrictions because of pre- and post-surgery self-isolation mandated to prevent COVID infection.

When one considers that surgery is increasingly offered to older, less-fit patients, the potential benefits of rehabilitation in preventing a significant proportion of all major complications following major surgery could produce a significant cost saving to the NHS [8]. A digital-based programme of prehabilitation and rehabilitation, which includes exercise training, is one solution to this problem that could be adopted across the NHS. It could also help achieve the targets set out in the NHS outcomes framework, namely, recovering quickly and successfully from episodes of ill health and ensuring patients have an excellent experience of care and long-term quality of life [9]. Furthermore, it would enable patients to manage their own rehabilitation/exercise programme at their convenience rather than having to schedule a time to do the exercise programme at the local hospital in the run-up to surgery, thus enabling them to take control of this aspect of their care.

Smartphone apps used as medical interventions offer an opportunity to deal with such healthcare challenges. Evidence indicates apps are successful in monitoring patients remotely, patient education, and disease self-management [28,29]. Systemic reviews and meta-analyses report apps have been used successfully as behaviour change tools to promote physical activity (PA) [9,10]. A review of smartphone apps for promoting PA highlighted their efficacy, particularly where apps are able to track PA/exercise behaviour, monitor progress toward PA goals, and incorporate options to undertake several types of PA [30,31].

Our team has developed and previously pilot-tested the Fit for Surgery (F4S) App on patients undergoing lung surgery within the NHS and concluded that the F4S app was feasible to be delivered in the prehabilitation stage [37]. The benefits of F4S include home-use, options of higher intensity exercises, patient convenience, and integrated bio-feedback to both patient and clinician. Patient and clinician feedback following the pilot indicated that F4S needed to be further refined for individual patients in a manner that facilitates their engagement with the app, to encourage participation in exercise and PA. Guided by self-determination theory (SDT), fostering patients' autonomous motivation to participate in exercise and PA is one avenue through which patient engagement with the app can be optimised in order to support the adoption and maintenance of exercise and PA. In version 2 of F4S, this has been addressed by incorporating an array of behaviour-change techniques (e.g., goal setting) underpinned by SDT, which posits that where an individual feels a sense of autonomy (voice and choice), competence (meets demands placed upon them), and connection (to others in a caring and supportive manner) in their exercise/PA attempts, this will promote greater autonomous motivation and encourage uptake of exercise/PA that can be sustained in the long-term.

Major surgeries are high-priority areas, as a digital-based programme of prehabilitation and rehabilitation has not been tested in this cohort of patients, as is evident in the literature. Hence, we developed a bespoke rehabilitation programme, the F4S app, involving patients and HCPs in the design process, both to identify barriers to prehabilitation and to create a solution. The Double Diamond is a user-centred co-design process that has previously been used in healthcare settings [66-70]. It distinguishes itself from others by systematically splitting the design process into two divergent-convergent processes, with two-stage engagement in end users. It is a creative process where a number of ideas are created (i.e., ‘divergent thinking’). These ideas are then narrowed down to the best concept or solution (i.e., ‘convergent thinking’). Therefore, in the Double Diamond, this happens twice, once to define the problem and once to create a feasible solution.

We report a case study to demonstrate how the Double Diamond method can be used for the digital-based programme of prehabilitation and rehabilitation within the pathway of elective major surgery.

## 3.2 Methods

### *3.2.1 Study design*

In this study, we employed the Double Diamond approach to intervention development, which is divided into four phases. The first diamond consists of two phases: Discover and Define. The second diamond comprises two further phases: Develop and Deliver. The Double Diamond method, including the workshops involved, is displayed in Figure 3.1. **Discover:** This phase aimed to develop a shared understanding of suitable physical exercises, appropriate health information, and technology use from the perspective of both patients and HCPs. This phase is *divergent* in its approach, as it explores the subject matter from multiple viewpoints. **Define:** The purpose was to improve and refine the breadth of insights emerging from the Discover phase, and therefore, the approach was convergent. **Develop:** The goal was to resume a *divergent* process by concentrating on creating a broad range of concepts for addressing the design brief. **Deliver:** The objective was to refine the breadth of ideas generated in the development phase, and so this approach was *convergent*.

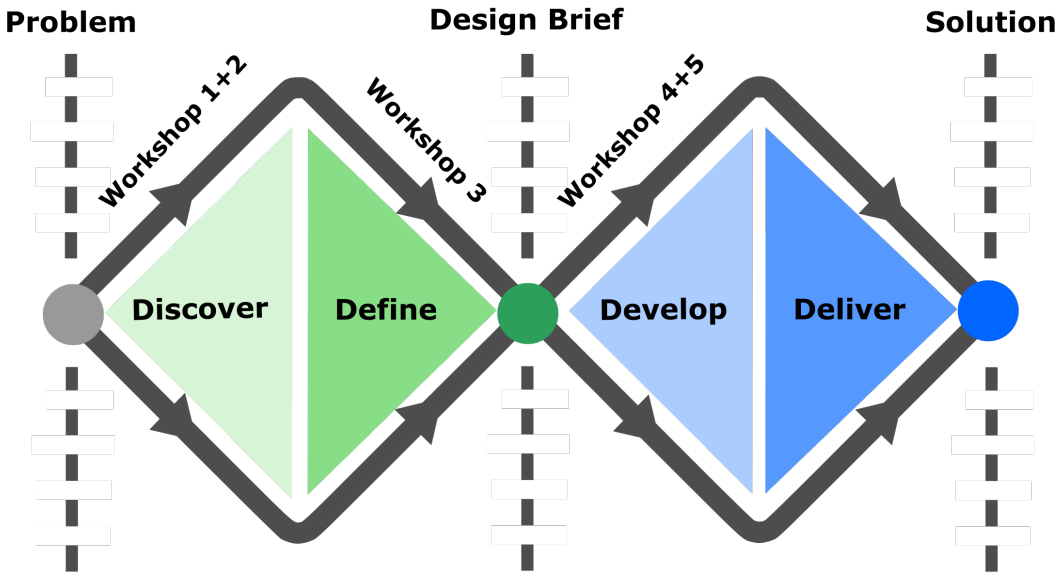



***Figure 0.1: Overview of the Double Diamond design approach and workshops in methods.***

### *3.2.2 Participants*

A series of workshops and public and patients involvement (PPI) meetings were held as part of the approved study (REC reference: 22/WM/0135) within the University Hospitals

Birmingham NHS Foundation Trust (UHB). Workshops and PPI were complemented with insights arising from HCPs who were part of the major surgeries' clinical pathways. The Discover Phase included Workshops 1 & 2; the Define Phase, Workshop 3; and the Deliver Phase included Workshops 4 (first PPI meeting) and 5 and the second PPI meeting.

In Workshop 1 (Formed from a core steering group), members of the core research team were selected with a range of expertise (n=5 in total), and from the University of Birmingham and UHB (n=11), as follows: a thoracic surgical consultant, a UGI surgical consultant, a UGI cancer specialist nurse, a lung cancer dietician, two UGI cancer dietician, two senior physiotherapists, two patients representatives with experience in research, and one research associate with a background in psychology. The role of this part of the team was to provide insight into the clinical pathways and HCP and patient needs. The core research team continued to provide input throughout the development of the app. Following these tasks, Workshop 1 included user profiles of prototypical service users, and HCPs were created, together with a mapping of the contexts of the digital intervention.

In Workshop 2 (Defining specialty-specific refinements), n=20 service users who were part of the thoracic surgery patient representative group (RESOLVE) and UGI patient group were invited to join by telephone and email. The RESOLVE group included previous patients who had undergone major thoracic surgery. The UGI patient group included previous patients who had undergone major UGI surgery. HCPs working within UHB as part of the lung cancer thoracic surgery and UGI surgery pathways were invited by email to join. This included n=9 in total: a thoracic surgeon (n=1), a UGI surgeon (n=1), pre-operative nurses (n=2), a lung CNS (n=1), dieticians (n=2) and thoracic advanced clinical practitioner (ACP) (n=2).

In Workshop 3 (Making and testing the amendments) the core research team members from Workshop 1 (n=16) were included. In Workshop 4, a qualitative usability test was conducted by inviting service users (n=20) who were members of the RESOLVE and UGI groups to test a prototype of the app via telephone and email, aiming to consider its acceptability from a patient perspective. Participants were asked to complete several tasks, including exercises and goal setting, and to complete questionnaires to provide their feedback.

In Workshop 5, a review of the impact following implementation through outcomes collected through the App as reported on the web portal was used to tweak and improve the programme

on a regular basis by specialty teams reporting to the steering committee. In this stage, the second PPI meetings were conducted (n=20) in which patients were asked to comment on the changes and the acceptability of the app from the patient perspective.

#### *3.2.3 Data collection and analysis*

Data were collected from the workshops, including field notes and questionnaires, and major themes and sub-themes were validated against insights gained from intervention observations, service shadowing, and the context mapping.

#### *3.2.4 User personas and user stories*

Based on the results from previous workshops with the patient groups, HCPs, and the core research team, it was possible to develop what is known in software as a User Persona. A User Persona is used to identify potential users, creating an example person and detailing who they are and why they will use the system.

#### *3.2.5 Agile project management*

In developing the F4S app, 'agile' and 'scrum' project management (2016) were used to create an initial project outline and a 'Product Backlog' where suggested changes were broken down into small 'app features'. Work was then conducted in 2-week cycles. Named 'sprints,' this is where a selection of items from the product backlog are addressed with. At the end of each sprint, a functional product was delivered. Following user testing, a final version of the web-based app, ready for release as part of the feasibility study, was developed.

## 3.3 Results

### 3.3.1 Discover

The outputs from the Discover phase and Workshop 1 included user mapping of the major surgery pathways showing the patients' journey, including interactions and touchpoints from when the patient first hears about the intervention, as well as people encountered on the journey and places visited (Figures 2-4).

#### 3.3.1.1 Mapping of the Lung Cancer Surgery Pathway

For this version of the intervention, the user mapping of the patient journey included four phases: Phase A (pre-operative outpatients), Phase B (day of surgery), Phase C (post-operative hospital stay), and Phase D (post-operative outpatients). Phase A is where the consultant's decision is made regarding whether patients will undergo lung cancer surgery or not. The remaining Phases (B-D) are common to all patient pathways if patients were to undergo lung cancer surgery. In cases of lung cancer diagnosis, patient cases are discussed in a multidisciplinary team meeting (MDT), where the patient is not present; this determines their further progression in the pathway. The lung cancer team initially sees the patient in the clinic and tells them about the MDT outcome and surgery, and then the patient attends the thoracic surgery clinic. The patient and research team members are present throughout this pathway. Important time points of this version of F4S formed the initial assessment in Phase A, then reassessment at Phase B (point of surgery) and Phase D (30 days after surgery) (Figure 3.2).

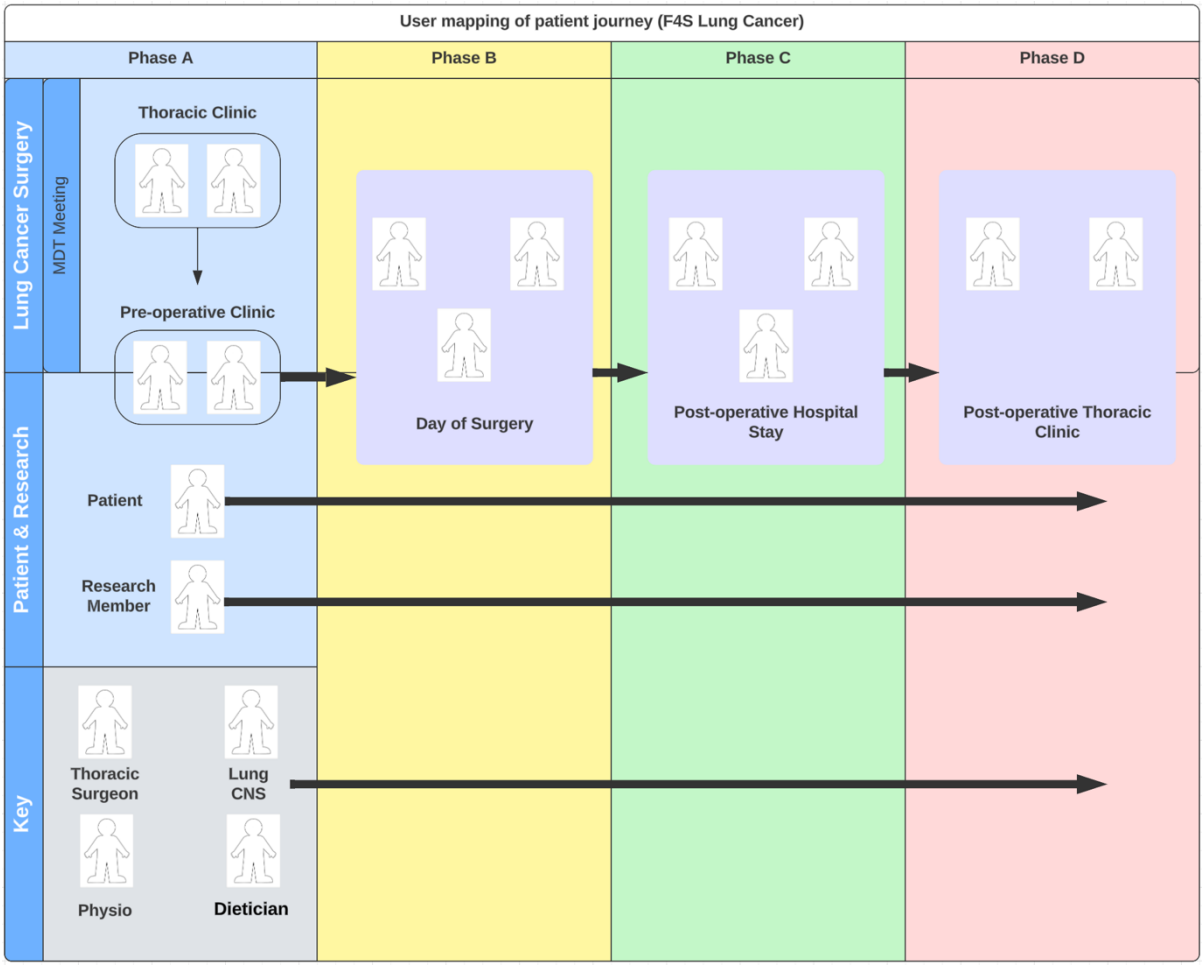



***Figure 0.2: Results from Workshop 1 - user mapping of patient journey in the major thoracic surgery pathway. MDT, multidisciplinary team; CNS, clinical nurse specialist.***

### 3.3.1.2 Mapping of the Lung Volume Reductions Surgery Pathway (LVRS)

For the F4S LVRS version, the user mapping of the patient journey included five phases: Phase A (pre-operative outpatients), Phase B (follow-up every 3 months before surgery), Phase C (day of surgery), Phase D (post-operative hospital stay), and Phase E (post-operative outpatients). Phase A is where those with an emphysema diagnosis are discussed in an MDT, in which the patient is not present; this determines further progression in the pathway. The thoracic surgery registrar initially informs the patient about the MDT outcome in writing, and the patient is then invited to attend the LVRS clinic. Furthermore, in this LVRS clinic, the consultant's decision is made depending on whether patients will undergo LVRS surgery or valve surgery, whereas the remaining Phases (B-E) are typical for all patient pathways if they are to undergo either one of the two surgeries. The patient and research team members are present throughout this pathway. Important time points of this version of F4S will be initial assessment in Phase A, Phase B (follow-up every 3 months before surgery), then reassessment at Phase C (point of surgery), and Phase E (30 days after surgery) (Figure 3.3).

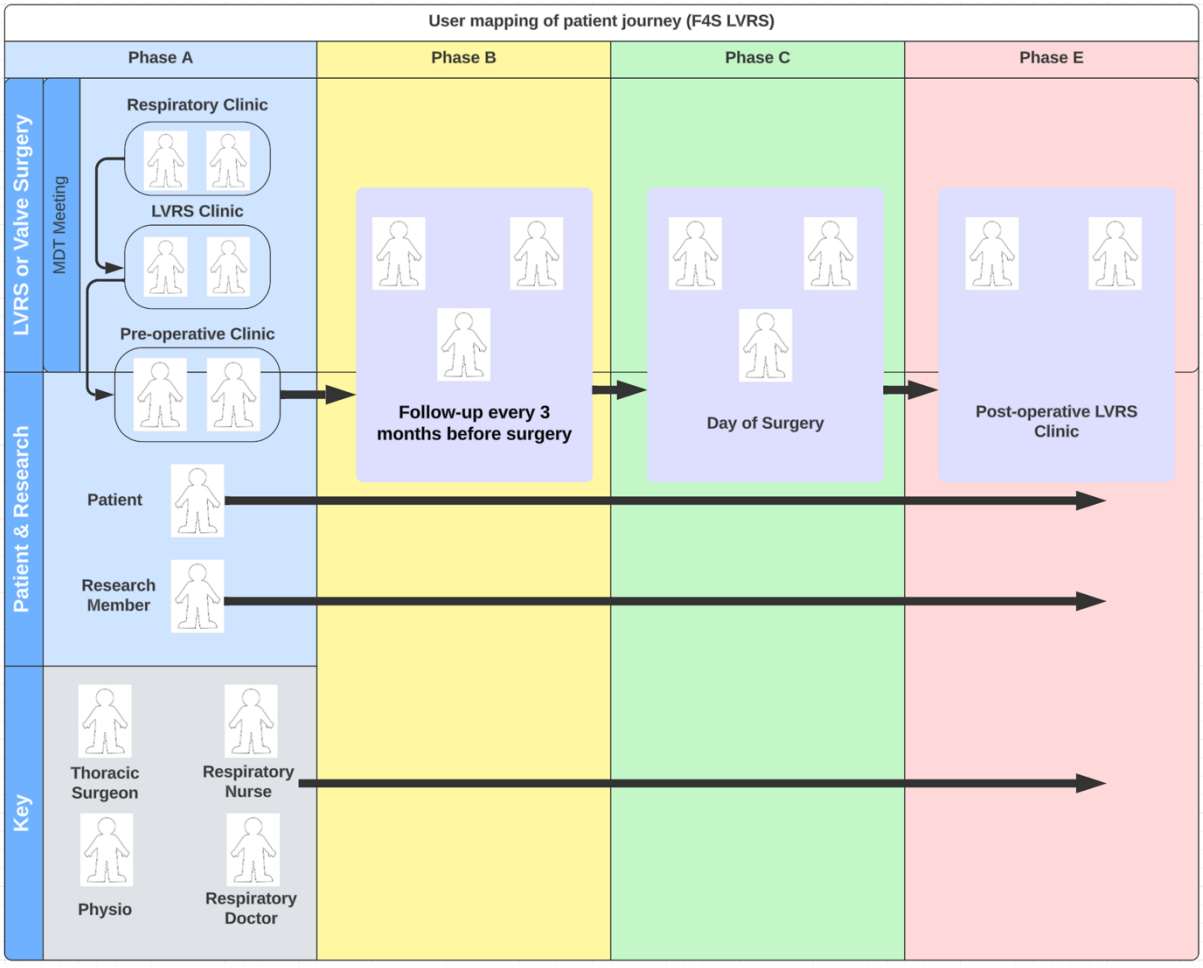



***Figure 0.3: Results from Workshop 1 - user mapping of patient journey in the major thoracic surgery pathway. MDT, multidisciplinary team***

#### 3.3.1.3 Mapping of the Upper Gastro-intestinal (UGI) Surgery Pathway

For the F4S UGI version, the user mapping of the patient journey included four phases: Phase A (pre-operative outpatients), Phase B (day of surgery), Phase C (post-operative hospital stay), and Phase D (post-operative outpatients). Phase A is where the UGI consultant sees those with an oesophageal-gastric cancer diagnosis in the clinic before their neo-adjuvant chemotherapy, in which the consultant's decision is made regarding whether patients will undergo oesophageal cancer surgery or gastro-oesophageal junctional cancer surgery. The remaining Phases (B-D) are common for all patient pathways if they are to undergo oesophageal-gastric cancer surgery. The patient and research team members are present throughout this pathway. Important time points for this version of F4S include the initial assessment in Phase A, followed by reassessment at Phase B (at the point of surgery) and Phase D (6 weeks after surgery) (Figure 3.4).

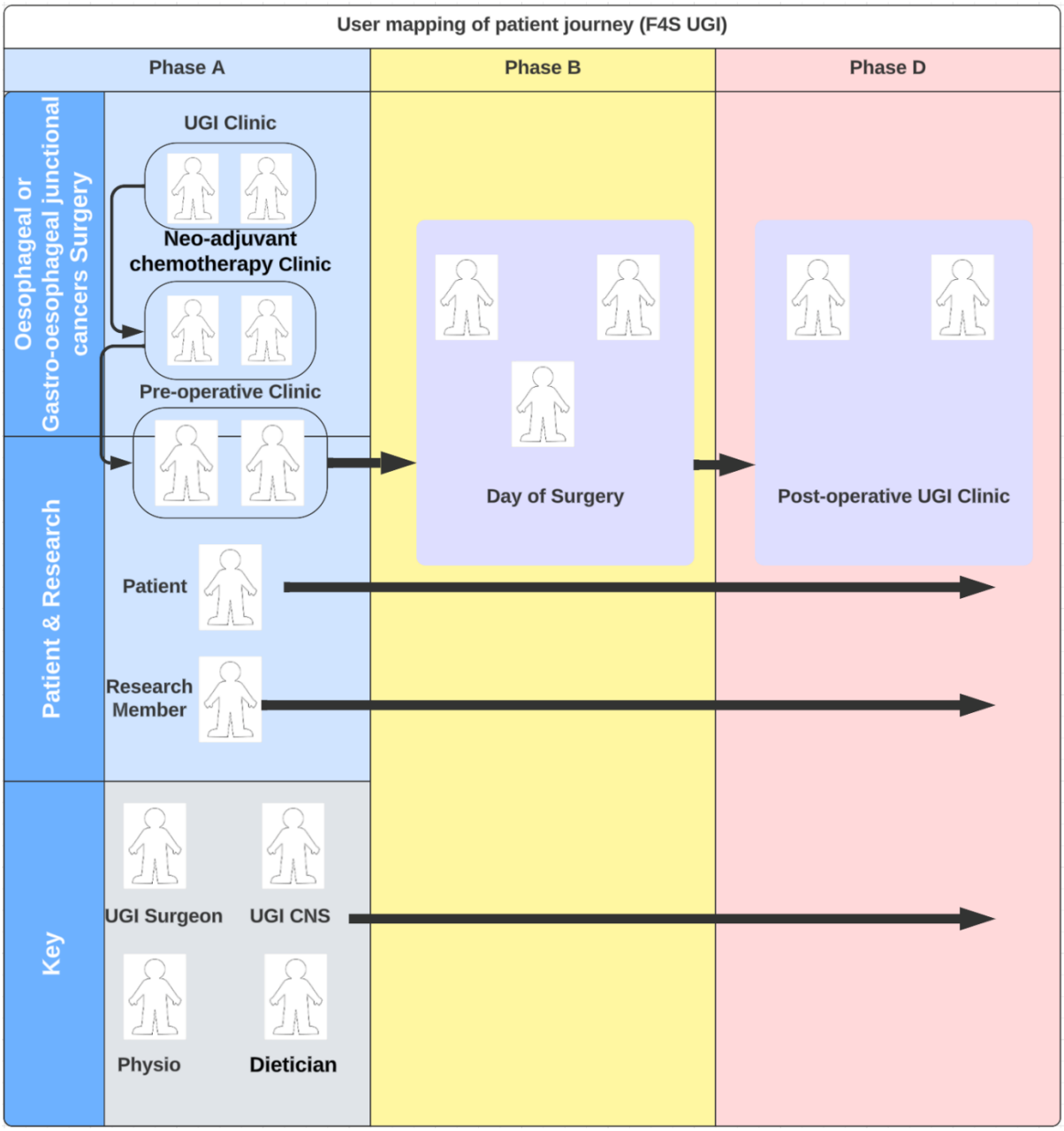



***Figure 0.4: Results from Workshop 1 - user mapping of patient journey in the major UGI surgery pathway. CNS, clinical nurse specialist.***

In Workshop 2, through focus group discussions, the following sub-themes were identified, which collectively form major themes (Figure 3.5). From the Discovery phase, in total 22 sub-themes were produced by the group, and these were narrowed down to 8 major themes. The major themes included personalised care and patient motivation, technology exclusion reduction, educating patients, feedback on patients' outcomes for HCPs, risk assessment & structuring of resources, pathway restructure & navigation, continuing support for patients, standardising training for HCPs.

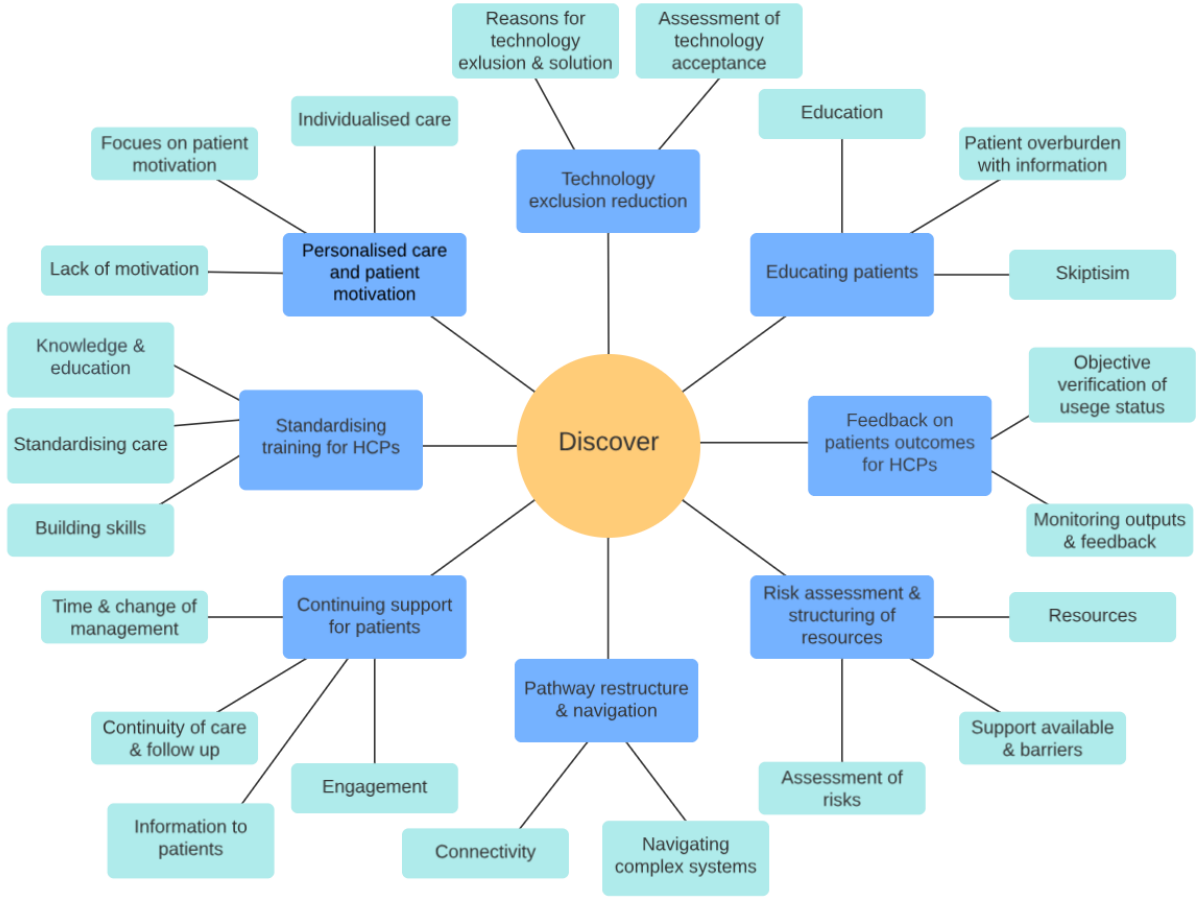



***Figure 0.5: Sub-theme and major themes generated through discover phase. HCP: healthcare practitioner***.

### 3.3.2 Define

The Define phase focused on creating the design brief by building on insights gathered during the discovery phase. This process involved conducting workshops to organise research findings into key themes and identify the most critical areas for enhancing surgical outcomes in major procedures. A comprehensive list of needs from both service users and clinicians was compiled, with each need evaluated based on its potential impact and ease of implementation. These findings informed the creation of a design brief that outlined the primary objectives and target areas for improvement. During ideation sessions with the core steering group, the most actionable solutions were identified and categorised into three main priorities to guide the design brief (Figure 3.6).

| Digital prehabilitation programme (Fit4Surgery) | Outcome tracking tool for HCPs | Technology exclusion reduction |
|---|---|---|
| • Hybrid app<br>• Goal setting support<br>• behavioural change support<br>• Delivery of information<br>• Tailor exercise programme<br>• Adding nutritional intervention<br>• Tailor health information<br>• Patient friendly information<br>• Motivation/engagement support<br>• IT feedback/monitoring<br>• Integrate digital into the pathway<br>• Chat bot<br>• Track other physical activities<br>• Embed stages of prehabilitation assessment<br>• Vital signs monitoring<br>• Including PROM | • Review current roles and process maps<br>• Opt out prehabilitation support<br>• Follow up phone calls<br>• Text messaging<br>• Tech infrastructure to enable connectivity across disciplines and systems<br>• Digital analytics<br>• Standardise follow ups.<br>• Digital tools to show rehabilitation status | • Hybrid app<br>• Tablets<br>• SIM cards<br>• Health bands<br>• TAM |

***Figure 0.6: The following solutions were derived to define the design brief. IT: information technology; HCP: healthcare practitioner; PROM: patient reported outcome measures; TAM: technology acceptance questionnaire.***

#### *3.3.2.1 Design Brief*

After the ideation phase, the team identified key priority areas for further exploration, which formed the basis of the design brief outlined below. The design brief established the goal of developing a web-based application to support the intervention process. The project aimed to create a comprehensive digital hub incorporating the following three main components:

1. Digital prehabilitation programme (F4S)
2. Outcome tracking tool for HCPs

3. Technology exclusion reduction

#### *3.3.2.2 Digital prehabilitation programme (F4S)*

- A hybrid app design is a tool required for development, which will help the patient to access the programme from anywhere, either through the app or the website, without losing their progress data. Also, it will aid in navigating the different pathways for major surgeries since the changes from one cohort of patients to another will be easier since it is a hybrid app design. The aim of this tool is to make the patient experience easier and the development process agile.
- The programme incorporates an array of behavioural change techniques (e.g., goal setting) underpinned by SDT, which posits that where an individual feels a sense of autonomy (voice and choice), competence (meets demands placed upon them), and connection (to others in a caring and supportive manner) in their exercise/PA attempts, this will promote greater autonomous motivation and encourage the uptake of exercise/PA, and will also aim to boost patient confidence overall.
- The programme can store data regarding where patients are along the pathway, including their current rehabilitation status, and can act as a centralised tool. There is an area, such as within a content management system, where the latest research can be input. Patients often self-refer, so there is signposting and a map of the pathway. In addition to this, a social interaction section has been researched. An investigation needed to be performed into how the tool could be tailored and personalised to individuals.
- The programme embeds the three stages of prehabilitation to allow patient progression guided by the BORG RPE scale. The nutritional assessment and personalisation of the information displayed within the app needed to be investigated so the programme could be tailored and personalised to individuals.
- An investigation was needed into the technologies used in this field and others, along with a decision on how the tool would look technologically. There was potential consideration of messaging as a communication method.

#### *3.3.2.3 Outcome tracking tool for HCPs*

- A tool is required to track and monitor patient progress effectively. The system should include features for providing feedback to both HCPs and stakeholders, with a focus on ensuring extensibility and compatibility with existing clinical systems.

- This tool could be implemented as a web-based dashboard, incorporating patient-reported outcome measures (PROMs) and clinician-reported outcome measures (CROMs), which can be recorded and accessed within the system.

#### *3.3.2.4 Technology exclusion reduction*

- Technology reduction solutions need to be investigated, and technology acceptance needs to be measured and incorporated in the pathways. The aim of this is to offer a solution to increase technology acceptance and improve patient experience and engagement in the programme.
- Different solutions were suggested during the workshop, including a hybrid app design that allows the patient access from any device. Also, offering a platform to access the programme, such as tablets, will help suitable patients without appropriate devices access the programme.
- There was a need to investigate these solutions and how to implement them in the pathway, and how to secure the funds required.

### 3.3.3 Develop

At the start of the Develop phase, concepts aligned with the design brief were created, assessed, and refined through collaboration among project designers, technologists, and HCPs. These concepts were then tested and validated with input from service users. Additionally, prototypes were developed to explore various methods for monitoring patient concerns.

#### *3.3.3.1 Prototype testing of service users*

The selected concepts were digitally prototyped and validated through testing with participants using a tablet. The validation process evaluated both verbal feedback and participants' interactions with the prototypes. Initially, participants were provided with an explanation of the app's purpose and a brief overview of its features. They were then encouraged to navigate the app independently and provide real-time feedback. The initial prototype was tested with groups of service users (n=20) representing various major surgical pathways.

#### *3.3.3.2 Logging in, navigation, and overall impression*

None of the participants had any problems with logging into the programme. The initial screening page was clear and organised, but the group identified issues with not being able to

easily navigate their way around the different sections due to the app being slow to respond and the lack of direction. Therefore, they discussed the need for a home button that would lead directly to the home screen. The home screen on the prototype listed different sections that included a list of health information related to the major surgery pathway; however, the group found it would be better categorised initially into 'essential to watch' based on the screening question and 'FYI' videos that can be watched anytime to prevent them having to scroll through a long list of health information each day the app is used.

#### *3.3.3.3 Information content*

With regard to information content to educate patients, the focus group from each cohort felt that a list of health information videos needed to be developed that would cover different surgical information and symptoms related to that specific surgical group. This list of suggested health information videos included how to take care of mental health around the surgery, explaining different surgery types, and managing different common symptoms around different major surgeries.

#### *3.3.3.4 fitness sessions and input of physical activates*

Regarding the daily fitness sessions and input of physical activities, members of the groups found it easier to manage their own exercise programme at their own pace and found it helpful to see what they had done in terms of physical activities the previous day. All members of the groups discussed the potential use of alternative therapies such as beathing exercises and yoga and adding them to the fitness session section.

#### *3.3.3.5 Feedback for service users*

The group also discussed the use of a graphical representation of all the exercises included in the programme. The groups liked the concept of choosing their own exercises with different levels and positions and felt it a good idea to be guided through the exercise session by being given a specific instruction on how well the performance was based on the BORG RPE scores. The groups also felt that the patient should be able to input their own physical activities in case they did not want to do the exercises within the programme at some point. The groups did not like the lack of instructions at the beginning of the fitness sessions and felt that a visual aid needed to be developed that would explicitly explain how to perform the fitness session step by step.

#### *3.3.3.6 Style of content*

Regarding the style of the prototype, participants noted that the font size was too small and suggested increasing it, especially for sub-headings and the information page. It would also be easier to read on a tablet than on a smartphone. They recognised this as a priority. The groups liked the idea of colourful designs for the different sections of the programme on the main screen. One of the members commented that the layout of the fitness session can be a little confusing and that it would be better to have a tick box (back) and (next) with the arrow rather than just having an arrow.

#### *3.3.3.7 Main suggestions from the service users*

Several main suggestions surfaced across all the groups of service users during the prototype testing of the programme; these include English subtitles to the videos, alternative therapies, a home button, adding a text message box in the 'contact us' section, and an introduction video that focuses on how to navigate through the different sections within the programme.

#### *3.3.3.8 Prototype testing for HCPs*

HCP feedback on the web-based app prototype was acquired during multiple half-day face-to-face training sessions on the novel digital prehabilitation intervention. The training addressed the feasibility study and offered an introduction to the web-based app, an overview of prehabilitation, existing or structuring new health information videos, a nutritional element, questionnaires, different scores, exercises, and levels/different positions, and changing behaviour. The feedback from the HCPs of a range of users from lung/UGI CNS to research nurses and thoracic/UGI surgeons was grouped into sub-themes and then major themes (Figure 3.7).

| **Aesthetics** | **Intervention content** | **Functionalities** |
|---|---|---|
| • Simplicity<br>• Visual appeal | • Usefulness<br>• Personalisation<br>• Motivational qualities<br>• Questionnaires & scores<br>• Pathway's related health information | • Regular updates<br>• Feedback capacity |

***Figure 0.7:The themes and sub-themes derived from the HCPs feedback.***

Regarding aesthetics, the HCPs found the hybrid app's design to be easy to use. Many praised the clarity of the different sections of the main screen when navigating through them. However, when asked about improvements, HCPs suggested that some names of the sections were not easily understandable and so highlighted the need for clearer names. The introduction of more visual aids was recommended. Generally, the HCPs found the content useful for both themselves and the patients perspective. They particularly liked the personalisation aspect, and they could easily see that it would help patients comply with a prehabilitation programme. Some suggested that personalisation can hold the patient responsible for their own prehabilitation programme. It was also suggested that some specific general health information videos should be developed for each cohort of patients to cover the main touchpoints of their surgical journey. HCPs were keen on having an extra feedback capability of the hybrid app so they could support their patients along the pathway. The regular updates of the patient progress through the clinician portal were appreciated, and they acknowledged the positive outcomes of having the consistent updates and notifications on app usage and the summary page, where they can have an overview of the patient's fitness for surgery.

### 3.3.4 Deliver

During the Deliver phase, wireframe storyboards were created for both in-session and out-of-session content, based on the selected concepts. These storyboards were iteratively developed and coded alongside user testing. The intervention redesign concepts were finalised, and a new version of the intervention was produced using rapid prototyping techniques. This process included user testing of a low-fidelity version to refine and validate the redesign.

Sessions for making and testing the amendments were conducted with both HCPs and patients. In those same sessions, a set number of iterations, called 'sprints', were run every few weeks in what is known as the Agile software methodology. In this strategy, at the end of each sprint, a modified version of the intervention based on the amendments defined above is delivered; this process offers feedback as to whether further 'tweaks' to the intervention are required or not, and this information is used in the next sprint. In this way, the high-level areas of the software are mapped out against how long they take to develop and how important they are to the users.

This can then be used to pinpoint the most critical areas to begin development work on. Once the high-level areas are clearly defined, it is then possible to 'drill down' into what makes up each area. This is done by appraising the impact following creation. The review of impact follows a step a user might take and what advantage such a step would have. For example, one of the agile software developments was a 'physical activity tracker'. This was the first priority. One of the reviews of impacts for this physical activity tracker was being able to track different physical activities other than the exercises within the digital programme, and a step counter as well. This was a priority based on what was extracted from the workshops and their requirements about what the intervention would do. Once each sprint was fleshed out and the impact reviewed, it became possible to create a 'Look and Feel' design of the clinical interface. The clinical interface aims to evaluate whether the intervention meets the functional requirements of both patients and clinicians. It provides a detailed outline of the programme's components and their intended roles, serving as a foundation for integration into clinical practice. After approval of this interface, along with the originally prioritised amendments, development work was initiated.

In response to concerns regarding technology exclusion and digital literacy identified during the co-design workshops, several mitigation strategies were incorporated into the programme pathway. These included provision of a tablet with a pre-installed SIM card for patients who did not own, or could not reliably access, a suitable device or internet connection. A hybrid digital delivery model was also implemented, enabling patients to access the programme either via a mobile application or through a web-based platform, thereby accommodating varying levels of digital confidence and device preference. To further enhance usability and technology acceptance, a pictorial step-by-step user guide and a short introductory video explaining app navigation and core functions were developed. Collectively, these measures were intended to reduce digital literacy barriers, improve accessibility, and support patient engagement and experience within the digital rehabilitation pathway.

The app's name, '*Fit4Surgery'*, was the product of brainstorming with the stakeholders, including clinicians, research psychologists, and software developers. Popular digital brand names were reviewed for inspiration, and name concepts were generated based on the themes of prehabilitation, physical fitness enhancement, motivation, and benefits around surgery. Finally, 'Fit4Surgery' was selected. Appendix 8.4 includes examples of the F4S app screens.

## 3.4 Discussion

We have developed a novel bespoke digital prehabilitation programme, F4S, designed to support patients and HCPs across major surgery pathways. To our knowledge, this is one of the first studies to use a Double Diamond design approach in the development of a digital prehabilitation programme. Mapping the thoracic surgery and other major surgery pathways alongside identifying key user interactions enabled the creation of a comprehensive framework for the intervention. Collaborative discussions during the Discover phase with multidisciplinary HCPs and patient representatives identified the primary barriers to implementing an integrated prehabilitation service. Insights from the Define phase allowed stakeholders to refine these findings into actionable solutions, leading to the creation of a design brief emphasising personalised exercise programmes, nutritional support, and outcome tracking tools for HCPs. The iterative Develop phase, incorporating patient feedback from prototype testing, culminated in the Deliver phase, where a final viable product was produced, ready for piloting and broader implementation.

Mobile and device-based applications have become an integral part of everyday life for many people, offering a convenient and accessible platform to deliver health interventions [71]. Mobile apps are increasingly recognised as feasible and acceptable tools for improving health outcomes and are generally well-received by users [72]. F4S leverages this accessibility to bridge gaps in care, providing patients with continuous support before and after surgery. This feature is particularly crucial in light of the logistical and motivational challenges patients face during the prehabilitation stage.

Although digital rehabilitation programmes exist, their efficacy often depends on their integration into broader care pathways. For example, Quit4Surgery, a smoking cessation app developed using the Double Diamond framework, demonstrated the importance of combining digital tools with trained HCP support [73]. Similar to F4S, Quit4Surgery includes behavioural therapy components and uses technology to provide continuity of care regardless of the patient's location. This hybrid approach mirrors findings in other studies, which indicate that combining digital interventions with traditional care models enhances efficacy, particularly in complex health pathways [74, 75].

The Double Diamond co-design process, as used in F4S, has previously been applied successfully in developing digital health tools for mental health and wellbeing, such as those by Craven et al. (2019) and Hardy et al. (2018) [77, 67]. This methodology is user-centred, emphasising iterative feedback and the integration of evidence-based behavioural frameworks and motivational theories. In the case of F4S, the design process drew upon SDT and other behavioural change techniques, ensuring the app met the diverse needs of patients undergoing major surgery. By involving stakeholders in every phase, from Discovery to Delivery, the F4S development process prioritised usability, patient engagement, and long-term adherence.

While there is no current standardised framework for developing digital health apps, the Double Diamond process has proven effective in creating features tailored to user needs [77]. In F4S, this approach resulted in a structured, patient-centred prehabilitation programme incorporating personalised exercise regimens, nutritional guidance, and progress-tracking tools. The development of F4S not only contributes to the growing field of digital health interventions but also highlights the potential of co-design methodologies to address unmet needs in surgical pathways and beyond.

## 3.5 Strengths and Limitations

### 3.5.1 Strengths

1. **Comprehensive User-Centred Design Approach:** The use of the Double Diamond co-design process ensures that the development of the F4S app was grounded in the needs and experiences of both patients and HCPs. This collaborative method integrates insights from diverse stakeholders, including clinicians, academics, and patients, creating a breadth of perspectives that enhances the app's relevance and usability.
2. **Evidence-Based Framework:** The incorporation of behavioural techniques and recommendations rooted in evidence-based practice, adds a robust foundation to the programme. This approach ensures that interventions align with proven best practices while tailoring content to major surgical pathways.
3. **Iterative Development with Feedback Integration:** The iterative Agile development process, involving multiple cycles of prototyping and user testing, allowed the app to evolve based on real-world feedback. This methodology enhances the likelihood of creating a practical and user-friendly tool.

4. **Hybrid Model for Broader Accessibility:** By integrating the app into a hybrid model that combines digital intervention with support from trained HCPs, the programme effectively bridges gaps in care and facilitates continuity irrespective of location.
5. **Potential for Adaptability:** The inclusion of features such as tailored exercise programmes, nutritional guidance, and outcome tracking demonstrates the app's potential for scalability across various surgical pathways. The app design also aligns with emerging trends in digital health and prehabilitation.

### 3.5.2 Limitations

1. **Small Sample Sizes in Workshops:** While group discussions and prototype testing provided valuable insights, the small sample sizes, typical for workshop settings, may have limited the detection of usability issues and generalisability of findings [24]. Nonetheless, qualitative research does not require large numbers to generate meaningful insights. Studies suggest that thematic saturation can often be achieved with relatively few participants if the data are robust, coherent, and internally consistent [78]. Furthermore, future studies will incorporate a larger sample in feasibility testing to validate usability findings [79].
2. **Incomplete Iterative Process:** Although the current version of F4S represents significant progress, the product remains a prototype. Insights from ongoing feasibility studies and qualitative interviews will be crucial to refining the app further, ensuring that the final version aligns with user needs before larger-scale trials [80].
3. **Potential Bias in PPI Representation:** Despite efforts to engage a range of stakeholders, PPI groups may not fully represent the broader patient population, particularly those with differing technological access or literacy. However, broader patient representation will be sought in future studies to include patients with limited technological literacy, ensuring findings are more generalisable to a wider population [81].
4. **Focus on Specific Pathways:** As it is tailored to thoracic surgery and similar pathways, the app's current design may not fully address the unique needs of other patient groups without significant modifications. Nevertheless, even though the current app design is tailored to thoracic surgery, it follows a modular framework, allowing future adaptation to other surgical pathways [82].
5. **Dependence on Digital Literacy:** As with many digital health tools, the app assumes a certain level of digital literacy among users, potentially excluding less tech-savvy

individuals or those without access to compatible devices. However, digital exclusion will be mitigated by providing alternative engagement methods, such as printed pictorial guides, telephone/technical-based support, and tablets with SIM cards for patients with limited technology access [83]. In addition, future usability testing will include older and less tech-savvy participants to refine app usability [84].

## 3.6Implications

In applying the Double Diamond methodology within the healthcare setting to develop the F4S app, we ensured that users were integral to the design process from its inception. Rather than being guided solely by the research team or other stakeholders, the methodology allowed both patients and HCPs to collaboratively identify barriers and challenges during the Discover phase. This process enabled the generation of insights directly from end-users, ensuring that the design addressed real-world needs. Furthermore, the Development phase provided additional opportunities for user engagement through iterative prototype testing and feedback sessions. By embedding user input at both the initial and final stages of the design process, the Double Diamond approach ensured a user-centric outcome. Workshops were carefully structured to minimise time commitments for both patients and HCPs while maximising the relevance and applicability of the final product, resulting in a digital prehabilitation tool tailored to the needs of its end-users.

## 3.7 Conclusion

F4S is the first app created to deliver personalised digital prehabilitation for major surgical pathways and was developed using the Double Diamond design process. Prehabilitation is a high-priority area, as effective digital strategies tailored to these patient cohorts remain underexplored. F4S is an innovative hybrid therapy combining digital tools with the support of HCPs to enhance patient readiness for surgery. The design process emphasises the critical role of focus groups involving patients, HCPs, and stakeholders, with iterative product testing ensuring usability and relevance for both groups. F4S will be evaluated in a multi-centre feasibility study to assess its impact on surgical outcomes and its integration into standard care pathways.

# Chapter 4

# A feasibility study exploring the efficacy of a personalised digital prehabilitation programme, Fit 4 Surgery (F4S), for patients undergoing major surgery

The manuscript for this chapter has been submitted to the Journal of Cardiothoracic Surgery under the title "**A feasibility study exploring the efficacy of a personalised digital prehabilitation programme, Fit 4 Surgery (F4S), for patients undergoing major surgery**" author contributions, as will be published, are listed.

Matar Alzahrani, [1,2,3] Joan Duda,[5] Fang Gao,[2] Babu Naidu[2,4]

**Names of the authors:**
1. College of Applied Medical Sciences, King Saud bin Abdulaziz University for Health Sciences, Jeddah, Saudi Arabia.
2. Institution of Inflammation and Aging, University of Birmingham, Birmingham, UK.
3. King Abdullah International Medical Research Center, Jeddah, Saudi Arabia.
4. Thoracic Surgery, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK.
5. School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, Birmingham, UK.

**- Authors' contributions**

Conception: BN, MA

Data extraction & cleaning: MA

Analysis and interpretation of data: MA

Draft the work: MA

Draft revision: BN, FG, JD

Approval of the version: MA, BN, FG, JD

# Abstract

**Background:**

Postoperative pulmonary complications (PPCs) significantly impact recovery following major chest and abdominal surgeries, contributing to prolonged hospital stays, intensive care admissions, and increased mortality. Prehabilitation, particularly preoperative exercise training, has shown promise in improving surgical outcomes. However, traditional face-to-face models face accessibility barriers. This study evaluated the feasibility, acceptability, and effectiveness of the Fit4Surgery (F4S) digital prehabilitation app in patients undergoing lung cancer (LC) resection and lung volume reduction surgery (LVRS).

**Methods:**

A multi-centre, non-randomised controlled observational study was conducted at Queen Elizabeth Hospital Birmingham. Eligible patients awaiting major thoracic surgery were enrolled and followed for up to six months. The F4S intervention included tailored exercise, nutrition, and behavioural support. Physical performance was assessed using the incremental shuttle walk test (ISWT) and sit-to-stand (STS) test. Patient-reported outcomes were evaluated using the EORTC QLQ-C30 and COPD Assessment Test (CAT). Engagement and acceptability were measured through app usage data and the Technology Acceptance Model (TAM) questionnaire.

**Results:**

Both LC and LVRS patient cohorts demonstrated statistically significant improvements in ISWT and STS scores from baseline to post-surgery. Improvements persisted despite lung tissue resection, suggesting enhanced physical functioning. QoL outcomes, including global health and functioning domains (physical, role, emotional, social), also improved significantly and exceeded the minimal clinically important difference (MCID). Symptom burden decreased in fatigue, dyspnoea, pain, and insomnia. CAT scores among LVRS patients showed clinically meaningful reductions, indicating improved respiratory health. Positive correlations were found between exercise time on the app and performance outcomes. Median hospital stay was 5 days (LC) and 3.5 days (LVRS), with most complications being minor (CDC grades 1–2). Only 13/38 LC and 4/10 LVRS patients experienced a PPC. Participants reported high satisfaction with the app's usability and motivational features.

**Conclusion:**

The F4S digital prehabilitation app is a feasible, acceptable, and potentially effective intervention for improving exercise capacity and QoL in thoracic surgery patients. While the findings are encouraging, further large-scale, randomised controlled trials are needed to establish the app's clinical efficacy and cost-effectiveness compared to standard care.

## 4.1 Introduction:

### 4.1.1 Problem & Importance

Over 50,000 patients each year in the UK undergo major chest or abdominal surgery, with a substantial number of patients developing serious complications that lead to extended hospital stays, intensive care admissions, and increased mortality risk [1-3]. In particular, postoperative pulmonary complications (PPCs) are among the most common and costly issues, affecting up to 20% of patients depending on surgical type [1,7]. Preventing these complications could offer significant benefits to both patients and the NHS. Evidence from systematic reviews and meta-analyses shows that structured preoperative exercise training—commonly referred to as surgical prehabilitation—can improve fitness and reduce complication rates when implemented 2 to 6 weeks before surgery [4,5].

Despite the growing evidence base, traditional prehabilitation services are typically delivered in face-to-face hospital settings, which limits accessibility due to resource constraints, travel demands, and more recently, COVID-19-related self-isolation protocols [85]. These barriers have highlighted the need for alternative delivery models that are both accessible and patient-centred. One potential solution is digital prehabilitation, which uses remote technologies to provide structured exercise, nutrition, and behavioural support programmes at home. This approach aligns with NHS goals of empowering patients to manage their own health, thus improving perioperative outcomes and reducing the burden on overstretched services [86,9].

Furthermore, digital health interventions have shown promise in other chronic disease contexts by improving patient adherence, promoting physical activity, and enhancing self-management behaviours [87]. Applying these principles to the surgical setting through digital prehabilitation could offer a feasible, low-cost method for optimising patients before surgery, especially as surgical candidates increasingly include older and more comorbid populations [8]. As the NHS continues to prioritise innovations that enhance recovery and reduce healthcare utilisation, digital prehabilitation may represent a critical advancement in perioperative care.

### 4.1.2 Study aim, hypothesis, and research question

The overarching aim of this research is to test whether the Fit 4 Surgery app (F4S), refined for a specific type of surgery, can be used before and after surgery to enhance the recovery of physical function after major elective surgery. The research will also explore whether the F4S

app is acceptable to patients and if a larger trial to evaluate the performance of the app in improving individual outcomes would be feasible.

The primary research question for this study is as follows: Is it feasible to use a personalised digital prehabilitation programme, Fit 4 Surgery (F4S), before and after surgery to enhance the recovery of physical function after major elective surgery?

The main hypothesis is as follows: Using a personalised digital prehabilitation programme, Fit 4 Surgery (F4S), before and after surgery enhances the recovery of physical function after major elective surgery

## 4.2 Research Aims and Objectives

### 4.2.1 Study aim

The overarching aim of this study is to test whether the F4S app, refined for a specific type of surgery, can be used before and after surgery to enhance the recovery of physical function after major elective surgery. The research will also explore whether the F4S app is acceptable to patients and if a larger trial to evaluate the performance of the app in improving individual outcomes would be feasible.

Feasibility studies are essential to examine the feasibility of a large and expensive full-scale study [44]. Therefore, we have designed this multi-centre feasibility study to test the efficacy of a personalised digital prehabilitation programme, F4S, for patients undergoing major surgery.

### 4.2.2 Objectives of the study

The goal of the feasibility study was to test whether the F4S app, refined for a specific type of surgery, can be used before and after surgery to enhance the recovery of physical function after major elective surgery.

### 4.2.3 Primary objective

To test if it is acceptable to patients to deliver a digital prehabilitation programme and feasible to do so before and after major surgery.

### 4.2.4 Secondary objectives

6. To assess the impact of the F4S app on surgical patients' recovery
7. To assess the effectiveness of the F4S app on the patients' quality of life throughout their surgical journey
8. To evaluate the impact of the F4S app on patients' physical capacity
9. To assess variation in use of F4S and so adherence/compliance rates

## 4.3 Study Methodology:

### 4.3.1 Ethical approval:

Ethical approval was obtained from the sponsor, namely, the University of Birmingham. Thereafter, this study received the HRA/REC approval with the reference number (22/WM/0135). Lastly, the study went through the UHB AAC process, and it was approved to open the study and start recruiting. The study was carried out following the Good Clinical Practice Guidelines and International Committee on Harmonisation principles.

### 4.3.2 Trial design:

A multi-centre controlled observational design was utilised for this study. The project team favoured a non-randomised design, as it was felt that the primary barrier to recruitment into a phase III study would be the use of F4S rather than the randomisation process itself.

### 4.3.3 Setting:

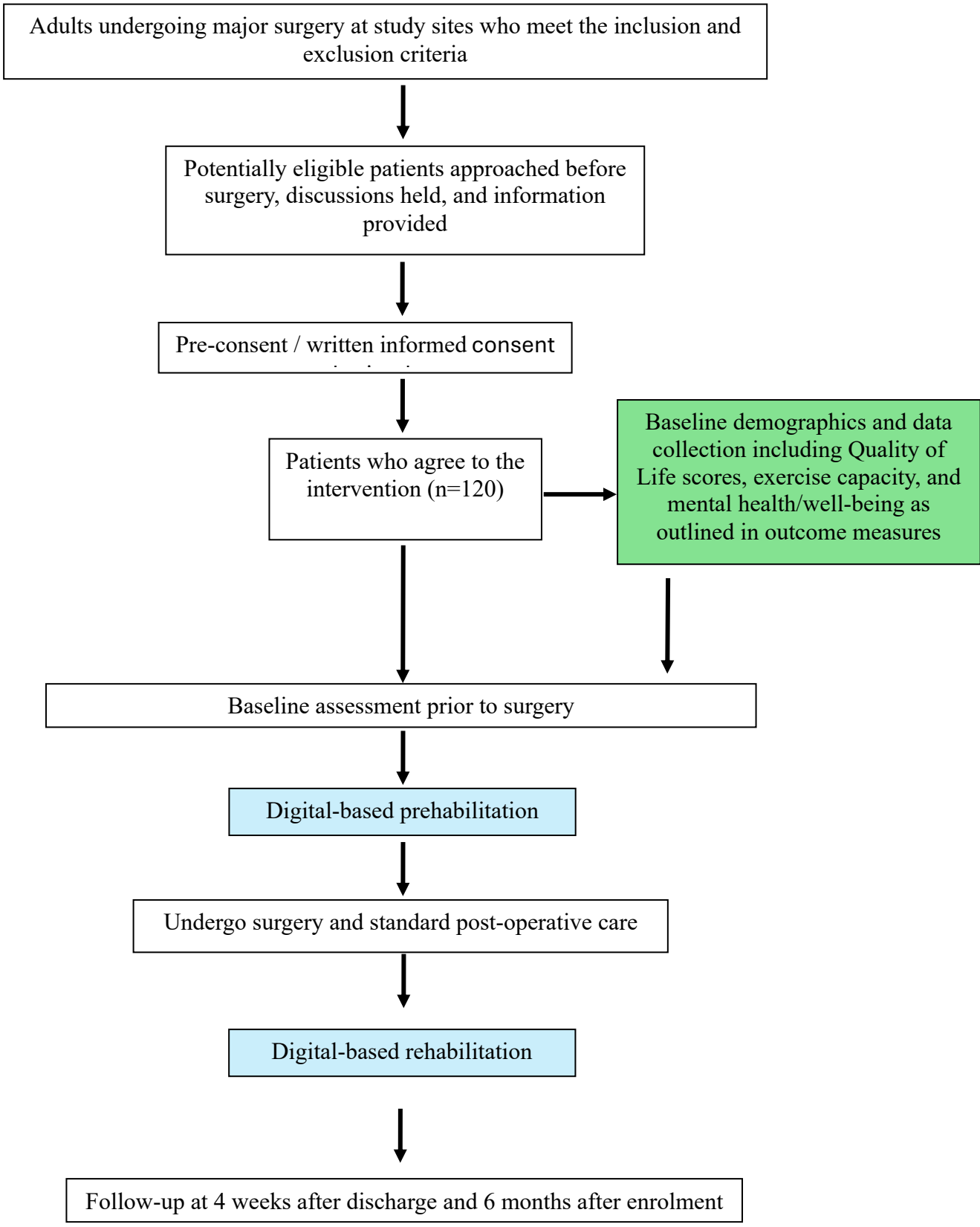
The study aimed for a recruitment period of 24 months with an additional 6-month follow-up. The initial recruitment was at Queen Elizabeth Hospital in Birmingham, UK. PIC sites directed potential participants to QE hospital without undertaking any further research activities for this study, as QE hospital is the tertiary referral centre that receives patients from surrounding hospitals. Patients listed for elective major surgery were identified and screened for eligibility in preoperative clinics and through referral letters for surgery. A surgical team member approached the patient at the preoperative screening clinic to assess their willingness to partake in the study. This clinic typically takes place two weeks before surgery due to the mandatory

self-isolation COVID-19 policy prior to surgery, allowing sufficient time to implement the intervention. Once the clinical team had initially identified probable candidates, members of the research team approached them to discuss the study and provided them with the information sheet.

### 4.3.4 Flow of participants during the trial:

The trial schema below illustrates the anticipated pathway for patients through the trial. All adults undergoing major surgery at study sites that fulfilled the inclusion and exclusion criteria were contacted to discuss the study, and written information sheets were provided. Written informed consent was obtained. Data collection was conducted both preoperatively and postoperatively, as well as through study questionnaires. Data on adverse events were collected throughout the entire study duration.

### 4.3.5 Trial Schema



### 4.3.6 Study eligibility

#### 4.3.6.1 Inclusion criteria

- Major elective surgery for benign or malignant diseases
- Able to provide written informed consent
- Before surgery at time of consent
- Age >18 years

#### 4.3.6.2 Exclusion criteria

- Emergency surgery
- Inability to perform project outcome measures

### 4.3.6 Sampling technique

Purposive sampling was utilised in this trial. Also referred to as judgement sampling, it is defined as the intentional selection of individuals based on their traits [88]. Purposive sampling is a non-random process that does not impose any underlying assumptions or a specific quantity of participants [88]. It was of benefit in this trial since the research team were already aware of what needed to be learned [88]. Purposive sampling was able to yield data that were both thorough and generalisable because participants were chosen depending on the trial's goal [89]. Thus, the sample comprised patients scheduled for major surgery who had consented to participate in the study and were willing to submit information about their knowledge or experience [88].

### 4.3.7 Sample Size:

Recruiting a very large sample size can result in unnecessary expenses and expose volunteers to research activities that are not required [90]. A small sample size, however, can produce misleading and biased results [90]. To prevent a type 2 error, that is, the failure to find a clear relationship between the objectives and the results, which is known as wrongly accepting a false null hypothesis, the sample must be statistically sufficient [91]. However, to avoid a type 1 error, that is, finding a relationship between the objectives and the results that is not there, which is known as falsely rejecting a true null hypothesis, statistical tests, such as power calculation, can be used to determine the sample size [91]. In this study, because it is a

feasibility trial, no formal sample size measurement was conducted. While sample size justification is critical, any formal calculation may not be proper, according to a study by Billingham et al. on sample size in feasibility studies [92]. The total sample size for this study, after the inclusion/exclusion criteria, was 60 participants. Thus, recruiting 60 participants would empower us to calculate compliance and recruitment rates with a 95% confidence interval (CI) width between 10 and 20%, permitting a 10% drop in our rate. It would also be sufficient to project the standard deviation (SD) of the quality of recovery scores for the upcoming preparation of a bigger trial [93].

### 4.3.8 Patient recruitment

Individuals listed for major elective surgery were assessed for eligibility based on preoperative clinic visits and referral letters for surgery. Recruitment was undertaken prospectively across preoperative outpatient clinics at three hospitals between January 2023 and March 2024. All patients who met the eligibility criteria were approached consecutively by a member of the surgical team during the preoperative screening clinic to determine their willingness to participate in the trial. In total, 136 eligible patients were approached, of whom 60 provided informed consent and were successfully recruited. Of the 76 patients who declined participation, 49 did not provide a reason, 19 reported feeling overwhelmed following a recent diagnosis of lung cancer and felt unable to engage with the study, and 8 cited limited digital literacy and lack of available support with technology as reasons for non-participation.

The preoperative screening clinic typically took place approximately two weeks before surgery, in line with mandatory COVID-19 self-isolation policies at the time, and therefore provided adequate time to implement the intervention.

The participant information sheet (PIS), constructed with comments from our PPI representative, was sent out to each patient prior to the first clinic appointment to allow the patient time to read the information and ask any questions. This was supported by discussion during the clinic appointment. If patients were happy to participate in the trial on the same day as the clinic appointment, they could do so, given that the intervention is low risk and is intended to be ’there and then’. Also, with delegated authority from the principal investigator, an appropriately trained research team member captured written informed consent or remote

consent (virtually by phone). After consent had been obtained, the patient performed the baseline assessments.

If a person who had given informed consent lost the ability to consent during the trial, they were to be removed. There would be no further data gathered, and no more study procedures performed on or in reference to the participant. However, identifiable data already collected with consent would be retained and used if the participant were to withdraw from the study. The participants were informed about this in the PIS and when their consent was being sought initially.

The participants were given a signed consent copy, with a copy being kept in the medical records. In addition, the original has been placed in the investigators' site file. Reconfirming consent was performed at every study communication, and participants could withdraw their consent at any time without reprisal and without needing to justify their decision.

### 4.3.9 F4S intervention

#### 4.3.9.1 Intervention:

F4S-2 is tailored for individual patient requirements, using baseline data gathered within the app. Particularly, the F4S app collects baseline demographic data, comorbidities, and symptom burden using simple questions and Visual Analogue Scales, and the outcome measure of QoL, health and wellbeing scores (see outcome measures in 4.3.10). This information is utilised to deliver personalised feedback, support, and guidance when using the F4S app, e.g., if the patient were diabetic, then they would receive guidance on avoiding a hypo.

The digital programme or 'app' comprises three prehabilitation interventions:

1. STRUCTURED HOME EXERCISE PROGRAMME - Patients are steered through a series of screens to build their own programme, including a variety of strengthening, mobility, and cardiovascular exercises. Baseline recommendations on programme level/ intensity are made based on a 'Sit to Stand test' (STS) preformed within the F4S app. Once the programme is created, patients are stimulated to preform PA daily to achieve at least 30 minutes of exercise/week in accordance with pulmonary rehabilitation guidelines [94]. Their heart rate is documented using a wearable sensor provided free of charge to the patients. Once each exercise

session is completed, the patient inputs their perceived intensity using the BORG perceived exertion scales into the F4S app [95]. This data is used to motivate patients through personalised messages, encouraging them to adjust exercise intensity in the next session to reach the target BORG perceived exertion level, in line with rehabilitation guidelines [94]. Regular data uploads enable HCPs to monitor patients' progress, while the app allows patients to request support from their HCP when needed. Patients can also log other activities they do, such as swimming or running. Although the program mainly targets pre-surgery, exercise can also aid recovery after surgery [96]. Therefore, patients were allowed to continue using the program post-surgery, with it being adapted or reset based on their performance in the post-surgery 'STS test' (performed on postoperative day 1).

2. INDIVIDUALISED NUTRITIONAL CONDITIONING- At the point of enrolment, patients filled out a nutritional screening questionnaire called the Patient-Generated Subjective Global Assessment (PG-SGA score) within the app [97]. This assessment helps customise nutritional advice and supplementation according to symptoms and nutritional risk. All patients were advised, using a "ready reckoner," to consume a high-protein (20g) snack within 90 minutes of exercise to promote muscle protein synthesis and support a positive protein balance. Patients recorded in the app when they had taken a protein snack. Patients classified as 'medium risk' (PG- SGA score 4-9) began a regimen of a low-volume, high-calorie, high-protein oral nutritional supplement (ONS), providing 20g of protein twice daily until surgery. High-risk patients (score $\geq 9$) began supplementation as described above and were referred to a dietitian for optimising their supplement regimen [97, 98]. We conducted a prospective audit in a busy thoracic surgery unit, identifying that 9% of patients fell into the high-risk category. While the programme mainly concentrates on pre-surgery preparations, it recognises that following surgery, calorie and protein needs are elevated, even though intake might be limited due to the side effects of the surgery. Therefore, nutritional intervention continued for 2 weeks post-surgery. Patients completed the PG-SGA score using the app on postoperative day 1 and based on this, therapy was tailored as described above.

3. PERSONALISED HEALTH INFORMATION Within the app, short informational videos with subtitles present relevant information. This content adapts based on symptom data and whether the patient is pre- or post-surgery, as recorded in the app. For instance, if a patient reports feeling breathless, guidance on managing this is shown. Surgery-related information appears prominently before surgery, while post-surgery content focusing on recovery and

symptom management, such as pain control, is highlighted afterward. Additional details about the program are available at www.Fit4surgery.uk.

### 4.3.10 Outcomes measures

#### 4.3.10.1 Primary

Qualitative interviews and technology acceptance questionnaires with patients were undertaken to provide an in-depth understanding of how F4S had been used, including compliance in practice and the barriers and facilitators to its optimal use. At the exit interview, we also assessed how well the recovery scores (outlined below) had captured the patient experience.

#### 4.3.10.2 Secondary

**1**. The primary outcome of the potential substantive study was patient recovery, assessed by questionnaires, 1 month post-surgery. In the feasibility study, we planned to measure at baseline, on the day of surgery, during hospital stay, day of hospital discharge, 6 weeks after surgery, and 6 months after surgery (Table 4.1):

A. Patient reported outcomes: generic health (EQ-5D-5L), and disease specific (e.g., EORTC-QLQ-C30)-related quality of life.

B. Exercise capacity by incremental shuttle walk test (ISWT) is an essential secondary outcome measure following rehabilitation studies [99,100].

C. Mental health/well-being, both negative due to the prevalence of anxious and depressive symptoms, were calculated utilising the 14-item Hospital Anxiety and Depression Scale; [101] and positive, subjective vitality was measured using the Subjective Vitality Scale, a 5-item scale assessing an individual's feelings of personal energy [102].

**2.** CLINICAL OUTCOMES - Complication rates were determined through a modified Clavien-Dindo classification (CDC) system, along with its derivative, the comprehensive complication index [103,104], as well as metrics such as hospital length of stay, high dependency or intensive care duration, 30-day mortality, and readmission rates.

***Table 0.1: Table of Outcome Measures***

| **Outcome measure** | ***Time points*** | | | | | |
|---|---|---|---|---|---|---|
| | ***Baseline clinic prior to surgery*** | ***Day of surgery*** | ***During hospital Stay*** | ***Day of hospital discharge*** | ***6 weeks (± 2 weeks) after surgery*** | ***6 months after surgery*** |
| *Collected by Paper* | | | | | | |
| *Eligibility and written informed consent*[1] | *X* | | | | | |
| *Demographic data*[2] | *X* | | | | | |
| *Previous medical history*[3] | *X* | | | | | |
| *Disease specific (e.g., EORTC-QLQ-C30)-related quality of life* | *X* | *X* | | | *X* | *X* |
| *Incremental shuttle walk test (ISWT)* | *X* | | | | *X* | |
| *Technology Acceptance Model (TAM)* | | | | | *X* | |
| *Surgery and anaesthetic data*[4] | | *X* | | | | |
| *Postoperative complications*[5,67] | | | *X* | *X* | *X* | |
| *Hospital readmission*[7] | | | | | *X* | |
| *Semi structured qualitative interviews*[8] | | | | | *X* | |

| *Collected through the F4S app* | | | | | | |
|---|---|---|---|---|---|---|
| Generic health EQ-5D-5L | *X* | | | | *X* | |
| Sit-to-Stand (STS) | *X* | *X* | *X* | *X* | *X* | |
| *Hospital Anxiety and Depression Scale (Conditional)* | *X* | *X* | *X* | *X* | *X* | *X* |
| *Subjective Vitality Scale (SVS)* | *X* | *X* | *X* | *X* | *X* | |

1) Continued verbal consent was obtained at each time point throughout the study duration.
2) Demographic data: gender, age, indication for surgery, height, weight, BMI, ASA grade, ECOG score, dyspnoea score, recent lung function from simple spirometry, operation type, and pathology.
3) Previous medical history: smoking history, alcohol intake per week, co-morbidities (COPD, ischaemic heart disease, congestive cardiac failure, hypertension, diabetes (diet-controlled/ oral therapy/ insulin), renal failure, previous stroke, thyroid disease (hyperthyroid/ hypothyroid).
4) Operation performed (surgical technique, site of surgery, operation).
5) **Post-operative data and observations**: routine blood results if done (full blood count, albumin, renal function, electrolytes, CRP).

   **Acute complications**: According to the CDC, data collected after surgery also included admission and length of stay on the ward (0), step-down (1), HDU (2), and ITU (3). Data was also collected from patients requiring mini-tracheostomy or further surgery.

   **Post-operative surgical complications:** using the Comprehensive Complication Index (CCI) after Surgery definitions of postoperative complications. Discharge data: LOS, home with flutter bag, histology data, and mortality.
6) Follow-up: Hospital readmission within 1 month following hospital discharge.
7) Between 4 and 8 weeks after surgery, patients also participated in semi-structured qualitative interviews. These interviews aimed to explore their experience, engagement, acceptability, unexpected outcomes or benefits, and ways to improve the intervention delivery. The findings from these interviews are presented in Chapter 5.

### 4.3.11 Questionnaires used for data collection

A literature search was carried out to explore related questionnaires of similar studies. The search was guided by the best principles of practice to select the highest quality of questions; hence, general and leading questions were avoided [105]. After evaluating the available questionnaires, TAM [106], generic health (EQ-5D-5L) [107], disease specific (EORTC-QLQ-C30 [59], and CAT [34])-related quality of life, and mental health/well-being HADS [101] were chosen as the most appropriate tools for this study. Permission was sought from and granted by EQ-5D and EORTC to use their questionnaires in this study (Appendices 8.5 and 8.6). Permission was not sought from the CAT and HADS since they are available for public use [108, 101].

Since the TAM was implemented to assess the acceptability of the F4S programme validity, reliability tests needed to be performed. Validity and reliability are used to examine the research quality, since they indicate how good the technique, method, or test is in measuring something [109]. Validity is the degree to which the questionnaire's questions reflect the problem being investigated [110]. According to Kimberlin and Winterstein (2008), reliability is a measure's ability to achieve consistent results when applied multiple times on an object under the same circumstances, which is also known as 'consistency of measurement' [111]. The study's validity and reliability for most of the questionnaires used were valid since they have been used in many published clinical trials and frequently used in this topic area, and they are considered reliable and valid [112]. Regarding the TAM questionnaire, the validity, reliability, and consistency of measurement tests were completed and can be found the results section.

### 4.3.12 Data analysis

A normality test was conducted to ensure the normal distribution of the data. The advantage of performing a normality test is to determine whether to use parametric or non-parametric tests and decide which would be suitable for analysing the data [113]. This minimises errors and increases the reliability of the study's results [113]. The normality tests showed the data were normally distributed and, thus, parametric statistical tests were utilised for the current study's findings [113].

To achieve the study objectives and analyse the collected data, several statistical methods were used, including RStudio version 2024.04.2+764. This program is usually utilised to analyse the

quantitative data in healthcare studies [114]. Frequencies and percentages were calculated to describe the study participants' demographic and clinical characteristics. The mean and standard deviation (SD) and median interquartile range (IQR) were used to summarise responses across various study sections. The Shapiro-Wilk normality test was performed to assess data distribution before conducting further analyses. For comparisons of exercise capacity pre- and post-surgery, a paired t-test was used to evaluate changes in ISWT scores. A Repeated Measures Analysis of Variance (ANOVA) test was used to assess differences in STS scores across multiple time points (baseline, pre-surgery, and 6 weeks post-surgery). Pearson correlation tests identified relationships between exercise time on the F4S app and performance in physical tests. Post-hoc pairwise comparisons with Bonferroni correction were conducted to determine specific differences of the EORTC QLQ-C30 responses between different time points. Statistical significance was set at $p \leq 0.05$.

#### 4.3.13 Ethical consideration:

Personal data and sensitive information were acquired directly from the trial's participants and hospital records on data collection forms for this investigation. It was then coded with each participant’s unique trial number and initials. Under NHS policies, all personal information collected in paper form was securely stored and handled with the utmost care during the trial as extremely confidential. Patients participating in the semi-structured qualitative interviews provided consent for their name, contact telephone number, and address to be shared with UoB. This information was used to facilitate telephone or face-to-face interviews as part of the trial. To mitigate the risk of loss of confidentiality to the interview response, these were not designated with personally identifiable information. These data are being stored. Interview response data are being preserved encrypted on a locked office computer. All study personnel, both clinical and academic, provide the same level of care to prevent unauthorised disclosure of private information details. No identifying information about an individual was or will be disclosed to the public. Under the requirements of the Data Protection Act (2018) and/or applicable laws and regulations, data are being saved on a secure server at Queen Elizabeth Hospital [115]. External regulatory bodies and research sponsor representatives may review the data, with participants' consent for this access documented on the consent form.

All interview audio recordings were stored securely on the trust system until anonymised and will be retained for 10 years in accordance with UoB's data storage policy. Data transfer was

conducted using secure methods in accordance with UoB IT protocols guidance. Personal data will be retained for 12 months. The F4S app will contain the data entered by participants about themselves and their exercise, along with the patient-reported outcome measures detailed in section 4.3.10. This data was stored solely within the app during the period patients were using it. All data were transferred through UHB.

### 4.3.14 Study dissemination:

This feasibility study aimed to determine whether a larger trial is feasible. While a definitive assessment of the F4S app's effectiveness in major surgery isn't available, this study's findings would still be scientifically valuable to others. The feasibility study was registered on https://www.isrctn.com/ (ISRCTN). Four strands form the dissemination strategy. The initial step will ensure that patients and the public are properly informed about the trial's findings. The second step will involve local practitioners and healthcare planners in implementing the findings. The third step will involve collaborating with policymakers to achieve maximum impact. Finally, the plan is to enhance the influence of this research by publishing its results in relevant journals and presenting them at appropriate local and international conferences. If its efficacy is proven, the research will be conducted internationally, extending beyond the scope of the UK.

### 4.3.15 Funding:

The research costs of the study were funded by a grant from University Hospitals Birmingham (UHB) Charity.

## 4.4 Results

### 4.4.1 Lung Cancer Surgery Cohort

#### 4.4.1.1 General Patient Characteristics

A total of 38 patients were recruited from 2022 until 2023 who underwent lung cancer surgery and were included in the statistical analysis. The participants' baseline characteristics and clinical data are shown in Table 4.2.

**Table 0.2: The distribution of the overall study sample according to *their characteristics (n=38)***

| Characteristic | Median (IQR); Range; n (%) |
|---|---|
| **Gender** | |
| **Male** | 21 (55%) |
| **Female** | 17 (45%) |
| **Age** | 70 (66, 76) |
| **BMI** | 27.5 (25, 30.5) |
| **Baseline lung function** | |
| **Preop_FEV1** | 2.19 (1.47, 2.62) |
| **Preop_FEV1P** | 76 (62, 94) |
| **Preop_FVC** | 3.23 (2.40, 4.00) |
| **Preop_FVCP** | 94 (77, 101) |
| **DLCO_P** | 81 (68, 96) |
| **FEV1/FVC** | 73 (61, 77) |
| **Pre-op smoking (self reported)** | |
| **Current** | 8 (22%) |
| **Ex** | 20 (54%) |
| **Never** | 9 (24%) |
| **Quit time** | |
| **Current** | 7 (19%) |
| **Ex < 6 weeks** | 2 (5.4%) |
| **6 weeks-1year** | 3 (8.1%) |
| **Ex > 1 year** | 16 (43%) |
| **never smoked** | 9 (24%) |
| **Unknown** | 1 |
| **Pack years** | 24 (2, 40) |
| **COPD** | 14 (38%) |
| **Obstructive Spirometry** | 37 (100%) |
| **Unknown** | 1 |
| **IHD** | 0 |

| | |
|---|---|
| **Cardiac failure** | 1 (2.7%) |
| **Hypertension** | 16 (43%) |
| **Diabetes** | |
| **Non** | 33 (89%) |
| **Diet** | 3 (8.1%) |
| **Oral** | 1 (2.7%) |
| **Insulin** | 0 |
| **renal failure** | 1 (2.7%) |
| **ASA Score** | |
| **Normal Healthy Patient** | 2 (5.4%) |
| **2** | 28 (76%) |
| **3** | 6 (16%) |
| **4** | 1 (2.7%) |
| **Stroke** | 1 (2.7%) |
| **Thyroid** | |
| **Non** | 34 (94%) |
| **Hyper** | 2 (5.6%) |
| **Hypo** | 0 |
| **Unknown** | 2 |
| **Anticoag** | |
| **0** | 35 (95%) |
| **1** | 0 |
| **2** | 0 |
| **3** | 2 (5.4%) |
| **4** | 0 |
| **5** | 0 |
| **Unknown** | 1 |
| **ECOG** | |
| **0** | 20 (54%) |
| **1** | 16 (43%) |
| **2** | 2 (5.4%) |
| **3** | 0 |
| **4** | 0 |
| **Unknown** | 1 |
| **Dyspnoea MRC** | |
| **0** | 12 (32%) |
| **1** | 23 (62%) |
| **2** | 2 (5.4%) |
| **3** | 0 |
| **4** | 0 |

| | |
|---|---|
| **other cancer** | 2 (5.4%) |
| **Unknown** | 1 |
| **alcohol excess** | 3 (8.1%) |
| **Unknown** | 1 |

Data are presented as mean (median), standard deviation (interquartile range), or numbers and percentages for categorical data. COPD; chronic obstructive pulmonary disease, IHD; ischemic heart disease, ASA; American Society of Anaesthesiologists, ECOG; The Eastern Cooperative Oncology Group, $FEV_1$; forced expiratory volume for 1 second, DLCO; diffusing capacity for carbon monoxide.

Table 4.2 represents the baseline demographic and general characteristics data for 38 patients. The median age is 70 years old, and around half of the patients are male. The mean BMI for 38 is 27.5. The majority of the patients reported they had quit smoking before their surgery. It can be seen that 43% of the patients suffered from hypertension, and 38% had chronic obstructive pulmonary disease (COPD).

**Table 0.3: The distribution of the overall study sample according to *their surgery characteristics (n=38)***

| Characteristic | Median (IQR); Range; n (%) |
|---|---|
| **Surgery** | |
| **Yes** | 38(100%) |
| **No** | 0 (0%) |
| **Incision** | |
| **Thoracotor** | 3 (7.9%) |
| **VATS** | 32 (84%) |
| **Unknowen** | 3 (7.9%) |
| **Side** | |
| **Right** | 22 (58%) |
| **Lift** | 13 (34%) |
| **Lobe** | |
| **Upper** | 16 (42%) |
| **Lower** | 15 (39%) |
| **Entire Lung** | 2 (5.3%) |
| **Upper Bilobe (UL/ML)** | 1 (2.6%) |
| **Multiple** | 0 |
| **Lower Bilobe (ML/LL)** | 1 (2.6%) |
| **Middle** | 0 |
| **Unknown** | 3 (7.9%) |
| **Analgesia** | |
| **Unknown** | 3 (7.9%) |

| | |
|---|---|
| **Intrathecal morphine** | 2 (5.3%) |
| **Paravertebral** | 30 (79%) |
| **PCA** | 3 (7.9%) |

Data are presented as mean (median), standard deviation (interquartile range), or numbers and percentages for categorical data. VATS; video-assisted thoracic surgery, PCA; Patient-controlled analgesia.

Table 4.3 shows the surgery characteristics data for 38 patients. Most patients underwent the surgery using the VATS technique (Table 4.3).

Table 4.4 shows the clinical outcomes focusing on the modified CDC system, the CCI during hospital stay and one month following surgery, LOS in hospital, 30-day mortality, and readmission rates, and PPC during hospital stay and one month following surgery.

***Table 0.4: Descriptive Statistics of Clinical Outcomes (n=38)***

| **Clinical outcome (n = 38) (na = 3) (7.9%)** | **Median (IQR)** |
|---|---|
| **LOS** | 5 (3 – 9.5) |
| **PPC**<br>Yes = 13 (34.2%)<br>No = 22 (57.9) | |
| **CDC stage**<br>I = 1 (7.7%)<br>II = 4 (30.8)<br>I/II = 3 (23.1%)<br>I/II/IIIa = 2 (15.4%)<br>IIIa = 2 (15.4%)<br>Iva = 1 (7.7%) | |
| **CCI** | 0 (0 – 20) |
| **PPC 1 month**<br>Yes = 2 (5.3%)<br>No = 33 (86.8%) | |
| **CDC 1 month**<br>I = 1 (50%)<br>II = 1 (50%) | |
| **CCI 1 month** | 0 (0 – 0) |
| **30 days readmission**<br>Yes = 2 (5.3%)<br>No = 33 (86.8%) | |
| **Hospital mortality**<br>No = 35 (92.1%) | |

Data are presented as mean (median), standard deviation (interquartile range), or numbers and percentages for categorical data. CDC; Clavien-Dindo classification, CCI; comprehensive complication index, LOS; length of stay, PPC; post-operative pulmonary complications.

Table 4.4 demonstrates that the median LOS for the lung cancer resection surgery patients in this study is 5 days. Interestingly, only 13 patients had a complication event after surgery while in hospital and only 2 patients had an event 1 month post-surgery (Figure 4.1). The CDC is a

standardised system used to grade surgical complications based on the severity of the intervention required to treat them. It categorises postoperative complications into five grades, and most of the patients in Table 4.4 were in grade 2, which requires minimal intervention (Figure 4.2). The CCI complements the CDC by quantifying the overall burden of postoperative complications. It sums all postoperative complications, weighted by their severity, into a single score ranging from 0 to 100 and as evident in the above table, the mean CCI score at hospital stay was 9 and at 1 month was 0.8 which indicates a mild complication after surgery.

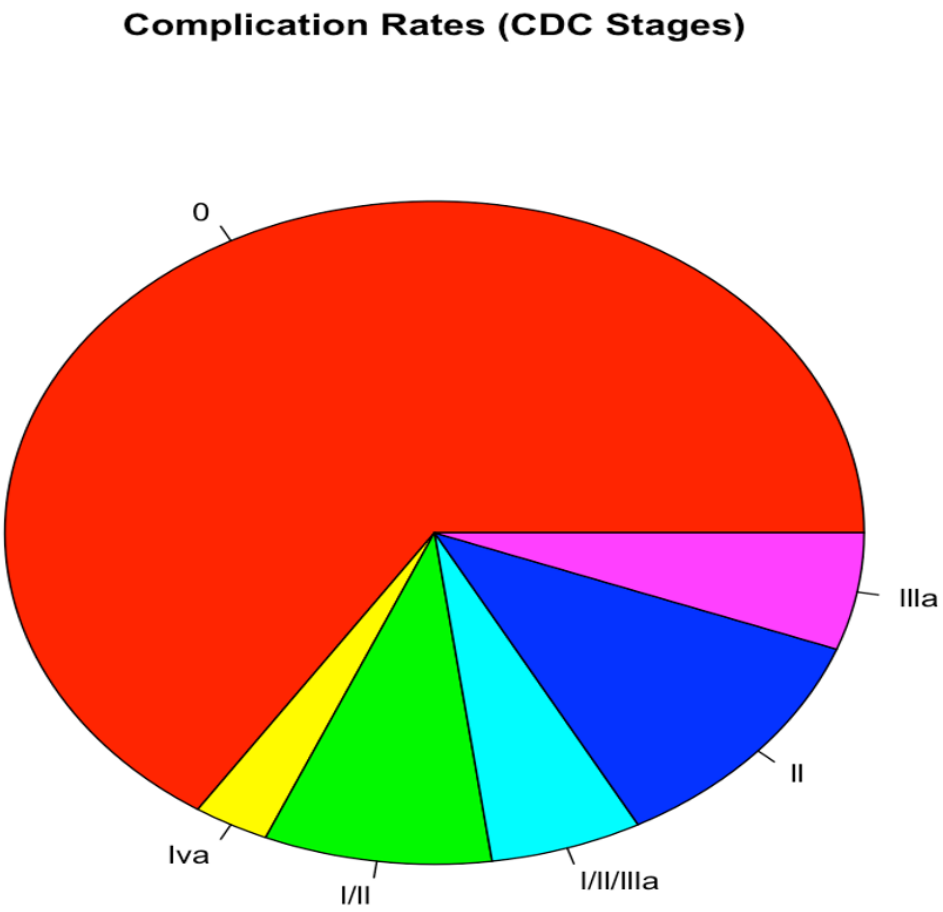



***Figure 0.1: Proportional Distribution of Postoperative Complications by Clavien-Dindo Classification Stages.***

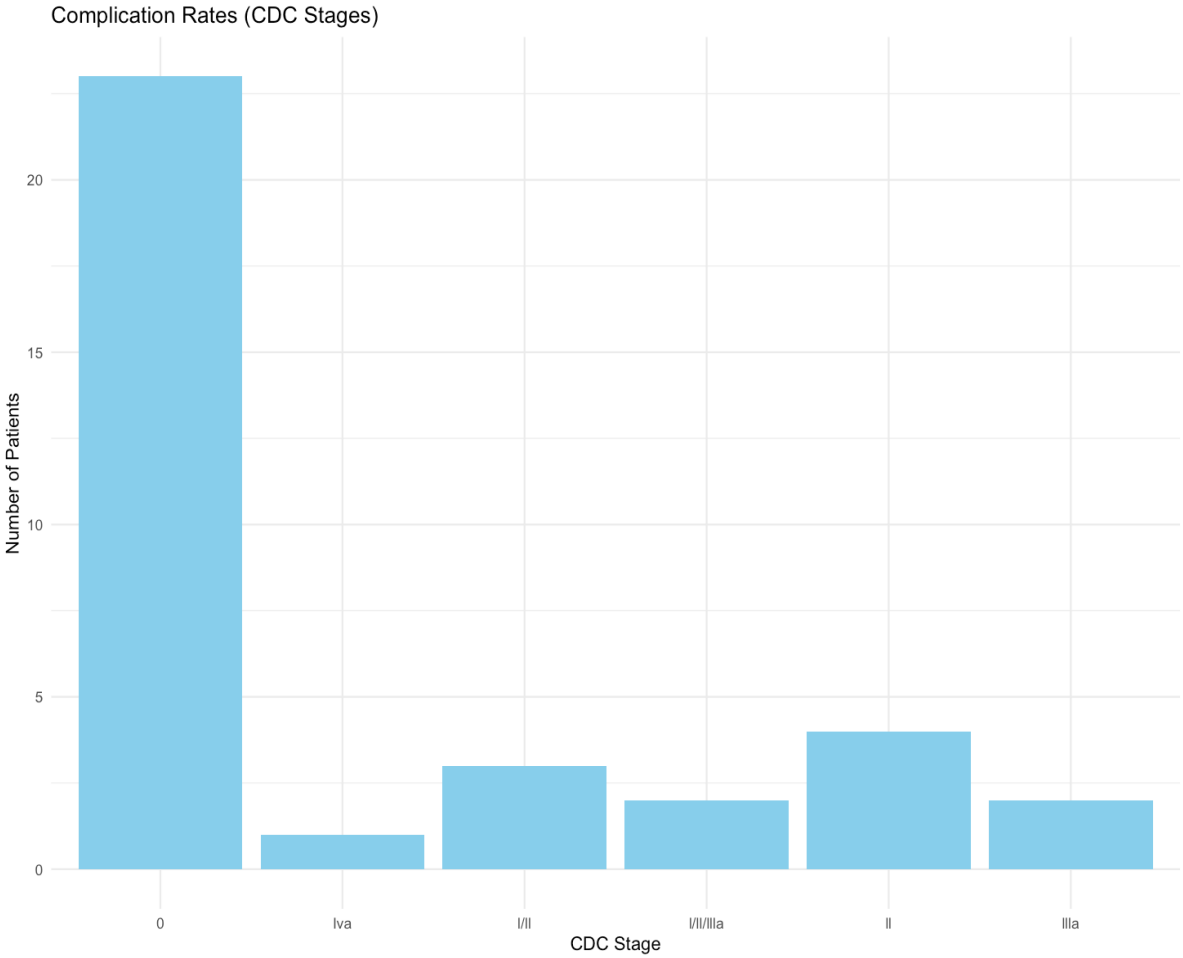



***Figure 0.2: Distribution of Postoperative Complication Rates by Clavien-Dindo Classification Stages.***

Given that only 13 out of the 38 participants experienced a complication, performing a regression analysis might be challenging due to the small sample size and the low event rate. This situation can lead to several issues, including overfitting and model convergence issues.

#### 4.4.1.2 Patient Exercise Capacity:

The ISWT and STS tests were collected from the patients at different time points in order to have a better understanding of the impact of the F4S app on the patients' exercise capacity (Table 4.5). Table 4.5 also shows the added physical activity by the patients within the app, exercise sessions performed before, during, and after surgery, total exercise time, and weekly average minutes of exercise.

**Table 0.5: The distribution of the overall study sample according to *their characteristics (n=38)***

| Characteristic | Median (IQR); Range; n (%) | Mean |
|---|---|---|
| **ISWT** | | |
| **Pre-rehab** | 259 meters (140, 350) | Unknown = 1 |
| **Post-rehab** | 360 meters (260, 510) | Unknown = 5 |
| **STS** | | |
| **Baseline** | 17.0 (11.0, 18.8) | |
| **pre-surgery** | 16.5 (15.0, 20.8) | Unknown = 24 |
| **1 month post surgery** | 20 (16, 25) | Unknown = 18 |
| **Added Physical Activity** | | 1.8 |
| **Exercise Sessions Performed** | | |
| **Pre-surgery** | 2 (2, 7) | 14.8 |
| **Post-surgery** | 0 (0, 2) | 12.6 |
| **Total** | 3 (2, 9) | 27.4 |
| **Total exercise time minutes** | 20 (10, 60) | 115 |
| **Weekly average minutes** | 3 (1, 9) | 16.1 |

Data are presented as mean (median), standard deviation (interquartile range), or numbers and percentages for categorical data. ISWT; Incremental shuttle walk test, STS; Sit to stand.

Table 4.5 indicates that each patient added on average two physical activities during their time of using the app. In addition, patients performed 15 exercise sessions before surgery compared to 12.6 sessions of exercises after surgery with the average of total exercise sessions performed by each patient to 27.4. The total exercise minutes within the app is 115 minutes on average for each participant with the weekly average of 16.1 minutes.

#### 4.4.1.2.1 Incremental shuttle walk test:

To determine the effect of the F4S app on the exercise capacity, patients performed the ISWT twice, the first time when they were recruited before surgery and then 6 weeks after surgery. Figure 4.3 is a histogram representing the differences in the ISWT data, comparing pre-surgery and post-surgery results.

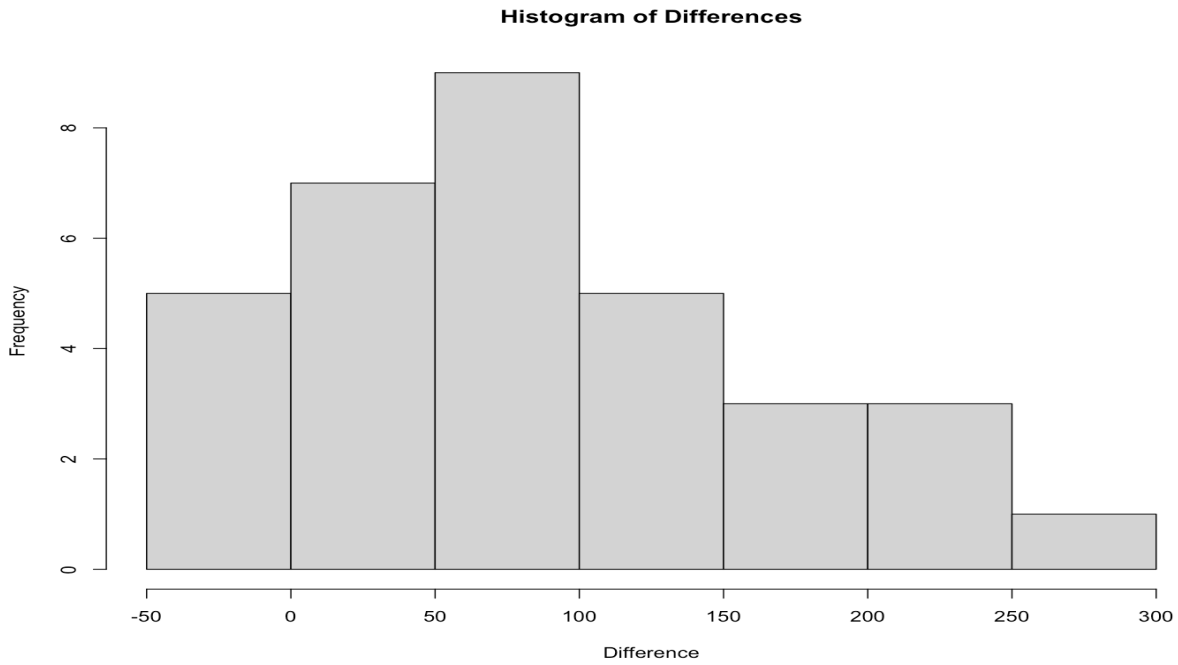



***Figure 0.3: A histogram representing the differences in ISWT data.***

Figure 4.3 shows that the largest number of patients experienced a positive change in their ISWT scores, particularly in the range of 50 to 100 metres, which suggests that most patients experienced an improvement in their ISWT scores post-surgery, with a clinically significant number showing an increase of around 100 metres. There are a few outliers with very high positive differences (200–300 metres), showing a significant improvement in their exercise capacity. Since there are a few outliers, a normality test is required to choose a suitable the statistical test for further analysis of the ISWT data.

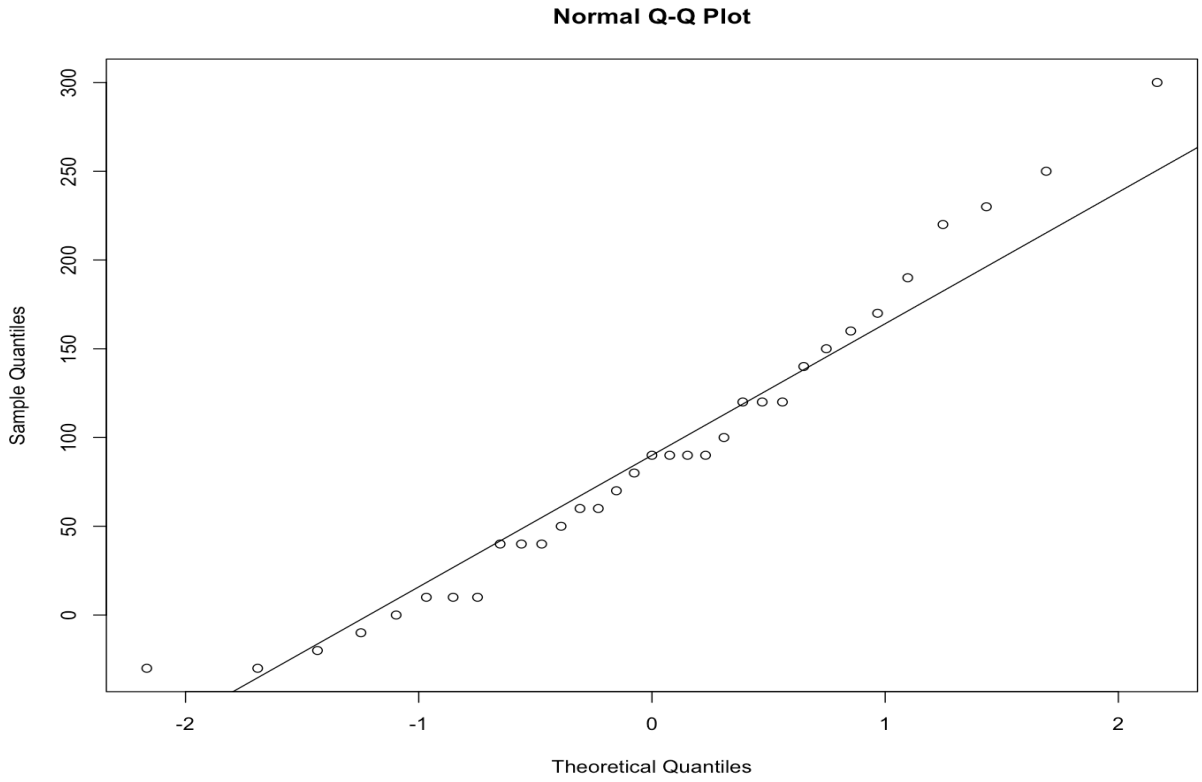



***Figure 0.4: Normal Q-Q (Quantile-Quantile) plot to assess the distribution of the ISWT data.***

Figure 4.4 points out that the ISWT data generally follows a normal distribution in the central region, but there are some deviations in the tails, suggesting possible outliers or a non-normal distribution at the extremes. Therefore, a Shapiro-Wilk normality test was conducted (p=0.2219), and based on the p value, the ISWT data can be considered normally distributed. Since the ISWT data are normally distributed, we performed the paired t-test to assess the difference between ISWT before and after surgery for patients who used the F4S app; the aim was to determine whether that difference is statistically significant. There was a statistically significant increase in ISWT scores from pre-surgery to post-surgery (p=0.000). Given the extremely small p-value and the positive mean difference (mean difference 91.21), we can conclude that the patients' exercise capacity, as measured by the ISWT, significantly improved after lung cancer resection surgery.

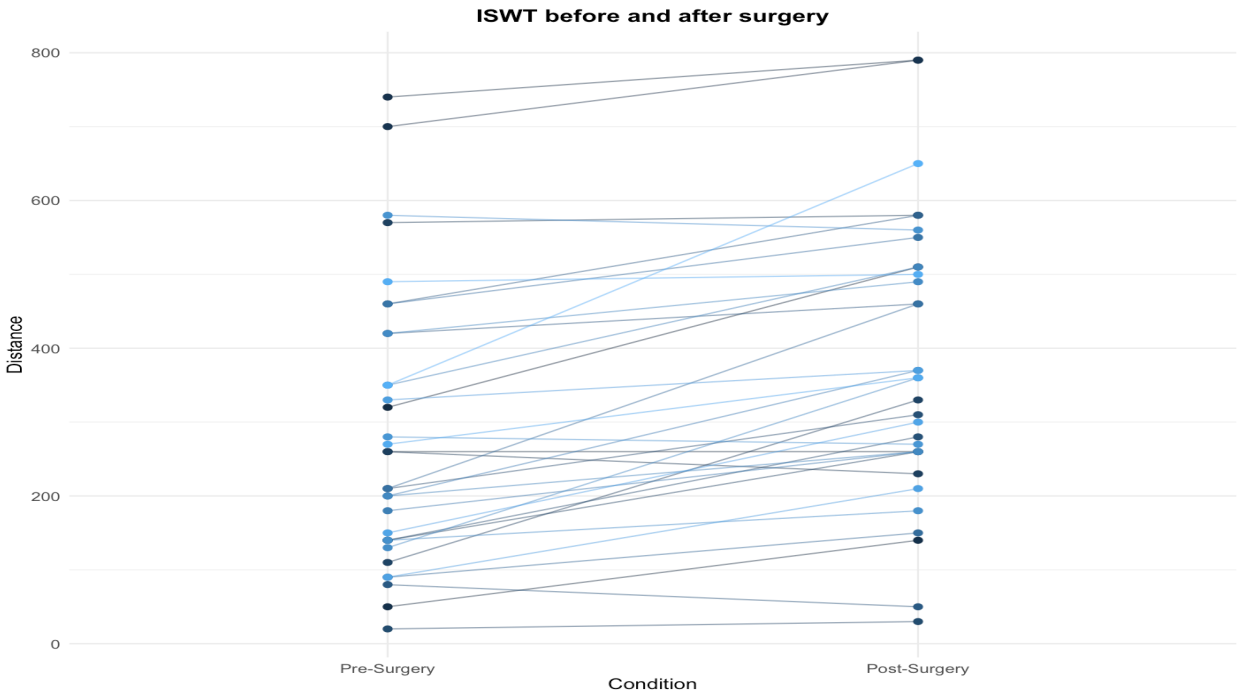



***Figure 0.5: Line plot that compares ISWT distances before and after surgery for individual patients.***

Furthermore, Figure 4.5 indicates that the majority of the lung cancer patients experienced an increase in their ISWT distance following surgery, which supports the idea of improved physical function post-surgery for most patients, though not all. This aligns with the previous statistical analysis showing a mean improvement in ISWT scores post-surgery. The almost 100 metre improvement after surgery compared to before starting the F4S rehabilitation programme is actually considered a clinically significant improvement, since the minimum is 40 metres.

#### 4.4.1.2.2 Sit to Stand test:

STS is another physical test used by patients to measure their physical capacity while rehabilitating through the F4S programme. The patients performed the STS tests at three different time points: upon recruitment, on the day of surgery, and 6 weeks after surgery. Table 4.6 presents the STS test data, including the mean (SD) scores at three time points (pre-surgery, day of surgery, and 6 weeks post-surgery), along with the p-values from the repeated measures ANOVA test.

***Table 0.6: STS test at three different time points***

| **STS** | **Mean (SD)** | **P Value** |
|---|---|---|
| **Pre-surgery** | 15.3 (5.19) | ***0.00 |

| | | |
|---|---|---|
| **Day of surgery** | 17.5 (6.47) | ***0.00 |
| **6 weeks post-surgery** | 20.8 (7.46) | ***0.00 |

Statistical tests: Repeated measures ANOVA. Data are presented as mean (median) and standard deviation (interquartile range). *p<0.05; **p<0.01; ***p<0.001

Table 4.7 shows an improvement in the STS scores in which the mean number of sit-to-stands increases progressively from baseline (15.3) to pre-surgery (17.5) and 6 weeks post-surgery (20.8). This suggests an improvement in physical function over time. In addition, the table shows that the p-values (p<0.001) across all time points indicate that the changes in STS scores are statistically significant. Thus, the repeated measures ANOVA test confirms that there is a statistically significant improvement in STS performance from pre-surgery to post-surgery, indicating enhanced physical function over time.

***Table 0.7: A post-hoc pairwise comparison of STS performance at different time points***

| Time points | Baseline vs pre-surgery Difference | P value | 95% CI | Baseline vs 6 weeks Difference | P value | 95% CI | pre-surgery vs 6 weeks Difference | P value | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| STS | 2.2 | 1.00 | 13.3 -17.3 | 5.5 | *0.00 | 13.6 – 19.6 | 3.5 | *0.00 | 18.4 – 23.6 |

Post-hoc pairwise comparison with Bonferroni correction. Statistical tests: paired t-test or Wilcoxon signed-rank test. *p<0.05; **p<0.001

Table 4.7 presents a post-hoc pairwise comparison of STS performance at different time points (baseline, pre-surgery, and 6 weeks post-surgery), using Bonferroni correction for multiple comparisons. The aforementioned table reveals that there is no significant difference in STS performance between baseline and pre-surgery (p=1.00). However, there is a statistically significant improvement in STS performance from baseline and 6 weeks post-surgery and pre-surgery to 6 weeks post-surgery (p=0.0024, p=0.0207), suggesting that the patients experienced a noticeable increase in physical function before surgery and during the recovery period. Hence, this post-hoc analysis indicates that the most meaningful improvements in patients' STS performance occurred between baseline and 6 weeks post-surgery.

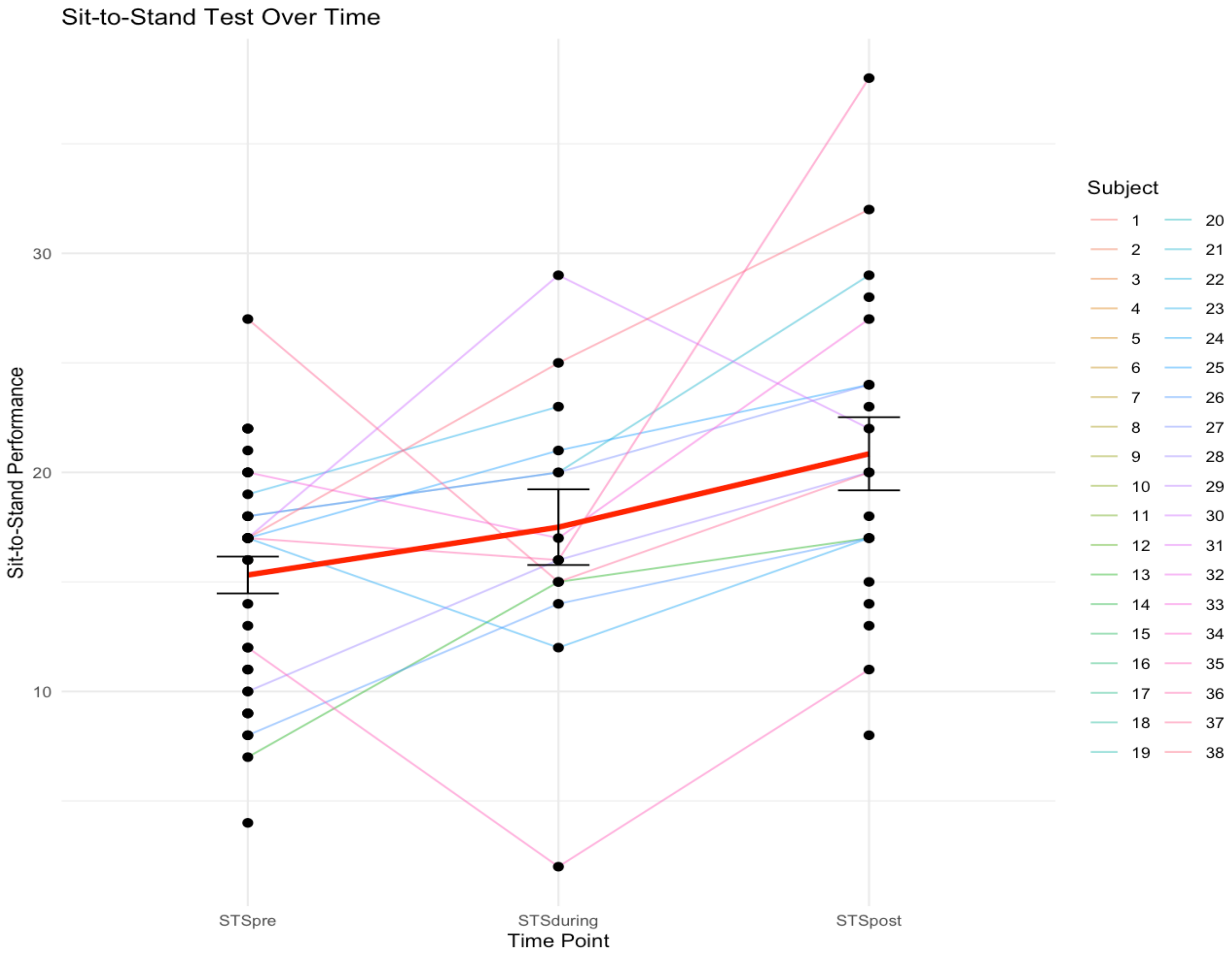



***Figure 0.6: line plot that compares STS performance over three time points for individual patients.***

Figure 4.6 illustrates the STS performance over three time points: baseline (STSpre), pre-surgery (STSduring), and 6 weeks post-surgery (STSpost) for individual participants. The above figure demonstrates that, on average, as evident by the bold red line, there is a notable improvement in STS performance from pre-surgery to post-surgery, with a moderate increase pre-surgery. However, individual responses vary significantly. This aligns with the statistical findings that suggest significant improvements in exercise capacity pre-surgery to 6 weeks post-surgery for many patients.

#### 4.4.1.2.3 Associations between exercise and performance:

One of the goals of this study is to examine whether the patients' exercise time on the F4S app is associated with their performance on the ISWT and STS tests. Figure 4.7 is a correlation matrix plot that visualises the relationships between exercise time on the F4S app, ISWT performance, and STS performance at different time points.

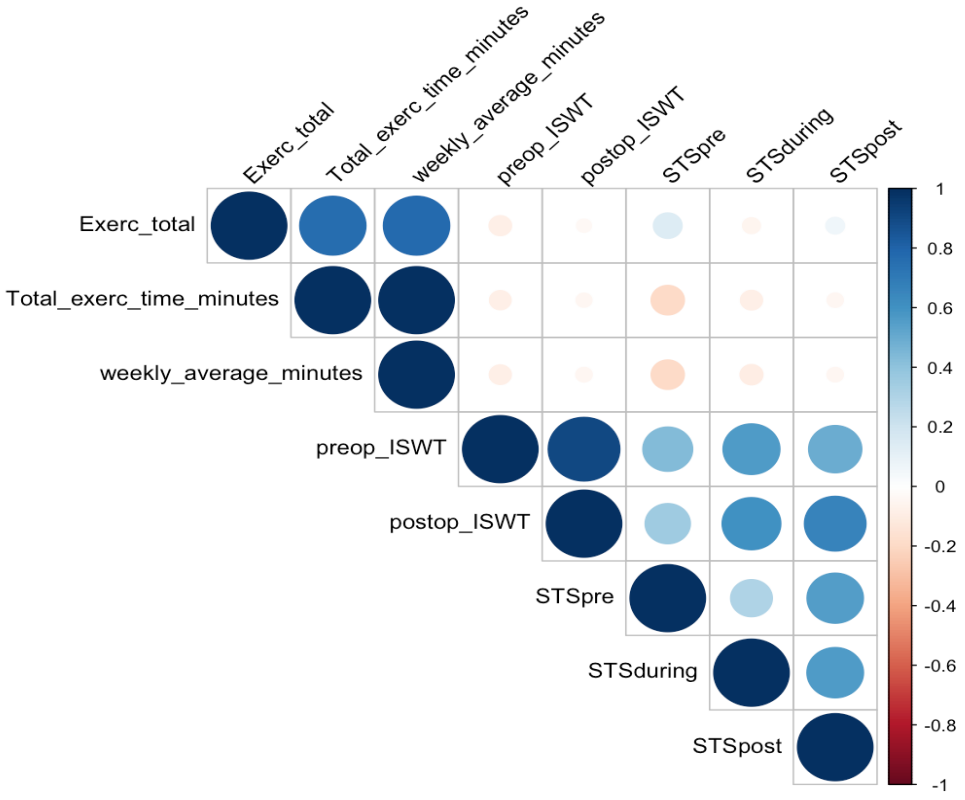



***Figure 0.7: Correlation matrix plot that visualises the relationships between different variables, such as exercise totals, and STS scores at different time points.***

Figure 4.7 illustrates that there are positive correlations between baseline ISWT, 6 weeks after surgery ISWT, and the STS measures (e.g., STSpre, STSduring, STSpost). This suggests that better performance in the ISWT is associated with better performance in the STS test. Furthermore, the figure demonstrates a moderate positive correlation between the exercise time on the F4S app and performance in physical tests, especially with the 6 weeks post-surgery ISWT and STS tests. This suggests that F4S patients' functional capacity remains consistent over time, and their exercise routines within the app may influence their performance on these tests. The next step was to further analyse these relationships by performing a Pearson correlation test to determine if these correlations were statistically significant. Table 4.8 includes the pairs of variables that have significant correlations ($p < 0.05$), along with their correlation coefficients and p-values.

*Table 0.8: Pearson correlation test to determine if the correlations are statistically significant*

| Variable 1 | Variable 2 | Correlation | p-value |
|---|---|---|---|
| **STSpost** | STSpre | 0.5579 | 0.0106 |
| **STSpost** | postop_ISWT | 0.6652 | 0.0014 |
| **STSpost** | preop_ISWT | 0.4959 | 0.0262 |
| **STSpre** | postop_ISWT | 0.3580 | 0.0408 |
| **STSpre** | preop_ISWT | 0.4354 | 0.0071 |
| **postop_ISWT** | preop_ISWT | 0.9005 | <0.0001 |
| **STSpost** | STSduring | 0.5620 | 0.0456 |
| **STSduring** | postop_ISWT | 0.6047 | 0.0220 |
| **STSduring** | preop_ISWT | 0.5685 | 0.0339 |

Statistical tests: Pearson correlation test

Table 4.8 suggests that there are significant correlations between performance in STS tests at different times and ISWT performance, particularly between pre-surgery/post-surgery STS and ISWT measures. However, some correlations, especially those between exercise measures (e.g., total exercise, total exercise time, and weekly average minutes) and performance metrics (ISWT and STS), do not show significant associations, indicating that there might not be a direct linear relationship. Nonetheless, this table provides a good overview of how exercise habits might relate to physical performance, with a few significant correlations standing out, especially between related measures.

#### 4.4.1.3 Health Related Quality of Life change

##### 4.4.1.3.1 Evaluation of changes and patterns in EORTC QLQ-C30 functioning and global health scores across various time points

To examine changes in the EORTC QLQ-C30, we compared the scores at baseline, day of surgery, 6 weeks after, and 6 months after. A minimal clinically important difference is defined as 10 points for QLQ-C30. Across the four time points, there was a statistically significant difference in the functioning and global health domains ($p = 0.00$) (Table 4.8). However, it is important to note that not all domain changes between time points were clinically significant. To further explore these changes, a pairwise comparison with Bonferroni correction was performed.

***Table 0.9: Comparison between EORTC QLQ-C30 functioning and global health domains***

| QoL domain | baseline | Pre-surgery | 6 weeks | 6 months | P value |
|---|---|---|---|---|---|
| Global health | 67 ± (17) | 83±(23) | 66.6 ± (33.3) | 100 ± (16.6) | ***0.00 |
| Physical functioning | 86.6 ± (20) | 100± (13.3) | 86± (31) | 100 ± (6.6) | ***0.00 |
| Role functioning | 83 ± (29.1) | 100± (16.6) | 75 ± (50) | 100 ± (0) | ***0.00 |
| Emotional functioning | 83± (31.3) | 91± (16) | 91.6 ± (25) | 100 ± (8.3) | ***0.00 |
| Cognitive functioning | 100 ± (16.6) | 100 ± (12.5) | 100 ± (16.6) | 100 ± (0) | ***0.00 |
| Social functioning | 91.9 ± (33.3) | 100± (16.6) | 100± (29.1) | 100 ± (0) | ***0.00 |

Statistical tests: Repeated measures ANOVA. Data are presented as mean (median) and standard deviation (interquartile range). *p<0.05; **p<0.01; ***p<0.001

***Table 0.10: Post hoc pairwise comparison for EORTC QLQ-C30 functional and global health domains***

| EORTC QLQ-C30 Functioning and global health domain | Baseline vs pre-surgery Difference | P value | 95% CI | Baseline vs 6 weeks Difference | P value | 95% CI | Baseline vs 6 months Difference | P value | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Global health | -13 | 0.09 | -26 – 0.5 | -6.1 | 1.0 | -19 -7.5 | -23.2 | **0.00 | -36 - -9.3 |
| Physical functioning | -8.9 | 1.00 | -22 - 4.7 | -1.2 | 1.0 | -14 -12.5 | -15 | *0.01 | -28 - -1.3 |
| Role functioning | -22 | **0.00 | 19.3 - 23.6 | -14.4 | **0.00 | 13 -17.3 | -7.6 | **0.00 | -7.7- -3.2 |
| Emotional functioning | -9.8 | 1.0 | -23 - 3.8 | -10 | 1.0 | -23 - 3.6 | -19 | **0.00 | -33 - -5.9 |
| Cognitive functioning | -9.2 | 1.0 | -22 - 4.5 | -4.3 | 1.0 | -18 - 9.3 | -12.2 | 0.22 | -26 - 1.4 |
| Social functioning | -11.8 | 0.33 | -25 -1.8 | -6.1 | 1.0 | -19 - 7.5 | -19.7 | **0.00 | -33 - -5.9 |

Post-hoc pairwise comparison with Bonferroni correction. Statistical tests: paired t-test or Wilcoxon signed-rank test. *p<0.05; **p<0.001

***Table 0.11: Post hoc pairwise comparison for EORTC QLQ-C30 functional and global health domains***

| EORTC QLQ-C30 Functioning and global health domain | pre-surgery vs 6 weeks Difference | P value | 95% CI | pre-surgery vs 6 months Difference | P value | 95% CI | 6 weeks vs 6 months Difference | P value | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Global health | 7 | 1.0 | -6 - 20.7 | -10 | 1.0 | -23 - 3.6 | -17 | *0.00 | -30 - -3.3 |
| Physical functioning | 7.7 | 1.0 | -6 - 21.4 | -6.1 | 1.0 | -19 - 7.5 | -13 | 0.04 | -0.1 - -3.8 |
| Role functioning | 14.9 | *0.00 | 1.1 - 28.6 | -5.7 | 1.0 | -19 - 8 | -20 | **0.00 | -34- -6.8 |
| Emotional functioning | -0.2 | 1.0 | -13 - 13 | -9.8 | 1.0 | -23 - 3.8 | -9.6 | 1.0 | -23 - 4 |
| Cognitive functioning | 4.8 | 1.0 | -8.9 - 18 | -3 | 1.0 | -16 - 10 | -7.8 | 1.0 | -21 - 5.8 |
| Social functioning | 5.7 | 1.0 | -8 -19.4 | -7.8 | 1.0 | -21 - 5.8 | -13 | 0.05 | -27 - 0.14 |

Post-hoc pairwise comparison with Bonferroni correction. Statistical tests: paired t-test or Wilcoxon signed-rank test. *p<0.05; **p<0.001

Tables 4.10 and 4.11 show the differences in EORTC QLQ-C30 functional and global health domains across various time points. Statistically, the difference in global health between baseline and pre-surgery (p=0.09) or baseline and 6 weeks (p=1.00) was not statistically significant; however, there was clinically meaningful improvement in the difference between baseline and pre-surgery of -13. On the other hand, global health has shown a significant improvement from baseline to 6 months (p=0.00), with a difference of -23.2, indicating a meaningful enhancement in quality of life. Similarly, the comparison between 6 weeks and 6 months also shows a significant improvement (p=0.00, difference of -17), with a consistent enhancement over time.

For physical functioning, there is a significant improvement between baseline and 6 months (p=0.01, difference of -15), reflecting an improvement in physical capabilities. However, the differences between baseline and pre-surgery (p=1.00) and baseline and 6 weeks (p= 1.00) were not significant nor clinically meaningful, suggesting that the main improvement in physical functioning occurred in the longer term. From pre-surgery to 6 months, there was no significant change (p = 1.00, difference of -6.1), but a significant improvement was observed from 6 weeks to 6 months (p=0.04, difference of -13), indicating some improvement, statistically and clinically, in physical functioning after the six-week mark.

Role functioning demonstrated significant improvements from baseline to pre-surgery (p=0.00, difference of 22), from baseline to 6 weeks (p = 0.00, difference of 14.4), and from baseline to 6 months (p = 0.00, difference of -7.6), indicating constant improvement statistically and clinically except from baseline to 6 months, which was not clinically meaningful. A similar pattern is seen when comparing pre-surgery to 6 months (p=0.00, difference of -5.7) and 6 weeks to 6 months (p = 0.00, difference of -20), highlighting a marked improvement in role functioning over time.

In terms of emotional functioning, there was a statistically significant improvement from baseline to 6 months (p = 0.00, difference of -19), reflecting an improving emotional well-being over time statistically and clinically. The changes between baseline and pre-surgery or 6 weeks were not statistically significant but were clinically meaningful between baseline and 6 weeks. Likewise, the comparison between pre-surgery and 6 months, and 6 weeks and 6 months, did not show any significant or meaningful clinical changes, indicating that emotional functioning remained relatively stable after the initial improvement.

Cognitive functioning showed no significant changes across most time points. The only clinically meaningful improvement was observed between baseline and 6 months (p = 0.22, difference of -12.2), but it was not statistically significant. This suggests that cognitive functioning remained largely unaffected over time.

Social functioning did not exhibit significant differences between most time points, except for a significant improvement statistically and clinically from baseline to 6 months (p=0.00, difference of -19.7), indicating an improved social engagement. Additionally, the comparison from 6 weeks to 6 months showed a borderline significance (p = 0.05, difference of -13) but clinically meaningful, suggesting some improvement in social functioning toward the six-month mark. Figure 4.8 shows EORTC QLQ-C30 functioning and global health patterns over 6 months following lung cancer surgery.

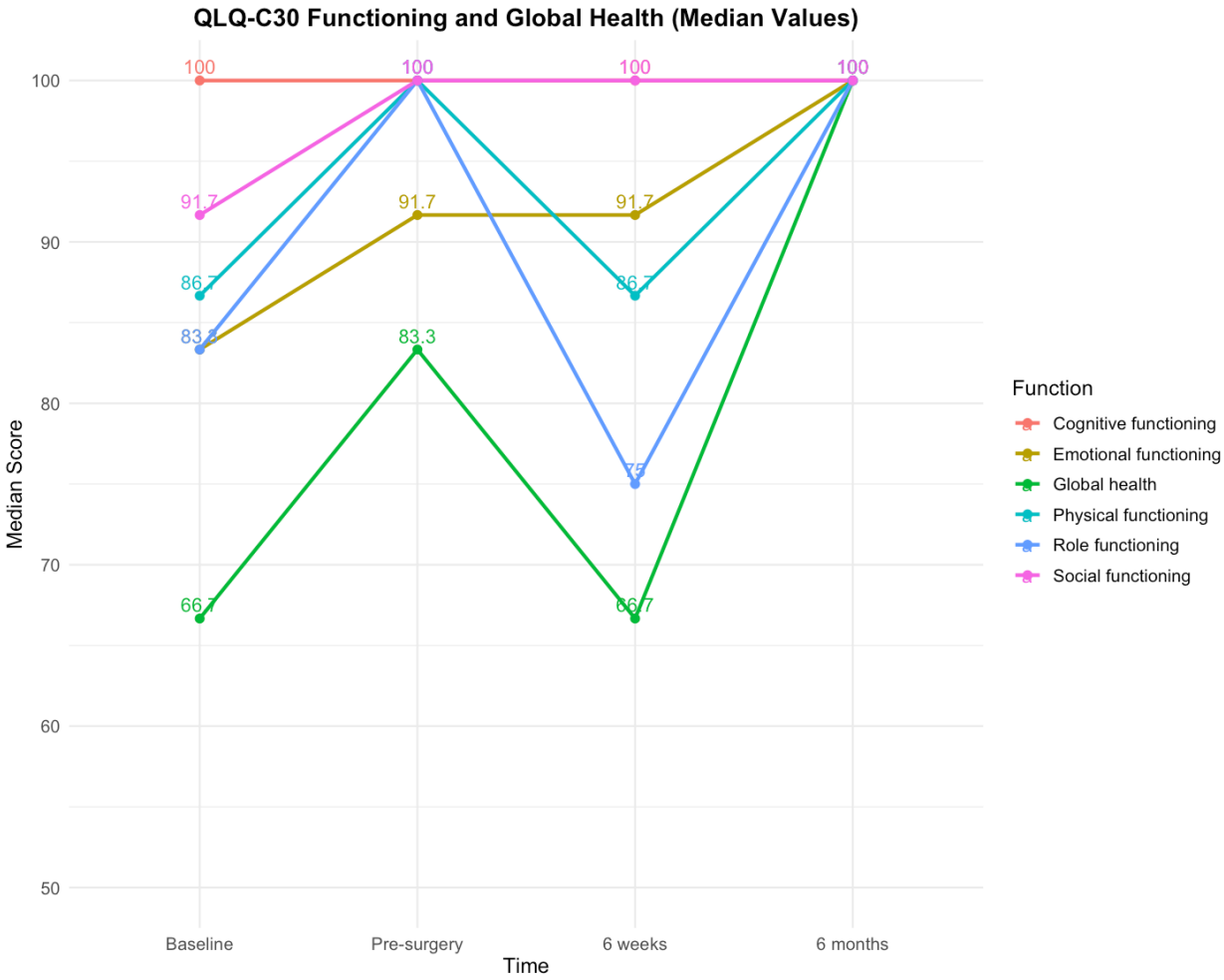



***Figure 0.8: The trajectories of EORTC QLQ-C30 functioning and global health domains at baseline, pre-surgery, 6 weeks, and 6 months after lung cancer surgery.***

#### 4.4.1.3.2 Evaluation of changes and patterns in EORTC QLQ-C30 symptoms scores across various time points

***Table 0.12: Comparison between EORTC QLQ-C30 functioning and global health domains***

| QoL domain | baseline | pre-surgery | 6 weeks | 6 months | P value |
|---|---|---|---|---|---|
| Fatigue | 22.2 ± (30) | 11±(22) | 22 ± (33.3) | 0 ± (0) | ***0.00 |
| Nausea and vomiting | 7 ± (17.6) | 0 ± (0) | 0 ± (0) | 0 ± (0) | ***0.00 |
| Pain | 17 ± (33) | 0 ± (0) | 16 ± (33.3) | 0 ± (0) | ***0.00 |
| Dyspnoea | 33± (33.3) | 0 ± (33.3) | 33.3 ± (33.3) | 0 ± (0) | ***0.00 |
| Insomnia | 33 ± (33.3) | 0 ± (33.3) | 0 ± (33.3) | 0 ± (0) | ***0.00 |
| Appetite loss | 15.5 ± (25) | 0 ± (0) | 0 ± (33.3) | 0 ± (0) | ***0.00 |
| Constipation | 17.9 ± (13) | 0 ± (0) | 0 ± (33.3) | 0 ± (0) | ***0.00 |
| Diarrhoea | 7.8 ± (21) | 0 ± (0) | 0 ± (0) | 0 ± (0) | ***0.00 |
| Financial difficulties | 0 ± (33.3) | 0 ± (0) | 0 ± (0) | 0 ± (0) | ***0.00 |

Statistical tests: Repeated measures ANOVA. Data are presented as mean (median) and standard deviation (interquartile range). *p<0.05; **p<0.01; ***p<0.001

Table 4.12 compares the differences between symptom domains at baseline, pre-surgery, 6 weeks, and 6 months after treatment. All symptom domains have demonstrated statistically significant differences at the four-time points (p = 0.00). We carried out a post-hoc pairwise comparison for each symptom domain to explore the differences in more detail.

***Table 0.13: Post hoc pairwise comparison for EORTC QLQ-C30 symptom domains***

| EORTC QLQ-C30 ***symptoms domains*** | Baseline vs pre-surgery Difference | P value | 95% CI | Baseline vs 6 weeks Difference | P value | 95% CI | Baseline vs 6 months Difference | P value | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Fatigue | 12.8 | 0.54 | -2 – 27 | 5.2 | 1.0 | -9 - 20 | 23 | **0.00 | 8 – 38.1 |
| Nausea and vomiting | 5.2 | 1.00 | -9 - 20 | 3 | 1.0 | -11 - 18.1 | 3.9 | 1.0 | -11 – 18 |
| Pain | 11.4 | 1.0 | -3.6 - 26 | - 3 | 1.0 | -18 -11.9 | 15.7 | *0.00 | 0.7 – 30 |
| Dyspnoea | 13.1 | 0.3 | -1.8 - 28 | - 4.3 | 1.0 | -19 - 10.6 | 17.5 | *0.00 | 2.5 – 32 |
| Insomnia | 13.1 | 0.3 | -1.8 - 28 | 7 | 1.0 | -8 - 22 | 24.5 | **0.00 | 9.5 – 39 |
| Appetite loss | 6.1 | 1.0 | -8 - 21 | 0 | 1.0 | -15 - 15 | 7 | 1.0 | -8 – 22 |
| Constipation | 2.6 | 1.0 | -12 - 17 | - 4.3 | 1.0 | -19 - 10 | 6.1 | 1.0 | -8 – 21.1 |
| Diarrhoea | 6.1 | 1.0 | -8 - 21 | 6.1 | 1.0 | -8 – 21.1 | 7 | 1.0 | -8 – 22 |
| Financial difficulties | 7.8 | 1.0 | -7 - 22 | 7.8 | 1.0 | -7 - 22 | 14 | 0.14 | -1 – 29 |

Post-hoc pairwise comparison with Bonferroni correction. Statistical tests: paired t-test or Wilcoxon signed-rank test. *p<0.05; **p<0.001

***Table 0.14: Post hoc pairwise comparison for EORTC QLQ-C30 symptom domains***

| EORTC QLQ-C30 ***symptoms domains*** | Pre-surgery vs 6 weeks Difference | P value | 95% CI | Pre-surgery vs 6 months Difference | P value | 95% CI | 6 weeks vs 6 months Difference | P value | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Fatigue | - 7.6 | 1.0 | -22 – 7 | 10.2 | 1.0 | -4 - 25 | 17.8 | *0.00 | 2.7 – 32 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Nausea and vomiting | -2.1 | 1.00 | -17 - 12 | -1.3 | 1.0 | -16 - 13 | 0.8 | 1.0 | -14 – 15 |
| Pain | -14.4 | 0.09 | -29 – 0.5 | 4.3 | 1.0 | -10 -19 | 18.8 | **0.00 | 3.8 – 33 |
| Dyspnoea | -17.5 | *0.00 | -32 - -2 | 4.3 | 1.0 | -10 - 19 | 21.9 | **0.00 | 6.8 – 36 |
| Insomnia | -6.1 | 1.0 | -21 – 8.8 | 11.4 | 1.0 | -3.6 – 26 | 17.5 | *0.00 | 2.5 – 32 |
| Appetite loss | -6.1 | 1.0 | -21 – 8.8 | 0.8 | 1.0 | -14 - 15 | 7 | 1.0 | -8 – 22 |
| Constipation | -7 | 1.0 | -22 - 8 | 3.5 | 1.0 | -11 - 18 | 10.5 | 1.0 | -4 – 25.5 |
| Diarrhoea | 0 | 1.0 | -15 - 15 | 0.8 | 1.0 | -14 - 15 | 0.8 | 1.0 | -14 - 15 |
| Financial difficulties | 0 | 1.0 | -15 - 15 | 6.1 | 1.0 | -8 - 21 | 6.1 | 1.0 | -8 - 21 |

Post-hoc pairwise comparison with Bonferroni correction. Statistical tests: paired t-test or Wilcoxon signed-rank test. *p<0.05; **p<0.001

Tables 4.13 and 4.14 display the differences in EORTC QLQ-C30 symptom domains across various time points. Statistically, fatigue improved significantly from baseline to 6 months (p=0.00, difference of -23), with a reduction that exceeds the minimal clinically important difference (MCID) of 10 points, indicating a meaningful and clinically significant improvement in fatigue over time. However, the differences between baseline and pre-surgery (p=0.54) and baseline and 6 weeks (p=1.00) were not statistically significant or clinically important except for baseline and pre-surgery, which had clinical improvement in fatigue score (-12.8), suggesting that the most noticeable and meaningful improvement in fatigue had occurred by the 6-months mark. Similarly, the comparison between 6 weeks and 6 months shows a significant and clinically meaningful improvement in fatigue (p = 0.00, difference of -17.8). However, there was no significant difference between pre-surgery and 6 months (p=1.0), but a clinically meaningful improvement was detected (10.2)

For pain, there was a significant and clinically important improvement between baseline and 6 months (p = 0.00, difference of -15.7), reflecting a reduction in pain levels that exceeds the MCID. No significant differences were found between baseline and pre-surgery (p=1.0) or between baseline and 6 weeks (p = 1.00), suggesting that the meaningful reduction in pain occurred mainly in the longer term except for a reduction from baseline to pre-surgery of -11.4. Furthermore, a significant and clinically meaningful reduction in pain was observed from 6 weeks to 6 months (**p = 0.00**, difference of **-18.8**). It should be noted that that was a

clinically meaningful increase in the pain score from pre-surgery to 6 weeks post-surgery indicating worsening pain in the weeks following surgery (14.4).

Dyspnoea also improved significantly and clinically from baseline to 6 months (p=0.00, difference of -17.5), indicating fewer breathing difficulties with an effect exceeding the MCID threshold. No significant or clinically important changes were observed between baseline and pre-surgery (p=0.33) or baseline and 6 weeks (p=1.00) except for a clinically improved dyspnoea score from baseline to pre-surgery (-13.1). The improvement continued from 6 weeks to 6 months, with a significant and clinically important reduction in dyspnoea (p = 0.00, difference of -21.9). It should be noted that that was a clinically meaningful increase in the dyspnoea score from pre-surgery to 6 weeks post-surgery indicating worsening dyspnoea in the weeks following surgery (17.5).

For insomnia, there was a significant and clinically meaningful reduction in symptoms from baseline to 6 months (p=0.00, difference of -24.5), indicating improved sleep quality. The observed change was well above the MCID threshold. No significant or clinically important differences were found between baseline and pre-surgery (**p = 0.33**) or baseline and 6 weeks (**p = 1.00**) except from baseline to pre-surgery (-13.1). However, a significant and clinically meaningful reduction was observed from 6 weeks to 6 months (p = 0.00, difference of -17.5).

Other symptoms, including nausea and vomiting, appetite loss, constipation, diarrhoea, and financial difficulties, showed no statistically significant or clinically important changes across the time points, indicating that these symptoms remained stable throughout the recovery period. None of the differences exceeded the MCID threshold except for financial difficulties from baseline to 6 months with a clinically meaningful improvement of -14, suggesting minimal change in these domains. Figure 4.9 illustrates EORTC QLQ-C30 symptom patterns over 6 months following lung cancer surgery.

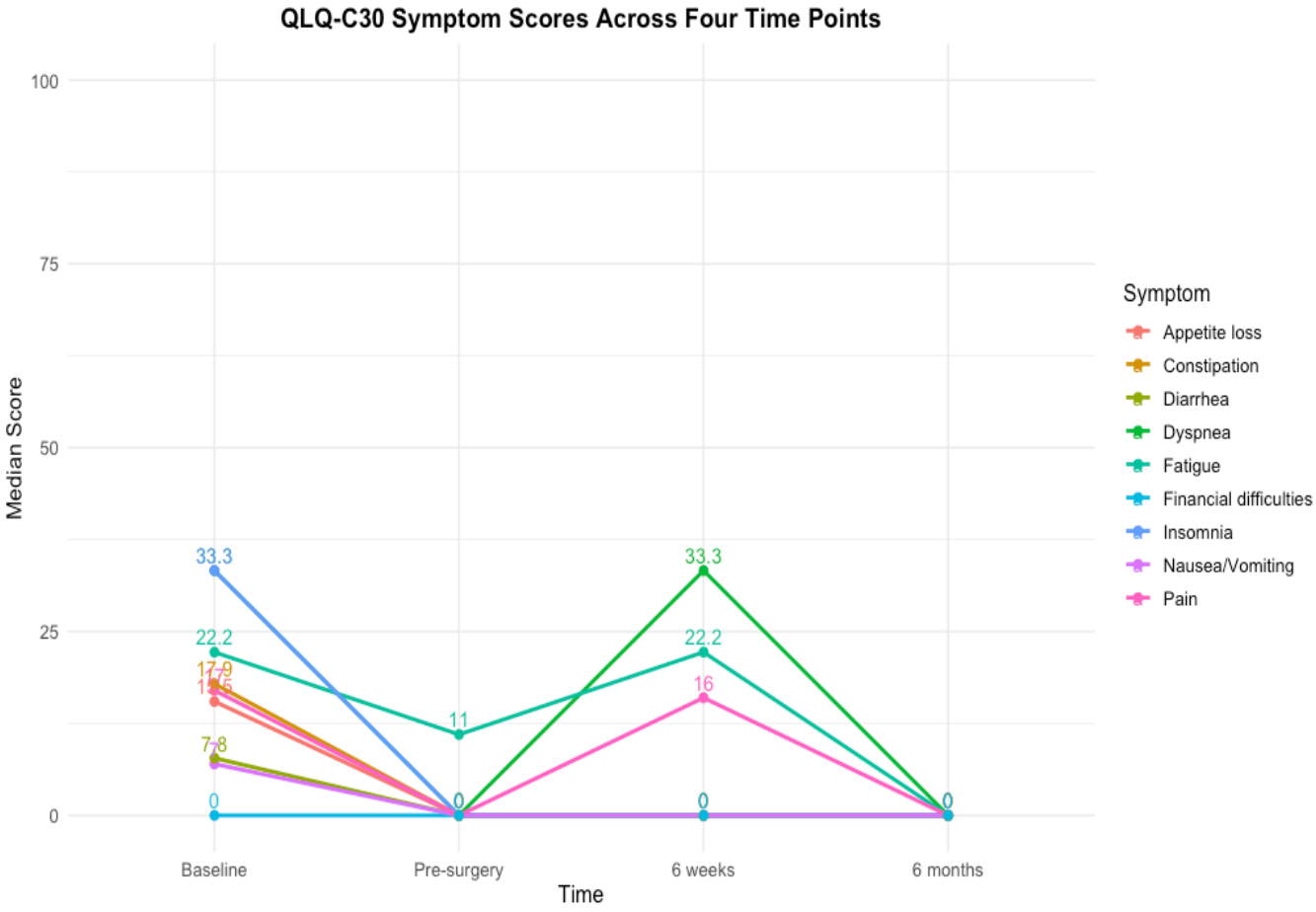



***Figure 0.9: The trajectories of EORTC QLQ-C30 symptoms domains at baseline, pre-surgery, 6 weeks, and 6 months after lung cancer surgery.***

#### 4.4.1.4 Technology Acceptance Model (TAM) Questionnaire:

The Technology Acceptance Model (TAM) questionnaire is a widely used tool designed to assess users' acceptance of new technologies. It measures seven key factors such as perceived usefulness and perceived ease of use, which influence an individual's attitude towards using technology and their intention to adopt it. The TAM has been employed in various fields to understand the factors driving user acceptance and to predict how likely individuals are to embrace new technologies. In this study, the TAM is used to evaluate the acceptance of a digital prehabilitation programme (F4S), providing insights into how patients perceive its usefulness and ease of use in improving their health outcomes at one month post-surgery, by which time the patients would have had sufficient opportunity to use the app. Table 4.10 demonstrates the patients' responses to the TAM questionnaire. All constructs in Table 4.10 were measured on seven-point Likert-type scales, from 1 = strongly disagree to 7 = strongly agree.

***Table 0.15: Descriptive Statistics of TAM questionnaire responses (n=38)***

| Construct | | mean | median | sd |
|---|---|---|---|---|
| Attitude (AT) | AT1: Rehabilitation through the Fit 4 Surgery App is a good idea | 5.2 | 5 | 2.32 |
| | AT2: Rehabilitation through Fit 4 Surgery is a wise idea | 4.87 | 5 | 2.1 |
| | AT3: I feel positive towards rehabilitation through the Fit 4 Surgery App | 5.12 | 5 | 2.21 |
| Behavioural intention (BI) | BI1: I intend to check my progress from Fit 4 Surgery App frequently | 5.3 | 5 | 2.23 |
| | BI2: I intend to be a heavy user of Fit 4 Surgery App | 5.45 | 5 | 2.18 |
| Perceived ease of use (PE) | PE1: I find the Fit 4 Surgery App easy to use. | 4.77 | 5.5 | 2.31 |
| | PE2: Learning how to use a Fit 4 Surgery app is easy for me | 4.97 | 5 | 2.06 |
| | PE3: It is easy to become skilful at using the Fit 4 Surgery app. | 4.87 | 5 | 2.18 |
| Perceived usefulness (PU) | PU1: Fit 4 Surgery app would improve my rehabilitation performance | 5.33 | 5.5 | 2.2 |
| | PU2: The Fit 4 Surgery app would increase rehabilitation productivity. | 4.45 | 5 | 2.1 |
| | PU3: The Fit 4 Surgery app could make it easier to my rehabilitation programme exercises. | 4.67 | 5 | 2.14 |
| Self- efficacy (SE) | SE1: I feel confident finding information in the Fit 4 Surgery app. | 5.6 | 5 | 2.15 |
| | SE2: I have the necessary skills for using the Fit 4 Surgery app. | 5.45 | 5 | 2.19 |
| Subjective norm (SN) | SN1: What the Fit 4 Surgery app stands for is important for me as a perioperative patient | 5.56 | 5 | 2.16 |
| | SN2: I like using Fit 4 Surgery app based on the similarity of my values and society values underlying its use. | 5.45 | 5 | 2.19 |
| | SN3: In order for me to prepare for future surgery, it is necessary to complete rehabilitation through the Fit 4 Surgery app. | 5.35 | 5 | 2.18 |
| System accessibility (SA) | SA1: I have no difficulty accessing and using the Fit 4 Surgery app in my home. | 4.93 | 6 | 2.28 |

Data are presented as mean (median), and standard deviation.

Table 4.15 shows that the participants' responses to all of the seven constructs reveal a more than average satisfaction level with the F4S app, which indicates that the F4S app was acceptable to the patients based on the TAM questionnaire. Figure 4.7 provides further details in terms of the distribution of scores to understand the distribution and variability of responses for each item.

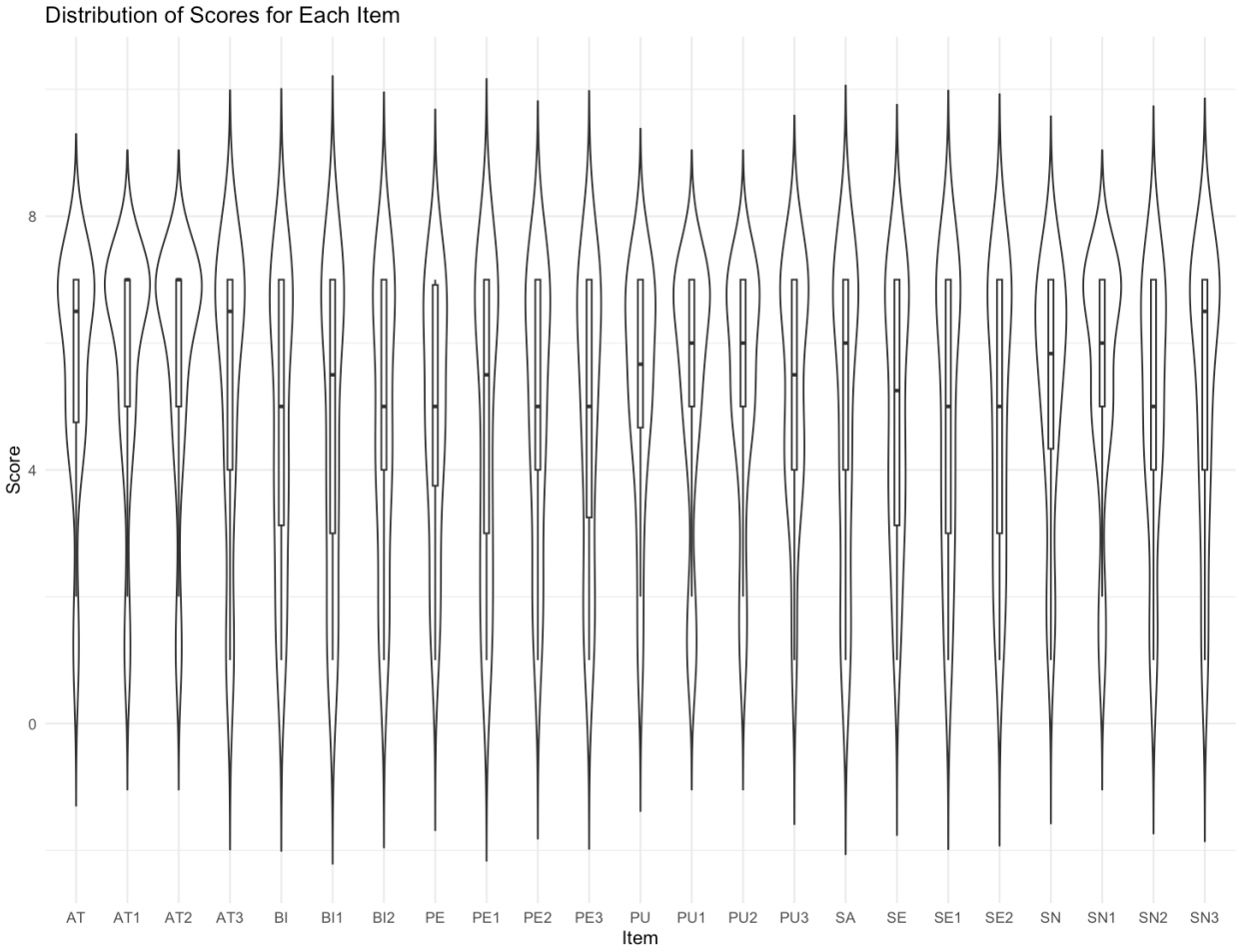



***Figure 0.10: Violin plots of the TAM responses to display the distribution of scores for each item.***

Figure 4.10 demonstrates that the overall median score across most items seems to fall in the middle range, suggesting that most responses are neither extremely high nor low which aligns with the results in Table 4.10. The distributions for items such as `PE1`, `PU1`, and `BI1` appear to have slightly more concentration around the median, suggesting that respondents often gave similar scores and have similar experiences. On the other hand, some items show more variability (wider violins) than others such as `AT`, `SA`, and `SE`, which might indicate differing levels of agreement or experience among respondents.

#### 4.4.1.4.1 Validity and Reliability of Technology Acceptance Model (TAM) Questionnaire:

Since the TAM questionnaire was implemented to measure the acceptance of the F4S digital prehabilitation programme, its validity and reliability needed to be evaluated. Therefore, Internal Consistency Reliability (ICR) also known as Composite Reliability, Cronbach's Alpha

(CA), and Average Variance Extracted (AVE) were utilised as metrics to measure the questionnaire's validity and reliability.

ICR values above 0.70 are generally considered acceptable, and all constructs here have ICR values significantly above this threshold, indicating strong internal consistency reliability (PE: ICR = 0.928, PU: ICR = 0.961, AT: ICR = 0.953, BI: ICR = 0.976, SE: ICR = 0.932, SN: ICR = 0.962, SA: ICR = 0.966). Cronbach's Alpha values above 0.70 also indicate good internal consistency, and all the constructs exceed this threshold, with values ranging from 0.854 (SE) to 0.950 (BI). This confirms that the constructs are reliably measured by their respective indicators. This means the items within each construct are measuring the same underlying concept consistently. High reliability suggests that the items are well-suited for their intended construct. All of the constructs had a CA score of more than 0.70, which means that the TAM questionnaire is reliable to measure the F4S acceptance level. AVE values above 0.50 indicate that more than 50% of the variance of the indicators is captured by the latent construct, which is desirable. All the constructs in this model have AVE values well above 0.50, suggesting that the constructs are well represented by their respective indicators (PE: AVE = 0.807, PU: AVE = 0.891, AT: AVE = 0.866, BI: AVE = 0.952, SE: AVE = 0.873, SN: AVE = 0.893, SA: AVE = 0.862). In conclusion, these metrics indicate that the TAM questionnaire has strong reliability and convergent validity to measure the acceptability levels of the F4S app. The constructs are well-defined and consistently measured by their respective indicators, which supports the overall validity of the model.

#### 4.4.1.5 The remaining outcome measures analysis:

The remaining outcome measures, including the EQ-5D, HADS, pain scale, and PG-SGA questionnaires, were collected through the app. However, a high proportion of missing data at later time points — specifically pre-surgery and post-surgery — made further analysis of these outcome measures unfeasible. Table 1 in Appendices presents the distribution of scores for the remaining outcome measures across different time points (Appendix 8.7).

### 4.4.2 Lung Volume Reduction Surgery (LVRS) Cohort

#### 4.4.2.1 General Patient Characteristics

A total of 22 patients were recruited from 2022 until 2024 who underwent lung cancer surgery, specifically, LVRS, and were included in the statistical analysis. The participants' baseline characteristics and clinical data are shown in Table 4.15.

**Table 0.16: The distribution of the overall study sample according to *their baseline characteristics (n=22)***

| Characteristic | Median (IQR); Range; n (%) |
|---|---|
| **Gender** | |
| **Male** | 15 (68%) |
| **Female** | 7 (32%) |
| **Age** | 68 (60, 74) |
| **BMI** | 24.5 (21.1, 27.9) |
| **Baseline lung function** | |
| **Preop_FEV1** | 0.96 (0.78, 1.31) |
| **Preop_FEV1P** | 35 (26, 45) |
| **Preop_FVC** | 3.19 (2.60, 3.86) |
| **Preop_FVCP** | 84 (68, 95) |
| **DLCO_P** | 45 (32, 54) |
| **FEV1/FVC** | 35 (30, 42) |
| **Pre-op smoking (self reported)** | |
| **Current** | 1 (4.5%) |
| **Ex** | 20 (91%) |
| **Never** | 1 (4.5%) |
| **Quit time** | |
| **Current** | 1 (4.5%) |
| **Ex > 1 year** | 19 (91%) |
| **never smoked** | 2 (9%) |
| **Pack years** | 30 (27, 50) |
| **COPD** | 22 (100%) |
| **IHD** | 0 |
| **Cardiac failure** | 0 |
| **Hypertension** | 7 (32%) |
| **Diabetes** | |
| **Non** | 21 (95%) |
| **Diet** | 1 (4.5%) |
| **renal failure** | 0 |

| | |
|---|---|
| **ASA Score** | |
| **Normal Healthy Patient** | 2 (9%) |
| **2** | 20 (91%) |
| **3** | 0 |
| **4** | 0 |
| **Stroke** | 0 |
| **Thyroid** | |
| **Non** | 21 (95%) |
| **Hyper** | 1 (4.5%) |
| **Hypo** | 0 |
| **Unknown** | 0 |
| **Anticoag** | 0 |
| **ECOG** | |
| **0** | 0 |
| **1** | 13 (59%) |
| **2** | 9 (41%) |
| **3** | 0 |
| **4** | 0 |
| **Dyspnoea MRC** | |
| **0** | 0 |
| **1** | 1 (50%) |
| **2** | 8 (36%) |
| **3** | 2 (9.1%) |
| **4** | 1 (4.5) |
| **Other cancer** | 3 (14%) |
| **Alcohol excess** | 3 (14%) |

Data are presented as mean (median), standard deviation (interquartile range), or numbers and percentages for categorical data. COPD; chronic obstructive pulmonary disease, IHD; ischemic heart disease, ASA; American Society of Anaesthesiologists, ECOG; The Eastern Cooperative Oncology Group, $FEV_1$; forced expiratory volume for 1 second, DLCO; diffusing capacity for carbon monoxide.

Table 4.16 reveals the baseline demographic and general characteristics data for the 22 patients. The median age is 68 years old, and more than half of the patients are male. We can see that the mean BMI for 22 is 24.5. The majority of the patients reported having quit smoking before their surgery. It is apparent that 32% of the patients suffered from hypertension, and only 14% had other cancers (Table 4.16).

**Table 0.17: The distribution of the overall study sample according to *their surgery characteristics (n=22)***

| Characteristic | Median (IQR); Range; n (%) |
|---|---|
| **Surgery** | |
| **Yes** | 10 (45%) |
| **No** | 12 (55%) |
| **Incision** | |
| **Thoracotor** | 0 |
| **VATS** | 10 (100%) |
| **Side** | |
| **Right** | 8 (80%) |
| **Lift** | 2 (20%) |
| **Lobe** | |
| **Upper** | 10 (100%) |
| **Analgesia** | |
| **Paravertebral** | 100 (0%) |

Data are presented as mean (median), standard deviation (interquartile range), or numbers and percentages for categorical data. VATS; video-assisted thoracic surgery.

Table 4.17 shows the surgery characteristics data for the 22 patients. Around half of the patients had undergone the surgery (45%), while 55% of the patients had not undergone their surgery yet.

Table 4.18 shows the clinical outcomes focusing on the modified CDC system, the CCI, during hospital stay and one month following surgery, LOS in hospital, 30-day mortality and readmission rates, and PPC during hospital stay and one month following surgery.

***Table 0.18: Descriptive Statistics of Clinical Outcomes (n=22)***

| **Clinical outcome (n = 10) (na = 12) (60%)** | **Median (IQR)** |
|---|---|
| **LOS** | 3.5 (6.5) |
| **PPC**<br>Yes = 4 (40%)<br>No = 6 (60%) | |

| | |
|---|---|
| **CDC stage**<br>I = 3 (75%)<br>II = 1 (25%)<br>I/II = 0<br>I/II/IIIa = 0<br>IIIa = 0<br>Iva = 0 | |
| **CCI** | 8.7 (3.05) |
| **PPC 1 month**<br>Yes = 0<br>No = 10 (100%) | |
| **CDC 1 month** | 0 |
| **CCI 1 month** | 0 |
| **30 days readmission**<br>Yes = 0<br>No = 10 (100%) | |
| **Hospital mortality**<br>No = 10 )100%) | |

Data are presented as mean (median), standard deviation (interquartile range), or numbers and percentages for categorical data. CDC; Clavien-Dindo classification, CCI; comprehensive complication index, LOS; length of stay, PPC; post-operative pulmonary complications.

Table 4.18 displays that the median LOS for the LVRS patients in this study is 3.5 days. Interestingly, only 4 patients had a complication event after surgery while in hospital, and no patients had an event 1 month post-surgery (Figure 4.11). The CDC is a standardised system used to grade surgical complications based on the severity of the intervention required to treat them. It categorises postoperative complications into five grades, and most of the patients in Table 4.18 were in grade 1, which requires no intervention (Figure 4.12). The CCI complements the CDC by quantifying the overall burden of postoperative complications. It sums all postoperative complications, weighted by their severity, into a single score ranging from 0 to 100; as evident in the above table, the median CCI score at hospital stay was 8.7 and at 1 month was 0, which indicates a mild complication after surgery.

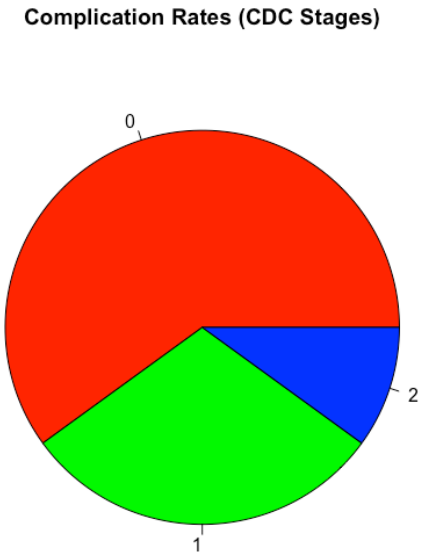



*Figure 0.11: Proportional Distribution of Postoperative Complications by Clavien-Dindo Classification Stages.*

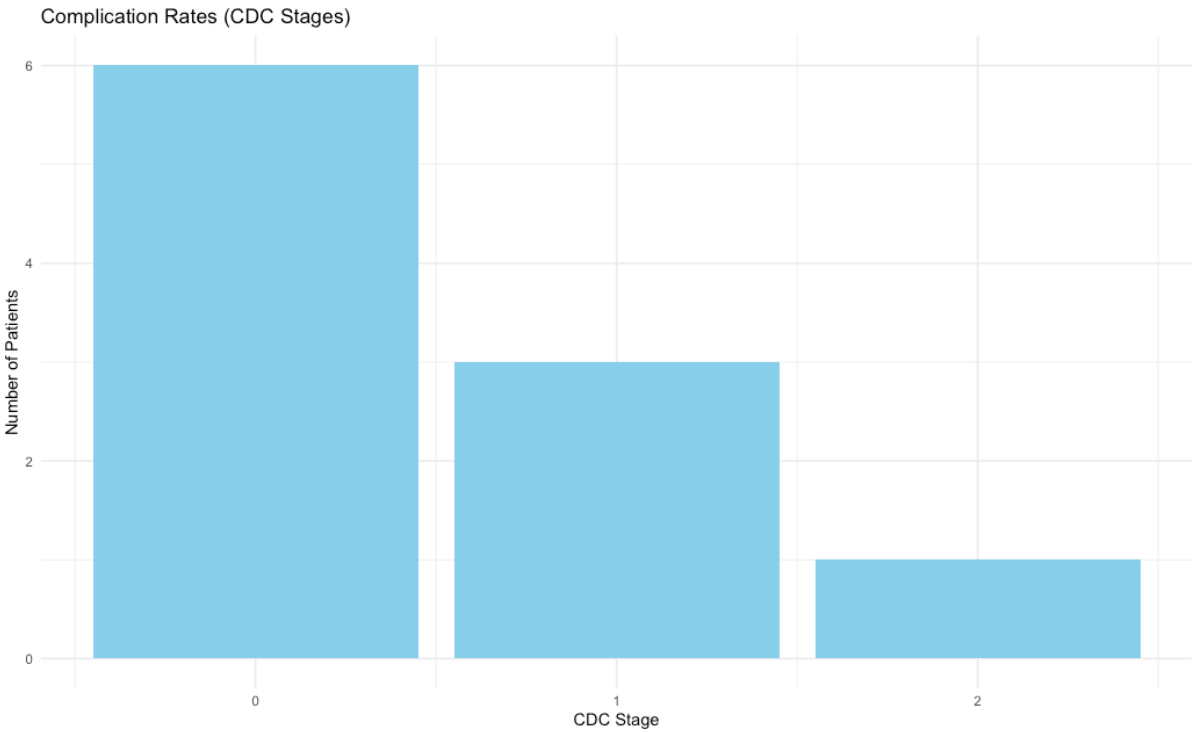



*Figure 0.12: Distribution of Postoperative Complication Rates by Clavien-Dindo Classification Stages.*

Given that only 4 out of 10 participants experienced a complication, performing a regression analysis might be challenging due to the small sample size and the low event rate. This situation can lead to several issues, including overfitting and model convergence issue.

ISWT and STS tests were collected from the LVRS patients at different time points in order to have a better understanding of the impact of the F4S app on the patients' exercise capacity (Table 4.19). Table 4.18 also shows the added physical activity by the patients within the app; exercise sessions performed before, during, and after surgery; total exercise time; and weekly average minutes of exercise.

**Table 0.19: The distribution of the overall study sample according to *their characteristics (n=22)***

| Characteristic | Median (IQR); Range; n (%) |
|---|---|
| **ISWT** | |
| **Baseline** | 150 (132, 190) |
| **3 months follow up** | 200 (197, 200) |
| **1 month post-surgery** | 275 (242, 395) |
| **STS** | |
| **Baseline** | 15.0 (14.0, 15.75) |
| **3 months follow up** | 15.0 (15.0, 15.75) |
| **pre-surgery** | 20 (20, 20) |
| **1 month post-surgery** | 20 (18.5, 20.75) |
| **Added Physical Activity** | 2 (1.0, 33.5) |
| **Exercise Sessions Performed** | |
| **Pre-surgery** | 81 (6.75, 128.7) |
| **Post-surgery** | 0.3 (0, 3) |
| **Total** | 108 (12.2, 166.2) |
| **Total exercise time minutes** | 916 (122.2, 1184.) |
| **Weekly average minutes** | 102 (15.2, 178) |

Data are presented as mean (median), standard deviation (interquartile range), or numbers and percentages for categorical data. ISWT; Incremental shuttle walk test, STS; Sit to stand.

Table 4.19 reveals that each patient added, on average, two physical activities during their time of using the app. In addition, patients performed 81 exercise sessions before surgery compared to 0.3 sessions of exercises after surgery. Thus, the average of total exercise sessions performed by each patient is 108. The total exercise minutes within the app is 916 minutes on average for each participant with the weekly average of 102 minutes.

***Table 0.20: Comparison between EORTC QLQ-C30 functioning and global health domains***

| QoL domain | baseline | 3-months follow up | Pre-surgery | 6 weeks | 6 months | P value |
|---|---|---|---|---|---|---|
| Global health | 33.3 ± (25) | 58.3 ± (22.9) | 66±(14) | 83.3 ± (6.2) | 100 ± (0) | ***0.00 |
| Physical functioning | 40 ± (20) | 63.3 ± (26.6) | 66.6 ± (25) | 80± (13) | 86.6 ± (11.6) | ***0.00 |
| Role functioning | 16.6 ± (50) | 66.6 ± (25) | 66.6 ± (50) | 75 ± (33) | 93.3 ± (18.3) | ***0.00 |
| Emotional functioning | 60± (46.6) | 86.6 ± (28.3) | 96.6± (21) | 86 ± (23) | 100 ± (5) | ***0.00 |
| Cognitive functioning | 50 ± (83.3) | 66.6 ± (66) | 66 ± (33) | 100 ± (0) | 100 ± (0) | ***0.00 |
| Social functioning | 33.3 ± (50) | 91.6 ± (54.1) | 66± (50) | 100± (16) | 100 ± (0) | ***0.00 |

Data are presented as mean (median), standard deviation (interquartile range). Statistical tests: Repeated measures ANOVA. Data are presented as mean (median) and standard deviation (interquartile range). *p<0.05; **p<0.01; ***p<0.001

Table 4.20 shows EORTC QLQ-C30 functioning and global health domains at five different time points. There is an overall trend of improvement from baseline up to 6 months after surgery in all five domains (Table 4.20). Across the five time points, there was a statistically significant difference in the functioning and global health domains (p = 0.00) (Table 4.20). A minimal clinically important difference is defined as 10 points for QLQ-C30. However, it is important to note that not all domain changes between time points were clinically significant.

***Table 0.21: Comparison between EORTC QLQ-C30 symptoms domains***

| QoL domain | baseline | 3-months follow up | Pre-surgery | 6 weeks | 6 months | P value |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| Fatigue | 66.6 ± (66) | 33.3 ± (50) | 33.3±(50) | 0 ± (33) | 0 ± (0) | ***0.00 |
| Nausea and vomiting | 16 ± (33) | 0 ± (0) | 0 ± (12) | 0 ± (0) | 0 ± (0) | ***0.00 |
| Pain | 66.6 ± (66) | 0 ± (0) | 0 ± (53) | 0 ± (25) | 0 ± (12) | ***0.00 |
| Dyspnoea | 83.3± (33) | 66 ± (0) | 66.6 ± (33) | 33.3 ± (0) | 22.2 ± (18) | ***0.00 |
| Insomnia | 55.5 ± (41) | 11.1 ± (16) | 7.7 ± (19) | 11.1 ± (19) | 5.5 ± (11) | ***0.00 |
| Appetite loss | 41.6 ± (50) | 16.6 ± (45) | 25 ± (16) | 0 ± (0) | 0 ± (0) | ***0.00 |
| Constipation | 0 ± (33) | 0 ± (0) | 0 ± (0) | 0 ± (0) | 0 ± (0) | ***0.00 |
| Diarrhoea | 16.6 ± (30) | 0 ± (0) | 0 ± (0) | 0 ± (0) | 0 ± (0) | ***0.00 |
| Financial difficulties | 0 ± (33.3) | 0 ± (0) | 0 ± (33) | 0 ± (0) | 0 ± (0) | ***0.00 |

Data are presented as mean (median), standard deviation (interquartile range). Statistical tests: Repeated measures ANOVA. Data are presented as mean (median) and standard deviation (interquartile range). *p<0.05; **p<0.01; ***p<0.001

Table 4.21 demonstrates EORTC QLQ-C30 symptoms domains at five different time points. There is an overall trend of improvement from baseline up to 6 months after surgery in all five domains (Table 4.21). A minimal clinically important difference is defined as 10 points for QLQ-C30. However, it is important to note that not all domain changes between time points were clinically significant.

***Table 0.22: Comparison between CAT scores***

| CAT | baseline | 3-months follow up | Pre-surgery | 6 weeks | 6 months | P value |
|---|---|---|---|---|---|---|

| | | | | | | |
|---|---|---|---|---|---|---|
| CAT score | 25 ± (8.5) | 22 ± (6.5) | 15.5 ± (9.2) | 11.5 ± (9.7) | 8 ± (10.5) | ***0.00 |

Data are presented as mean (median), standard deviation (interquartile range). Statistical tests: Repeated measures ANOVA. Data are presented as mean (median) and standard deviation (interquartile range). *p<0.05; **p<0.01; ***p<0.001

Table 4.22 explains CAT scores at five different time points. There is an overall trend of improvement from baseline up to 6 months after surgery in the patients' CAT scores (Table 4.22). A minimal clinically important difference is defined as 2 points for the CAT questionnaire, which indicates that all the patients who improved had a clinically significant improvement from pre-surgery and continued to improve up to 6 months after surgery (Table 4.22).

#### 4.4.4.2 Patient Exercise Capacity:

##### 4.4.4.2.1 Incremental shuttle walk test:

To determine the effect of the F4S app on the patients' exercise capacity, patients performed the ISWT thrice, the first time when they were recruited before surgery, 3-month follow-up for patients who had not undergone surgery yet (n=12), and 6 weeks after surgery for patients who had successfully undergone surgery (n=10). Figure 4.13 shows histograms representing the differences in ISWT data, comparing pre-surgery, 3-month follow-up, and post-surgery results.

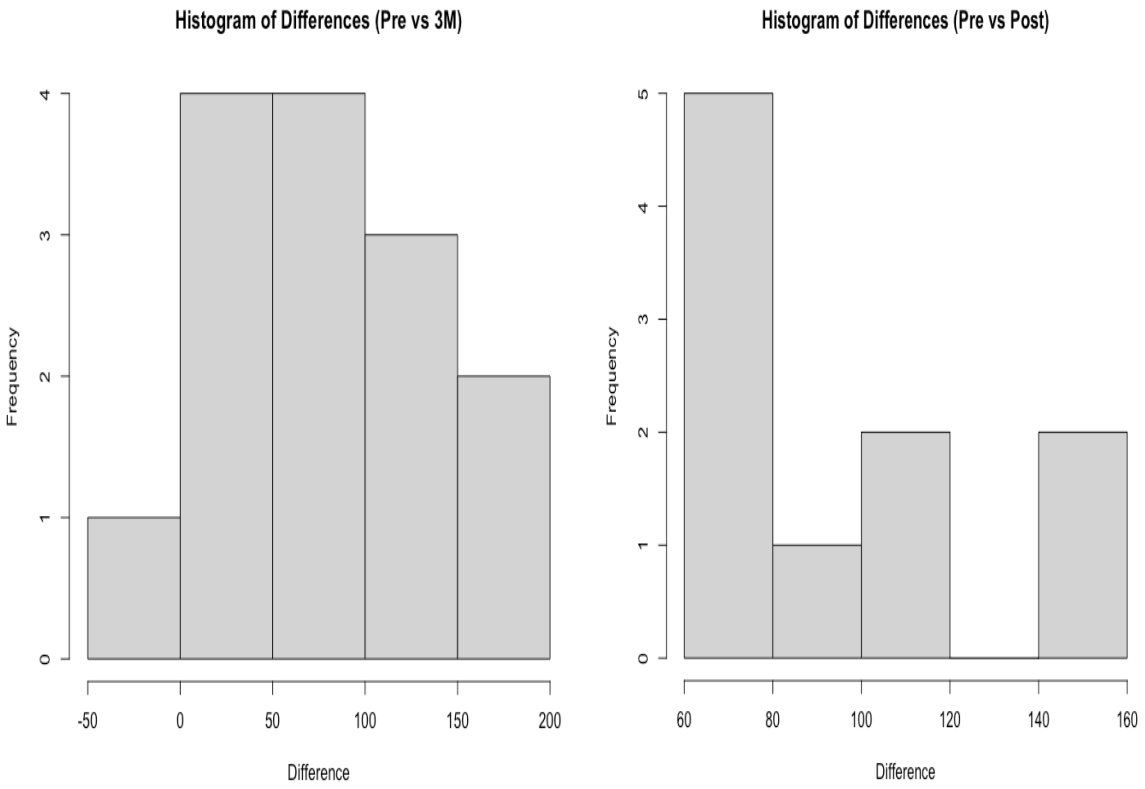



***Figure 0.13: Histograms representing the differences in ISWT data.***

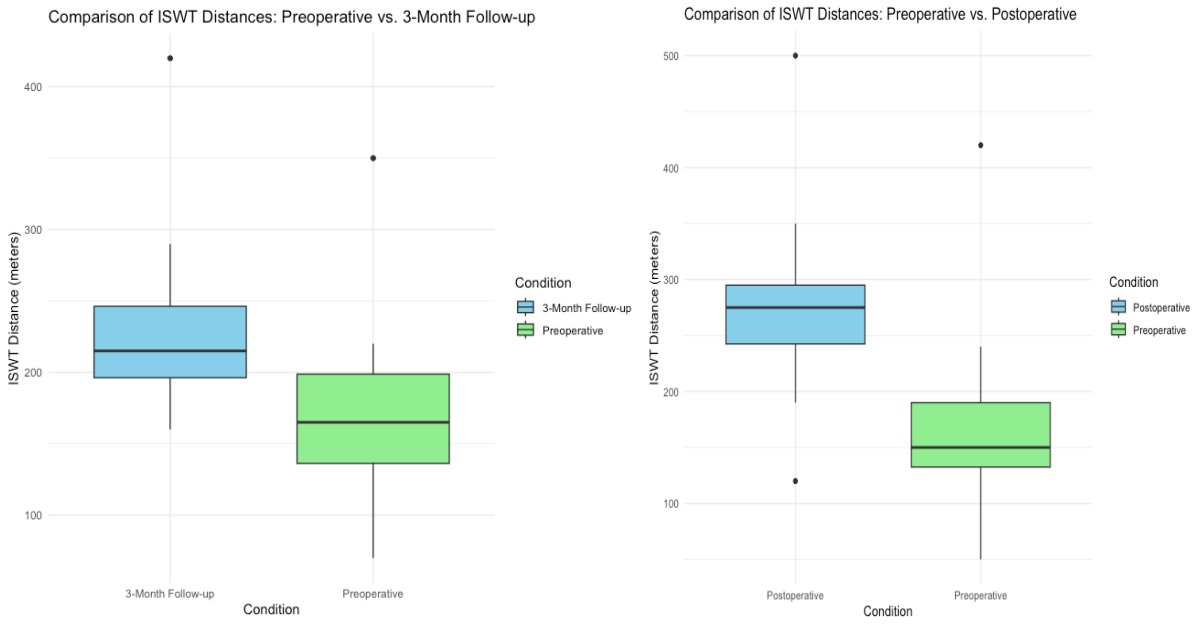



***Figure 0.14: Boxplots explaining the differences in the ISWT distances.***

Figure 4.13 illustrates that the largest number of patients who had not undergone surgery experienced a positive change in ISWT scores, particularly in the range of 0 to 100 metres, which suggests that most patients experienced an improvement in their ISWT scores 3 months

post-recruitment, with a clinically significant number showing an increase of around 100 metres. Similarly, the patients who had undergone LVRS experienced a positive change in their ISWT scores, particularly in the range of 60 to 80 metres, which suggests that most patients experienced an improvement in their ISWT scores 6 weeks post-surgery, with a clinically significant number showing an increase of around 80 metres (Figure 4.13). Figure 4.14 shows the boxplots comparing the ISWT distances between preoperative and postoperative conditions. Both boxplots suggest that most patients showed a positive change in ISWT scores after 3-month follow-up and after surgery. The IQR in both boxplots is positioned higher than the baseline, indicating better overall performance. The median ISWT distance in both boxplots is higher than the baseline, further supporting the improvement in functional capacity. There are a few outliers in both boxplots, showing that some patients experienced substantial improvements in their ISWT scores (Figure 4.14).

There are a few outliers with very high positive differences (200–300 metres), showing a significant improvement in these patients' exercise capacity. Since there are a few outliers, a normality test is required to choose a suitable statistical test for further analysis of the ISWT data.

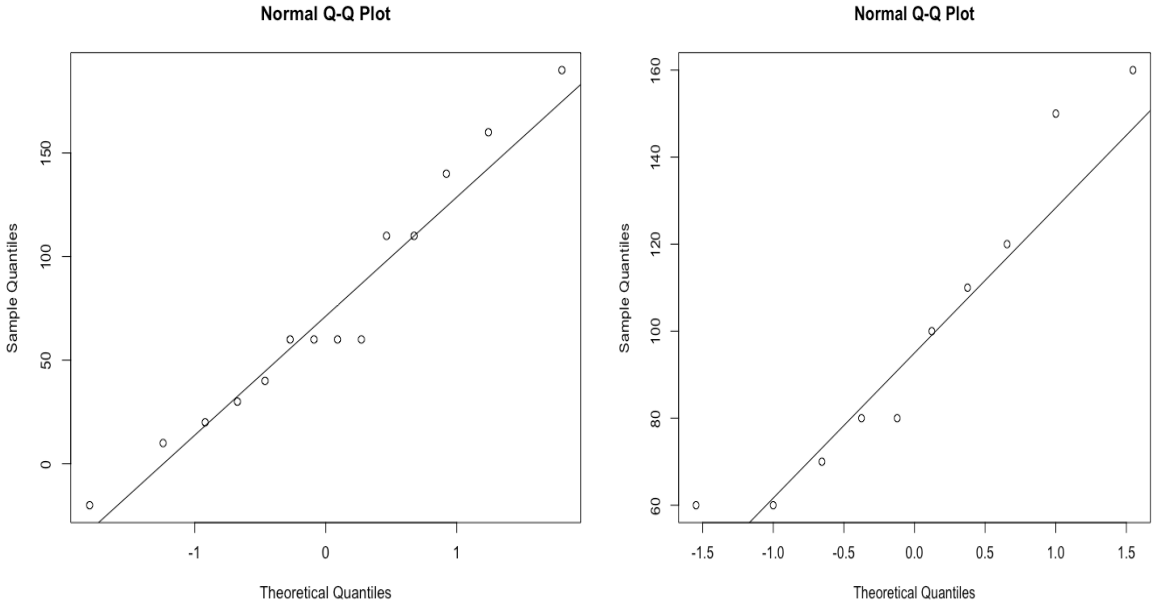



***Figure 0.15: Normal Q-Q (Quantile-Quantile) plot to assess the distribution of the ISWT data.***

Figure 4.14 points out that the ISWT data generally follow a normal distribution in the central region, but there are some deviations in the tails, suggesting possible outliers or a non-normal

distribution at the extremes. Therefore, a Shapiro-Wilk normality test was conducted (p=0.584, p=0.272), and based on the p values, the ISWT data can be considered normally distributed. Since the ISWT data are normally distributed, we performed the paired t-test to assess the difference between ISWT before and after 3-month follow-up and after surgery for patients who used the F4S app to determine whether that difference is statistically significant. There was a statistically significant increase in the ISWT scores from baseline to 3-month follow-up (p=0.000) and from baseline to post-surgery (p=0.000). Given the extremely small p-value and the positive mean difference (mean differences 73 and 99), we can conclude that the patients' exercise capacity, as measured by the ISWT, significantly improved after using the F4S app.

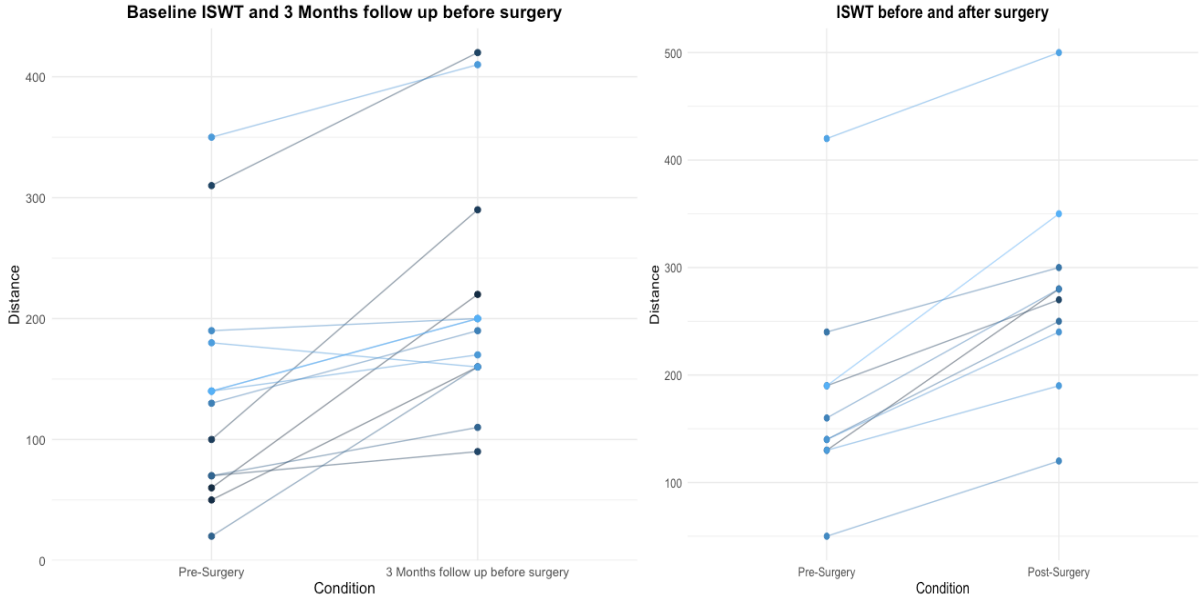



***Figure 0.16: Line plots that compare ISWT distances after 3-month follow-up and after surgery for individual patients.***

Additionally, Figure 4.16 suggests that the majority of the LVRS patients experienced an increase in their ISWT distance after 3 months for patients who had not undergone surgery and after surgery for those who had undergone surgery, which supports the idea of improved physical function post F4S app usage and post-surgery for most patients, though not all. This aligns with the previous statistical analysis showing a mean improvement in the ISWT scores post 3-month follow-up and post-surgery. The improvement of almost 70 metres post 3-month follow-up and after surgery compared to before starting the F4S rehabilitation programme is actually considered clinically significant since the minimum is 40 metres.

#### 4.4.4.2.2 Sit to Stand test:

STS is another physical test used by patients to measure their physical capacity while rehabilitating through the F4S programme. The patients performed the STS tests at four different time points: upon recruitment, 3-month follow-up, on the day of surgery, and 6 weeks after surgery. For patients who did not have surgery, Figure 4.16 indicates an increase in STS performance compared to the baseline scores. For patients who had undergone surgery, the STS performance gradually improved from the preoperative phase to the postoperative phase, with steady increases observed at pre-surgery and 6 weeks post-surgery. Furthermore, looking at 6 weeks post-surgery, participants had significantly improved their STS scores compared to baseline levels (Figure 4.17).

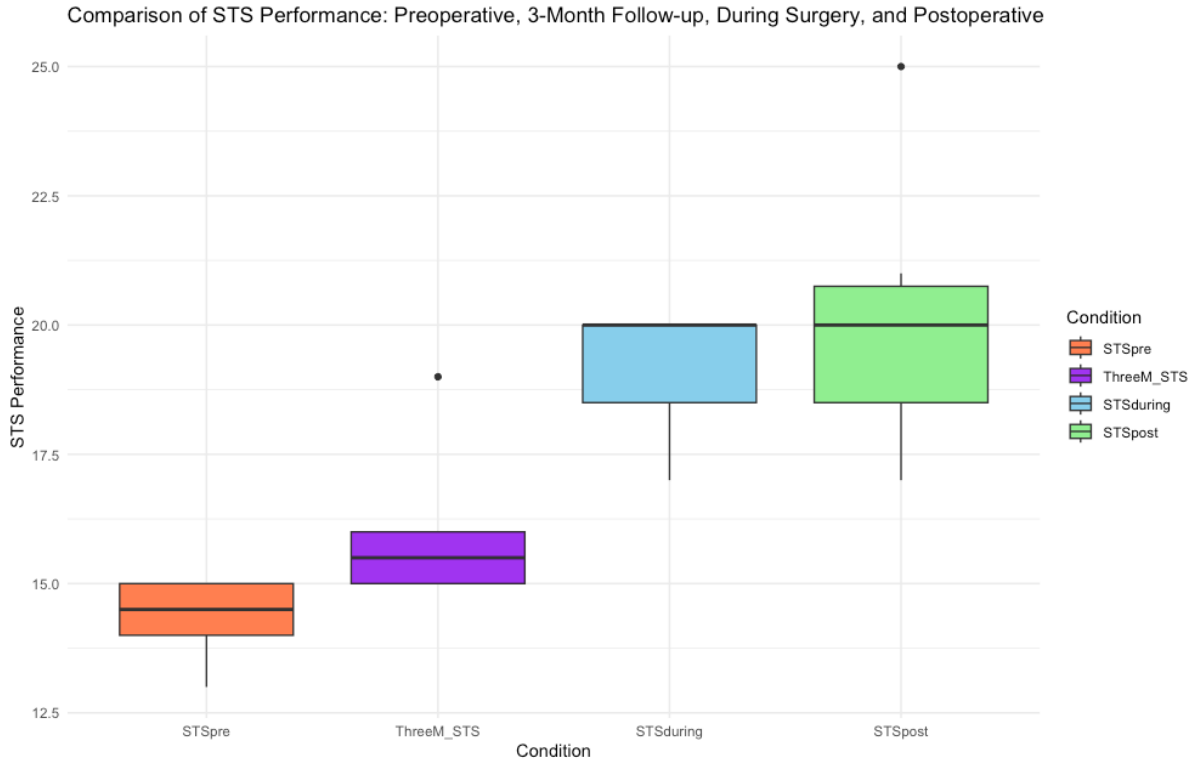



***Figure 0.17: illustrates the STS performance across four different time points.***

Table 4.22 presents the STS test data, including the mean (SD) scores at four time points (baseline, 3-month follow-up, pre-surgery, and 6 weeks after surgery), along with the p-values from the repeated measures ANOVA test.

***Table 0.23: STS test at three different time points***

| STS | Mean (SD) | P Value |
|---|---|---|
| **Baseline** | 13.4 (4.41) | ***0.00 |
| **3--month follow-up** | 18.4 (5.08) | *0.042 |
| **Pre-surgery** | 19.7 (0.99) | ***0.00 |
| **6 weeks post-surgery** | 20.2 (2.79) | ***0.00 |

Statistical tests: Paired t-test and repeated measures ANOVA. Data are presented as mean (median) and standard deviation (interquartile range). *p<0.05; **p<0.01; ***p<0.001

Table 4.23 displays improvement in the STS scores in which the mean number of sit-to-stands increases progressively from baseline (13.4) to 3-month follow-up (18.4) for patients who had not undergone their LVRS yet. Also, improvement in the STS scores continued from baseline (13.4) to pre-surgery (19.7) and 6 weeks post-surgery (20.2) for patients who had undergone surgery. This suggests an improvement in physical function over time. In addition, the table indicates that with the exception of the 3-month follow-up, which is still significant (p=0.042) but not as strong as the other time points, the p-values (p<0.001) across all time points indicate that the changes in the STS scores are statistically significant. Thus, the paired t-test and repeated measures ANOVA test confirm that there is a statistically significant improvement in STS performance from baseline, 3-month follow-up, and pre-surgery to post-surgery, indicating enhanced physical function over time.

***Table 0.24: A post-hoc pairwise comparison of STS performance at different time points***

| Time points | Baseline vs 3-month follow-up Difference | P value | 95 % CI | Baseline vs Pre-surgery Difference | P value | 95 % CI | Baseline vs 6 weeks Difference | P value | 95 % CI | Pre-surgery vs 6 weeks Difference | P value | 95 % CI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| STS | 5 | 0.019 | 1.86 - 8.14 | 5.36 | *0.00 | 3.02 – 7.70 | 5.83 | 0.045 | 2.36 – 9.31 | 1.0 | 1.0 | -2.18 – 4.18 |

Post-hoc pairwise comparison with Bonferroni correction. Statistical tests: paired t-test or Wilcoxon signed-rank test. *p<0.05; **p<0.001

Table 4.24 presents a post-hoc pairwise comparison of STS performance at different time points (baseline, 3-month follow-up, pre-surgery, and 6 weeks post-surgery), using Bonferroni correction for multiple comparisons. The aforementioned table reveals that there is a significant difference in STS performance between baseline and 3-month follow-up (p=0.019). Also, Table

4.20 shows that there is a significant difference in STS performance between baseline and pre-surgery (p=0.001). Moreover, there is a significant difference in STS performance between baseline and 6 weeks post-surgery (p=0.045), suggesting that the patients experienced a noticeable increase in physical function before surgery and during the recovery period. However, there was no statistically significant improvement in STS performance from pre-surgery to 6 weeks post-surgery (p=1.0). Hence, this post-hoc analysis indicates that the most meaningful improvements in patients' STS performance occurred between baseline to 3-month follow-up for patients who had not undergone LVRS, baseline to pre-surgery, and baseline to 6 weeks post-surgery (Table 4.24).

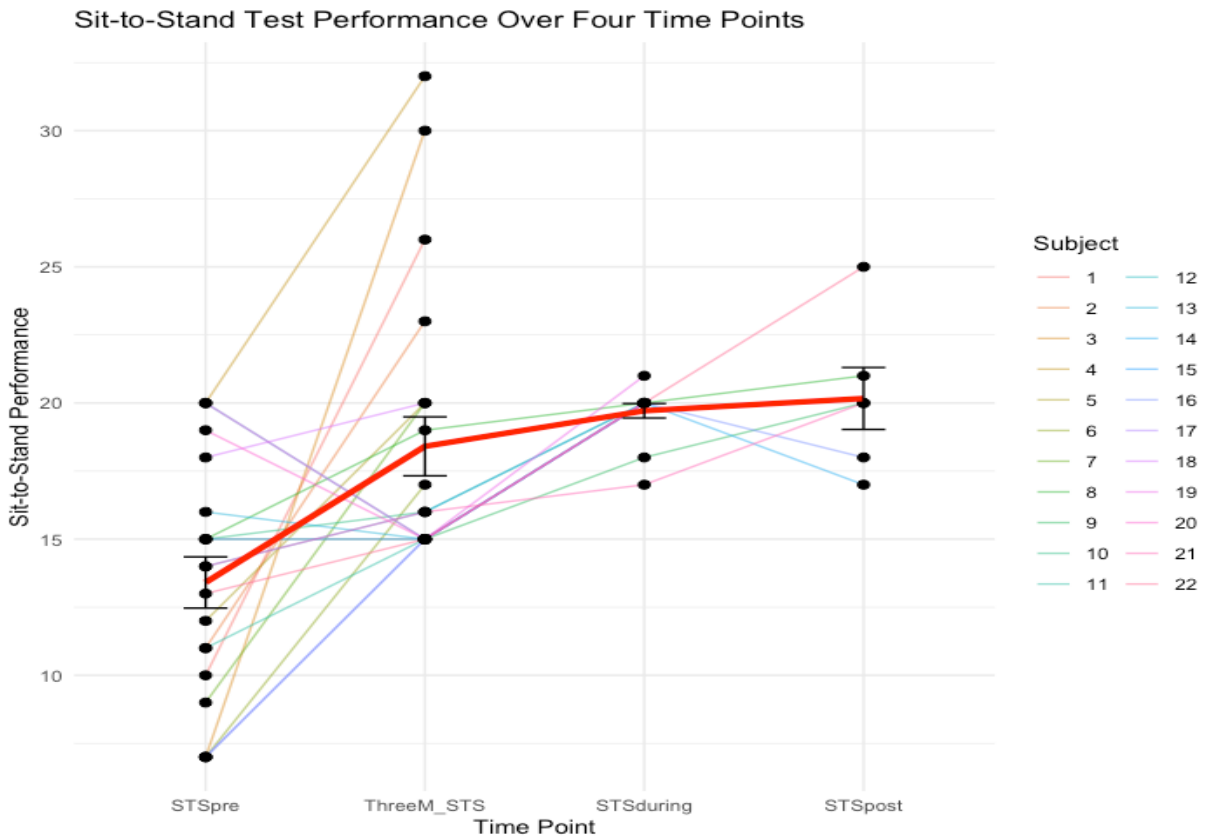



***Figure 0.18: Line plot that compares STS performance over four time points for individual patients.***

Figure 4.18 illustrates the STS performance over four time points: baseline (STSpre), 3-month follow-up (ThreeM-STS), pre-surgery (STS during), and 6 weeks post-surgery (STSpost) for individual participants. The above figure demonstrates that, on average, as evident by the bold red line, there is a notable improvement in STS performance from pre-surgery to post-surgery, with a moderate increase pre-surgery. However, individual responses vary significantly. This

aligns with the statistical findings that suggest significant improvements in exercise capacity pre-surgery for patients who had not undergone LVRS to 6 weeks post-surgery for patients who had undergone LVRS.

#### 4.4.4.2.2 Associations Between Exercise and Performance:

One of the goals of this study is to examine whether the LVRS patients' exercise time on the F4S app is associated with their performance on the ISWT and STS tests. Figure 4.19 is a correlation matrix plot that visualises the relationships between exercise time on the F4S app, ISWT performance, and STS performance at different time points.

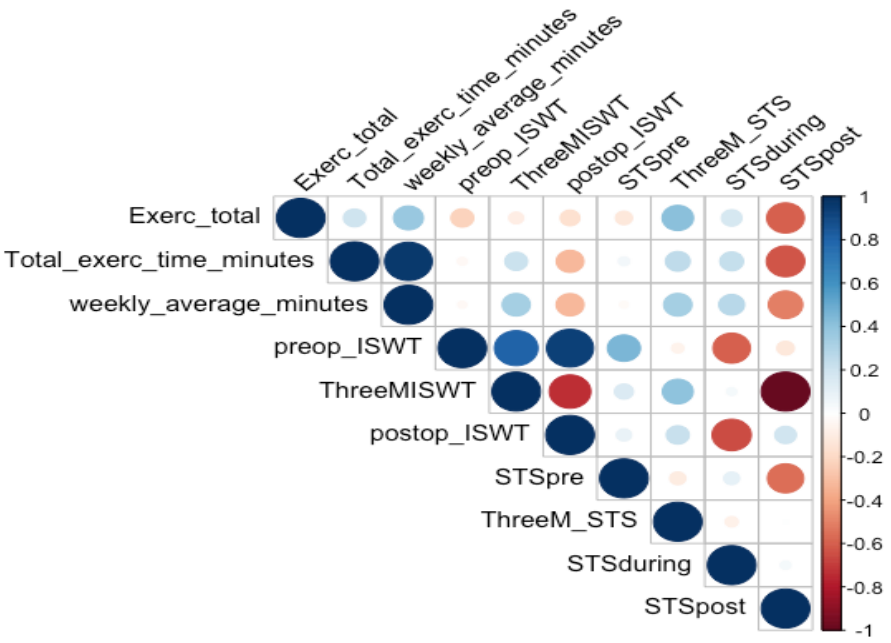



***Figure 0.19: Correlation matrix plot that visualises the relationships between different variables, such as exercise totals, and STS scores at different time points.***

Figure 4.19 shows that there are positive correlations between baseline ISWT, 3-month follow-up, 6 weeks post-surgery ISWT, and the baseline STS. This indicates that better performance in the ISWT is linked to better performance in the STS test. Additionally, the figure reveals a moderate positive correlation between exercise time on the F4S app and performance in physical tests, particularly the 3-month follow-up ISWT and STS tests. This implies that F4S

patients' functional capacity improves over time, and their exercise routines within the app may impact their performance on these tests. The next step was to further analyse these relationships by performing a Pearson correlation test to determine if these correlations are statistically significant. The only significant pair was total exercise time to 3-month follow-up STS ($p=0.050$), which supports the previous statement on the positive correlation between exercise time on the F4S app and performance in physical tests, especially the STS test, suggesting that LVRS patients' exercise routines within the app may influence their performance on these tests.

#### 4.4.4.3 Health-Related Quality of Life change

##### 4.4.3.3.1 Evaluation of changes and patterns in EORTC QLQ-C30 functioning and global health scores across various time points

To examine changes in the EORTC QLQ-C30, we compared the scores at baseline, 3-month follow-up, pre-surgery, 6 weeks, and 6 months. A minimal clinically important difference is defined as 10 points for QLQ-C30 (Table 4.18). However, it is important to note that not all the domain changes between time points were clinically significant. To further explore these changes, a pairwise comparison with Bonferroni correction was performed.

***Table 0.25: Post hoc pairwise comparison for EORTC QLQ-C30 functional and global health domains***

| EORTC QLQ-C30 Functioning and global health domain | Baseline vs 3-month follow-up Difference | P value | 95% CI | Baseline vs Pre-surgery Difference | P value | 95% CI | Baseline vs 6 weeks Difference | P value | 95% CI | Baseline vs 6 months Difference | P value | 95% CI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Global health | -28 | **0.00 | -46.7 – -10.3 | -33 | **0.00 | -51.4 – -15 | -50 | **0.00 | -68.9 – -32.5 | -61 | **0.00 | -79.8 – 43.3 |
| Physical functioning | -21 | *0.00 | -39.4 – -2.9 | -32 | **0.00 | -41.4 – -4.9 | -35 | **0.00 | -53.4 – -16.9 | -44 | **0.00 | -62.7 – -26.2 |
| Role functioning | -39 | **0.00 | -58.1 – -21.6 | -27 | **0.00 | -45.3 – -8.8 | -47 | **0.00 | -65.3 – -28.8 | -55 | **0.00 | -74 – -37.5 |
| Emotional functioning | -23 | **0.00 | -41.4 – -5 | -27 | **0.00 | -45.6 – -9.2 | -27 | **0.00 | -45.6 – -9.2 | -38 | **0.00 | -56.3 – -19.8 |
| Cognitive functioning | -16 | 0.17 | -34.8 – 1.5 | -20 | *0.00 | -38.2 – -1.7 | -40 | **0.00 | -58.2 – -21.7 | -44 | **0.00 | -63.2 – -26.7 |
| Social functioning | -47 | **0.00 | -65.9 – -29.4 | -34 | **0.00 | -52.6 – -16.1 | -59 | **0.00 | -77.6 – -41.1 | -69 | **0.00 | -87.6 – -51.1 |

Post-hoc pairwise comparison with Bonferroni correction. Statistical tests: paired t-test or Wilcoxon signed-rank test. *p<0.05; **p<0.001

***Table 0.26: Post hoc pairwise comparison for EORTC QLQ-C30 functional and global health domains***

| EORTC QLQ-C30 Functioning and global health domain | Pre-surgery vs 6 weeks Difference | P value | 95% CI | Pre-surgery vs 6 months Difference | P value | 95% CI | 6 weeks vs 6 months Difference | P value | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Global health | -17 | 0.09 | -35.7 – 0.7 | -28 | *0.00 | -46.5 – -10.1 | -10 | 1.0 | -29 – 7.3 |
| Physical functioning | -12 | 1.0 | -30.2 – 6.2 | -21 | *0.00 | -39.5 – -3 | -9.3 | 1.0 | -27.5 – 8.9 |
| Role functioning | -20 | *0.00 | -38.2 – -1.7 | -28 | **0.00 | -46.8 – -10.4 | -8.6 | 1.0 | -26.8 – 9.5 |
| Emotional functioning | 0 | 1.0 | -18.2 –18.2 | -10 | 1.0 | -28.8 – 7.5 | -10 | 1.0 | -28.8 – 7.5 |
| Cognitive functioning | -20 | *0.00 | -38.2 – -1.7 | -24 | **0.00 | -43.2 – -6.7 | -4.9 | 1.0 | -23.2 – 13.2 |
| Social functioning | -25 | **0.00 | -43.2 – -6.7 | -34 | **0.00 | -53.2 – -16.7 | -9.9 | 1.0 | -28.2 – 8.2 |

Post-hoc pairwise comparison with Bonferroni correction. Statistical tests: paired t-test or Wilcoxon signed-rank test. *p<0.05; **p<0.001

Tables 4.25 and 4.26 demonstrate the differences in EORTC QLQ-C30 functional and global health domains across various time points. Statistically, the difference in global health between pre-surgery and 6 weeks post-surgery (p=0.09) or 6 weeks and 6 months (p=1.00) was not significant; however, there was clinically meaningful improvement in the difference between pre-surgery and 6 weeks post-surgery of -17 and of 10 between 6 weeks and 6 months. On the other hand, global health has shown a significant improvement from baseline to 3-month follow-up for those who had not undergone surgery (p=0.00), with a difference of -28, indicating a meaningful enhancement in quality of life. Similarly, for those who had undergone LVRS, the comparison between baseline and pre-surgery, 6 weeks, and 6 months also shows a significant

improvement (p=0.00, difference of >10), with a consistent enhancement over time. Also, there were significant and clinical improvements between pre-surgery and 6 months (p=0.00, difference of -28).

For physical functioning, the difference between pre-surgery and 6 weeks post-surgery (p=1.0) or 6 weeks and 6 months (p=1.00) was not statistically significant; however, there was a clinically meaningful improvement in the difference between pre-surgery and 6 weeks post-surgery of -12. Yet, physical functioning showed a significant improvement from baseline to 3-month follow-up for those who had not undergone surgery (p=0.00), with a difference of -21, indicating a meaningful enhancement in quality of life. Comparably, for those who had undergone LVRS, the comparison between baseline and pre-surgery, 6 weeks, and 6 months, also shows a significant improvement (p=0.00, difference of >10), with a consistent enhancement over time. Additionally, there were significant and clinical improvements between pre-surgery and 6 months (p=0.00, difference of -21).

Role functioning demonstrated significant improvements from baseline to 3-month follow-up for patients who had not undergone LVRS (p=0.00, difference of -39). Additionally, for those who had undergone LVRS, the comparison between baseline and pre-surgery, 6 weeks, and 6 months, also shows a significant improvement (p=0.00, difference of >10), with a consistent enhancement over time. Furthermore, there were significant and clinical improvements between pre-surgery, 6 weeks, and 6 months (p=0.00, difference of > 10). However, the difference between 6 weeks and 6 months post-surgery (p=1.0) was not statistically significant.

In terms of emotional functioning, there was a significant improvement from baseline to 3-month follow-up for those who had not undergone surgery (p=0.00), with a difference of -23, indicating a meaningful enhancement in QoL. Comparably, for those who had undergone LVRS, the comparison between baseline and pre-surgery, 6 weeks, and 6 months, also shows a significant improvement (p=0.00, difference of >10), with a consistent enhancement over time. In contrast, the difference in emotional functioning between pre-surgery and 6 weeks post-surgery (p=1.0), pre-surgery and 6 months (p=1.00), or 6 weeks and 6 months (p=1.00) was not statistically significant; however, there was a clinically meaningful improvement in the difference between pre-surgery and 6 months post-surgery of -10 and likewise between 6 weeks and 6 months post-surgery.

Cognitive functioning showed no significant difference between baseline and 3-month follow-up (p=0.17) for patients who had not undergone surgery; however, there was a clinically meaningful improvement in the difference between baseline and 3-month follow-up of -16. On the other hand, for those who had undergone LVRS, the comparison between baseline and pre-surgery, 6 weeks, and 6 months, showed significant improvements (p=0.00, difference of >10), with a consistent enhancement over time. Additionally, the same applied during pre-surgery and 6 weeks and 6 months (Table 4.21b). However, the difference between 6 weeks and 6 months post-surgery (p=1.0) was not statistically significant.

Social functioning did not exhibit significant differences between 6 weeks and 6 months (p=1.0, difference of -9.9). Nonetheless, social functioning demonstrated significant improvements from baseline to 3-month follow-up for patients who had not undergone their LVRS (p=0.00, difference of -47). Moreover, for those who had undergone LVRS, the comparison between baseline and pre-surgery, 6 weeks and 6 months, also shows a significant improvement (p=0.00, difference of >10), with a steady enhancement over time. Likewise, there were significant and clinical improvements between pre-surgery and 6 weeks and 6 months (p=0.00, difference of > 10). Figures 4.20 and 4.21 show EORTC QLQ-C30 functioning and global health patterns over 6 months following LVRS.

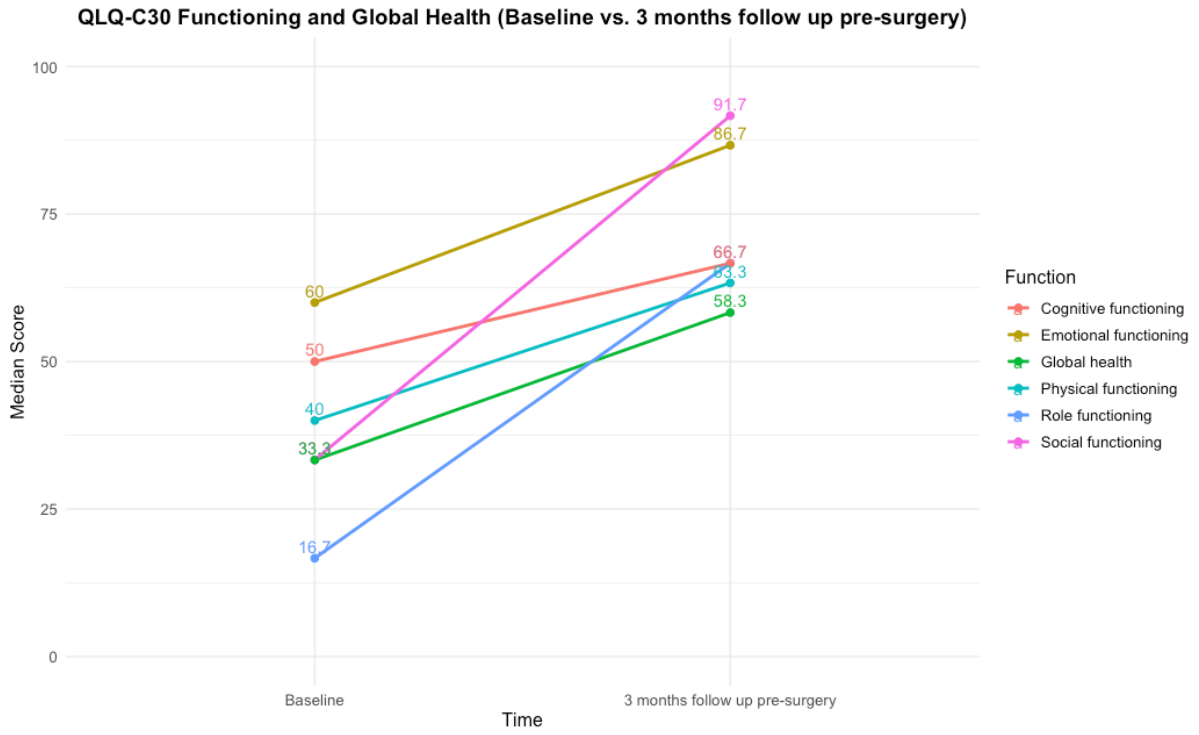



***Figure 0.20: The trajectories of EORTC QLQ-C30 functioning and global health domains at baseline and 3-month follow-up for LVRS patients who had not undergone surgery.***

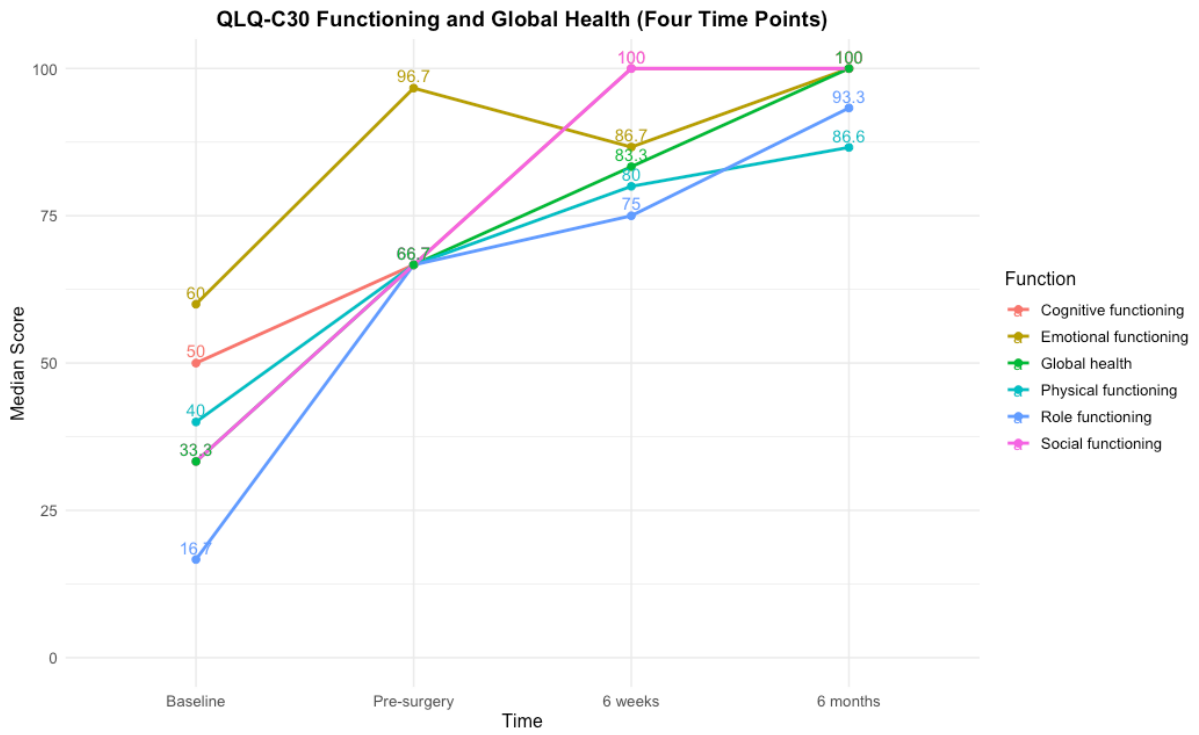



***Figure 0.21: The trajectories of EORTC QLQ-C30 functioning and global health domains at baseline, pre-surgery, 6 weeks, and 6 months after LVRS.***

#### 4.4.3.3.2 Evaluation of changes and patterns in EORTC QLQ-C30 symptoms scores across various time points

To examine changes in the EORTC QLQ-C30, we compared the scores at baseline, 3-month follow-up, pre-surgery, 6 weeks, and 6 months. A minimal clinically important difference is defined as 10 points for QLQ-C30 (Table 4.19). However, it is important to note that not all symptom changes between time points were clinically significant. To further explore these changes, a pairwise comparison with Bonferroni correction was performed.

***Table 0.27: Post hoc pairwise comparison for EORTC QLQ-C30 symptom domains***

| EORTC QLQ-C30 symptoms domains | Baseline vs 3-month follow-up Difference | P value | 95% CI | Baseline vs Pre-surgery Difference | P value | 95% CI | Baseline vs 6 weeks Difference | P value | 95% CI | Baseline vs 6 months Difference | P value | 95% CI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fatigue | 21.7 | *0.00 | 40.9 – 4.6 | 23.3 | **0.00 | 43.1 – 5 | 40.6 | **0.00 | 59.8 – 8.6 | 58.3 | **0.00 | 77.6 – 12.4 |
| Nausea and vomiting | 17.4 | 0.23 | 36.6 – 3.7 | 12.4 | 1.0 | 31.6 – 2.6 | 15.7 | 0.86 | -3.4 – 35 | 16.3 | 0.56 | -2.9 – 35.5 |
| Pain | 35.8 | **0.00 | 16.6 – 55.1 | 20.3 | *0.00 | 1 – 39.5 | 33.6 | **0.00 | 14.3 – 52.8 | 40.3 | **0.00 | 21 – 59.5 |
| Dyspnoea | 14.6 | 1.0 | -4.6 – 33.8 | 29 | **0.00 | 9.8 – 48.3 | 42.4 | **0.00 | 23.1 – 61.6 | 59.6 | **0.00 | 40.4 – 78.9 |
| Insomnia | 34.6 | **0.00 | 15.4 – 53.9 | 20.6 | *0.00 | 1.3 – 39.8 | 31.7 | **0.00 | 12 – 50.9 | 40 | **0.00 | 20.8 – 59.3 |
| Appetite loss | 20.9 | *0.00 | 1.7 – 40.2 | 14.8 | 1.0 | -4.4 – 34 | 34.8 | **0.00 | 15.5 – 54 | 38.1 | **0.00 | 18.9 – 57.4 |
| Constipation | 12.6 | 1.0 | -6.6 – 31.8 | 14.4 | 1.0 | -4.4 – 34 | 14.8 | 1.0 | -4.4 – 34 | 16.5 | 0.48 | -2.7 – 35.7 |
| Diarrhoea | 21.1 | **0.00 | 1.9 – 40.4 | 21.1 | **0.00 | 1.9 – 40.4 | 21.1 | **0.00 | 1.9 – 40.4 | 21.1 | **0.00 | 1.9 – 40.4 |
| Financial difficulties | 14.6 | 1.0 | -4.6 – 33.8 | 9 | 1.0 | -10 – 28.3 | 15.7 | 0.86 | -3.4 – 35 | 21.3 | **0.00 | 2 – 40.5 |

Post-hoc pairwise comparison with Bonferroni correction. Statistical tests: paired t-test or Wilcoxon signed-rank test. *p<0.05; **p<0.001

***Table 0.28: Post hoc pairwise comparison for EORTC QLQ-C30 symptom domains***

| EORTC QLQ-C30 symptoms domains | Pre-surgery vs 6 weeks Difference | P value | 95% CI | Pre-surgery vs 6 months Difference | P value | 95% CI | 6 weeks vs 6 months Difference | P value | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Fatigue | 16.6 | 0.43 | 35.9 – 3.5 | 34.4 | **0.00 | 53.6 – 7.3 | 17.7 | 0.17 | 37 – 3.7 |
| Nausea and vomiting | 3.33 | 1.0 | -15.9 – 22.5 | 3.8 | 1.0 | -15.3 – 23.1 | 0.55 | 1.0 | -18.6 – 19.8 |
| Pain | 13.3 | 1.0 | -5.9 – 32.5 | 20 | *0.00 | 39.2 – 4.2 | 6.6 | 1.0 | -12.5 – 25.9 |
| Dyspnoea | 13.3 | 1.0 | -5.9 – 32.5 | 30.5 | **0.00 | 11.3 – 49.8 | 17.2 | 0.27 | -2 – 36.4 |
| Insomnia | 11.1 | 1.0 | -8.1 – 30.3 | 19.4 | *0.00 | 0.2 – 38.7 | 8.3 | 1.0 | -10.9 – 27.5 |
| Appetite loss | 20 | *0.00 | 0.7 – 39.2 | 23.3 | **0.00 | 4 – 42.5 | 3.3 | 1.0 | -15.9 – 22.5 |
| Constipation | 0 | 1.0 | -19.2 – 19.2 | 1.6 | 1.0 | -17.5 – 20.9 | 1.6 | 1.0 | -17.5 – 20.9 |
| Diarrhoea | 0 | 1.0 | -19.2 – 19.2 | 0 | 1.0 | -19.2 – 19.2 | 0 | 1.0 | -19.2 – 19.2 |
| Financial difficulties | 6.6 | 1.0 | -12.5 – 25.9 | 12.2 | 1.0 | -7 – 31.4 | 5.5 | 1.0 | -13.6 – 24.8 |

Post-hoc pairwise comparison with Bonferroni correction. Statistical tests: paired t-test or Wilcoxon signed-rank test. *p<0.05; **p<0.00

Tables 4.27 and 4.28 exhibit the differences in EORTC QLQ-C30 symptom domains across various time points. Statistically, the difference in fatigue between pre-surgery and 6 weeks post-surgery (p=0.43) or 6 weeks and 6 months (p=0.17) was not statistically significant; however, there was clinically meaningful improvement in the difference between pre-surgery and 6 weeks post-surgery of 16.6 and of 17.7 between 6 weeks and 6 months with a reduction that exceeds the minimal clinically important difference (MCID) of 10 points, indicating a meaningful and clinically significant improvement in fatigue over time. On the other hand, fatigue shows a significant improvement from baseline to 3-month follow-up for those who had not undergone surgery (p=0.00), with a difference of 21.7. Similarly, for those who had undergone LVRS, the comparison between baseline and pre-surgery, 6 weeks, and 6 months also shows a significant improvement (p=0.00, reduction of >10), with a consistent enhancement over time. Also, there were significant and clinical improvements between pre-surgery and 6 months (p=0.00, reduction of 34.4).

For pain, there was a significant improvement from baseline to 3-month follow-up for those who had not undergone surgery (p=0.00), with a difference of 35.8, reflecting a reduction in pain levels that exceeds the MCID. Equally, for those who had undergone LVRS, the comparison between baseline and pre-surgery, 6 weeks, and 6 months also shows a significant improvement (p=0.00, reduction of >10), with a consistent reduction in pain over time. No significant differences were found between pre-surgery and 6 weeks (p=1.0) or between 6 weeks and 6 months post-surgery (p = 1.00), suggesting that the meaningful reduction in pain occurred mainly in pre-surgery to 6 weeks post-surgery (13.3). Nonetheless, there were significant and clinical improvements in pain scores between pre-surgery and 6 months (p=0.00, reduction of 20).

Dyspnoea also improved significantly and clinically from baseline to pre-surgery, 6 weeks, and 6 months post-surgery (p=0.00, reduction of >10), indicating fewer breathing difficulties with an effect exceeding the MCID threshold. However, for those who did not have LVRS, no significant reduction between baseline and 3-month follow-up was found (p=1.0), yet that reduction of 14.6 was clinically meaningful. No significant differences were found between pre-surgery and 6 weeks (p=1.0) or between 6 weeks and 6 months post-surgery (p= 0.27), but there was a clinically meaningful reduction in both times of >10. The improvement continued from pre-surgery to 6 months, with a significant and clinically important reduction in dyspnoea (p = 0.00, reduction of 30.5).

For insomnia, there was a significant improvement from baseline to 3-month follow-up for those who had not undergone surgery (p=0.00), with a difference of 34.6, indicating a reduction in insomnia that exceeds the MCID. Similarly, for those who had undergone LVRS, the comparison between baseline and pre-surgery, 6 weeks, and 6 months also shows a significant improvement (p=0.00, reduction of >10), with a consistent reduction in insomnia over time. No significant or clinically important differences were found between pre-surgery and 6 weeks (p = 1.0) or baseline and 6 weeks (p = 1.0) except for pre-surgery to 6 weeks (-11.1). However, a significant and clinically meaningful reduction was observed from pre-surgery to 6 months (p = 0.00, reduction of 19.4).

For patients who had not undergone LVRS, appetite loss showed a significant improvement both clinically and statistically (p=0.00, reduction of 20.9). In addition, for patients who had undergone LVRS, appetite loss showed significant improvements both clinically and statistically in baseline to 6 weeks and 6 months (p=0.00, reduction of >10). On the other hand, there was no statistically significant difference between baseline and pre-surgery (p=1.0), yet a clinically meaningful reduction of 14.8 was found. Nevertheless, appetite loss showed significant improvements both clinically and statistically in pre-surgery to 6 weeks and 6 months (p=0.00, reduction of >10). In contrast, no statistically or clinically significant differences were observed in appetite loss from 6 weeks to 6 months after surgery (p=1.0, reduction of 3.3).

For diarrhoea, there was a significant improvement from baseline to 3-month follow-up for those who had not undergone surgery (p=0.00), with a difference of 21.1, showing a reduction in diarrhoea that exceeds the MCID. Comparably, for those who had undergone LVRS, the comparison between baseline and pre-surgery, 6 weeks, and 6 months also shows a significant improvement (p=0.00, reduction of >10), with a consistent reduction in diarrhoea over time. However, no significant or clinically important differences were found in the other time points.

Financial difficulties showed significant and clinical improvements between baseline and 6 months after surgery (p=0.00, reduction of 21.3). However, no significant or clinically important differences were found in the other time points except for baseline to 3 months for patients who had not yet undergone LVRS yet (reduction of 14.6), baseline to 6 weeks post-surgery (reduction of 15.7), and pre-surgery to 6 weeks (reduction of 12.2).

Other symptoms, including nausea, vomiting, and constipation, exhibited no statistically significant changes across the time points. Nonetheless, most of the time points exceeded the MCID threshold in both symptoms from baseline to 3-month follow-up for patients who had not undergone LVRS and baseline to pre-surgery, 6 weeks, and 6 months as indicated in Table 4.27. Figures 4.22 and 4.23 illustrate the EORTC QLQ-C30 symptom patterns over 6 months following LVRS.

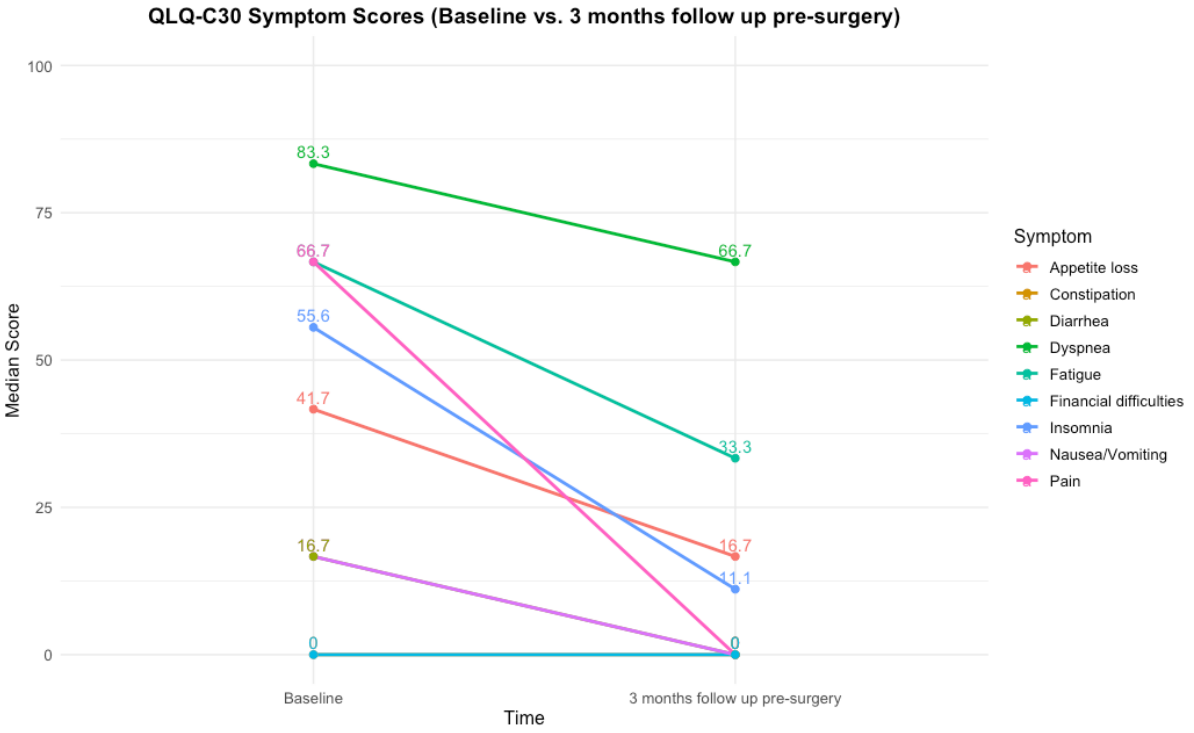



***Figure 0.22: The trajectories of EORTC QLQ-C30 symptoms domains at baseline and 3 months follow-up pre-surgery.***

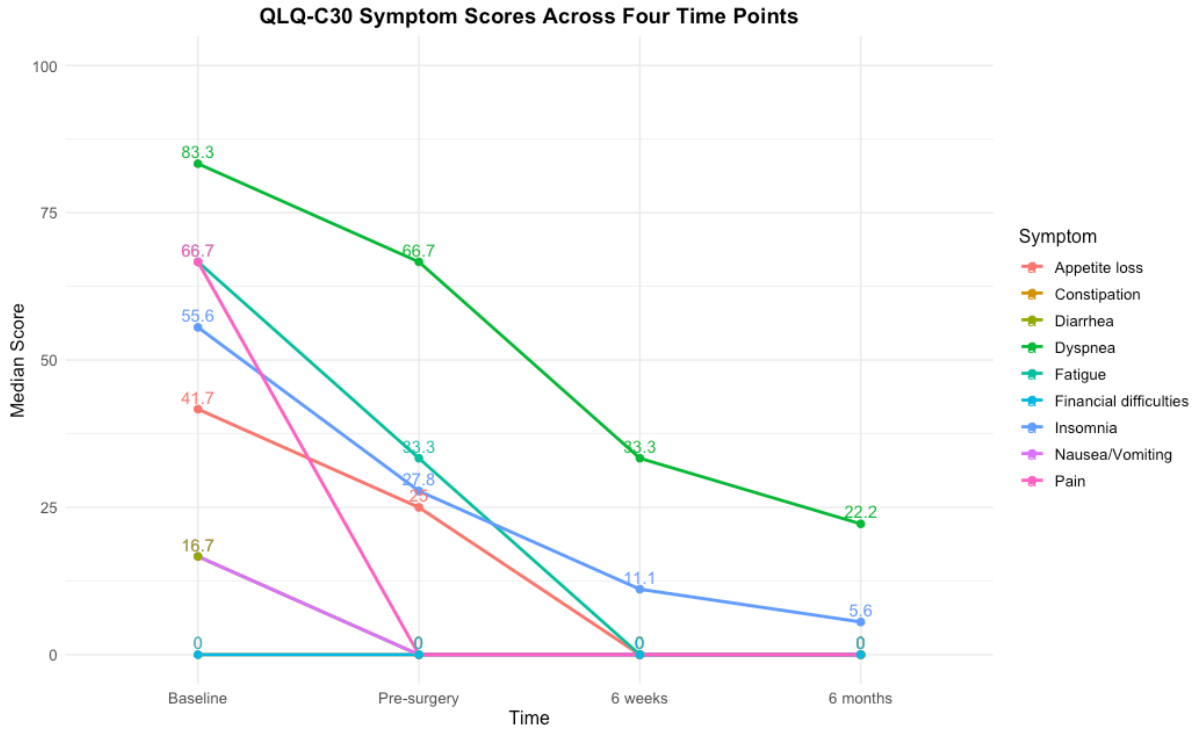



***Figure 0.23: The trajectories of EORTC QLQ-C30 symptoms domains at baseline, pre-surgery, 6 weeks, and 6 months after LVRS.***

### 4.4.4.4 Technology Acceptance Model (TAM) Questionnaire:

The TAM questionnaire is a widely used tool designed to assess users' acceptance of new technologies, as explained in section 4.1.4.4. In this study, the TAM is used to evaluate the acceptance of a digital prehabilitation programme (F4S), providing insights into how patients perceive its usefulness and ease of use in improving their health outcomes, at 1 month post-surgery in which the patients by that time would have had sufficient period to use the app. Table 4.26 demonstrates the patients' responses to the TAM questionnaire. All the constructs in Table 4.26 were measured on 7-point Likert-type scales, from 1 = strongly disagree to 7 = strongly agree.

***Table 0.29: Descriptive Statistics of TAM questionnaire responses (n=10)***

| Construct | | mean | median | sd |
|---|---|---|---|---|
| Attitude (AT) | AT1: Rehabilitation through the Fit 4 Surgery app is a good idea. | 6.8 | 7 | 0.40 |
| | AT2: Rehabilitation through the Fit 4 Surgery is a wise idea. | 6.6 | 7 | 0.67 |
| | AT3: I feel positive towards rehabilitation through the Fit 4 Surgery app. | 6.5 | 7 | 0.68 |
| Behavioural intention (BI) | BI1: I intend to check my progress from the Fit 4 Surgery app frequently. | 5.9 | 6 | 1.37 |
| | BI2: I intend to be a heavy user of the Fit 4 Surgery app. | 5.5 | 6 | 1.63 |

| | | | | |
|---|---|---|---|---|
| Perceived ease of use (PE) | PE1: I find the Fit 4 Surgery app easy to use. | 6 | 6 | 1 |
| | PE2: Learning how to use a Fit 4 Surgery app is easy for me. | 6 | 7 | 1.5 |
| | PE3: It is easy to become skilful at using the Fit 4 Surgery app. | 5.8 | 6 | 1.6 |
| Perceived usefulness (PU) | PU1: The Fit 4 Surgery app would improve my rehabilitation performance. | 6.7 | 7 | 0.46 |
| | PU2: Fit 4 Surgery app would increase rehabilitation productivity. | 6.8 | 7 | 0.40 |
| | PU3: Fit 4 Surgery app could make it easier to do my rehabilitation programme exercises. | 6.9 | 7 | 0.30 |
| Self- efficacy (SE) | SE1: I feel confident finding information in the Fit 4 Surgery app. | 5.6 | 6 | 1.96 |
| | SE2: I have the necessary skills for using the Fit 4 Surgery app. | 5.2 | 6 | 2 |
| Subjective norm (SN) | SN1: What the Fit 4 Surgery app stands for is important for me as a perioperative patient. | 6.7 | 7 | 0.64 |
| | SN2: I like using the Fit 4 Surgery app based on the similarity of my values and society values underlying its use. | 6.6 | 7 | 1.2 |
| | SN3: In order for me to prepare for future surgery, it is necessary to complete rehabilitation through the Fit 4 Surgery app. | 6.72 | 7 | 0.90 |
| System accessibility (SA) | SA1: I have no difficulty accessing and using the Fit 4 Surgery app in my home. | 5.9 | 7 | 2.07 |

Data are presented as mean (median), and standard deviation.

Table 4.29 displays that the LVRS participants' responses to all of the seven constructs reveal a more than average satisfaction level with the F4S app, which indicates that the F4S app was acceptable to the patients based on the TAM questionnaire. Figure 4.24 provides further details in terms of individual responses for each item to understand how individual responses are spread across the scale.

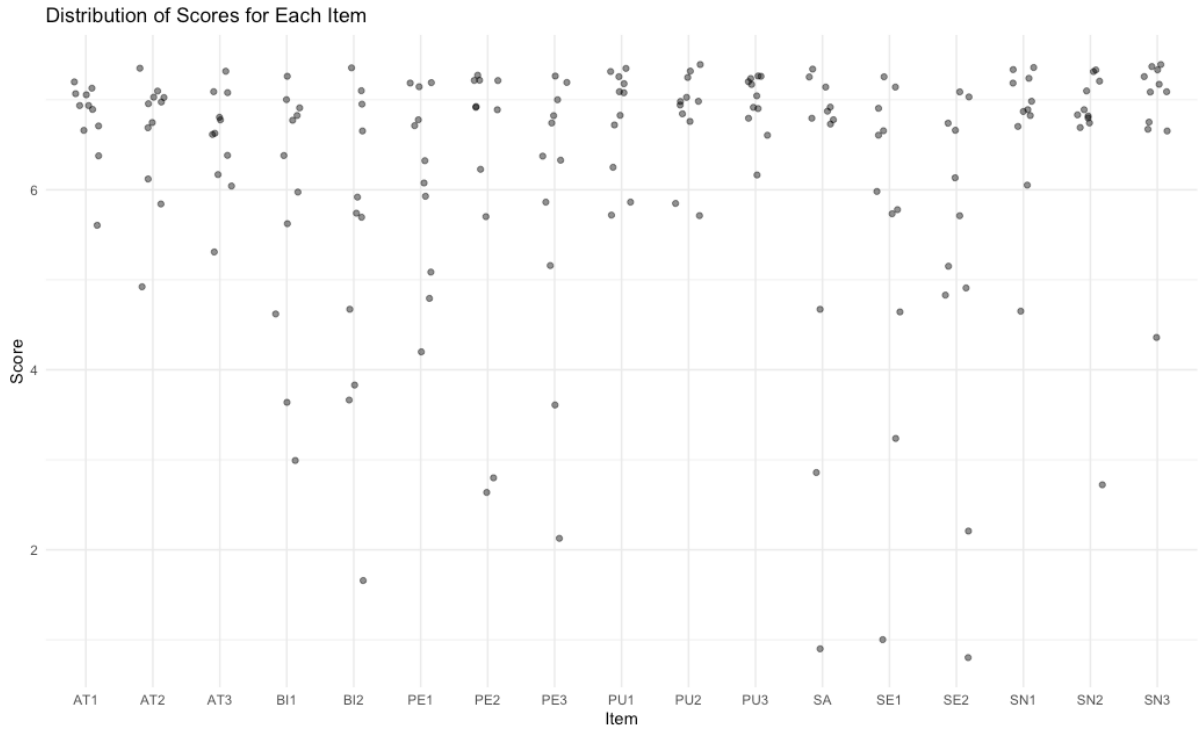



***Figure 0.24: Scatter plots of the TAM responses to display the individual responses for each item.***

Figure 4.24 demonstrates that the overall median score across most items seems to fall in the upper range; this suggests that most responses tend to be high, which aligns with the results in Table 4.26.

#### 4.4.4.4.1 Validity and Reliability of Technology Acceptance Model (TAM) Questionnaire:

As explained in section 4.4.1.4.1, the Cronbach's Alpha values will be shown only in this section. Cronbach's Alpha values above 0.70 also indicate good internal consistency, and all the constructs exceed this threshold, with values ranging from 0.84 (PU) to 0.97 (SE). This confirms that the constructs are reliably measured by their respective indicators. This means the items within each construct are measuring the same underlying concept consistently. High reliability suggests that the items are well-suited for their intended construct. All of the constructs had an alpha score of more than 0.70, which means that the TAM questionnaire is reliable to measure the F4S acceptance level.

#### 4.4.4.5 COPD Assessment Test (CAT) score analysis:

Table 4.22 presents the CAT scores across five time points, showing a consistent improvement from baseline to 6 months post-surgery. The observed changes exceed the MCID of 2 points, indicating that all patients who improved experienced a clinically significant enhancement in their symptoms from pre-surgery, with continued improvement to 6 months post-surgery. However, it is important to note that not all changes between time points were clinically significant. To further explore these changes, a pairwise comparison with Bonferroni correction was performed.

***Table 0.30: Post hoc pairwise comparison for CAT scores***

| CAT | Baseline vs 3 months follow up Difference | P value | 95% CI | Baseline vs Pre-surgery Difference | P value | 95% CI | Baseline vs 6 weeks Difference | P value | 95% CI | Baseline vs 6 months Difference | P value | 95% CI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CAT score | -4.44 | **0.00 | -3.05 – -5.83 | -7.5 | 0.07 | -0.5 – -15.5 | -10.8 | **0.00 | 2.7 – 18.8 | -16.2 | **0.00 | -8.1 – -24.2 |

Post-hoc pairwise comparison with Bonferroni correction. Statistical tests: paired t-test or Wilcoxon signed-rank test. *p<0.05; **p<0.001

***Table 0.31: Post hoc pairwise comparison for CAT scores***

| CAT | Pre-surgery vs 6 weeks Difference | P value | 95% CI | Pre-surgery vs 6 months Difference | P value | 95% CI | 6 weeks vs 6 months Difference | P value | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| CAT score | -3.33 | 1.0 | -5.8 – 12.5 | -8.7 | 0.071 | -0.4 – -17.9 | -5.4 | 0.66 | -3.7 – 14.6 |

Post-hoc pairwise comparison with Bonferroni correction. Statistical tests: paired t-test or Wilcoxon signed-rank test. *p<0.05; **p<0.001

Tables 4.30 and 4.31 reveal the differences in the CAT scores across various time points. Statistically, the difference in the CAT score shows a significant improvement from baseline to 3 months follow-up for those who had not undergone surgery (p=0.00), with a difference of -4.44. Similarly, for those who had undergone LVRS, the comparison between baseline and 6 weeks and 6 months also shows a significant improvement (p=0.00, reduction of >2), with a consistent enhancement in COPD symptoms over time. On the other hand, while the CAT score did not change significantly in the other time points, the CAT score in all of these time points exceeded the MCID of 2 points. Figure 4.25 illustrates the CAT score patterns over 6 months following LVRS.

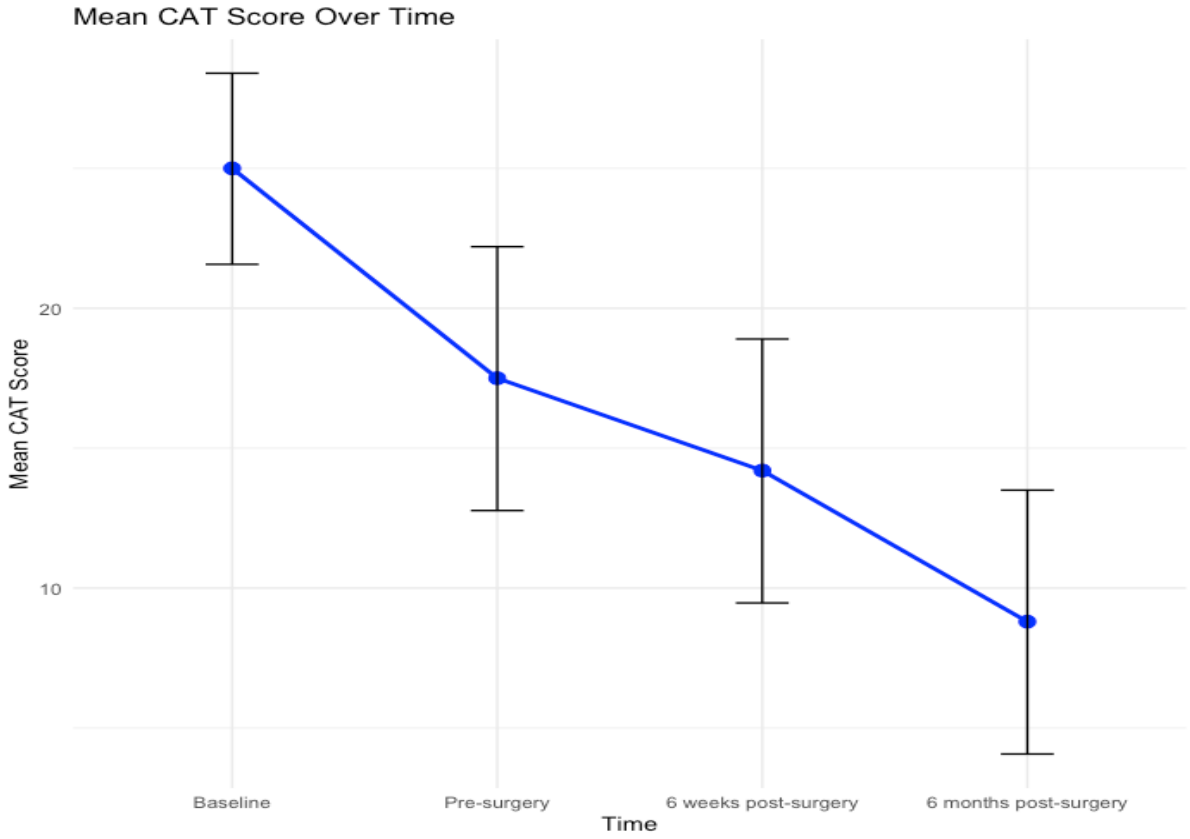



***Figure 0.25: The trajectories of the CAT score at baseline, pre-surgery, 6 weeks, and 6 months after LVRS.***

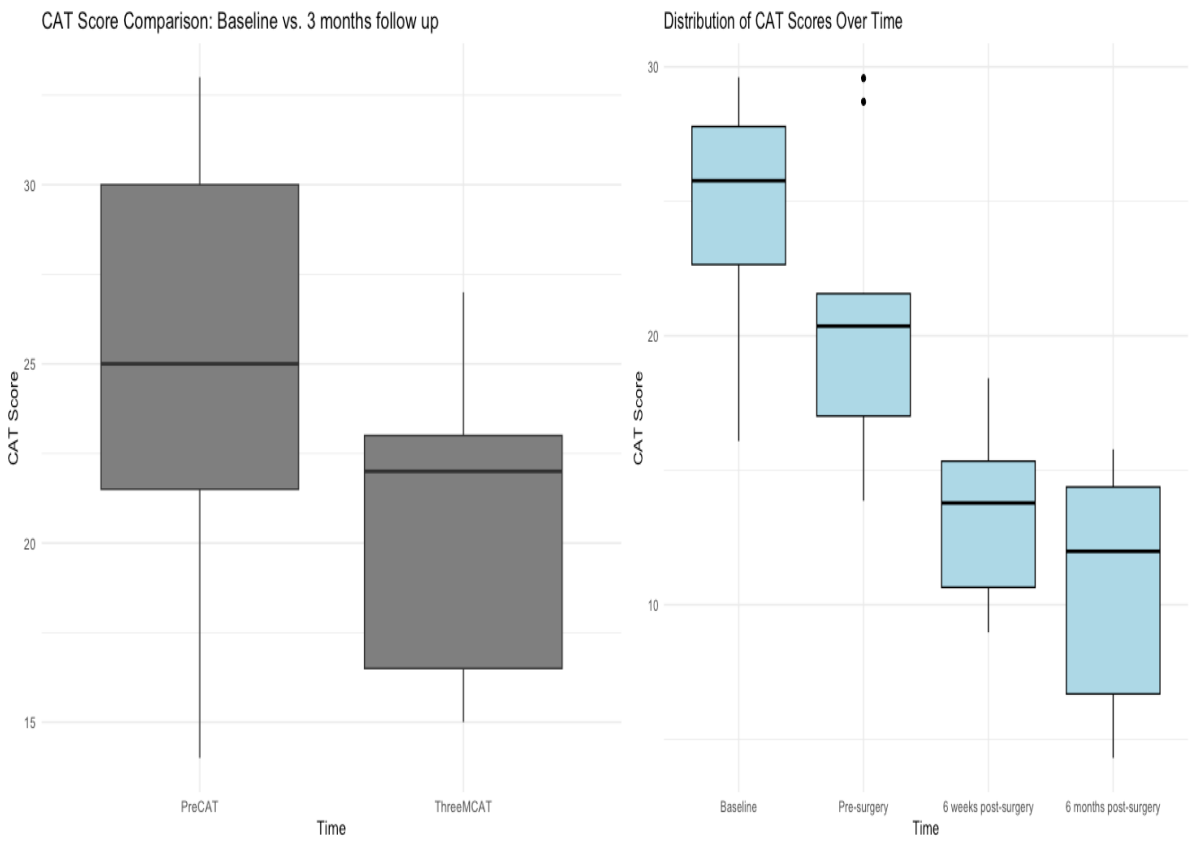



***Figure 0.26: Boxplots that show the changes in the CAT score at baseline, 3-month follow-up, pre-surgery, 6 weeks, and 6 months before and after LVRS.***

Figure 4.26 explains the change in the CAT scores in different time points for patients who had undergone LVRS and for those who had not yet undergone surgery. There is a trend of improvement in the CAT score from baseline to 6 months post-surgery, and the improvement is clinically significant (Figure 4.26).

**4.4.4.6 The remaining outcome measures analysis:**

The remaining outcome measures, including the EQ-5D, HADS, pain scale, and PG-SGA questionnaires, were collected through the app. However, a high proportion of missing data at later time points — specifically pre-surgery and post-surgery — made further analysis of these outcome measures unfeasible. Table 2 in the Appendices presents the distribution of scores for the remaining outcome measures across different time points (Appendix 8.8).

## 4.5 Discussion:

The effectiveness of digital prehabilitation programmes on surgical outcomes remains inconclusive. Despite some RCTs being conducted, the lack of rigorous inclusion and exclusion criteria in many studies can limit the generalisability of their findings. Overall, this study pointed out that there was a statistically significant increase in exercise capacity from baseline to post-surgery as evident in the ISWT scores from pre-surgery to post-surgery ($p=0.000$) in both patients' cohorts (LC and LVRS) and from baseline to 3-month follow-up before surgery in LVRS patients ($p=0.000$). In terms of the STS performance for the LC surgery patients, there was a statistically significant increase from baseline to 6 weeks post-surgery and pre-surgery to 6 weeks post-surgery ($p=0.0024$, $p=0.0207$). Regarding the STS performance for the LVRS patients, there was a statistically significant increase from baseline to 3-month follow-up before surgery, baseline to pre-surgery, and baseline to 6 weeks post-surgery ($p=0.019$, $p=0.001$, $p=0.045$). As evident in the patients' performance in the ISWT and STS tests, the exercise capacity of both patient cohorts (LC and LVRS) improved from baseline to post-surgery; even though parts of the functioning lung had been removed, the patients still performed better after surgery. Also, this research revealed a moderate positive correlation between the exercise time on the F4S app and performance in the two physical tests, which means that F4S patients' functional capacity remains consistent over time, and their exercise routines within the app may influence their performance on these tests (Figures 4.7 and 4.19).

Regarding the EORTC QLQ-C30 functioning and global health domains, the study shows significant improvements in global health, and physical, role, emotional, and social functioning from baseline to 6 months post-surgery, with most changes being both statistically and clinically meaningful in both patient cohorts (LC and LVRS). However, cognitive functioning showed no significant changes in LC surgery patients and from baseline to 3 months before surgery in LVRS patients, and certain improvements, like in emotional functioning, were more stable after the initial improvement. Moreover, the EORTC QLQ-C30 symptom domains showed significant and clinically meaningful improvements in fatigue, pain, dyspnoea, and insomnia from baseline to 6 months post-surgery, with reductions that exceeded the MCID in

both patient cohorts. Other symptoms, such as appetite loss, showed significant and clinically meaningful improvement only in the LVRS patients.

In addition, this study's results demonstrated that participants from the LC surgery and the LVRS cohorts generally expressed satisfaction with the F4S app, indicating that it was perceived as acceptable and useful for their rehabilitation, as apparent in the TAM questionnaire. The difference in the CAT scores for the LVRS patients shows a significant improvement from baseline to 3-month follow-up for those who had not undergone surgery ($p=0.00$), with a difference of -4.44. Similarly, for those who had undergone LVRS, the comparison between baseline and 6 weeks and 6 months also shows a significant improvement ($p=0.00$, reduction of >2), with a consistent enhancement in COPD symptoms over time. Furthermore, the CAT score at all of the time points exceeded the MCID of 2 points (Figures 4.25 and 4.26). Finally, the clinical outcomes analysis displayed that the median LOS was 5 days for LC surgery patients and 3.5 days for LVRS patients, with a mild complication burden reflected by the mean CCI scores of 9 for LC and 8.7 for LVRS during the hospital stay and 0.8 and 0 for 1 month after surgery. Most complications were minimal (CDC grades 1 and 2), and only 13 out of 38 patients experienced a PPC in the LC cohort and 4 out of 10 in the LVRS cohort.

This study's findings correlate with findings from a prospective, single-arm feasibility trial that showed a home-based prehabilitation programme was associated with enhancing exercise capacity in patients undergoing lung cancer surgery from baseline to 5 weeks post-surgery STS test ($p=0.001$) [42]. However, the other physical tests in Machado et al.'s (2023) study, such as ISWT, were not statistically significant, which contradicts the findings of this study. In contrast to our study, the RCT by Ferreira et al. (2021) investigated whether a multimodal prehabilitation programme was more effective than the same intervention delivered postoperatively in patients undergoing lung cancer surgery. Their results showed no significant difference in exercise capacity, measured by the 6-minute walk test, between the two groups at any perioperative timepoint. However, this does not necessarily contradict our findings, since the primary aim of their study was to assess the effect of the timing of the intervention rather than comparing prehabilitation to standard care. Importantly, both groups received structured exercise, nutritional support, and psychological strategies—components known to aid recovery. Thus, the absence of a difference reflects that prehabilitation was equally effective as rehabilitation, and not that it lacked any benefit. Moreover, they found that patients

with lower baseline functional capacity gained the most from prehabilitation, which supports its potential value in appropriately selected patients [21]. Nonetheless, one of the limitations in the aforementioned RCT is the small and imbalanced sample size, which could explain the lack of a statistically significant difference between the two groups regarding their exercise capacity [24].

Our findings correlate with the findings of Machado et al.'s (2023) study in terms of the QoL scores after the intervention [42]. Machado et al. (2023) indicated significant changes in the QoL scores measured by EORTC QLQ-C30 from baseline to post-rehabilitation programme before the surgery. However, the study also mentioned that there were no statistically significant changes 5 weeks post-surgery compared with baseline with most patients reporting a clinically meaningful deterioration in physical functioning (66.6%), which does not correlate with our findings [42]. Furthermore, this single-arm feasibility trial concurred with our results in terms of the EORTC QLQ-C30 symptom domains, which showed significant and clinically meaningful improvements especially in fatigue from baseline to before surgery, with most patients having reported a clinically meaningful deterioration in pain, dyspnoea, and fatigue 5 weeks post-surgery [42]. However, it should be noted that one of the limitations in Machado et al.'s (2023) study is the lack of long-term follow-up, which could lead to several issues including potential bias in outcome interpretation especially when we notice that in our study, most of patients showed meaningful and significant improvements in their QoL scores 6 months post-surgery [42]. On the other hand, this study's findings contradict those of a recent systemic review that examined prehabilitation for cancer patients and concluded that while some prehabilitation programmes showed benefits, many did not significantly improve postoperative outcomes, including QoL compared to usual care [65]. However, it should be mentioned that the results of this systemic review could be limited by the heterogeneous tools for outcome measurement for the study included in the review [65].

Van der Velde et al. (2021) conducted an RCT measuring the acceptability and satisfaction rate on patients undergoing major surgery after using their mHealth app, which provides solutions that include accessible support for modifying behaviours such as PA [43]. Similarly, Van der Velde et al. (2021) found the app's acceptable usability (mean System Usability Scale score of 68.2), with efficiency and learnability rated highly by users, concurred with our study's findings as apparent in the TAM questionnaire [43]. However, despite these improvements in behaviour, the mHealth app did not significantly impact functional recovery 30 days post-

surgery, suggesting that while effective in motivating short-term behaviour changes, additional support may be necessary for meaningful postoperative outcomes. Nonetheless, feedback from users in Van der Velde et al.'s (2021) study highlighted a need for greater personalisation of the app to better address individual patient needs and capabilities; this might have influenced engagement and effectiveness, which might have led to the unmeaningful impact on postoperative outcomes [43].

The latter findings align with a systemic review indicating that prehabilitation is linked to better clinical outcomes, such as reduced length of stay (LOS) and postoperative pulmonary complications (PPC) in patients undergoing cardiac and vascular procedures [19]. Similarly, another systemic review has demonstrated that prehabilitation enhances PPC, exercise capacity, and QoL compared to standard care in patients undergoing non-small cell lung cancer resection [20]. This study's findings, along with those from existing literature, indicate that prehabilitation programs may enhance surgical outcomes, such as reducing LOS, PPC, and improving QoL for patients undergoing cardiac, vascular, and lung cancer surgeries [42,19,20]. Interestingly, this study's results oppose those of the earlier RCT, which found that prehabilitation did not impact clinical outcomes, such as PPC and LOS, in patients undergoing lung cancer resection surgery [21]. However, the same study agreed with this study's findings in showing the influence of prehabilitation on improving QoL, including physical functioning following lung cancer surgery [21]. Nonetheless, it should be noted that this RCT had a small and imbalanced sample size, a weakness that could not demonstrate the impact of prehabilitation on surgical outcomes such as PPC and LOS [24].

Our study had some limitations common to observational research; the findings might not apply to other major surgeries, different populations, or various settings. Additionally, the small sample size in our study could limit the generalisability of our findings to other settings. Moreover, the missing data in our study represented a limitation that could potentially affect the robustness of the findings. Nonetheless, this is a feasibility study, and the main goal of such studies is addressing uncertainties and refining study designs, which can lead to building a strong foundation for subsequent research phases, thus increasing the likelihood of valid, reliable, and impactful outcomes.

## 4.6 Conclusion:

In summary, the F4S app seemed to be acceptable for lung cancer surgery patients and might improve their QoL, clinical outcomes, and exercise capacity. However, due to the limitations of the feasibility design and the heterogeneity in the design of studies and patient populations in the literature, the impact of F4S app on lung cancer surgical outcomes could not be concluded. Hence, we suggest there is a need for bigger and more rigorous methodological clinical trials such as RCTs to be conducted to investigate the F4S digital prehabilitation programme's impacts on perioperative clinical outcomes compared to usual treatment on patients undergoing lung cancer surgery.

# Chapter 5

# A qualitative study investigating the factors related to the use of the Fit4Surgery digital prehabilitation programme for patients undergoing major surgery

The manuscript for this chapter has been submitted to the Journal of Cardiothoracic Surgery under the title "**A qualitative study investigating the factors related to the use of the Fit4Surgery digital prehabilitation programme for patients undergoing major surgery**" author contributions, as will be published, are listed.

Matar Alzahrani, [1,2,3] Joan Duda,[5] Salma Kadiri,[4] Babu Naidu[2,4]

**Names of the authors:**
1. College of Applied Medical Sciences, King Saud bin Abdulaziz University for Health Sciences, Jeddah, Saudi Arabia.
2. Institution of Inflammation and Aging, University of Birmingham, Birmingham, UK.
3. King Abdullah International Medical Research Center, Jeddah, Saudi Arabia.
4. Thoracic Surgery, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK.
5. School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, Birmingham, UK.

**- Authors' contributions**

Conception: BN, MA, JD

Data extraction & cleaning: MA

Analysis and interpretation of data: MA

Draft the work: MA

Draft revision: BN, SK, JD

Approval of the version: MA, BN, SK, JD

## Abstract

**Background:** Digital prehabilitation programs have emerged as a flexible alternative to traditional rehabilitation, offering potential benefits in improving physical, psychological, and social outcomes for patients preparing for surgery. This study evaluates user experiences with the Fit4Surgery (F4S) app, exploring its acceptability including facilitators and barriers, motivations, perceived benefits accrued via engagement with the app programme and areas for improvement.

**Methods:** A qualitative analysis was conducted using semi-structured interviews with 16 patients (males n=9, females n=7, median age of 69) who used the F4S app during their prehabilitation journey before their major surgery. Questions posed examined the patients' perspectives on the acceptability of the F4S app including facilitators and barriers, their motivations for engaging with the app, as well as the perceived benefits from using the app. Themes and sub-themes were identified through thematic analysis.

**Results:** The app was deemed to be highly acceptable, with features such as its user-friendly design and instructional videos acting as a facilitator, although some users faced initial apprehensions about technology as a barrier. Patients highlighted several motivations for using the app, including complying with family support, improving fitness for surgery, and recovering quickly to return to normal activities. Reported perceived benefits included physical and functional improvements, enhanced psychological well-being, and self-regulation of rehabilitation routines. The app also served as a flexible alternative to traditional rehabilitation options, particularly for users with barriers to in-person sessions. However, patients suggested improvements such as adding breathing exercises, increasing exercise intensity, and providing clearer instructions for novice users.

**Conclusion:** The F4S app demonstrates strong potential as a digital prehabilitation tool, addressing barriers in traditional rehabilitation while delivering, in the patients' views, comprehensive physical, psychological, and social benefits. Future iterations of the F4S app should focus on incorporating user feedback to enhance its features and accessibility, ensuring it meets diverse patient needs effectively. These findings contribute to the growing evidence supporting the role of digital tools in modern prehabilitation programs.

## 5.1 Introduction

Over 50,000 patients/year in the UK undergo major chest and abdominal surgery. Major complications following these operations are common and are linked to an increased risk of death, admission into an intensive care unit, and a longer stay in hospital [1,2,3]. Avoidance of these complications would offer significant benefits both to patients and the NHS.

A systematic review and a meta-analysis of preoperative exercise training/rehabilitation programmes suggest that fitness for surgery is better in those who undergo exercise training for between 2 to 6 weeks prior to chest or abdominal surgery [4,5]. However, these 'face-to-face' interventions require immediate access to expensive and over-stretched rehabilitation programmes, which is hampering NHS adoption of these strategies at present. This is further compounded by restrictions because of pre- and post-surgery self-isolation mandated to prevent COVID infection [120].

When one considers that surgery is increasingly offered to older, less-fit patients, the potential benefits of prehabilitation in preventing a significant proportion of all major complications following major surgery could produce a significant cost saving to the NHS [8]. A digital based programme of prehabilitation as well as rehabilitation, which includes exercise training, is one solution to this problem that could be adopted across the NHS. It could also help achieve the targets set out in the NHS outcomes framework, namely, recovering quickly and successfully from episodes of ill health, and ensuring patients have an excellent experience of care and long-term quality of life [9]. Furthermore, it would enable patients to manage their own rehabilitation/exercise programme at their convenience rather than travelling to the nearest rehabilitation centre in the run-up to surgery, thus enabling them to take control of this aspect of their care.

Beside the advantages associated with digital based exercise programme to the NHS, there are the potential benefits of an improved patient experience and quality of life and the consequent effects of an enhanced recovery, such as an earlier return to work and less distress and disruption to the wider family unit, e.g., hospital visits, child care etc.

We have developed and pilot-tested a Fit4Surgery (F4S) app on patients undergoing major surgeries (Lung cancer, lung volume reduction, upper gastro-intestinal) within the NHS. It

contains short descriptive videos of each suggested exercise as well as educational advice based on well-tested rehabilitation programmes. A participant's heart rate is actively recorded so they can track their progress on easy-to-read diagrams within F4S. This information advises them on the most appropriate intensity for each exercise. The information is also sent electronically to their clinician so that progress can be monitored.

The overarching aim of this research is to test whether using a bespoke and personalised exercise-based App, F4S, used at home over the weeks before and after surgery is acceptable to patients and also investigating patients' views are factors linked to and facilitating app use, barriers to, and suggestions for improvements.

### 5.1.1 Research questions

The primary research question for this study is: Is it feasible to use a personalised digital prehabilitation programme, Fit 4 Surgery (F4S), before and after surgery and is it acceptable to patients undergoing major elective surgery?

Secondary research questions:

- What is the acceptability of the F4S app including factors facilitate/enable F4S app use?
- What are the motivations for using the F4S digital prehabilitation program?
- What are the perceived consequences/impacts of engagement in the F4S programme on social, physical, and mental health?
- Is the app used as an alternative to other rehabilitation options?
- What are suggestions for improvement of the current version of the F4S app?

## 5.2 RESEARCH AIMS

### 5.2.1 Study aims

The overarching aim of this research is to test whether the Fit 4 Surgery app (F4S), refined for a specific type of surgery, can be used before and after surgery to enhance the recovery of physical function after major elective surgery. The study will also explore whether the F4S app

is acceptable to patients, what are the motivations for using the Fit4Surgery (F4S) digital prehabilitation programme, and what are the perceived impacts of engagement with the F4S app on social, physical (physical and function), and mental health.

## 5.3 STUDY METHODOLOGY:

### 5.3.1 Ethical approval:

Ethical approval was obtained as part of the HRA/REC approval with the reference number (22/WM/0135) as detailed in section 4.3.1.

### 5.3.2 Setting:

As part of the recruitment process mentioned in chapter four section 4.3.3, the patients were interviewed approximately one month after they had their major surgery. Patients listed for elective major surgery were identified and screened for eligibility from preoperative clinics and referral letters for surgery. A surgical team member approached the patient at the preoperative screening clinic to assess their willingness to participate in the study. This clinic takes place 2 weeks before surgery because of the mandatory self-isolation COVID policy before surgery and so provides adequate time to implement the intervention. Once the clinical team had initially scanned probable candidates, members of the research team approached them to discuss the study and give them the information sheet.

### 5.3.3 Study eligibility

#### 5.3.3.1 Inclusion criteria

- Major elective surgery for benign or malignant diseases
- Able to provide written informed consent
- Before surgery at time of consent
- Age >18 years

#### 5.3.3.2 Exclusion criteria

- Emergency surgery
- Inability to perform project outcome measures

### 5.3.4 Sampling technique

Purposive or judgement sampling was utilised in this study, which is defined as the intentional selection of individuals based on their traits [88]. Purposive sampling is a non-random process that doesn't necessitate any underlying assumptions or a specific quantity of patients [88]. It benefited this study since the research team would already be aware of the research questions being addressed and it would enhance the selection process for patients who had varied experiences with the app [88].

### 5.3.5 Sample Size

Recruitment was continued until saturation of data was achieved (n=16). Thirteen patients were recruited from the lung cancer surgery cohort while the remaining three patients were recruited from the lung volume reduction surgery (LVRS) cohort as evident in (Table 5.2).

### 5.3.6 Outcomes measure

Qualitative interviews with patients were undertaken to provide an in-depth understanding of how and why F4S has been used, including compliance in practice and the barriers and facilitators to its optimal use (Table 5.1).

***Table 0.1: Topic Guide main questions***

| **Study Questions** | Topic guide main questions |
|---|---|
| **Q1:** Acceptability of the F4S **app** | - After using the app, describe your experience in terms of the app usability?<br>- Was the app easy to use? Why/why not?<br>- Was the language used in the app appropriate? Why/why not?<br>- Was the app's design appealing to you? Why/why not? |
| **Q2:** Motivation to use the app | - What motivated you to use the app?<br>- How effective was staff communication and written communication on using the app?<br>- Were your family involved in you using the app?<br>- What aspects of the app were particularly useful for you? |

| | |
|---|---|
| **Q3:** The perceived consequences/impacts of engagement with the F4S app | - What was the impact of the app on your levels of fitness?<br>- How effective was staff communication and written communication on using the app?<br>- Were your family involved in you using the app?<br>- What aspects of the app were particularly useful for you? |
| **Q4:** challenge to use of the F4S app | - Which parts of the app did you not find very useful?<br>- Is there anything we could have added to the app that you would have found helpful? |

### 5.3.7 Topic guide for the semi-structured interviews

The topic guide for the semi-structured patient interviews was developed based on existing literature on pulmonary rehabilitation apps and apps used for rehabilitation in other long-term conditions, as well as the preceding experience of executing the F4S feasibility study [37,121, 122]. PPI groups also informed the topic guide and the PPI co-applicant, who is a lung cancer patient, and also by a public health researcher with extensive experience in qualitative methodology.

The topic guide included core questions that would be asked of all patients covering the following topics: acceptability and compliance with F4S, including barriers and facilitators to the F4S app, details of how, when, and why F4S was used and not used; motivation to use the F4S app (appendix 8.9). Interviewees were also prompted, using open-ended questions, to consider how useful the F4S app was for themselves and other patients with similar conditions. Four pilot interviews were conducted to test and refine the topic guide, and no further changes were made.

### 5.3.8 Qualitative plans

#### 5.3.8.1 Patients' interviews

Patient interviews were carried out throughout the 12-month period of patient recruitment. Patients were selected to ensure maximum variation [89], allowing for rich descriptions of the

use of F4S in as many differing relevant settings as possible. The key sampling parameters were agreed upon with the steering committee.

The need for a maximum variety sample was balanced against the goal of evenly spacing the interviews throughout the 12-month trial, ensuring that any differences in how F4S is implemented were reflected in the patient sample. Until saturation was achieved, interviews were carried out, which was 16 patients. The criteria for saturation were based on the point at which no new themes or insights emerged from the data, indicating that additional interviews were unlikely to yield further information [123].

Digitally recorded interviews and focus group discussions were transcribed verbatim and anonymised. A suitable room within the NHS was booked to interview the patients. Transcripts were analysed for patients following Braun and Clarke's method for thematic analysis [116]. Analysis would take an iterative approach, where data collection and analysis occurred concurrently, allowing the topic guide to be modified throughout to reflect emergent and/or priority themes.

#### 5.3.8.2 Qualitative analysis

The following steps were undertaken in the analysis process of the interviews which follows the Braun and Clarke's method for thematic analysis [116]. These steps include familiarisation with the data, generating initial codes, searching for themes, reviewing themes, and lastly defining and naming themes.

##### 5.3.8.2.1 Familiarisation with the data

The patients' interviews were audio-recorded and field notes were taken to capture the interviewer's thoughts subsequent to completing each interview. Audio-recordings were transcribed in full and analysed thematically [117] concurrently with data collection in order to allow emerging identified themes from the interview transcripts to be included in subsequent interviews.

##### 5.3.8.2.2 Generating initial codes

In NVivo 14 (release 14.24.0), the coding process begins with importing data sources, in this case is interview transcripts. Once the data is uploaded, and after the initial familiarization with

the materials, initial coding of the first 4-6 transcripts were undertaken and then discussed within the research and supervisory team in order to agree on the initial coding framework and allowing us to gain a preliminary understanding of the data. Coding in NVivo starts by selecting passages within the interview transcripts and assigning them to relevant nodes, which act as containers for specific themes or codes. One of the main reasons for selecting NVivo as the software for the analysis is its ability to provide tools for creating and managing nodes, making it easy to either code inductively (by identifying patterns and themes emerging from the data) or deductively (by applying pre-established codes based on existing theory or literature). This process was repeated with a second sample to finalise the coding framework. Ten percent of transcripts was coded by a second researcher to ensure inter-rater reliability, and any coding discrepancies was resolved through discussion at team meetings. Figure 5.1 visualises coding frequency and coverage, which in return would aid in the identification of dominant themes and patterns in the next steps.

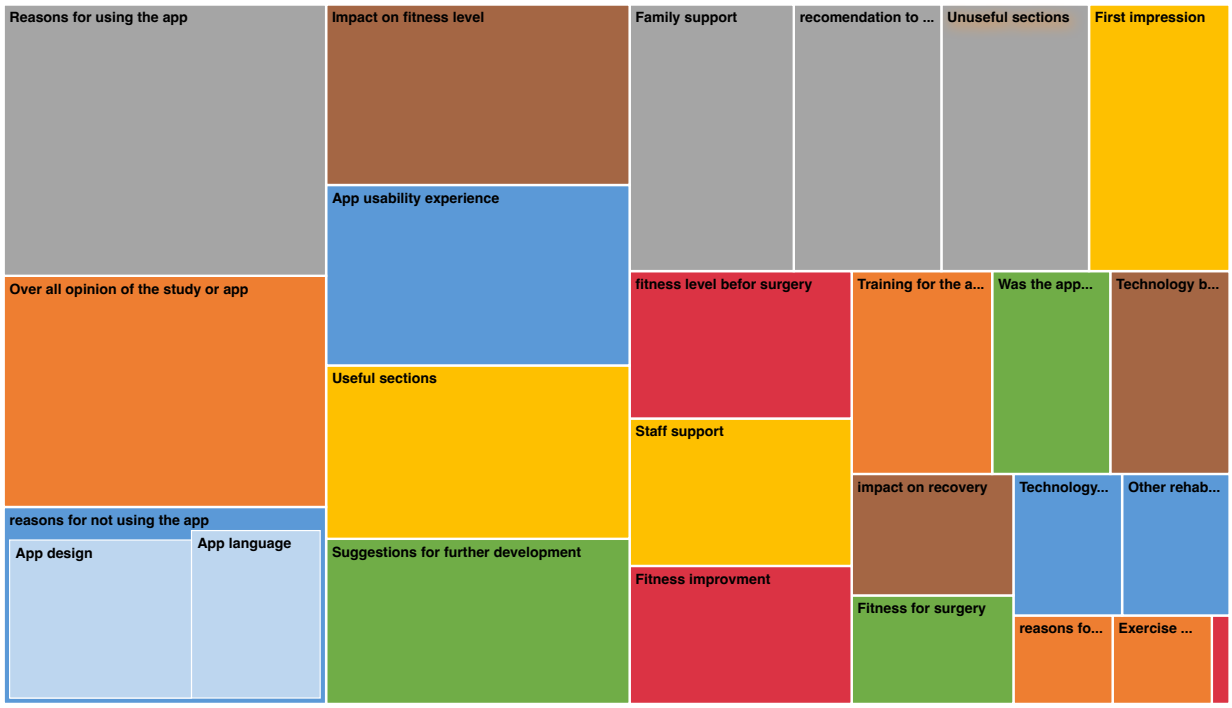



***Figure 0.1: coding frequency and coverage.***

#### 5.3.8.2.3 Searching for themes

As coding progresses, we started to organise themes hierarchically, allowing for the creation of parent and child themes to capture nuanced subthemes (Figure 5.2).

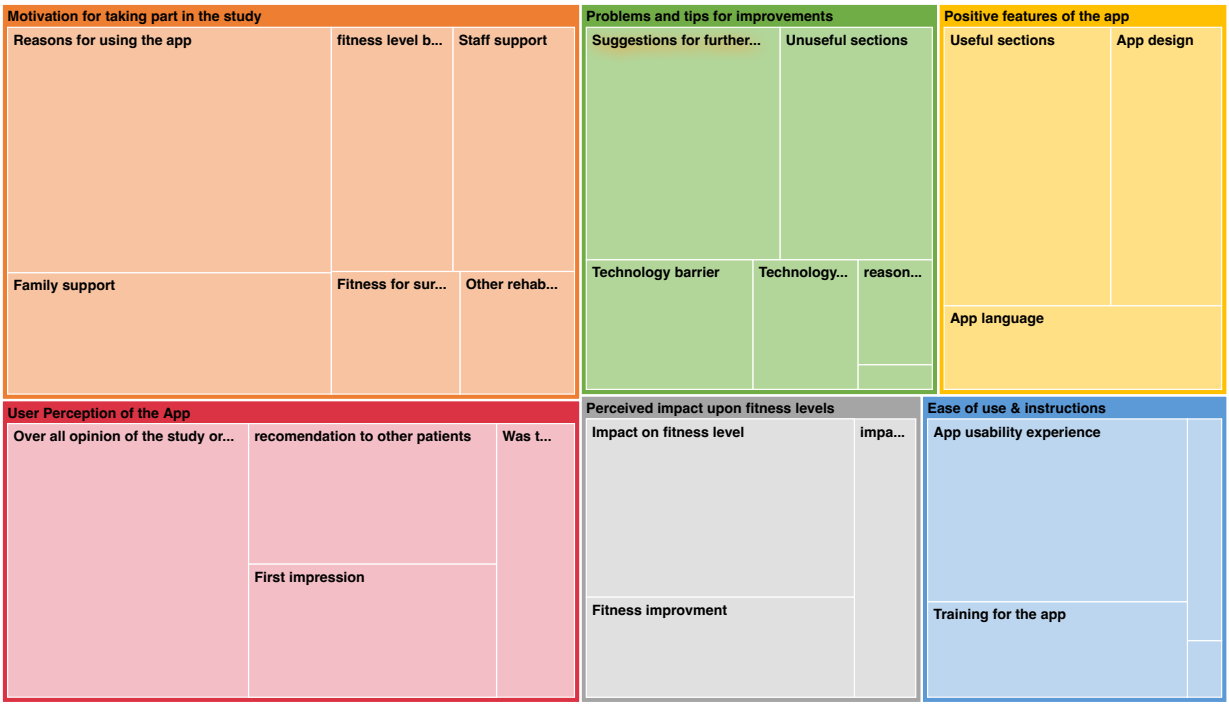



***Figure 0.2: Creation of parent and child themes to capture nuanced subthemes.***

#### 5.3.8.2.4 Reviewing themes

Initial analysis identified emerging themes based on the data rather than on pre-determined categories and also looked for consistency and variation across and within interviews. These themes were discussed and refined through team meetings. Where data did not fit into existing themes, new ones were created, or old ones were modified until all data could be coded by theme. The construction of themes was discussed with the research and supervisory team members to ensure the analysis's credibility and trustworthiness.

#### 5.3.8.2.5 Defining and naming themes

In the process of defining and naming the themes for this thematic analysis, we aimed to capture the overarching concepts that encapsulate patients' experiences and perceptions with the F4S app. Themes were named to succinctly convey the essence of each grouping of coded data. For instance, "The acceptability of the F4S app" was selected as a theme title to reflect patients' initial reactions, levels of apprehension, and eventual acceptance or rejection of the app, which emerged consistently across various responses. Hence, the subthemes, such as "Barriers/restrictions" and "Enablers/facilitators," were named to represent the distinct challenges and supporting factors patients encountered, ensuring these names aligned with the

nuanced data within each subtheme. Similarly, "The app as an alternative to other rehab options" was named to capture discussions around the app's role in replacing or complementing traditional rehabilitation practices, highlighting its perceived value in that context. In addition, other themes like "Motivations and enablers of using the F4S programme" and "Benefits/consequences of using the F4S app" were identified to encapsulate different aspects of patients' journeys with the app. "Motivations and enablers" was chosen to represent the factors that encouraged patients to use the app, such as the goal of fitness for surgery and family support, highlighting the importance of both internal and external motivators in adopting the program. "Benefits/consequences of using the F4S app" was named to encompass the physical, psychological, and social impacts reported by patients, including improvements in physical readiness for surgery, psychological empowerment, and enhanced social involvement. Subthemes within this category, such as "Psychological" and "Physical function," were further refined to capture more specific benefits like improved fitness, self-regulation, and mental well-being, ensuring that each name accurately reflected the positive outcomes experienced by users.

Each theme title was chosen to be clear, concise, and indicative of the core content, allowing for easy interpretation by readers while ensuring alignment with the study's research objectives. This process of defining and naming was iterative, involving continuous refinement with the research and supervisory team to ensure each theme accurately reflected the grouped data and was distinct from other themes. This naming and defining process aimed to balance specificity with readability, enabling a clear understanding of each theme's role in the broader analysis.

#### 5.3.8.3 Rationale for choosing the thematic analysis approach

The chosen approach for thematic analysis in this study, based on Braun and Clarke's (2006) framework, is well-suited for exploring the depth and complexity of patients' experiences with the F4S app [116]. Thematic analysis allows for an accessible yet rigorous method to identify, analyse, and report patterns (themes) within qualitative data, making it ideal for studies focused on understanding subjective experiences and perceptions. According to Braun and Clarke (2006), thematic analysis is particularly valuable for its flexibility, as it is not bound by any specific theoretical framework and can be used within various epistemological perspectives

[116]. This flexibility allowed us to focus on both the semantic (explicit) and latent (implicit) meanings within the data, enabling a comprehensive exploration of patients' responses.

Furthermore, thematic analysis is advantageous for highlighting shared and diverse experiences across patients, which is crucial in studies like ours that aim to capture the nuances of individual interactions with a digital prehabilitation programme (F4S). The use of thematic analysis also aligns with the study's inductive approach, where themes were developed from the data rather than being pre-determined. This inductive coding allowed the analysis to remain grounded in patients' words and perspectives, thus enhancing the validity and relevance of the findings [118].

Additionally, thematic analysis is an effective method for producing findings that are accessible to a wide audience, including practitioners and policymakers. This accessibility is essential when translating complex qualitative insights into actionable recommendations for app design and implementation in healthcare settings [119]. The method also facilitated systematic data analysis through the use of software like NVivo, which supported the organization and refinement of themes, further strengthening the rigor of the analysis process.

Overall, the thematic analysis approach chosen in this study, supported by Braun and Clarke's (2006) guidelines, offers a structured yet adaptable method to deeply explore and accurately represent the diverse experiences of F4S app users, aligning with the study's aim to understand and improve user engagement with the digital prehabilitation programme [116].

### 5.3.9 Ethical consideration:

Detailed ethical considerations were explained in section 4.3.13. Patients participating in the semi-structured qualitative interviews provided consent for their name, contact telephone number, and address to be shared with UoB. This was necessary to facilitate the telephone or face-to-face interviews conducted as part of the study trial. To mitigate the risk of loss of confidentiality to the interview response, the transcriptions of the interviews were not designated with personal identifiable information. This data was stored on an encrypted and locked office computer. Under the requirements of the Data Protection Act (2018) and/or applicable laws and regulations, data were saved on a secure server at Queen Elizabeth Hospital [115].

All the audio recordings of the interviews have been stored on the trust system until anonymised, and they will be kept for 10 years in accordance with UoB policy for data storage. Data transfer took place via secure methods as per UoB IT guidance.

### 5.3.10 Study dissemination:

This study aimed to investigate the acceptability of the F4S app. Although a precise response on the efficacy of the Fit 4 Surgery app in major surgery cannot be given, the findings of this study would be of scientific interest to others. The feasibility study was registered on https://www.isrctn.com/ (ISRCTN). Four strands will make up the dissemination strategy, which are detailed in section 4.3.14.

## 5.4 RESULTS

### 5.4.1 General Patient Characteristics

A total of 16 patients were recruited from 2022 until 2024 who underwent lung cancer surgery and lung volume reduction surgery (LVRS). The patients' baseline characteristics are shown in Table 5.2.

***Table 0.1: The distribution of the semi-structured qualitative interview sample according to their characteristics (n=16)***

| Characteristic | Median (IQR); Range; n (%) | Mean |
|---|---|---|
| **Gender** | | |
| **Male** | 9 (56.25 %) | |
| **Female** | 7 (43.75 %) | |
| **Age** | 69 (66, 76) | 69.31 |
| **Surgery** | | |
| **Lung cancer** | 13 (81.25 %) | |
| **LVRS** | 3 (18.75 %) | |
| **Users' levels of using the app** | | |
| **High** | 6 (37.5 %) | |
| **Medium** | 6 (37.5 %) | |
| **Low** | 4 (25 %) | |

Data are presented as mean (median), standard deviation (interquartile range), or numbers and percentages for categorical data.

Table 5.2 represents baseline demographic and general characteristics data for the 16 patients. The median age was 69 years old, and we can notice that more than half of the patients are males. We can see that the majority of the patients underwent lung cancer surgery (n=13). Most of the patients reported through answering the questions during the interview that they were medium and heavy users of the F4S app before and after their surgery.

### 5.4.2 Thematic analysis for the main themes & sub themes results

In our thematic analysis of patients' experiences with the F4S app, several key themes emerged that shed light on their perceptions and interactions with the programme. Firstly, "**The acceptability of the F4S app**" captures users' initial reactions, apprehensions, and eventual acceptance or rejection of the app with subthemes around "Barriers and restrictions" and "Enablers and facilitators," which delve into the challenges users faced and the factors that supported their engagement with the app (Figure 5.3). Secondly, "**The app as an alternative to other rehabilitation options**" explores how patients view the app in relation to traditional rehabilitation programmes, highlighting its perceived value and effectiveness (Figure 5.3). Additionally, "**Motivations and enablers of using the F4S program**" examines the internal and external factors that encouraged patients to utilise the app, such as personal health goals and family support (Figure 5.4). Another important theme, "**Benefits and consequences of using the F4S app**" encompasses the physical, psychological, and social impacts reported by users, including improvements in fitness, mental well-being, and social involvement (Figure 5.4). Lastly, **"Problems and tips for improvements"** includes feedback on areas where users felt the app could be enhanced, providing suggestions for further development to improve user satisfaction and functionality (Figure 5.3). These themes collectively provide a comprehensive understanding of the user experience with the F4S app, offering valuable insights for enhancing digital health interventions.

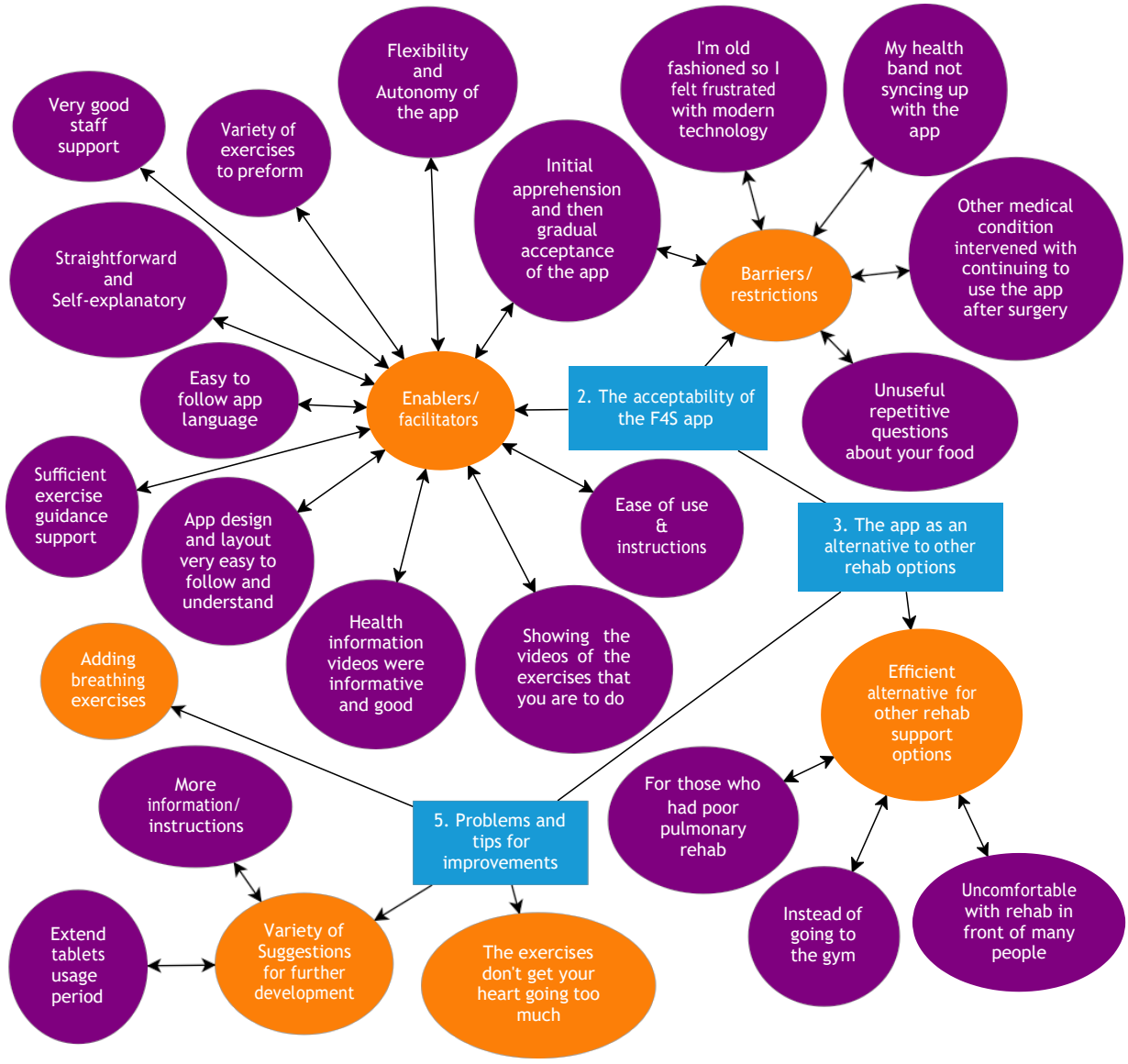



***Figure 0.1: Mind maps of the main themes and subthemes.***

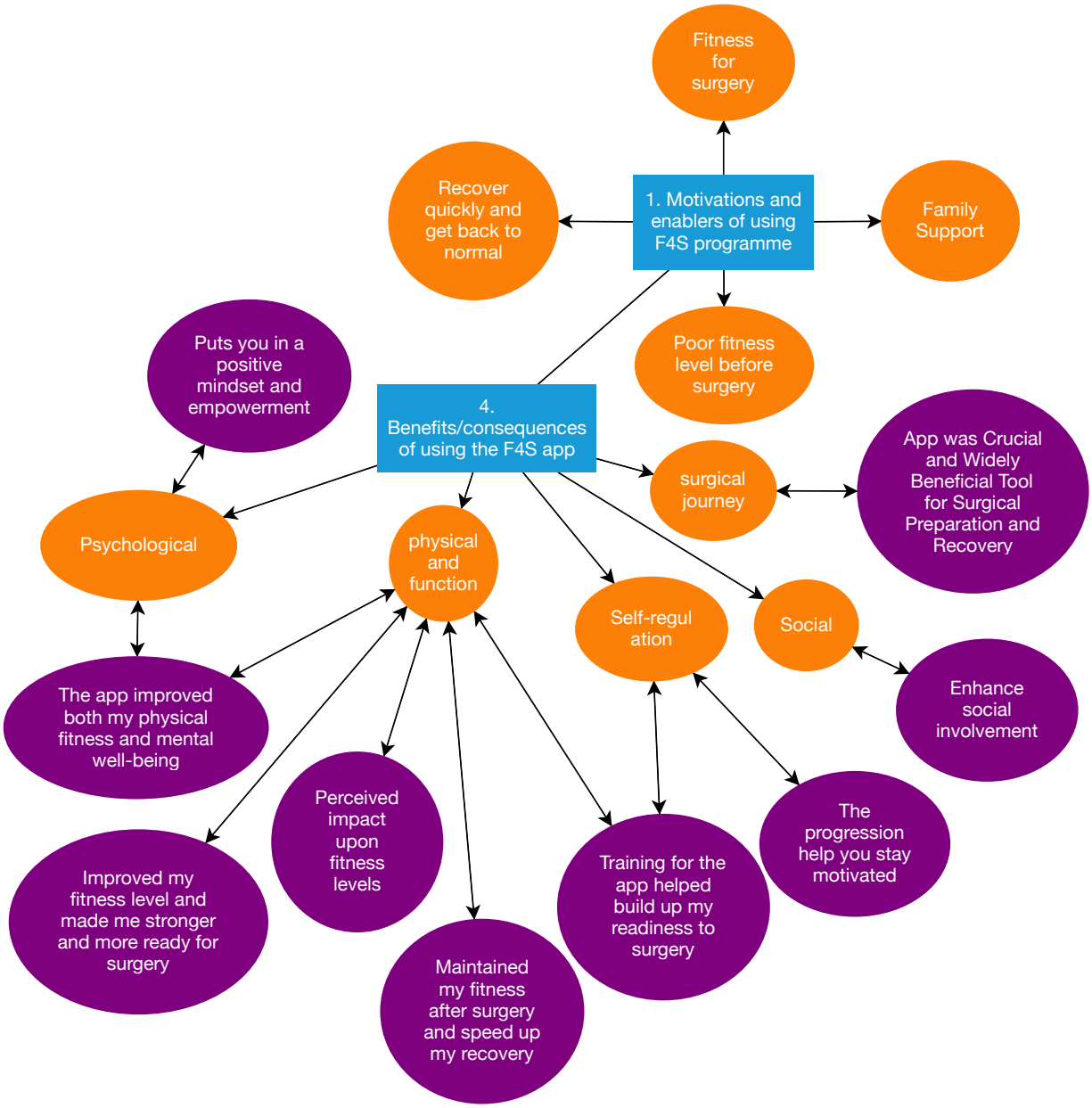



***Figure 0.2: Mind maps of the main themes and subthemes.***

### 5.4.3 Linking themes to research questions

#### 5.4.3.1 Research Question 1: What is the acceptability of the F4S app that include factors facilitate/enable F4S app use and challenge to use of the F4S app?

**The Acceptability of the F4S App**:

This theme addresses the first research question by exploring patients' perceptions of the app's usability and functionality. This theme captures users' initial impressions, reactions, and overall acceptance of the F4S app. It reflects how comfortable and accessible patients found the app

in terms of functionality and ease of use. This theme is essential because it reveals how design, usability, and first-time user experience impact the likelihood of long-term engagement with digital health interventions such as the F4S app.

Sub-themes like **"Enablers and facilitators"** emphasise the app's user-friendly design, including clear instructions and supportive features such as video demonstrations, which made it accessible even for those with limited technological expertise. Conversely, **"Barriers and restrictions"** highlight initial apprehensions or technical challenges, particularly for patients unfamiliar with digital tools. Collectively, these sub-themes provide insights into how the app's design influenced its acceptability and engagement.

#### 5.4.3.1.2 Description:

"The acceptability of the F4S app" encompasses both positive and negative experiences as patients navigated the app for the first time. Many users expressed initial apprehension, particularly regarding technology use, but quickly adapted with familiarity. This theme highlights two significant subthemes/aspects that influenced acceptability: **barriers and restrictions** (factors that hindered engagement) and **enablers and facilitators** (elements that made the app user-friendly and encouraged continued use). patients' feedback on these elements sheds light on the app's strengths and areas for improvement, making it a critical theme for understanding user experience (Figure 5.3).

#### 5.4.3.1.3 Supporting quotes:

To capture the essence of this theme, the following quotes from patients illustrate both apprehension and positive experiences with the app:

- "A bit frightened at first, because I'm not brilliant in technology. But like I said, once I've got behind a bit, it was easy to do was easy to follow."
- "The range of exercises" —patients noted the variety as a beneficial feature.
- "It was very easy to follow."
- "The layout very easy to follow and understand."

- "But for me, overall, it's just the aspects of looking, reading the written word and then watching the video was very helpful."
- "Actually showing the videos of the exercises that you are to do. So as you know, physically what you've got to do."
- "Yeah, it is. Training for the app with you was helpful."
- "It was self-explanatory. And when she got the initial, you know, height, weight and personal information in, it was literally click on it and pick your exercises."
- "I found it difficult at first, …so I followed these instructions, and obviously I come to what I wanted to get to know."

These quotes emphasise the combination of initial apprehension and eventual ease of use, underlining the importance of accessible design and supportive materials.

**5.4.3.1.4 Analysis:**

This theme, with its subthemes **Barriers and restrictions** and **Enablers and facilitators**, highlights a critical aspect of user engagement with digital health tools. **Barriers and restrictions** include users' initial technological apprehensions or difficulties, particularly for those less familiar with apps or digital interfaces. Quotes like "A bit frightened at first, because I'm not brilliant in technology" reflect this hesitancy, emphasising that users may need additional support or training to overcome their initial concerns.

On the other hand, **Enablers and facilitators** such as a straightforward layout, clear instructions, and helpful video demonstrations significantly enhanced the app's acceptability. Comments like "It was very easy to follow" and "The layout very easy to follow and understand" underscore how intuitive design can build users' confidence and comfort. Additionally, patients appreciated video tutorials, which provided a tangible and clear guide for exercises, as indicated by the quote, "Actually showing the videos of the exercises that you are to do. So as you know, physically what you've got to do."

This theme reveals that user acceptability is driven by both the removal of barriers and the presence of clear, supportive features. By making the app intuitive and providing supportive tools (like instructional videos), the app can address users' initial technological apprehensions and support sustained engagement. This analysis suggests that for digital health interventions

to succeed, especially among populations with varying tech familiarity, user-friendly design and comprehensive onboarding are essential components.

#### 5.4.3.2 Research Question 2: What are the motivations for using the F4S digital prehabilitation program?

**Motivations for Using the F&S Program**: This theme directly answers the second research question by identifying both intrinsic and extrinsic motivators that encouraged patients to engage with the program. This theme captures the key factors that motivated patients to engage with the F4S app and the external support that motivated them to use it effectively. It reflects the underlying reasons for participation and the supportive role of family and personal health goals.

The sub-themes highlight the driving forces behind patients' commitment to the F4S programme and how these factors supported their engagement and progress. Sub-themes such as **"Family support"** demonstrate the importance of external encouragement and assistance, while **"Fitness for surgery"** and **"Poor fitness level before surgery"** highlight patients' personal drive to improve their physical readiness for surgery. The sub-theme **"Recover quickly and get back to normal"** emphasises how the F4S app fulfilled patients' goal of restoring everyday functionality post-surgery, providing a strong rationale for their engagement.

##### 5.4.3.2.1 Description

This theme brings together the motivations and enablers that played a significant role in patients' decision to use the F4S app. Many patients cited family support as a crucial factor, both in terms of encouragement and practical assistance with the app. Additionally, the desire to improve fitness for surgery and recover more quickly afterward were major motivators. Patients also discussed how poor fitness levels before surgery drove their engagement, recognising the need for improvement. Lastly, the aim of returning to normality post-surgery emerged as a key motivator, reflecting the app's perceived value in aiding recovery and restoring everyday functionality (Figure 5.4).

#### 5.4.3.2.2 Supporting Quotes

The following quotes highlight the patients' motivations and enablers:

- **Family Support**:
    - "My family kept me motivated and interested."
    - "Only as far as helping me get it started, trying to understand it."
    - "Yeah, they help keep me on track."
    - "I stuck with the level five and didn't go up to the level six? I did try one of the levels six or my granddaughter laughed at me hilariously because I couldn't do it."
    - "Family support, definitely. I think that in order for the app to be successful with a patient, I think that because the patient is poorly, and they can't always concentrate on what is best for them, it's important to have a network of people that have the ability to work with technology."
    - "If I hadn't got my son there, yeah, which I kept asking him, and he put me in the right direction, okay, and I found the app easy. Yes, very important, you need somebody to give you that push."
- **Fitness for Surgery**:
    - "So I think it's a good idea to get them started before surgery. So at least you've got some sort of fitness there."
    - "I thought something like the surgery I was going to have, I need to sort of try to be fitter for it and also after it, obviously."
    - "Try and build the fitness up a bit more before and after."
    - "Well, I suppose really, I wanted to feel stronger before taking the surgery. Okay. Because I was told that I needed to be stronger for the recovery, you know, and I'll see why now."

- "Well, obviously, one for my surgery, and two, to feel better and get better afterwards, which, as I said, I think it did help me."
- "Because I want to get fit for my surgery."
- "Basically because I haven't been doing any exercises recently."

- **Poor Fitness Level Before Surgery**:
  - "It was very bad. Very poor shot."
  - "Before surgery, I didn't feel I felt fine, I smoked, which obviously dragged me down. And I know that I couldn't walk too far without struggling after this."
  - "Well, I couldn't walk so far, okay, I couldn't do things for too long."
  - "Before, when I used to walk from the car park up to the main door, I used to stop five times. The last time I went to the respiratory man, I stopped three times."
  - "I was weak. Yes, I'll tell you another instance, when I was going in the bath, I was finding I could not get out. My legs were that weak. I had to come rent to get up, sometimes, falling back, bumping my shoulder, bumping my head. Now I could get back."
  - "Terrible."
- **Recover Quickly and Get Back to Normal**:
  - "I wanted to make sure I was fully fit for surgery. And by doing it through the app, it made me concentrate and do."
  - "I thought something like the surgery I was going to have, I need to sort of try to be fitter for it and also after it, obviously."
  - "Get myself into some sort of a fit state, so hopefully, I can live a bit longer to see my grandkids, great grandkids grow up."
  - "Well, I wanted to know how fit I was."

- "Well, yeah, I wanted to be as fit as I could and get through the surgery and then be okay on the other side."
- "Yes, you get to get fit again. I'd like to be fit, okay, to feel fit."
- "Going back to my original level of fitness."
- "It's helpful; it improves your health, through chances to come in out of surgery much quicker."
- "Try to get back to normal."
- "Because when I spoke to yourself, it was going to be aiding my surgery. So to get ready for surgery, which really did, and then after surgery, also to get you moving."
- "Because obviously, you want to, you want to, you like to be more at ease. You want to do more things daily, don't you? And plus your surgery, you want to recover quickly and get back to normal so that you can hopefully do more."

#### 5.4.3.2.3 Analysis

This theme, with its sub-themes **"Family support"**, **"Fitness for surgery"**, **"Poor fitness level before surgery"**, and **"Recover quickly and get back to normal,"** illustrates how external and internal factors influenced patients' engagement with the F4S programme.

- **Family Support**: Family played a critical role in motivating patients and assisting with the app's functionality. For some, family members provided the push needed to engage with the programme, while for others, family involvement created a supportive environment that kept them on track. Quotes such as "My family kept me motivated and interested" and "You need somebody to give you that push" reflect the importance of a strong support network for successful F4S programme engagement.
- **Fitness for Surgery**: Many patients were motivated to use the app to improve their physical readiness for surgery and ensure a smoother recovery. The desire to feel stronger and more prepared was a common sentiment, as reflected in quotes like "I need to sort of try to be fitter for it and also after it, obviously." This sub-theme emphasises

the app's role in helping users achieve pre-surgical fitness goals to prepare them for their incoming surgery.

- **Poor Fitness Level Before Surgery**: Patients recognised their poor physical condition before surgery as a key motivator to engage with the app. Comments such as "It was very bad. Very poor" and "I couldn't walk too far without struggling" highlight the challenges they faced and the urgent need for intervention. This sub-theme demonstrates how the app addressed the critical gap in their pre-surgical fitness levels.
- **Recover Quickly and Get Back to Normal**: The desire to recover quickly and return to the original normal condition post-surgery was a powerful motivator. Patients emphasised the importance of regaining fitness and functionality, as seen in quotes like "Try to get back to normal" and "Going back to my original level of fitness." This sub-theme emphasises the app's perceived value in facilitating recovery and improving quality of life.

This theme reveals how a combination of external support, personal health goals, and pre-existing fitness challenges drove patients' engagement with the F4S programme. Addressing these motivations and enablers in app design and implementation could enhance user engagement and overall effectiveness.

#### 5.4.3.3 Research Question 3: What are the perceived consequences/impacts of engagement in the F4S programme on social, physical, and mental health??

This theme addresses the third research question by detailing the wide-ranging impacts of the app. This theme encapsulates the diverse benefits and outcomes patients experienced while engaging with the F4S app, ranging from physical and psychological improvements to social and self-regulation benefits. It highlights how the app supported patients in their surgical journey and recovery, addressing key health and fitness goals. The sub-themes **"Social consequences"**, **"Surgical journey"**, **"Psychological benefits"**, **"Self-regulation"**, and **"Physical and functional benefits"** reflect the app's multifaceted impact on users' lives, making it an essential component of their prehabilitation and recovery process.

#### 5.4.3.3.1 Description

This theme reveals the positive impacts and experiences users associated with the F4S app. Patients noted enhanced social interactions, particularly with family members who engaged in the exercises alongside them. The app was seen as a supportive tool during the surgical journey, aiding both pre- and post-operative fitness. Psychological benefits such as improved mindset and reduced stress were frequently reported, as were improvements in physical function and self-regulation. These sub-themes demonstrate the app's holistic role in addressing the mental, physical, and social dimensions of the individuals' health (Figure 5.4).

#### 5.4.3.3.2 Supporting Quotes

The following quotes illustrate patients' experiences with each sub-theme:

- **Social Consequences**:
    - "I mean, obviously it's going to be adapted to whatever your condition. I mean, mine was to surgery fitness before surgery, but you could have one light for fitness for diabetes, fitness for arthritis failure, and it doesn't only have to it could be adapted for young people as well."
    - "My grandchildren loved my app because they were doing the exercises with me."
- **Surgical Journey**:
    - "I just because I felt that I was sticking with it, I could see that I was—it was, I mean, strength."
    - "When you first come out of surgery, you feel a bit sorry for yourself. Unless you've got something there that you are going to aim for, that's going to help you rehabilitate, don't rehabilitate or get better."
    - "I did find it quite helpful and supportive during my surgery."
- **Psychological Benefits**:
    - "Mentally, as well as physically, I will try to cope better."

- "I think it put me in a positive mindset going into the surgery, because it's a worrying thing, cancer."
- "I don't see why people can't embrace stuff that improves people's lives and gives them a more positive mindset."
- "The fit for surgery thing was a help before the surgery. And it is a help after the surgery, just getting you back up to a level of fitness."

- **Self-Regulation**:
  - "The app just gives you the motivation to go off and do something rather than just sit there looking at the gogglebox or whatever or reading a book."
  - "I think when I checked back and you could see how far you've done, the progression helped you be motivated."

- **Physical and Functional Benefits**:
  - "The training for the app helped build my strength up and my readiness to surgery when it was due."
  - "There was definite improvement, especially in the strength of my legs, more stamina to improve."
  - "Now, don't get out of breath so easily now. So, general fitness has improved."
  - "If I hadn't have used it, then maybe I wouldn't have recovered as quickly or been able to get back to my normal routine as quickly."

#### 5.4.3.3.3 Analysis

This theme, with its sub-themes **"Social consequences"**, **"Surgical journey"**, **"Psychological benefits"**, **"Self-regulation"**, and **"Physical and functional benefits"** highlights the holistic value of the F4S app.

- **Social Consequences**: The app fostered engagement and interaction among patients and their families. Some users found that involving loved ones in the exercises

enhanced their experience, making the app not only a prehabilitation tool but also a means of strengthening family bonds.

- **Surgical Journey**: Patients described the app as a helpful companion throughout their surgical journey. Pre-surgery, it prepared them physically and mentally, while post-surgery, it facilitated recovery by helping them rebuild strength and stamina. This sub-theme emphasises the F4S app's role in providing continuity of care during a critical period.

- **Psychological Benefits**: Many patients highlighted the psychological benefits of using the app, such as a positive mindset, reduced anxiety, and improved coping mechanisms. Comments like "I think it put me in a positive mindset" demonstrate how the app contributed to mental well-being, which is crucial for recovery.

- **Self-Regulation**: The app encouraged users to take responsibility for their own progress, helping them stay motivated and track their achievements. Quotes like "The progression helped you be motivated" illustrate how the app fostered self-discipline and a sense of accomplishment.

- **Physical and Functional Benefits**: Users consistently reported improvements in physical strength, stamina, and overall fitness. The app's exercises were seen as instrumental in enhancing lung function, muscle strength, and recovery speed. For example, "There was definite improvement, especially in the strength of my legs" underscores its role in addressing specific physical deficits.

This theme demonstrates the F4S prehabilitation programme's ability to provide comprehensive support across multiple dimensions of the patients' health. By addressing social, psychological, and physical needs, the app proves to be a valuable tool for holistic prehabilitation and recovery. Its benefits extend beyond physical fitness, enhancing users' overall quality of life and readiness for surgery.

#### 5.4.3.4 Research Question 4: Is the app used as an alternative to other rehabilitation options?

**Efficient Alternative for Other Rehab Support Options**: This theme directly answers the fourth research question by demonstrating how patients used

the app as a replacement or complement to traditional rehabilitation programs. Sub-themes such as **"For those who had poor pulmonary rehab"** highlight instances where patients turned to the app due to limited availability or inefficiency of existing programs. **"Instead of going to the gym"** reflects how patients substituted gym-based rehab with the app's at-home exercises, while **"Uncomfortable with rehab in front of many people"** shows how the app catered to individuals who preferred privacy and self-paced routines. This theme is significant as it demonstrates how digital prehabilitation programmes can meet the needs of users who may not fully benefit from conventional rehabilitation settings.

#### 5.4.3.4.1 Description:

The theme **"Efficient alternative for other rehab support options"** captures patients' feedback on how the app served as a practical and preferred alternative to traditional rehabilitation methods. Patients expressed dissatisfaction with certain rehabilitation programs, such as in-hospital pulmonary rehabilitation, due to limited availability or inefficiencies. Others found gym-based exercises inaccessible or inconvenient due to physical conditions like osteoarthritis or their personal preferences. For some, the app offered a solution to the discomfort they experienced during in-person group rehabilitation, providing a private and self-paced alternative. The sub-themes **"For those who had poor pulmonary rehab," "Instead of going to the gym,"** and **"Uncomfortable with rehab in front of many people"** reflect these varying challenges and how the app addressed them, showcasing its adaptability to different user needs (Figure 5.3).

#### 5.4.3.4.2 Supporting Quotes

The following quotes illustrate patients' perspectives on how the app addressed their needs and replaced traditional rehab methods:

- **For those who had poor pulmonary rehab**:
    - "Yes. What I had the poor, poor pulmonary rehab, okay, but it was at the same time, because I was listed for it, and they've got no places at that time."

- "I went to the to take me rehab, okay for two weeks, and then it came up as the COVID-19, okay, but I enjoy feeling now the event after two weeks."

- **Instead of going to the gym**:
  - "Because I hadn't been going to the gym and because of my osteoarthritis, not doing as much exercise as I used to."
  - "Yes, they were, because I have to have done some of the other ones. But I will say most of those things would be when I'm in the gym again. So the other way I've been doing other exercises, or short walks, basically that so."

- **Uncomfortable with rehab in front of many people**:
  - "To use the app? The thought to be honest, the thought of not having to go on a pulmonary rehab course? Yeah, that was I thought, well, let's let's do this. Because it was a, I could do it on my own, in my own home. And I didn't have to go out every day to do it to a hospital and do it with lots of a group of people. Yeah. Which made me feel uncomfortable last time. So that's why I prefer the app."

These quotes highlight how the app provided a flexible and private solution to challenges patients faced with other rehab options.

#### 5.4.3.4.3 Analysis:

This theme, with its sub-themes **"For those who had poor pulmonary rehab," "Instead of going to the gym,"** and **"Uncomfortable with rehab in front of many people,"** highlights the app's ability to address diverse barriers to traditional rehabilitation settings.

- **For those who had poor pulmonary rehab**: Patients who didn't get enough help with their pulmonary rehabilitation programs liked that the app was available and easy to use. Quotes like "I was listed for it, and they don't have any places at that time" show problems with the program's availability, while others talked about how COVID-19 caused problems. During these times of trouble, the app was a reliable and constant option.

- **Instead of going to the gym**: Some patients couldn't go to the gym for rehab because they had physical problems or couldn't get there. Some people said things like "Because I hadn't been going to the gym and because of my osteoarthritis" to talk about their physical challenges. Others said that the app's flexibility let them perform exercises at home instead of going to the gym.
- **Uncomfortable with rehab in front of many people**: For patients who didn't like being in groups, the app offered a private and self-paced option. Quotes like "I could do it on my own, in my own home" reveal the importance of personal comfort and the ability to avoid potentially anxiety-inducing group interactions.

This theme demonstrates how the app served as a personalised solution to the limitations of traditional rehabilitation programs. By offering flexibility, privacy, and accessibility, the app effectively addressed the barriers patients faced, showing its potential as a scalable alternative to conventional rehabilitation options.

#### 5.4.3.5 Research Question 5: What are suggestions for improvement of the current version of the F4S app?

**Problems and Tips for Improvements**: This theme addresses the fifth research question by detailing patient feedback on potential improvements for the app. This theme encompasses patients' constructive feedback regarding potential enhancements to the F4S app aimed at improving user satisfaction and engagement. Patients offered insights regarding deficiencies and presented practical recommendations for future development. The sub-themes "**Adding breathing exercises**" "**The exercises don't get your heart going too much**" and "**Variety of other suggestions for further development**" show the main areas where users think the program may be better. This theme is essential since it shows ways to improve the app and make it more useful for users. It also underscores the importance of iterative development based on user feedback to enhance the app's usability and effectiveness.

#### 5.4.3.5.1 Description:

The theme **"Problems and Tips for Improvements"** brings together the issues patients encountered while using the app and their suggestions for enhancements. Patients pointed out specific problems, like the app not having breathing exercises, workouts that were too easy or didn't raise the heart rate, and other features or instructions that were needed to make the app easier to use. These sub-themes underscore users' desire for a more tailored and comprehensive rehabilitation experience, reflecting the importance of user-centred design in digital health tools (Figure 5.3).

#### 5.4.3.5.2 Supporting Quotes

The following quotes illustrate the patients' feedback for each sub-theme:

- **Adding Breathing Exercises**:
    - "I don't know whether we [have] breathing exercise[s] in there."
    - "Breathing exercises might be a good idea."
    - "So I think breathing exercise is something to add."
- **The Exercises Don't Get Your Heart Going Too Much**:
    - "But those sorts of exercises, even they're not quite enough to get your heart rate going too much."
    - "And so the exercise is now I must admit, I thought they'd be more exercises than they were. Because I sort of half expected it to be not just exercises that are on there, but sort of lower heart rate exercises."
    - "They're not, you know, heart-pumping type things."
    - "I found some of the exercises almost too easy. Because they were just going on forever, and it wasn't getting [me] hardly out of breath at all. So I don't know whether I should either just keep those and just go on to a different one instead, or whether I should persevere... find some way of making them a little bit harder for myself to do get out of breath."

    - "Also, some of the exercises were extremely easy."

- **Variety of Other Suggestions for Further Development**:
    - "Talk about how to do it, and perhaps [provide] written [instructions] so they've got something to refer back to, or if there's any sort of questions."
    - "It's okay. But I think novices might need a bit more information."
    - "The instructions [on] how to use this here, basically. Other than that, I mean, once you know how to use it, it is really easy to use, [but] sort of [adding] instructions within the app to say [how to do it would help]."
    - "Yeah, I think the tablet should be extended."
    - "And so the exercise is now I must admit, I thought they'd be more exercises than they were."

These quotes capture patients' feedback on areas where the app could be made more effective and user-friendly.

#### 5.4.3.5.3 Analysis

This theme, with its sub-themes **"Adding breathing exercises," "The exercises don't get your heart going too much,"**and **"Variety of other suggestions for further development,"** shows critical areas for improvement in the F4S app.

- **Adding Breathing Exercises**: Patients reported that the app didn't include any breathing exercises and advised adding them as a useful feature. Patients' comments like "Breathing exercises might be a good idea" show how important they think breathing exercises are for rehabilitation, especially for recovering from lung surgery. Adding this functionality could make the app more comprehensive and better suit the needs of certain users.
- **The Exercises Don't Get Your Heart Going Too Much**: Some patients thought the exercises were too easy and didn't push them hard enough. Quotes like "They're not, you know, heart-pumping type things" and "I found some of the exercises almost too easy" demonstrate there has to be a wider range of difficulty levels to meet the needs

and goals of different users. Patients also advised adding activities that raise heart rate or let the intensity go up over time to make the app more engaging and beneficial for fitness improvement.

- **Variety of Other Suggestions for Further Development**: Patients suggested other ways to make the app easier to use and more efficient, such as clearer instructions, written materials for reference, and longer durations for devices like tablets. "Talk about how to do it, and maybe write down the steps" and "Novices might need a bit more information" are two quotes that highlight how important it is to provide less experienced users with more specific support.

This theme illustrates how input from participants may inform iterative app improvements. Adding breathing exercises, making the exercises harder, and improving information content could significantly enhance the user experience and efficacy of the F4S app as a digital prehabilitation tool. These insights underline the importance of ongoing user engagement in the development process to create a product that is truly tailored to users' needs.

#### 5.4.3.6 In summary

By linking the themes to the research questions, it becomes evident how the F4S app addressed motivations, acceptability, alternative use, impacts, and improvement needs. These links show that the app is useful for digital prehabilitation and has the ability to address a wide range of user demands.

### 5.4.4 Summary of Findings

The findings from this qualitative analysis reveal a comprehensive picture of patients' experiences with the F4S app, showing how acceptability and usability, motives, effects, and areas for improvement are connected and all work together. The app's acceptability played a vital role in enabling patients to benefit from it, with user-friendly design features facilitating engagement despite initial apprehensions around technology. Patients were encouraged to use the F4S app because of a mix of outside support, such family assistance, as well as internal factors, like the desire to get fit for surgery and recover quickly. Patients were encouraged to use the F4S app because of a mix of outside support, such family assistance, as well as internal factors, like the desire to get fit for surgery and recover quickly.

The reported benefits of the app were wide-ranging, encompassing social, psychological, and physical improvements, all of which were instrumental in supporting patients throughout their surgical journey. The F4S digital prehabilitation programme also served as a flexible and accessible alternative to traditional rehabilitation programmes, particularly for those who faced barriers such as limited availability, discomfort with group settings, or physical constraints. However, patients also identified areas for improvement, such as incorporating breathing exercises, increasing exercise intensity, and enhancing instructions for novice users.

Together, these themes illustrate how the F4S app not only addressed patients' immediate health and surgical recovery needs but also provided a platform for long-term behavioural change and self-regulation. These findings provide a strong foundation for the discussion section, where the implications of these insights for digital prehabilitation programmes, user-centred design, and future app development will be explored.

## 5.5 Discussion

This study highlights the multilayered role of the F4S app in supporting patients' prehabilitation and recovery journeys, offering insights into its usability, impact, and areas for enhancement. Patients' feedback highlights the app's effectiveness in facilitating physical, psychological, and social benefits, while its user-friendly design was fundamental in overcoming initial apprehensions about technology. The findings demonstrate that the F4S programme successfully addressed key motivators for engagement, such as improving fitness for surgery and accelerating recovery, while also serving as a flexible alternative to traditional prehabilitation programs. However, areas for improvement, including the addition of more tailored exercises and enhanced features for novice users, reveal opportunities to further optimise the app for diverse user needs. These results emphasise the potential of digital prehabilitation tools like the F4S app to enhance healthcare accessibility and outcomes, particularly for individuals with barriers to traditional rehabilitation options.

Drudi et al. (2019) performed a systemic review study that provided qualitative findings to assess the impact of preoperative exercise training (prehabilitation) on perioperative clinical outcomes in individuals who had vascular and cardiac procedures [19]. Notably, the study highlights significant improvements in both physical and psychological domains, particularly

through structured and supervised exercise regimens. These findings align with our qualitative results of the current study on the F4S app, which also demonstrated improvements in patients' physical readiness for surgery, enhanced psychological well-being, and accelerated recovery. Both studies highlight the value of prehabilitation in preparing patients for surgery and improving postoperative outcomes.

However, the approaches differ, as Drudi et al.'s (2019) study primarily focuses on structured, supervised programs, while the F4S app provides a flexible, home-based, and self-regulated digital alternative. This flexibility addresses barriers such as limited access to supervised programs or discomfort with group settings, which were highlighted by patients in the current study. Additionally, the F4S programme promotes self-regulation and autonomy, enabling patients to tailor their prehabilitation to their individual needs. While both approaches demonstrate effectiveness, the F4S app's digital and accessible format broadens its potential applicability to diverse patient populations.

One of the strengths of Drudi et al.'s (2019) study is that they conducted a systemic interview that considered the highest-quality evidence on a research topic [22]. Moreover, a systemic review gives a complete, unbiased summary of several pertinent studies, thus, increasing the validity of Drudi et al.'s (2019) findings [19]. On the other hand, one of the limitations that might undermine the strength of their findings is the heterogeneity of the included studies in many aspects such as the study design and patient populations which may limit the generalisation of the findings to other populations [19,10]. However, Drudi et al.'s (2019) study emphasis on structured and supervised programs may limit its applicability to settings where digital tools like the F4S app could provide a more practical and adaptable solution. These results show that traditional and digital prehabilitation solutions work well together and stress how important it is to adjust interventions to each patient's needs and situation.

Another study by Powell et al. (2023), explores the emotional well-being impact of a multimodal prehabilitation program combining physical activity, well-being support, and nutritional guidance for individuals undergoing cancer surgery [40]. Patients reported emotional benefits, including reduced anxiety, improved mood, and increased confidence in

their ability to manage surgery and recovery. The program offered patients a sense of control, focus, and mental support through physical fitness specialists who created a caring and supportive environmen [40]. Additionally, patients valued opportunities to connect with peers facing similar challenges, which facilitated conversations about their cancer experiences [40].

In comparison to the current study on the F4S programme, Powell et al.'s (2023) findings highlight several points of similarities. Both studies incorporated multimodal prehabilitation program combining physical activity, well-being support, and nutritional guidance [40]. Furthermore, both studies report emotional and psychological benefits of prehabilitation programs, including reduced anxiety, improved mentality, and a sense of empowerment in managing surgery and recovery. However, Powell et al.'s (2023) study puts more focus on how important relationships with others, such peer and professional support, are for patients' emotional health [40]. In contrast, the F4S app focuses on the flexibility of a digital and self-regulated prehabilitation tool, with less emphasis on external support systems.

A notable strength of the Powell et al.'s (2023) study is its multi-perspective design, which integrates qualitative insights from both patients and healthcare professionals involved in the programme [40]. This approach provides a more comprehensive understanding of the program's impact and highlights the importance of professional support as a complement to physical activity in prehabilitation. This broader context contrasts with the digital and largely autonomous nature of the F4S programme, suggesting that hybrid models incorporating digital tools alongside professional guidance could address a wider range of patient needs.

In contrast, a study by Buch et al. (2024), evaluates a digital rehabilitation platform designed to streamline rehabilitation planning and improve care access for patients [41]. Key findings include that the platform was able to help stakeholders work together across disciplines and give patients structured rehabilitation plans [41]. However, challenges such as technical usability issues, limited stakeholder communication, and unclear processes limited its effectiveness [41]. Patients valued the social worker's support but felt excluded from decision-making processes. Compared to the findings from our study, which reported high levels of user engagement and acceptability due to its user-friendly design, the Buch et al.'s (2024) study

highlights notable weaknesses in usability and communication [41]. While both studies underscore the benefits of digital platforms for enhancing care access, the Buch et al.'s (2024) study platform faced barriers in fostering active patient participation and simplifying processes [41]. In contrast, the F4S programme successfully engaged patients through its intuitive interface, clear instructions, and personalised support.

A strength of the Buch et al.'s (2024) study is its comprehensive exploration of stakeholder perspectives, including patients, primary care physicians, and other stakeholders involved in rehabilitation planning [24]. This multi-perspective approach provides a whole understanding of the platform's implementation challenges and strengths, offering valuable insights for improving future digital rehabilitation tools. However, its limited performance in including patient preferences in decision-making indicates that this is an important area that needs to be improved in order to comply with the principles of patient-centred care.

## 5.6 Strengths and limitations of the study

A key strength our qualitative study lies in its exploration of user experiences with the F4S programme through detailed thematic analysis, offering valuable insights into the motivations, enablers, and outcomes of engaging with a digital prehabilitation program. The study highlights the F4S app's flexibility, accessibility, and user-friendly design, which enabled patients to overcome barriers associated with traditional prehabilitation programmes. Additionally, the findings emphasise the app's holistic impact, addressing physical, psychological, and social scopes of health, and its potential as an adaptable solution for diverse patient populations. The app's success in satisfying patients' requirements is shown by the fact that user input and program design are in alignment, which leads to high acceptability and engagement. In addition, while this study included user feedback that provided rich qualitative data, it was accompanied by quantitative outcome measures, such as complication rates and length of hospital stay as reported in chapter 4, which enhances the ability to objectively evaluate the F4S programme's efficacy.

However, this study is not without limitations; the inclusion of a specific user population may limit the generalisability of the findings to broader patient groups with different health conditions or levels of technological skill [10]. Furthermore, making direct comparisons with

traditional or hybrid prehabilitation programmes may miss small variations in the results of these approaches. [23]. Also, another constraint is that this study was a single-center study, which could lead to a limited external validity [27].

## 5.7 Future directions

The findings from this theme directly informed iterative refinement of the F4S app, ensuring that patient feedback translated into tangible changes rather than remaining descriptive. Specifically, feedback regarding the absence of breathing exercises led to the planned integration of structured respiratory exercise content tailored to patients undergoing lung surgery. Concerns that exercises were insufficiently challenging informed revisions to exercise progression, including clearer intensity guidance and the introduction of higher-intensity options where clinically appropriate. In response to requests for clearer guidance and support for less digitally confident users, additional in-app instructions, pictorial guides, and an introductory video were developed to improve usability and onboarding. Practical suggestions regarding device access and duration also informed pathway-level adaptations, including extended tablet loan periods. These changes, alongside planned future enhancements, are summarised in Table 5.3, which maps key qualitative findings to implemented app modifications and proposed next steps, demonstrating how user feedback was systematically embedded within the ongoing development of the F4S app.

***Table 0.3: Summary of user feedback, implemented app refinements, and planned next steps (n=16)***

| **Key finding / user feedback** | **Evidence source (theme / sub-theme)** | **Action taken / app refinement** | **Status** |
|---|---|---|---|
| **Absence of breathing exercises within the app** | *Problems and Tips for Improvements – Adding breathing exercises* | Development of structured breathing exercise content (e.g. breathing control and respiratory exercises) to complement existing physical exercises | Planned for next app iteration |
| **Exercises perceived as too easy and insufficient to raise heart rate** | *The exercises don't get your heart going too much* | Revision of exercise progression with clearer intensity guidance and inclusion of higher- | Implemented / ongoing refinement |

| | | | |
|---|---|---|---|
| | | intensity exercise options where clinically appropriate | |
| **Limited tailoring of exercise difficulty to individual capability** | *The exercises don't get your heart going too much* | Improved progression logic and encouragement of self-paced intensity increases | Implemented |
| **Need for clearer instructions and guidance, particularly for novice users** | *Variety of other suggestions for further development* | Development of in-app written instructions, pictorial step-by-step user guide, and introductory video demonstrating app navigation and core functions | Implemented |
| **Challenges related to digital confidence and access to technology** | *Variety of other suggestions for further development* | Introduction of a hybrid digital delivery model (mobile app and web-based access), alongside provision of tablets with pre-installed SIM cards for suitable patients | Implemented |
| **Requests for longer access to provided devices** | *Variety of other suggestions for further development* | Extension of tablet loan duration within the clinical pathway where feasible | Implemented |

## 5.8 Conclusion

In conclusion, this study demonstrates the potential of digital prehabilitation tools like the F4S app to address barriers in traditional prehabilitation programs, providing accessible, flexible, and holistic support for patients preparing for surgery. The findings emphasise the importance of user-centred design and iterative improvements based on participant feedback to optimise digital health interventions. By highlighting both the strengths and limitations of the current study, these results contribute to the broader understanding of the role of digital tools in prehabilitation and offer valuable directions for future research and development in this field.

# Chapter 6

# General Discussion

This study set out to evaluate the feasibility, acceptability, and clinical impact of the Fit4Surgery (F4S) digital prehabilitation programme in patients undergoing lung cancer and lung volume reduction surgeries. Drawing on a mixed-methods approach, the research examined the theoretical basis, design, implementation, and evaluation of the F4S app. This chapter critically discusses the key findings presented throughout the thesis, compares them with existing literature, highlights their theoretical and clinical implications, and reflects on the thesis's strengths, limitations, and future research directions.

In parallel, this PhD represented a significant process of personal and professional development, providing extensive experience in designing and delivering applied clinical research. This included authoring core study documentation such as the research protocol and participant-facing materials, coordinating patient recruitment, and conducting data collection within busy clinical settings. Close collaboration with multidisciplinary teams, including clinicians, researchers, and patients, enhanced understanding of surgical pathways and the importance of patient-centred, implementation-aware intervention design. From the research findings, it became clear that the F4S app is broadly feasible and acceptable, with patients valuing its convenience and home-based delivery; however, the work also identified clear optimisation requirements, including enhanced exercise progression, incorporation of breathing exercises, improved onboarding, and strategies to mitigate digital exclusion. These insights emphasise that both intervention content and delivery context are critical to successful digital prehabilitation. Moving forward, these insights directly inform the design of future studies, as outlined in section 6.5 which is Future Research Directions.

## 6.1 Interpretation of Key Findings

This thesis presents a comprehensive examination into the feasibility, acceptability, and potential impact of the F4S digital prehabilitation programme for patients undergoing lung cancer (LC) and lung volume reduction surgeries (LVRS). The findings encompass five interconnected chapters, each enhancing the comprehensive understanding of digital prehabilitation in surgical care.

The literature review pointed out a growing amount of evidence supporting the role of prehabilitation in improving postoperative outcomes, particularly among high-risk surgical patients. Notably, digital and remote prehabilitation models have been found to be as effective as traditional in-person approaches, with added benefits of accessibility and flexibility [25, 26]. However, limitations in standardisation and evidence on digital tools underscored the need for the current study [40 – 43].

The matched-case study using propensity score analysis (PSA) showed that engagement in real-world pulmonary rehabilitation (PR) before lung surgery was associated with reduced postoperative pulmonary complications (PPC), shorter length of hospital stay (LOS), and improved quality of life (QoL). Moreover, the reduction in PPC by 60% and a modest LOS reduction of up to 1.8 days consistent with earlier systematic reviews indicating the advantages of preoperative rehabilitation in minimising perioperative risk [19,20]. This evidence supports previous literature showing that both PR and prehabilitation can play critical roles in enhancing perioperative outcomes by targeting respiratory function, fitness, and recovery preparedness [64,19,20].

Chapter 3 focused on the development of the F4S app using the Double Diamond co-design framework. This structured approach enabled the integration of user needs and behavioural change techniques—such as goal setting, progress tracking, and personalised feedback—into the digital intervention [66-70]. The incorporation of Self-Determination Theory (SDT) within the app design aimed to foster intrinsic motivation by supporting users' autonomy, competence, and relatedness. The resulting programme provided personalised exercise prescriptions, nutritional support, and biofeedback, addressing a gap in digitally delivered, user-centred prehabilitation tools [38, 39].

The results of this thesis collectively demonstrate the potential of the F4S app to improve physical functioning, symptom burden, and overall quality of life in patients preparing for major thoracic surgery. Quantitative data displayed statistically and clinically meaningful improvements in physical performance measures such as ISWT and STS, particularly in both the LC and LVRS cohorts. These improvements were observed despite lung resection surgery, suggesting that prehabilitation through F4S contributed to functional enhancements. Further,

moderate positive correlations between app engagement and physical test performance support the app's influence on clinical outcomes.

In parallel, the EORTC QLQ-C30 results shown continuous improvements in global health and functioning domains (physical, emotional, social, and role), alongside reductions in key symptoms such as fatigue, dyspnoea, and pain. These findings are associated with prior studies showing that structured prehabilitation can enhance postoperative recovery. Notably, other digital interventions such as those evaluated by Sui et al. (2020) and Houchen-Wolloff et al. (2018) also reported improvements in QoL domains, suggesting digital approaches can match or exceed traditional rehabilitation in patient-centred outcomes [36,32].

Qualitative findings strengthened the quantitative results. Participants reported that the F4S app supported their preoperative preparation by enhancing physical fitness, reducing anxiety, and providing a sense of control. Essentially, the app's usability and accessibility were central to overcoming digital apprehension and maintaining engagement. These insights reflect the value of embedding behavioural change techniques and user-centred design—such as goal setting, feedback, and flexibility—into digital health interventions.

## 6.2 Integration with Existing Literature

This thesis builds on growing evidence supporting the role of prehabilitation in surgical recovery. Chapter 1 highlighted that prehabilitation is often more effective than postoperative rehabilitation, especially for high-risk patients [19 – 21]. It also identified digital models as promising alternatives to outpatient programmes, particularly under constraints like the COVID-19 pandemic [25, 26]. It also investigated the effectiveness of app/website rehabilitation compared to conventional rehabilitation in the literature [32,34,36]. Lastly, chapter 1 examined the feasibility and acceptability of digital prehabilitation programmes in the literature and concluded that these programmes are feasible and accepted across recent studies [40 – 43]. Consistent with the literature, this study found that remote delivery through the F4S app was not only feasible but highly acceptable.

Previous reviews have shown that digital interventions may improve physical activity, QoL, and reduce perioperative complications. However, as Chapters 2 and 4 noted, the heterogeneity

of interventions, lack of standardisation, and variable inclusion criteria have made it difficult to draw firm conclusions [19 – 21, 42, 43, 65]. The findings of this thesis contribute new evidence by showing that a structured, user-informed digital programme can achieve improvements typically associated with traditional in-person rehabilitation models.

Furthermore, this thesis advances the field by incorporating the Double Diamond design model—a structured co-design approach that is underutilised in digital health development. As demonstrated in Chapter 3, engaging patients in the iterative design of the F4S app led to an intervention that is theoretically grounded and practically applicable. The similarity of our methodology with prior research on stakeholder-led digital tool development highlights its significance in generating effective and acceptable digital intervention [124].

## 6.3 Theoretical and Practical Implications

The incorporation of self-determination theory (SDT) in the design of the F4S app seems to have enhanced patient engagement. The app facilitated behavioural change by promoting autonomy, competence, and relatedness, thereby serving as both a functional tool and a motivational environment. These findings support the role of theory-driven design in enhancing digital intervention uptake and adherence. Similar behaviour change techniques were incorporated in other successful app interventions for cardiac and orthopaedic rehabilitation, as demonstrated by Houchen-Wolloff et al. and Wijnen et al. [32,34].

From a clinical perspective, the app offers a scalable, cost-effective, and accessible solution to the challenges facing traditional prehabilitation. Particularly for patients with limited mobility, time, or geographical access to hospital-based programmes, F4S represents a viable alternative to ensure continuity of care. Further, digital delivery facilitates real-time monitoring, adaptive feedback, and could ultimately reduce healthcare system burdens.

Policy-wise, the findings of chapter 2 stress the need for systemic support for rehabilitation pathways, including funding mechanisms such as tariffs. If digital prehabilitation is to be implemented at a broader scale, health systems must adapt to accommodate and incentivise

these emerging models. These policy adaptations must include integration with electronic health records and address digital equity to promote inclusive uptake.

## 6.4 Strengths and Limitations

One of the key strengths of this thesis lies in its mixed-methods approach. The quantitative analysis demonstrated strong evidence of clinical outcomes, whereas the qualitative research provided depth and context regarding patient experiences and app engagement. These approaches generated a thorough understanding of the intervention's impact.

The application of user-centred design principles, through the Double Diamond process, represents another strength. It ensured that the intervention was responsive to the needs and preferences of its target users, which likely contributed to the app's high usability and satisfaction ratings. Additionally, the use of PSA in chapter 2 allowed adjustment for important covariates, improving the internal validity of observational data.

Nonetheless, the study was conducted at a single centre, which may limit the generalisability of the findings. The relatively small sample size, especially in the LVRS cohort, and missing data at follow-up points may have introduced bias and affected statistical power. The absence of a control group and the feasibility design further limit causal inferences. These concerns are consistent with those noted in other feasibility studies of digital interventions [21,34]. Finally, while PSA adjusted for known confounders, unmeasured variables such as technological literacy or social support may still have affected the results.

## 6.5 Future Research Directions

Future studies should focus on conducting large-scale, multicentre randomised controlled trials to evaluate the efficacy of the F4S app against standard care. Furthermore, future studies should also explore how social and cultural backgrounds influence the acceptability of the F4S app, ideally by conducting research in diverse international settings. These trials should incorporate health economic evaluations to determine cost-effectiveness and long-term follow-up to assess sustained benefits.

Importantly, the F4S app should be considered an evolving intervention rather than a finalised product. Findings from this thesis, particularly the qualitative evaluation and co-design feedback, have already informed iterative refinements to the app and its delivery pathway, with further enhancements planned. These include expansion of respiratory exercise content, improved exercise progression and personalisation, clearer onboarding and in-app guidance, and continued strategies to reduce digital exclusion. Future research should therefore adopt an iterative, adaptive development approach, whereby ongoing user feedback and trial findings are used to refine the intervention in parallel with evaluation. This approach is consistent with best practice for complex digital health interventions and supports progression towards a scalable, trial-ready version of the F4S app.

There is also scope to explore adaptations of the app for other surgical populations and chronic disease cohorts. Customisation of content, integration with wearable devices, and enhanced support for technologically inexperienced users are potential avenues for improvement. In addition, investigating hybrid models that combine digital and in-person components may offer further flexibility and effectiveness. Such adaptations may help overcome adherence issues, which continue to challenge the implementation of digital health interventions.

## 6.6 Conclusion

In conclusion, this thesis demonstrates that the F4S app is a feasible, acceptable, and potentially effective digital prehabilitation intervention for patients undergoing lung surgery. By integrating behavioural theory, user-centred design, and structured development processes, the F4S programme addresses several limitations of traditional prehabilitation models. The demonstrated improvements in functional performance, quality of life, and patient experience underscore the value of digital tools in modernising perioperative care. As the healthcare landscape increasingly embraces remote and personalised approaches, digital prehabilitation tools like F4S represent a practical and adaptable solution for preoperative optimisation. Continued research and refinement will be key to unlocking their full potential in diverse clinical settings.

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# 8. List of Appendices

## Appendix 8.1

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Perioperative Medicine

RESEARCH Open Access

# Effect of pulmonary rehabilitation on lung cancer surgery outcomes: a matched-case analysis

Matar Alzahrani[1,2,3*], Rajnikant Mehta[4], Salma Kadiri[5], Saffana Algaeed[6], Aya Osman[5], Mohammed Alsanad[1,3,7], Joan Duda[8], Fang Gao[2] and Babu Naidu[2,5]

**Abstract**

Pulmonary rehabilitation programs for COPD patients are extensively accessible throughout the UK and have demonstrated efficacy in enhancing outcomes, including recovery from exacerbations. Numerous lung cancer surgery patients possess COPD, and the surgery may be regarded as a definitive aggravation of COPD. It is ambiguous in practical application whether referral to pulmonary rehabilitation programs enhances surgical and patient-reported results. We want to address this topic by conducting a propensity-score analysis (PSA) of participants in an enriched cohort trial.

**Methods** An enriched cohort research was conducted, providing rehabilitation both pre- and post-surgery pragmatically through local pulmonary rehabilitation providers for patients undergoing lung cancer resection, and compared to a contemporaneous control group receiving standard treatment. The study enrolled 873 participants (pulmonary rehabilitation (PR) $n=135$, non-intervention or control (NG) $n=738$). Regression analyses for exposed and unexposed matching, effect estimation, and standard error estimations were conducted.

**Results** A total of 114 participants were matched PR ($n=57$) and NG ($n=57$). The multivariate-linear regression indicated a reduction in length of stay (LOS) of 0.2 days of LOS compared to the usual care group (EE = −0.20), and that reduction could potentially go up to 1.8 days (95% CI = −1.8–1.6). The multivariate log-binomial regression revealed that PR had a reduction of 60% postoperative pulmonary complications (PPC) rate (EE = −0.60, 95% CI = −1.8–0.5). Lastly, the multivariate-linear regression showed an improvement in quality of life 6 weeks and 6 months after surgery (QoL) in patients in PR, especially in the physical functioning score in which an improvement of 6.6% was noted for the PR group compared to the NG group following surgery (EE = 6.6). Conclusion Participation in "real world" pulmonary rehabilitation prior to and following surgery seems to yield improved patient and clinical results post-lung cancer surgery. Nonetheless, prompt access to pulmonary rehabilitation may be a significant challenge following COVID.

**Keywords** Pulmonary rehabilitation, Prehabilitation, Postoperative pulmonary complications, Quality of life, Propensity score analysis, Hospital length of stay, Rehabilitation programs

*Correspondence:
Matar Alzahrani
rainalzahrani@gmail.com
Full list of author information is available at the end of the article

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## Introduction

Major complications occur in up to 20% of patients undergoing chest or abdominal surgery, with up to 13% of patients developing postoperative pulmonary complications (PPC) following curative lung cancer surgery, which is often exacerbated by underlying COPD (Smith et al. 2012; Taylor et al. 2023; Jeganathan et al. 2022). PPC significantly increases mortality, intensive therapy unit (ITU) admissions, length of hospital stay, and 30-day hospital readmissions, and its occurrence across various surgeries highlights the potential for cost savings through improved rehabilitation (Myles et al. 2020; STARSurg Collaborative. Impact of postoperative non-steroidal anti-inflammatory drugs on adverse events after gastrointestinal surgery. 2014; Jones et al. 2019; Katsura et al. 2013; Bradley et al. 2013).

As surgery is increasingly performed on older and less-fit patients, structured post-surgical programs, including physical activity, nutritional guidance, and psychological interventions, have shown effectiveness in reducing mortality, improving quality of life (QoL), and preventing hospital readmissions (Bowel cancer statistics 2020; McCann et al. 2019; Arora et al. 2018). These successes have sparked interest in prehabilitation as a proactive strategy to enhance surgical outcomes and further reduce complications (McCann et al. 2019; Arora et al. 2018).

Prehabilitation before surgery has been recognized as a critical step to improve postoperative outcomes. It enhances an individual's functional capacity to withstand the stress of major surgery (Banugo and Amoako 2017). Prehabilitation can lead to significant improvements in patients' physical fitness, mental well-being, and overall readiness for surgery (Tew et al. 2020). The American College of Surgeons highlights that prehabilitation helps enhance the functional capacity of patients before surgery, making them more resilient to postoperative inactivity and decline (The American College of Surgeons (n.d.)). This multimodal approach includes exercise training, nutritional support, and psychological interventions, which collectively help in reducing perioperative complications and improving recovery times (Banugo and Amoako 2017).

Access to prehabilitation services in the UK and globally remains limited despite its recognized benefits in improving surgical outcomes. In the UK, a significant proportion of patients are not offered prehabilitation due to inconsistent implementation across health services (Wade-Mcbane et al. 2023). For example, a study revealed that while the need for prehabilitation is widely acknowledged, only a small percentage of patients actually receive these services (Wade-Mcbane et al. 2023). This gap is often attributed to a lack of resources, standardized protocols, and sufficient training for healthcare providers (Myles et al. 2020). Globally, the situation is similar. For instance, a survey of thoracic surgeons in Australia found that although there is a high perceived need for prehabilitation, only a small fraction of patients had access to these services (Grocott et al. 2023). This disparity highlights the broader issue of unequal access to prehabilitation across different countries and healthcare systems (Grocott et al. 2023).

In response to this rising need to enhance outcomes, prehabilitation may have significant relevance for frail and elderly populations awaiting an elective major operation (Bowel cancer statistics 2020). There is currently no established pathway for engaging these patients in improving their health as they wait for their major surgical interventions (Arora et al. 2018). Furthermore, in real-world practice, it is uncertain whether referral to pulmonary prehabilitation classes improves surgical and patient-reported outcomes. Using real-world data improves generalizability by including diverse patient populations often excluded from randomized controlled trials (RCTs) and better reflects routine clinical practice, capturing real-world treatment effectiveness, adherence, and patient behaviors (Sherman et al. 2016; Califf 2016). Recent studies have demonstrated that pulmonary rehabilitation significantly reduces postoperative complications, particularly pulmonary complications, and improves recovery in lung cancer surgery patients, supporting its potential role in this context (Wang et al. 2023; Mao et al. 2021). Therefore, whether referral to pulmonary rehabilitation classes could be an alternative for patients who are waiting for lung cancer surgery to reduce the incidence or severity of postoperative complications should be investigated (McCann et al. 2019; Arora et al. 2018). By performing a propensity-score analysis (PSA), we aim to investigate whether the prehabilitation program, which is a referral to pulmonary rehabilitation classes, had an impact on perioperative care compared to the usual care, no prehabilitation, on patients who underwent lung cancer surgery.

## Methods

### Study design

This study is a prospective, longitudinal, single-center study. The Institutional Review Board approved the study (REC number: 10/H1208/41).

### Participants and procedures

This enriched cohort study involved consecutive recruitment of patients undergoing lung cancer resection at University Hospital Birmingham NHS Foundation Trust by offering rehabilitation pre- and post-surgery pragmatically by local providers compared to a contemporaneous control group who just had usual care. Informed

consent was obtained from all participants, and quality of life (QoL) measures were self-reported by all participants following lung surgery. Data was collected prospectively from patients' medical records including length of stay (LOS) and postoperative pulmonary complications (PPC) using the Melbourne group scale (MGS) (Lugg et al. 2016).

The study recruited 873 participants who underwent lung cancer surgery from 2010 to 2020. Participants were allocated to two groups: pulmonary rehabilitation (PR) ($n=135$) and non-intervention or control (NG) ($n=738$). Participants in the PR offered rehabilitation pre- and post-surgery pragmatically by local providers, and participants in the NG received usual care. The inclusion criteria were above the age of 18 years, undergoing lung cancer curative resection, able to provide written informed consent, and before surgery at the time of consent. The exclusion criteria were unable to provide written informed consent. Participants were recruited at least 2 weeks prior to surgery and were followed up to 5 months after surgery in both groups.

#### PR program

The participants were recruited from 11 hospitals across the UK, of which only three—Walsall Manor, Heartlands, and Worcester—had pulmonary rehabilitation programs in place (British Thoracic Society Standards of Care Committee. BTS guideline on pulmonary rehabilitation in adults 2013). Patients in the PR group were enrolled in a 12-week pulmonary rehabilitation program at these three hospitals, commencing before their lung cancer surgery. Each patient attended at least two sessions prior to their surgery. Worcester offered a community-based program, while Heartlands and Walsall Manor hospitals provided in-hospital, class-based programs. These programs aligned with the British Thoracic Society's guidelines, which recommend a minimum 6-week PR program with twice-weekly supervised sessions, incorporating tailored aerobic and resistance exercise training, structured education, and a multidisciplinary team approach to improve functional capacity, symptom management, and quality of life for patients with chronic respiratory conditions (British Thoracic Society Standards of Care Committee. BTS guideline on pulmonary rehabilitation in adults 2013).

#### Outcome measures

The primary outcome measures were hospital length of stay (LOS), postoperative pulmonary complications (PPC) defined using the MGS (Lugg et al. 2016), and quality of life (QoL). The LOS and PPC were extracted from the medical records. The QoL for the participants was measured in baseline before surgery, 6 weeks after surgery, and 6 months after surgery. The EORTC QLQ-C30 is a standardized questionnaire designed to measure the quality of life in cancer patients. It evaluates three main domains: functional (physical, role, emotional, cognitive, and social aspects); symptom (issues such as fatigue, pain, nausea, and financial difficulties); and global health, which provides an overall perspective on health and quality of life (Aaronson et al. 1993). Scores are derived using a 0–100 scale for clarity, with raw scores averaged for each domain and linearly transformed for final interpretation. The tool consists of 30 items organized into multi-item and single-item scales. The QoL domains' scores were interpreted based on the clinically meaningful difference defined as a change of 10 units.

For functional scales and the global health status/QoL scale, higher scores indicate better functioning and quality of life (Aaronson et al. 1993). Conversely, for symptom scales, higher scores indicate greater symptom severity or more problems (Aaronson et al. 1993). These standardized scores facilitate comparison across different studies and patient populations, allowing clinicians and researchers to assess and monitor patients' quality of life effectively (Fayers et al. 2001).

#### Matching, covariates, and statistical analysis

To create a comprehensive and current database, it was essential to clean the existing data and collect new data prospectively from patients' electronic medical records. To address this challenge, research fellows have been gathering data and building multiple databases over the last decade. Matching was then performed using propensity score analysis (PSA). PSA is a statistical technique used to estimate the effect of a treatment, policy, or intervention by accounting for covariates that predict receiving the treatment (Austin 2011). This method is particularly useful in observational studies where random assignment is not feasible (Austin 2011). By using PSA, researchers aim to reduce selection bias and simulate a randomized controlled trial. The key concept is the propensity score, which is the probability of a unit (e.g., a person) receiving the treatment given their observed characteristics. PSA is widely used in fields such as epidemiology, economics, and social sciences to draw causal inferences from non-experimental data.

Due to the missing values within the data set, as presented in Fig. 1, imputation techniques were applied using RStudio version 2024.04.2+764 before moving to univariate regression for the outcomes. The data imputation approach that was used is the MICE package installed in R (Buuren and Groothuis-Oudshoorn 2011). The package creates multiple imputations

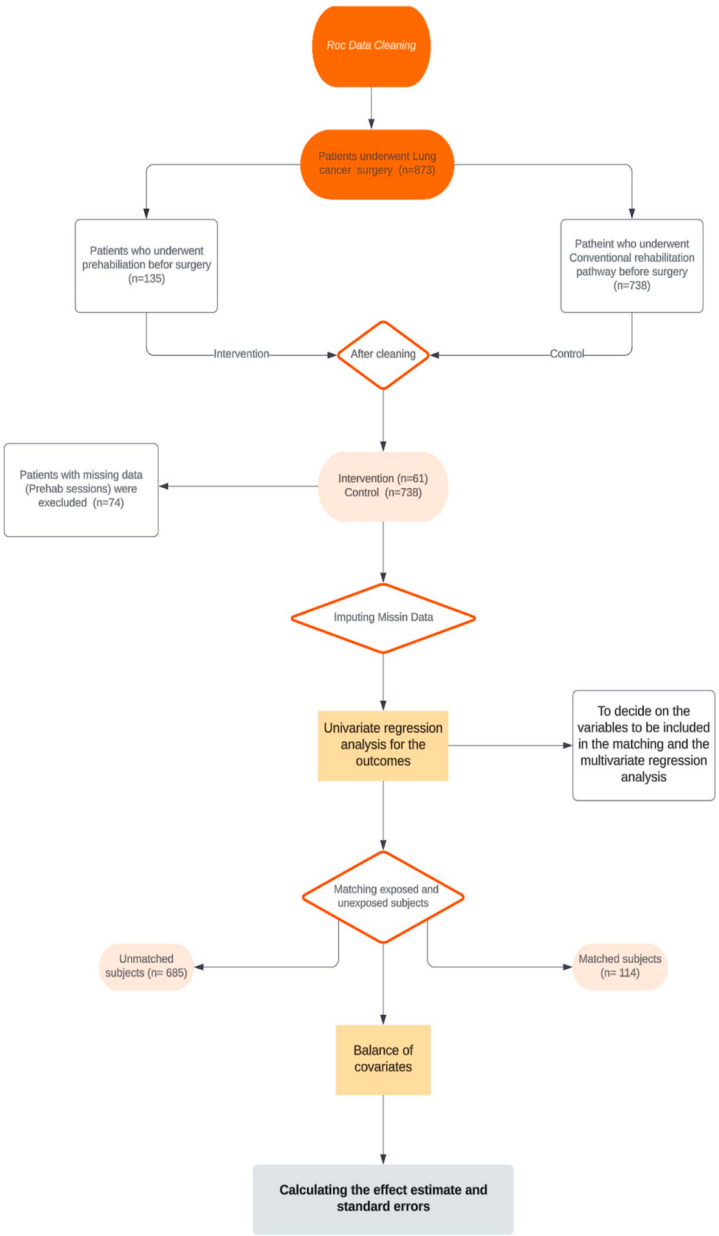



**Fig. 1** PSA steps flowchart for evaluating pulmonary rehabilitation impact on lung cancer surgery patients

(replacement values) for multivariate missing data. The approach relies on fully conditional specification, wherein each incomplete variable is imputed using an individual model. The MICE algorithm can impute combinations of continuous, binary, unordered categorical, and ordered categorical data. Furthermore, MICE is capable of imputing continuous two-level data while ensuring consistency among imputations by passive imputation. Numerous diagnostic plots are utilized to evaluate the quality of the imputations.

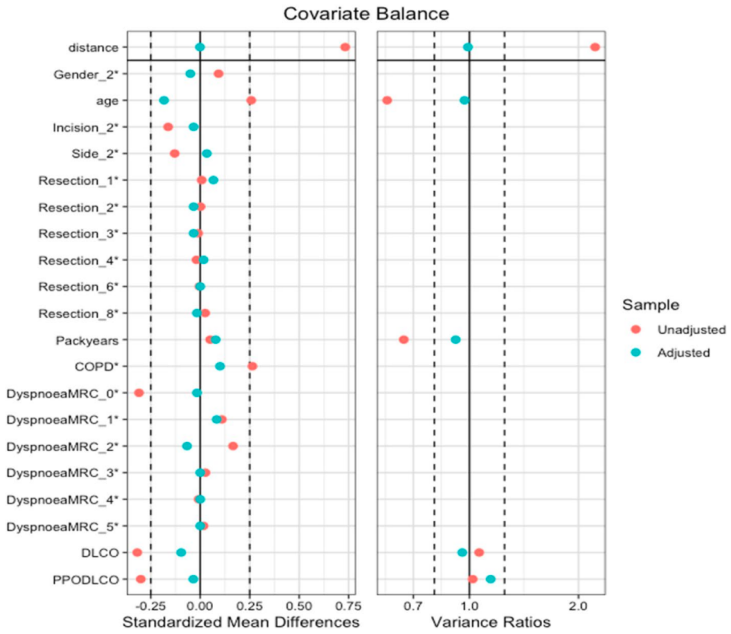



**Fig. 2** Covariates balance assessment before and after propensity score matching

Figure 1 summarises the propensity score analysis (PSA) steps. After carrying out the regression analysis for the outcomes, the following covariates were included in the matching: COPD, gender, age, incision, side, resection, MRC dyspnoea, DLCO, and packyears. After deciding on the variables to include and performing the regression for each outcome, the next steps in PSA are to match exposed and unexposed subjects, then check the balance of covariates in the exposed and unexposed groups after matching, and finally calculate the effect estimate and standard errors with this match population. After matching, it is essential to check the balance of covariates between the treated and control groups. This step ensures that the matching process successfully creates comparable groups (Fig. 2). Figure 2 shows the standardised mean differences for covariates before (red) and after (blue) adjustment in PSA. The two vertical dashed lines represent the thresholds for acceptable balance, typically set at ± 0.1, indicating that covariates with differences within these lines are considered well balanced (Fig. 2).

### Propensity score model

After selecting covariates and performing regression for each subject, the propensity score analysis (PSA) proceeded with matching exposed and unexposed subjects, checking covariate balance post-matching, and calculating effect estimates and standard errors. The matching process was conducted in R using the MATCHiT version 4.6.0 package, with nearest neighbor matching within a calliper of 0.02 to ensure that the propensity scores (PS) of matched pairs were close enough for comparability (Ho et al. 2011). A calliper of 0.02 was chosen to balance precision and confidence in match quality, as values too small or large could compromise matching effectiveness. A 1:1 matching ratio without replacement was used, meaning each unexposed subject was matched to only one exposed subject, enhancing precision by maximizing the use of available subjects.

## Results

### General patient characteristics

A total of 873 patients were recruited from 2010 to 2020 who underwent lung cancer surgery and were included in the statistical analysis (Fig. 1). After data cleaning, 74 patients were excluded from the intervention arm since there was no information about how many prehabilitation sessions they had (Fig. 1). The participants' baseline characteristics and clinical data are shown in Table 1.

Table 1 represents baseline demographic and smoking data for 799 patients. The median age is 70 years old, and it can be noticed that around half of the patients are male. It can be seen that the mean BMI for 799 is 26.9.The majority of the patients reported that they had

quit smoking before their surgery, while almost a third of the patients in both groups were never smokers. It is apparent that 45% of the patients suffered from hypertension, and 20% had chronic obstructive pulmonary disease (COPD). Regarding postoperative outcomes, only 7% of patients had postoperative pulmonary complications (PPC), and the median length of hospital stay (LOS) was 4 days (Table 1).

#### Quality of life scores

Table 2 shows the difference in functional or global health domains at different time points (Supplementary Material: Fig. 3). Clinically, global health has deteriorated from baseline to 6 weeks, generally indicating lower quality of life. Similarly, physical functioning has clinically declined between preoperative 6-week and 5-month scores. Also, emotional functioning has clinically declined between preoperative and 6-week scores; however, there has been a marginal improvement, but not to the point of clinical difference. Regarding the dyspnoea symptom domain clinically, the patients' scores declined significantly post-surgery at 6 weeks and 6 months compared to that before surgery.

Following propensity score matching, Table 3 shows the difference in functional and global health domains at different time points after matching. Clinically, global health and physical functioning declined from baseline to 6 weeks, indicating a reduction in overall quality of life postoperatively, with a slightly greater decline in the NG group. Role functioning also showed a decrease at 6 weeks, with some recovery at 6 months, though scores remained lower than baseline. Emotional and cognitive functioning showed minor fluctuations over time, with no clinically significant differences between groups. Dyspnoea scores worsened significantly postoperatively in both groups at 6 weeks and remained elevated at 6 months, with NG patients experiencing a greater impact compared to PR patients.

#### Other analyses

Table 4 shows the baseline characteristics of 114 patients included in the study after matching. Once the balance of the matched population is ensured, as indicated in Fig. 2, the final step of the PSA is to calculate the effect estimate (EE) and standard errors (SE) for the outcomes, which are the length of stay (LOS), postoperative pulmonary compilations (PPC), 6 weeks postoperative physical functioning (PF 6W) domain, 6 weeks postoperative dyspnoea (DY 6W), 6 weeks postoperative global health (QoL 6W), and 6 months postoperative global health (QoL 6 M) as indicated in Table 5. Supplementary Material: Fig. 4 points out the forest plot of key outcomes.

In Table 5, it can be noted that the PR group had a reduction of 0.2 days in LOS compared to the usual care group (EE = −0.20), with the potential reduction extending up to 1.8 days, though the confidence interval also includes the possibility of an increase of 1.6 days (95% CI = −1.8 to 1.6). In regard to the PPC, the PR group had a reduction of 60% (EE = −0.60, 95% CI = −1.8–0.5). There was an indication of a 6.6% improvement in the physical functioning score for the PR group compared to the usual care group following surgery (EE = 6.6). Although it is only 6.6%, the 95% CI indicated that the maximum could be 14 units, which is considered a clinically significant improvement. Also, there was a slight reduction of −0.4 in the dyspnoea score for the PR group 6 weeks following surgery.

In regard to the QoL global health score 6 weeks following surgery, there was an improvement of 5.1% for the PR group. Furthermore, there was an indication of a 4.7% improvement in the QoL global health score for the PR group compared to the usual care group 6 months following surgery (EE = 4.7). Although it is only 4.7%, the 95% CI indicated that the maximum could be 13 units, which is considered a clinically significant improvement.

## Discussion

The comparative effectiveness of research evaluating the impact of "real world" pulmonary rehabilitation on surgical outcomes is not extensively documented. Randomized controlled trials (RCTs) have strict patient inclusion and exclusion criteria that might restrict the generalisability of the study results. Overall, in this case, matched analysis, the participants in the PR group were matched to the NR group in their demographic characteristics, BMI classification, smoking status, lung function, surgery incision, surgery side, lobe, lung resection technique, comorbidities, and other measures as presented in Table 1. The PPC and LOS showed a trend of being higher in the PR group compared to the NG group, which could be attributed to the PR group having a trend toward a higher prevalence of COPD and greater pack-year histories. Furthermore, this study revealed that the PR group had a reduction of 0.2 days of LOS compared to the usual care group (EE = −0.20) and that reduction can potentially go up to 1.8 days (95% CI = −1.8–1.6). Also, in the PPC, the PR group had a reduction of 60% (EE = −0.60). In the PR group, the QoL domains, including physical functioning, dyspnoea score, and global health score, all improved 6 weeks following surgery, with a maximum improvement of more than 10 units in physical functioning and global health scores 6 weeks and 6 months following surgery, which is considered a clinically significant improvement. Patient participation in the PR program

**Table 1** Baseline characteristics of 799 patients included in the study

| Characteristic | Pulmonary rehabilitation (PR) ($n=61$) | Non-intervention or control (NG) ($n=738$) |
|---|---|---|
| **Patient demographics** | | |
| Age | 71 (66, 75) | 70 (63, 75) |
| Gender (male) | 26 (43%) | 383 (52%) |
| BMI | 25.2 (22.8, 28.5) | 26.9 (24.0, 30.3) |
| **BMI classification** | | |
| Healthy weight | 26 (43%) | 212 (29%) |
| Obese | 9 (15%) | 180 (24%) |
| Overweight | 21 (34%) | 296 (40%) |
| Severely obese | 1 (1.6%) | 16 (2.2%) |
| Underweight | 4 (6.6%) | 34 (4.6%) |
| **Smoking status** | | |
| Current | 9 (15%) | 76 (10%) |
| Ex-smoker | 42 (69%) | 512 (70%) |
| Never smoker | 10 (16%) | 142 (19%) |
| Pack years | 40 (15, 50) | 28 (5, 45) |
| Unknown pack years | 9 | 46 |
| **Lung function** | | |
| $FEV_1$ (L) | 2.14 (1.70, 2.55) | 2.02 (1.56, 2.30) |
| % $FEV_1$ | 87 (74, 100) | 81 (66, 99) |
| %DLCO | 77 (65, 91) | 71 (58, 84) |
| $PpoFEV_1$ | 69 (56, 81) | 62 (46, 81) |
| PpoDLCO | 61 (51, 73) | 57 (48, 66) |
| **Surgical incision** | | |
| Open | 37 (61%) | 327 (44%) |
| VATS | 24 (39%) | 409 (56%) |
| **Surgery side** | | |
| Right | 43 (70%) | 425 (58%) |
| **Lobe** | | |
| Upper | 37 (63%) | 402 (56%) |
| Middle | 2 (3.4%) | 44 (6.1%) |
| Lower | 15 (25%) | 227 (31%) |
| Upper bilobe | 4 (6.8%) | 10 (1.4%) |
| Lower bilobe | 0 | 5 (0.7%) |
| Entire lung | 1 (1.7%) | 26 (3.6%) |
| **Lung resection** | | |
| Wedge | 10 (16%) | 129 (17%) |
| Segmentectomy | 2 (3.3%) | 23 (3.1%) |
| Lobectomy | 45 (74%) | 539 (73%) |
| Bilobectomy | 3 (4.9%) | 18 (2.4%) |
| Sleeve | 0 | 3 (0.4%) |
| Pneumonectomy | 1 (1.6%) | 26 (3.5%) |
| **Comorbidity** | | |
| COPD | 27 (44%) | 132 (18%) |
| Hypertension | 20 (34%) | 316 (46%) |
| **Other measures** | | |
| MRC dyspnoea score > 2 | 4 (6.6%) | 21 (3%) |
| **Rehabilitation sessions** | | |
| Pre-surgery | 2 (1, 5) | |

**Table 1** (continued)

| Characteristic | Pulmonary rehabilitation (PR) ($n=61$) | Non-intervention or control (NG) ($n=738$) |
|---|---|---|
| Post-surgery | 0 (0, 2) | |
| **Perioperative outcomes** | | |
| Postoperative pulmonary complications | 7 (11%) | 46 (6.2%) |
| Hospital length of stay (days) | 5.0 (4.0, 7.0) | 4.00 (3.00, 6.00) |

Data are presented as mean (median), standard deviation (interquartile range), or numbers and percentages for categorical data

*$FEV_1$* forced expiratory volume for 1 s, *DLCO* diffusing capacity for carbon monoxide, *$PpoFEV_1$* or *PpoDLCO* predicted postoperative $FEV_1$ or DLCO, *VATS* video-assisted thoracic surgery, *COPD* chronic obstructive pulmonary disease

was higher before surgery than after, demonstrating that the intervention is both feasible and acceptable to patients. This increased preoperative engagement highlights the program's ability to complement patients' needs effectively during the pre-surgical period.

**Table 2** Comparison between EORTC QLQ-C30 functioning and global health domains, and dyspnoea symptom domain

| QoL domain | baseline | 6 weeks | 6 months |
|---|---|---|---|
| Global health | 75 (67, 92) | 67 (50, 83) | 67 (50, 83) |
| Physical functioning | 93 (80, 100) | **80 (60, 87)** | **80 (60, 93)** |
| Role functioning | 85 (60, 87) | **63 (50, 83)** | **70 (67, 92)** |
| Emotional functioning | 83 (67, 100) | 76.6 (67, 92) | 83 (67, 100) |
| Cognitive functioning | 85 (60, 87) | 80 (60, 87) | 83 (67, 100) |
| Social functioning | 85 (60, 87) | 83 (67, 100) | 85 (60, 87) |
| Dyspnoea | 20.5 ± (25.4) | **41.9 ± (29.6)** | **39.2 ± (29.4)** |

Data are presented as mean (median) and standard deviation (interquartile range). Highlighted numbers indicate clinically meaningful differences of 10 units or more

A preoperative exercise rehabilitation program, pulmonary rehabilitation, has been shown to reduce LOS and PPC and is associated with better QoL. Pulmonary rehabilitation focuses on improving respiratory function and overall health in patients with chronic lung conditions through exercise, education, and support (Spruit et al. 2013). Similarly, prehabilitation, a preparatory intervention aimed at enhancing a patient's physical and mental fitness before surgery, has demonstrated the potential to improve outcomes and recovery (Drudi et al. 2019; Gravier et al. 2021; Ferreira et al. 2021). Furthermore, pulmonary rehabilitation reduces LOS by enhancing recovery as patients become fitter, and it reduces PPC by improving mobility, enabling more effective coughing, decreasing the likelihood of atelectasis, and enhancing overall breathing (Spruit et al. 2013; Drudi et al. 2019; Gravier et al. 2021). However, due to study heterogeneity, no firm recommendations can be made regarding the optimal exercise modality, delivery method, frequency, or preoperative duration of these interventions. Nonetheless, a preoperative exercise rehabilitation program should be considered, particularly for patients with borderline lung function or limited exercise capacity, to optimize surgical readiness and recovery.

The latter findings correlate with findings from a systemic review that showed prehabilitation was associated with decreased LOS, postoperative complications, improved objective physical functioning, and improved QoL measures in patients undergoing cardiac and vascular procedures (Drudi et al. 2019). Similarly, evidence from another systemic review has shown that prehabilitation improves PPC, exercise capacity, and QoL

**Table 3** Comparison between EORTC QLQ-C30 functioning and global health domains, and dyspnoea symptom domain after matching

| QoL domain | baseline | | 6 weeks | | 6 months | |
|---|---|---|---|---|---|---|
| | PR | NG | PR | NG | PR | NG |
| Global health | 75.42 (20.84) | 66.81 (20.61) | 62.92 (15.83) | 58.06 (20.87) | 66.81 (21.89) | 61.81 (23.13) |
| Physical functioning | 85.89 (16.56) | 78.78 (21.06) | 72.22 (17.79) | 66.44 (23.19) | 74.33 (20.68) | 66.56 (25.26) |
| Role functioning | 87.50 (21.18) | 79.72 (27.97) | 65.28 (28.67) | 58.61 (28.87) | 68.06 (30.73) | 63.33 (34.00) |
| Emotional functioning | 80.00 (18.04) | 72.36 (22.21) | 75.83 (22.27) | 70.51 (24.79) | 77.78 (21.19) | 75.42 (25.28) |
| Cognitive functioning | 88.33 (17.71) | 84.72 (16.89) | 80.56 (24.39) | 78.61 (20.83) | 84.17 (21.13) | 78.89 (19.13) |
| Social functioning | 90.28 (18.49) | 85.28 (23.59) | 73.06 (27.46) | 70.56 (29.17) | 74.72 (29.67) | 76.39 (28.17) |
| Dyspnoea | 21.1 (27.2) | 26.6(27.7) | 47.20 (28.07) | 51.07 (30.71) | 42.7 (29.2) | 51.6 (31.2) |

Data are presented as mean and standard deviation

**Table 5** Multivariate regression results for the outcomes in the PR group after matching

| Outcomes<br>Values | PPC | LOS | PF 6W | DY 6W | QoL 6W | QoL 6 M |
|---|---|---|---|---|---|---|
| EE | −0.60 | −0.20 | 6.6 | −0.44 | 5.1 | 4.7 |
| SE | 0.59 | 0.82 | 3.71 | 0.38 | 3.34 | 3.35 |
| Antilog | 1.8 | - | - | 0.64 | - | - |
| 95% CI | −1.8–0.5 | −1.8–1.6 | −0.80–14 | −1.1–0.24 | −1.5–12 | −3.5–13 |

*CI* confidence interval, *EE* effect estimate, *SE* standard error

compared to usual care in patients undergoing non-small lung cancer resection (Gravier et al. 2021). The findings of this study and of those studies presented in the literature suggest that prehabilitation could improve surgical outcomes, including LOS, PPC, and QoL, in patients undergoing cardiac, vascular, and lung cancer procedures (Drudi et al. 2019; Gravier et al. 2021).

Interestingly, this study's findings contradict findings from an RCT, which showed that prehabilitation had no effect on PPC and LOS in patients scheduled for non-small cell lung cancer resection (Ferreira et al. 2021). However, the same study concurred with this study's findings in showing the impact of prehabilitation and its association with better QoL, including physical functioning following lung cancer surgery (Ferreira et al. 2021). Nonetheless, it should be noted that this RCT had a short follow-up period, a weakness that may have limited the ability to demonstrate the long-term impact of prehabilitation on QoL (Ferreira et al. 2021).

**Table 4** Baseline characteristics of 114 patients included in the study after matching

| Characteristic | Pulmonary rehabilitation (PR) ($n=57$) | Non-intervention or control (NG) ($n=57$) |
|---|---|---|
| **Patient demographics** | | |
| Age | 70.48 (7.25) | 71.80 (7.36) |
| Gender (male) | 32 (56.7%) | 35 (61.7%) |
| **Smoking status** | | |
| Pack years | 32.67 (23.58) | 30.82 (24.63) |
| **Lung function** | | |
| %DLCO | 71.38 (18.70) | 73.19 (19.13) |
| PpoDLCO | 57.22 (15.41) | 57.76 (14.40) |
| **Surgical incision** | | |
| Open | 35 (60%) | 33 (56.7%) |
| VATS | 22 (40%) | 24 (43.3%) |
| **Surgery side** | | |
| Right | 16 (30%) | 14 (26.7%) |
| **Lung resection** | | |
| Wedge | 10 (17.5%) | 12 (21.1%) |
| Segmentectomy | 2 (3.5%) | 4 (7%) |
| Lobectomy | 41 (71.9%) | 37 (64.9%) |
| Bilobectomy | 3 (5.3%) | 4 (7%) |
| Sleeve | 0 | 0 |
| Pneumonectomy | 1 (1.8%) | 0 |
| **Comorbidity** | | |
| COPD | 25 (45%) | 19 (34.2%) |
| **Other measures** | | |
| MRC dyspnoea score > 2 | 3 (5.3%) | 3 (5.3%) |

Data are presented as mean (median), standard deviation (interquartile range), or numbers and percentages for categorical data

*DLCO* diffusing capacity for carbon monoxide, *PpoDLCO* predicted postoperative DLCO, *VATS* video-assisted thoracic surgery, *COPD* chronic obstructive pulmonary disease

In addition, this study's findings oppose those of a recent systemic review that examined prehabilitation for cancer patients and concluded that while some prehabilitation programs showed benefits, many did not significantly improve postoperative outcomes, including postoperative complications, LOS, and QoL compared to usual care (Meneses-Echavez et al. 2023). However, it should be mentioned that the results of this systemic review could be limited by the heterogeneous tools for outcome measurement for the study included in the review (Meneses-Echavez et al. 2023).

Our analyses faced certain limitations typical of observational studies; the results may not be applicable to other major surgeries, different populations, or various settings. Additionally, the uneven availability of PR across sites could introduce site-related bias, as the outcomes observed in patients receiving PR might not be generalisable to those from non-PR sites or to the broader patient population. This limited accessibility could also affect the representativeness of the study sample. Furthermore, the widespread implementation of PR faces multiple barriers, including resource constraints such as funding, infrastructure, and trained personnel, particularly in rural areas, as well as patient adherence challenges such as logistical difficulties, low motivation, and competing medical priorities (Spruit et al. 2013). Inadequate referral pathways, sociocultural factors, and the absence of long-term follow-up further limit accessibility and effectiveness, highlighting the need for targeted interventions to improve enrolment and adherence (Spruit et al. 2013).

While propensity score analysis (PSA) was employed to minimize confounding and improve the comparability of groups, the potential for unmeasured confounding

remains a limitation. Certain variables, such as patient motivation, informal caregiver support, or individual clinician practices, may not have been fully accounted for, which could influence both engagement in PR and postoperative outcomes. Despite the use of robust analytical methods, residual confounding cannot be entirely ruled out, and future studies with additional adjustments for such factors may provide further insights into the true impact of PR.

## Conclusion

In summary, engagement in "real-world" pulmonary rehabilitation before surgery appears to result in better patient and clinical outcomes after lung cancer surgery. However, due to the limitations and heterogeneity in study design and patient populations in the literature, the impact of pulmonary rehabilitation before major surgery could not be conclusively determined. Hence, we suggest the need for further rigorous methodological clinical trials to investigate the impact of rehabilitation on perioperative clinical outcomes compared to usual care in major surgeries. Additionally, the public health importance of integrating PR into standard perioperative care should be recognized, including the implementation of a tariff system to promote uptake and accessibility. Future research should also explore what the optimal PR program should be to maximize benefits for patients undergoing major surgery.

**Abbreviations**

| | |
|---|---|
| PR | Pulmonary rehabilitation |
| NG | Non-intervention or control group |
| LOS | Length of stay |
| PPC | Postoperative pulmonary complications |
| QoL | Quality of life |
| PSA | Propensity score analysis |
| COPD | Chronic obstructive pulmonary disease |
| MRC | Medical research council |
| FEV1 | Forced expiratory volume in 1 s |
| DLCO | Diffusing capacity for carbon monoxide |
| PpoFEV1 | Predicted postoperative forced expiratory volume in 1 s |
| PpoDLCO | Predicted postoperative diffusing capacity for carbon monoxide |
| VATS | Video-assisted thoracic surgery |
| MGS | Melbourne Group Scale |
| EORTC QLQ-C30 | European Organisation for Research and Treatment of Cancer Quality of Life Questionnaire (version C30) |
| EE | Effect estimate |
| SE | Standard error |
| CI | Confidence interval |
| BMI | Body mass index |
| VATS | Video-assisted thoracic surgery |

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13741-025-00510-2.

Supplementary Material 1.

**Authors' contributions**

Conception: BN and RM Data extraction & cleaning: MA, SK, SA, AO Analysis and interpretation of data: MA, RM Draft the work: MA Draft revision: BN, FG, JD, RM, MS Approval of the version: MA, BN, RM, MS, SK, SA, AO, FG, JD.

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**Data availability**

Yes, I have research data to declare. The data supporting the results of this manuscript is being saved on a secure server at Queen Elizabeth Hospital under the Data Protection Act (2018) requirements. Upon request through the corresponding author's email, access to data could be provided.

## Declarations

**Ethics approval and consent to participate**

The Institutional Review Board approved the study (REC number: 10/H1208/41).

**Consent for publication**

No individual personal data or images were included in the manuscript, and patient consent for publication is not applicable.

**Competing interests**

The authors declare no competing interests.

**Author details**

[1]College of Applied Medical Sciences, King Saud Bin Abdulaziz University for Health Sciences, Jeddah, Saudi Arabia. [2]Institution of Inflammation and Aging, University of Birmingham, Birmingham, UK. [3]King Abdullah International Medical Research Center, Jeddah, Saudi Arabia. [4]Wolfson Institute of Population Health, University of London, Mile End, Queen Mary, UK. [5]Thoracic Surgery, University Hospitals Birmingham NHS Foundation Trust, Birmingham, UK. [6]King Saud University, Riyadh, Saudi Arabia. [7]Warwick Clinical Trials Unit, University of Warwick, Coventry, UK. [8]School of Sport, Exercise and Rehabilitation Sciences, University of Birmingham, Birmingham, UK.

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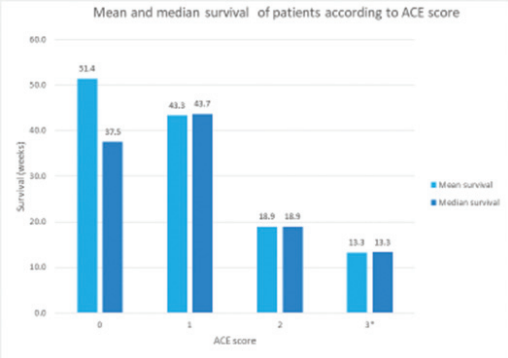
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# Appendix 8.2





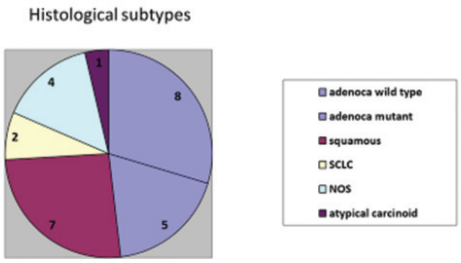




**Fig. 1** (abstract 183).

## 184 Outcomes of radical resection of advanced thymic malignancy

Billè, Andrea[1]; Bilkhu, Rajdeep[2]; Lucchese, Gianluca[2]; Smith, Daniel[1]; Ahmed, Shahreen[1]; Nonaka, Daisuke[1]; Karapanagiotou, Eleni[1]
[1]*Guy's Hospital, London, United Kingdom,* [2]*St Thomas' Hospital, London, United Kingdom*

**Objective:** Surgery for locally advanced and recurrent thymic tumours can significantly improve survival in the contest of multimodality treatment. The role of surgery is complete resection and may require resection of lung, diaphragm, pericardium or great vessels. We aim to assess outcomes of patients undergoing surgery for advanced thymoma and evaluate the outcome of extended resection.
**Methods:** Data for patients undergoing surgery for infiltrative and recurrent thymoma between 2015 and 2022 under a single surgical team was retrospectively reviewed. Treatment modalities before surgery, surgical approach and outcomes were analysed. Patients undergoing minimally invasive thymectomy were excluded.
**Results:** Thirty-five patients underwent surgery for advanced thymoma. Of these, 16 had recurrent thymoma. Two had thymic carcinoma, 12 had thymoma stage III and 21 stage IVa. Median age was 58 (range 29-78) and 16 patients (45.7%) were male. Nineteen underwent neoadjuvant chemotherapy then surgery. Surgical approach is shown in Table 1. Seven required extra-pleural pneumonectomy and 3 required lobectomy. SVC resection and reconstruction was performed in 4 patients and 3 required pericardial resection. Chest wall resection was required in 3 patients and 8 had diaphragmatic resection and reconstruction. No patients required cardiopulmonary bypass for instability or for resection of great vessels. There was 1 in-hospital mortality. One patient required a posterolateral thoracotomy to reposition pericardial mesh to correct cardiac herniation. Tracheostomy was performed in one patient. Complete resection was achieved in 25 (71.4%) patients. At a median follow up of 1.7 years (0.1 to 6.8 years), mortality was 2.9% and disease free survival was 60%.

| Approach | N=35 (%) |
|---|---|
| Posterolateral thoracotomy | 10 (28.6%) |
| Median sternotomy and posterolateral thoracotomy | 6 (17.1%) |
| Median sternotomy | 5 (14.3%) |
| Hemiclamshell thoracotomy | 3 (8.6%) |
| Hemiclamshell thoracotomy and posterolateral thoracotomy | 2 (5.7%) |
| Clamshell thoracotomy and sternotomy | 1 (2.9%) |
| Redo median sternotomy | 1 (2.9%) |
| ***Recurrence*** | |
| Minimally invasive (video assisted thoracoscopic or robotic resection), | 6 (17.1%) |
| Sternectomy | 1 (2.9%) |

**Table 1** (abstract 184). Surgical approach.

**Conclusion:** Surgery for invasive and recurrent thymoma is feasible and safe, even when extensive resection is required. Complete macroscopic resection can be achieved in most cases. A combination of surgical approaches may be required to achieve a complete resection with appropriate reconstruction of great vessels, diaphragm and/or pericardium.
**Disclosure:** No significant relationships.

## 185 Successful agile co-redesign of a personalised digital prehabilitation programme: Fit4Surgery app (F4S)

Alzahrani, Matar[1,2]; Naidu, Babu[2,1]; Kadiri, Salma[2]; Duda, Joan[1]; Fenton, Sally[1]; Stonehewer, Louisa[2]
[1]*University of Birmingham, Birmingham, United Kingdom,* [2]*University Hospitals Birmingham, Birmingham, United Kingdom*

Using a 'double-diamond' [1] codesign method with health care professionals (HCPs) and patients led to improvements in F4S, resulting in a product that is acceptable to patients and ready for a large clinical trial.
**Methods:** To develop the F4S App's current version, we:
1. Formed a core steering group.
2. Defined refinements through co-design workshops. (patients, carers and HCPs)
3. Embedding behaviours change theory e.g. goal setting [2]
4. Made and tested incremental amendments to F4S in a series of 'sprints' [3]
5. Performed a Qualitative Usability test of the patients and clinical interface functions
6. Reviewed of impact following implementation.

**Results:** Incorporated changes can be summarised:
1. Outcome measures such as sit to stand test, EQ5D, and HADS questionnaires.
2. Tailored health information videos based on symptoms.
3. Enhancement of exercise programmes based on Macmillan prehabiliation principles with exercise rules for guiding progression [4].
4. Tailored nutritional intervention based on the PG-SGA questionnaire.
5. Tracking other physical activates such as cycling and gardening.

The app was highly acceptable to patients and HCPs (Fig. 1).

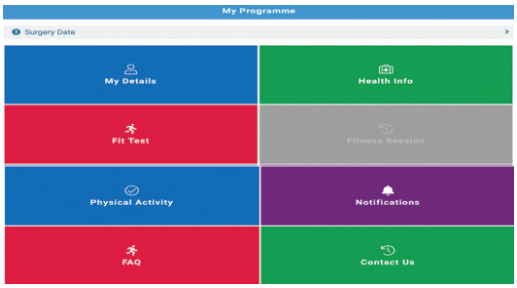



**Fig. 1** (abstract 185).

More information can be found in the following link (Fit4surgery.uk) or by scanning the QR-code below:

**Conclusion:** The double-diamond approach was successful in redesign the digital prehabiliation app. The F4S team has been awarded an NIHR grant of 1.7 million to conduct multi-centre study.

**References:**

[1] West J, Fusari G, Raby E, et al. (eds). Developing the Double Diamond Process for Implementation. International Conference on Design4Health; 2017; Melbourne.
[2] Ng JY, Ntoumanis T-N, Deci R, Duda W. Self-determination theory applied to health contexts: A meta-analysis. Perspectives on Psychological Science 2012;7(4):325-40.
[3] Edeki C. Agile Software Development Methodology. European Journal of Mathematics and Computer Science 2015;2(1).
[4] Woodard, Mahajan, Allen. Principles and guidance for prehabilitation within the management and support of people with cancer (1st ed.). Macmillan Cancer Support. 2020.

**Disclosure:** No significant relationships.

## 186 Surgery versus stereotactic ablative radiation therapy for stage I lung cancer: a real-world series

Josephides, Eleni[1,2]; Farinelli, Eleonora[3]; Fabbri, Giulia[4]; Volpi, Sara[4]; Routledge, Tom[4]; Karapanagiotou, Eleni[4]; Ahmad, Shahreen[4]; Smith, Daniel[4]; Billè, Andrea[4]
[1]*Guy's Hospital, London, United Kingdom,* [2]*King's College, London, United Kingdom,* [3]*University of Bologna (UNIBO), Bologna, Italy,* [4]*Guy's and St Thomas' Hospitals, London, United Kingdom*

**Introduction:** For patients with Stage I non-small cell lung cancer (NSCLC), standard of care is lobectomy for standard-risk medically operable patients or sub-lobar resection for high-risk patients. Stereotactic ablative radiotherapy (SABR) is standard for inoperable patients but its role in operable patients is unclear. Prospective randomised trials comparing surgery and SABR in early-stage NSCLC have been unable to accrue. Randomising to these treatments is challenging, so we compared outcomes of patients undergoing either treatment using real-world data.

**Methods:** We reviewed data from patients with clinical stage I NSCLC treated with surgery or SABR between 2015-2021 within a single UK centre. Overall survival (OS) and progression free survival (PFS) were compared with Kaplan-Meier method and Cox proportional hazards model.

**Results:** 894 patients with stage I NSCLC treated with surgery (n=624) or SABR (n=270) between 2015-2021 were included. Median age was 72 (range 32-94) in the surgery group and 74 (45-93) in the SABR group. 155 (24.8%) patients died in the surgery group (8 within 30 days of operation). 152 (56.3%) died in the SABR group (1 within 30 days). Recurrence occurred in 68 (10.9%) patients in the surgery group and 39 (14.4%) in the SABR group. Recurrences were locoregional in 33 (48.5%) and 25 (64.1%) of the surgery and SABR groups, respectively. Surgery was associated with superior OS [hazard ratios (HR) 0.40 (95% confidence interval (CI) 0.32-0.50)] compared with SABR but there was no significant difference in PFS between the groups [HR 0.70 (95% CI 0.49-1.05)].

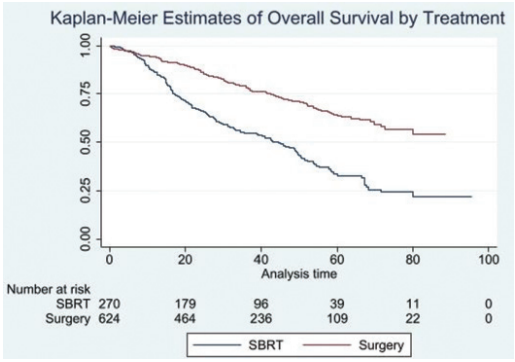



**Fig. 1** (abstract 186).

**Conclusion:** This Real-World series revealed superior OS for patients undergoing surgery compared to SABR in stage I NSCLC. There was no difference in PFS between the groups. OS outcomes may be influenced by comorbid factors which require further evaluation. Further prospective studies are awaited to clarify the efficacy of both treatments in this population.

**Disclosure:** No significant relationships.

## 187 Impact of prehabilitation on pre-operative function, post-operative complications and length of stay in resectable lung cancers

Finch, Alice[1]; Assadourian, Anthony[1]; Grant, Duncan[1]; Redman, Joel[1]; Jalali, Sahra[1]; Ricketts, William[1]
[1]*Barts Health NHS Trust, London, United Kingdom*

**Introduction:** Prehabilitation has been shown to improve pre-operative functional capacity and reduce post-operative complications (POC) and length of stay (LOS). Lung cancer patients often have extensive smoking history, multiple co-morbidities, poor exercise tolerance and low performance status thus increasing their risk of post-operative morbidity and mortality. Barts Health NHS Trust has recently expanded its prehabilitation service for surgical lung cancer patients with the aim of reducing POC and LOS.

## Appendix 8.3

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# User-centered design of an integrated, hybrid personalised digital prehabilitation intervention in the lung volume reduction surgical pathway ('Fit4Surgery'): A case study of the double diamond method

Matar Alzahrani | Salma Kadiri | Joan Duda Show More

European Respiratory Journal 2024 64(suppl 68): OA2874;
DOI: https://doi.org/10.1183/13993003.congress-2024.OA2874




This article appears in:

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Vol 64 Issue suppl 68

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## Abstract

Lung Volume Reduction Surgery (LVRS) requires pulmonary rehabilitation(PR). COVID disrupted rehabilitation services, and several UK hospitals have 2-year PR waiting lists. The

LVRS waiting list is long, and even if patients went through PR, they might finish before surgery and lose rehabilitation benefits. A digital PR initiative could improve PR access and enable patients to continue their programme till surgery. The double diamond (DD) methodology (figure 1) will be used to alter fit4surgery (F4S) software for COPD patients to improve LVRS eligibility and surgery success.

**Methods:** The DD process involved 'discovering' various insights into the problem, 'identifying' areas to focus on, 'creating' broad prospective solutions, and choosing 'deliverable' ideas to implement. These were achieved through workshops involving patient groups (n=5), healthcare professionals (HCP) (n=9), and the main study team of academic researchers and software designers (n=8).

**Results:** Incorporated summary changes into the F4S LVRS: 1- Sit-to-stand test, EQ5D, HADS, and CAT questionnaires. 2- Symptom-specific health videos. 3- Improving exercise programmes with progression guidelines. 4- PG-SGA questionnaire-based nutritional intervention. 5- Tracking other physical activities such as cycling and gardening. Patients and HCPs liked the app (Figure 2); Fit4surgery.uk has further information.

**Conclusion:** Fit4Surgery, an acceptable app, was developed using DD user-centered design to complement face-to-face prehabilitation in the LVRS pathway. Fit4Surgery LVRS feasibility study results will be presented during the meeting.

**Footnotes**

Cite this article as *Eur Respir J* 2024; 64: Suppl. 68, OA2874

This article was presented at the 2024 ERS Congress, in session “Innovative perspectives on cellular mechanisms in lung diseases”.

This is an ERS International Congress abstract. No full-text version is available. Further material to accompany this abstract may be available at www.ers-education.org (ERS member access only).

Focus Previous Next

**We recommend**

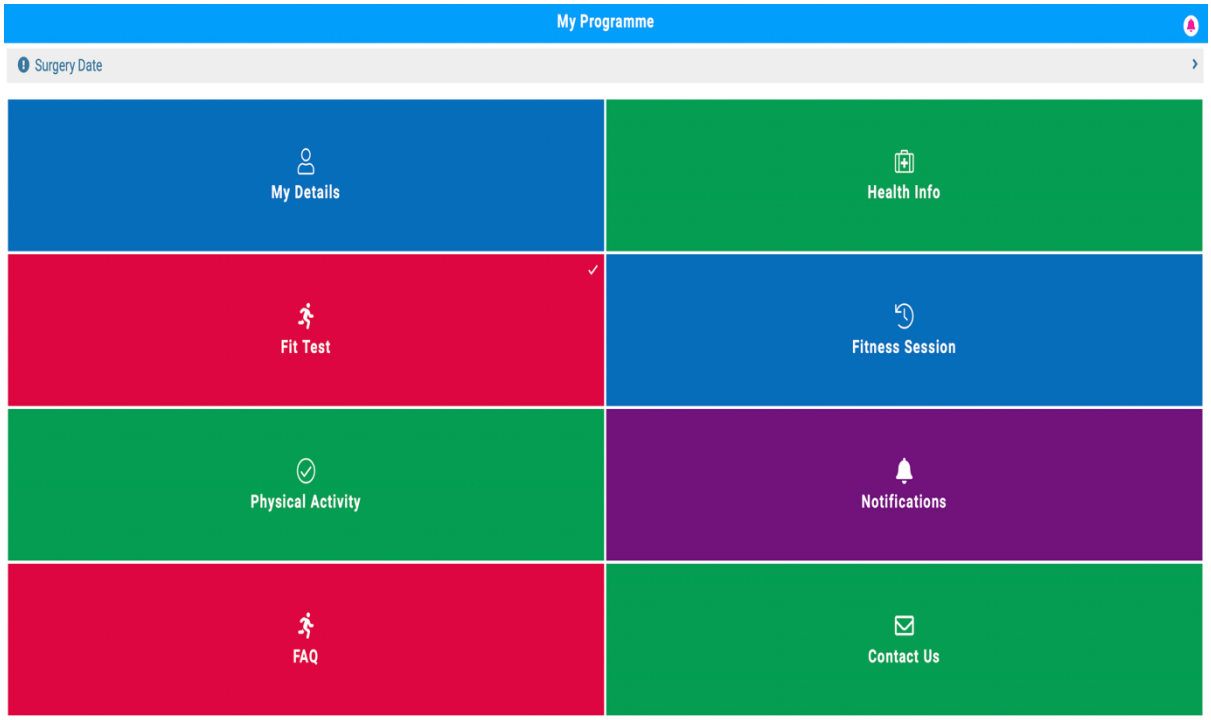
Emerging Pulmonary Rehabilitation (PR) in the digital world
Samantha Pilsworth, European Respiratory Journal, 2021

Digital pulmonary rehabilitation (PR)
S Pilsworth, European Respiratory Journal, 2022

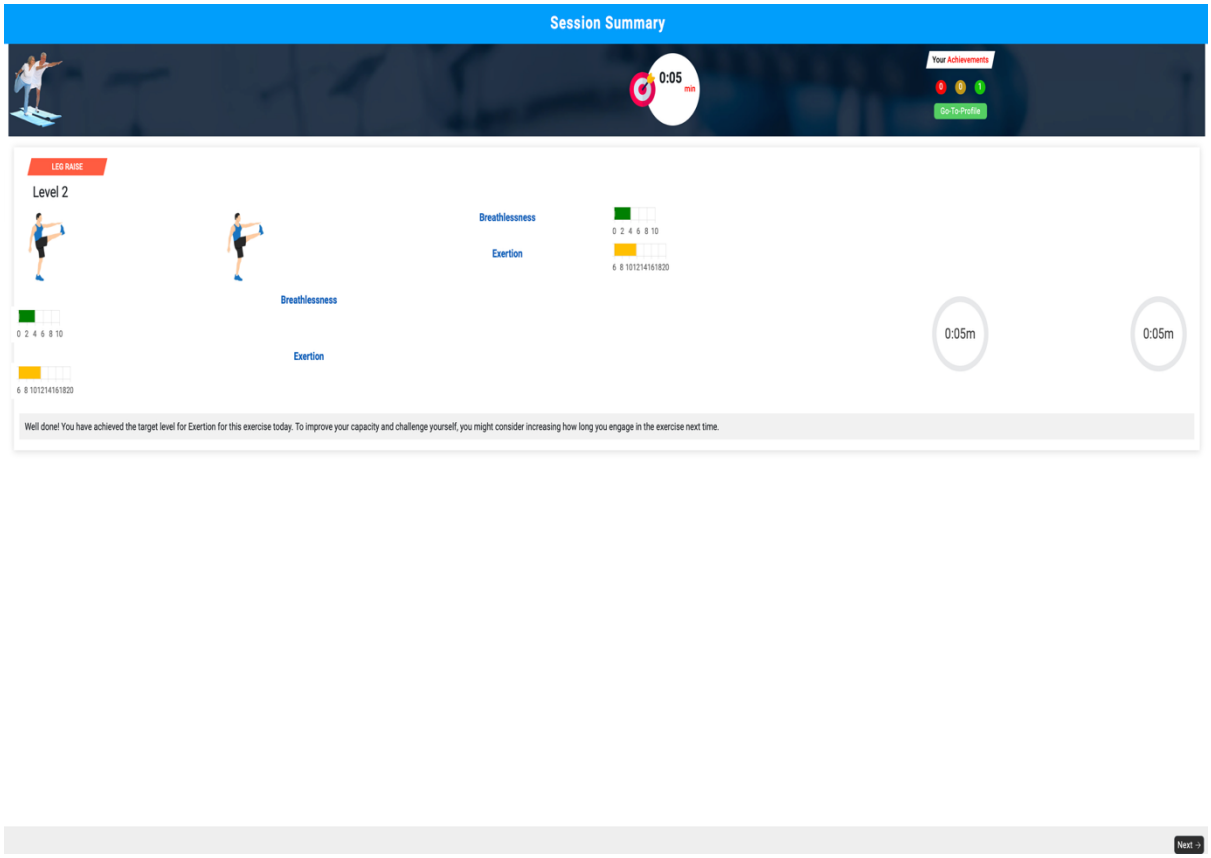
Feasibility and Design Factors for Home-Based Pulmonary Rehabilitation of Patients With Chronic Obstructive Pulmonary Disease and Chronic Lung Diseases Based on...
Shih-Ying Chien, JMIR Human Factors, 2023

## Appendix 8.4

### F4S main screen



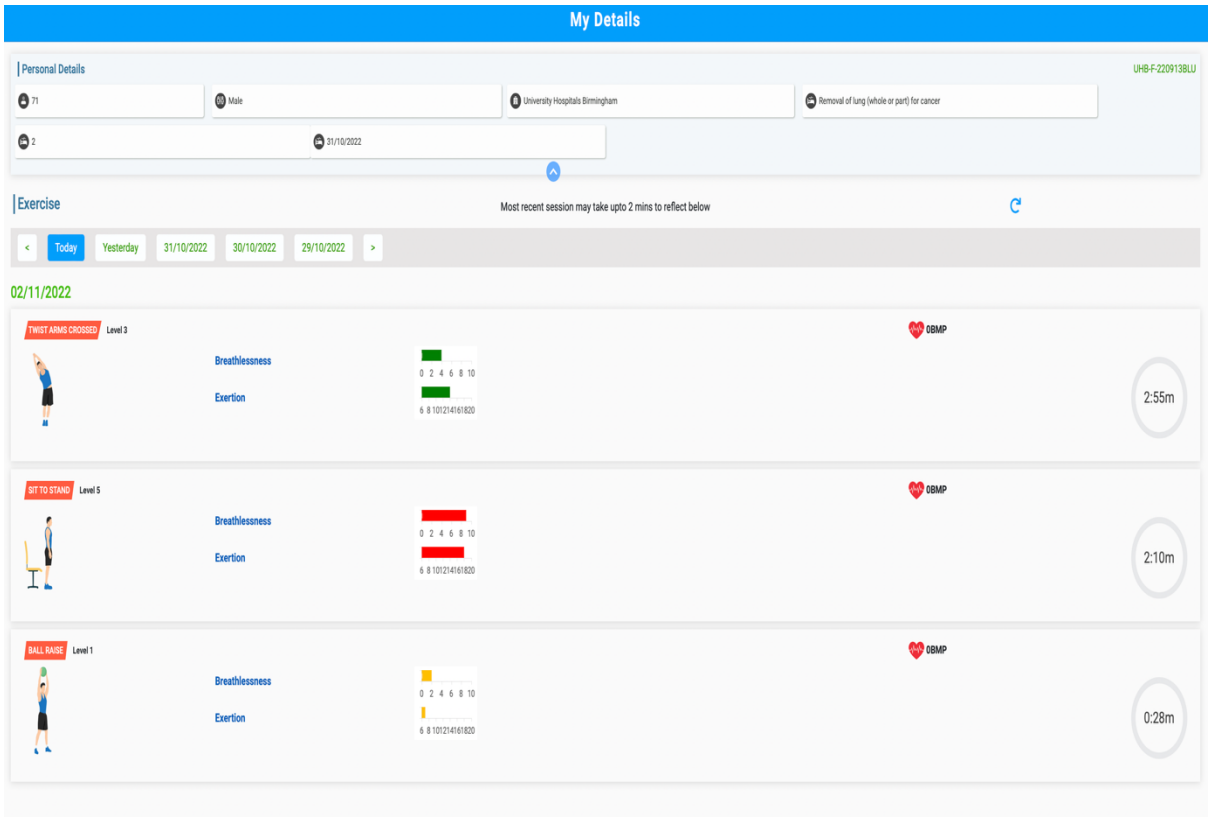

### Session summary



## Physical activity section




## My details section



**Appendix 8.5**

**RE: EQ5D screen shots**

D

dwarkasing@euroq... Tuesday, 22 November 2022...

To: Matar Alzahrani (PhD Inflamm + Ageing FT (A300))

Cc: Babu Naidu (Inflammation and Ageing)

Dear Babu,

I confirm safe receipt of the FE letter.

I will release the version through the portal.

Best regards,

**Anita Dwarkasing**
Legal Counsel
**EuroQol Research Foundation**

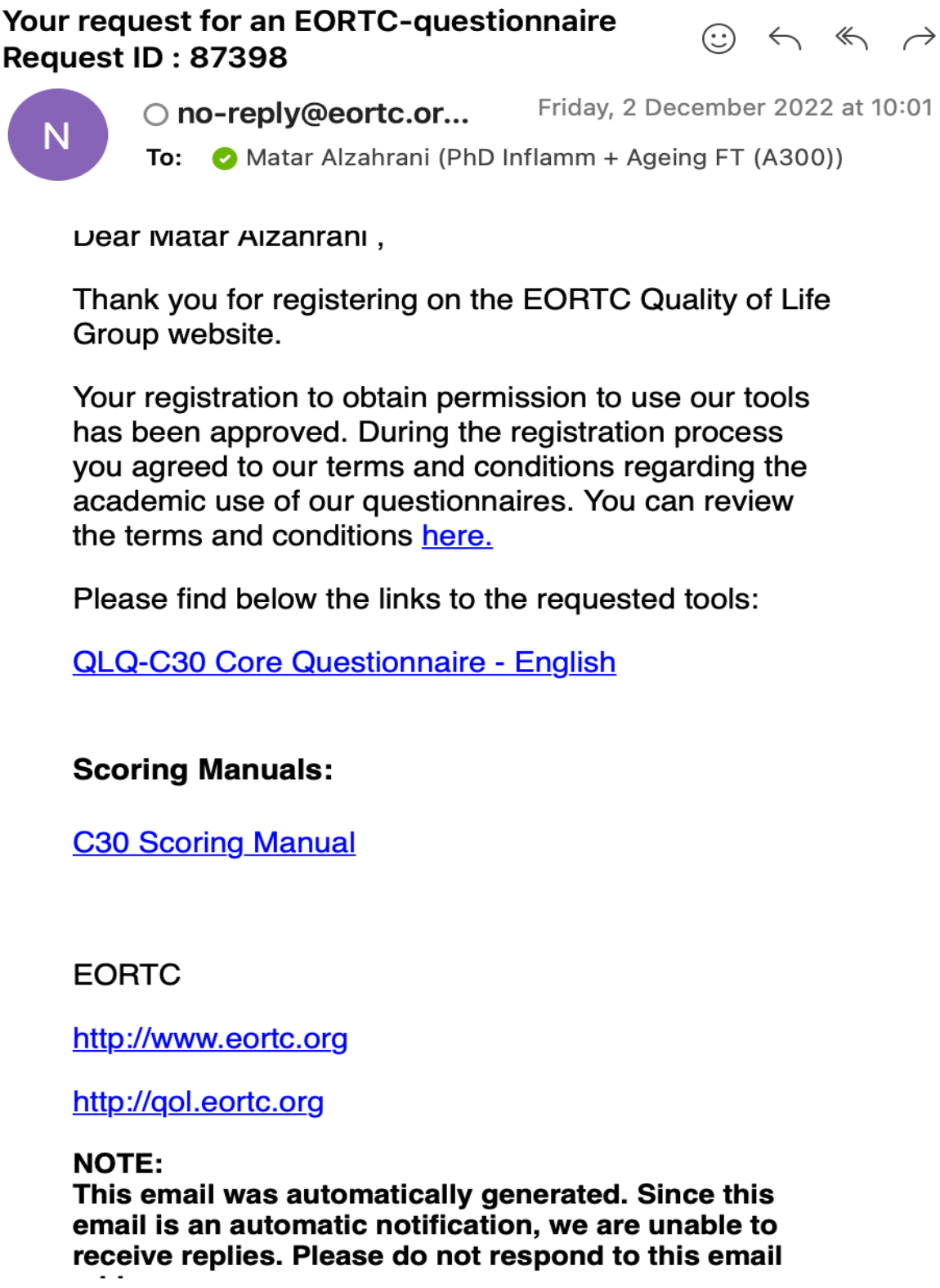
- **Upcoming OOO: 26DEC 22-10 JAN23**

**A reply to e-mails can be expected within approximately 5 business days.**

EQ-5D

T +31882026892 | E dwarkasing@euroqol.org | www.euroqol.org
Marten Meesweg 107 | 3068 AV Rotterdam The Netherlands
EQ-5D on Twitter

**Appendix 8.6**



**Your request for an EORTC-questionnaire**
**Request ID : 87398**

N

no-reply@eortc.or... Friday, 2 December 2022 at 10:01

**To:** Matar Alzahrani (PhD Inflamm + Ageing FT (A300))

Dear Matar Alzahrani ,

Thank you for registering on the EORTC Quality of Life Group website.

Your registration to obtain permission to use our tools has been approved. During the registration process you agreed to our terms and conditions regarding the academic use of our questionnaires. You can review the terms and conditions here.

Please find below the links to the requested tools:

QLQ-C30 Core Questionnaire - English

**Scoring Manuals:**

C30 Scoring Manual

EORTC

http://www.eortc.org

http://qol.eortc.org

**NOTE:**
**This email was automatically generated. Since this email is an automatic notification, we are unable to receive replies. Please do not respond to this email**

## Appendix 8.7

**Table 1: the distribution of the other outcome measures**

| Characteristic (n=38) | Mean (sd) |
|---|---|
| **EQ5D5L** | |
| **Baseline** | 86 (16.4) |
| **Pre-surgery** | 100 (0); Unknown (n=29) |
| **Post-surgery** | 100 (0); Unknown (n=29) |
| **HADS** | |
| **Baseline** | 1 (0) |
| **Pre-surgery** | 1 (0); Unknown (n=29) |
| **Post-surgery** | 1 (0); Unknown (n=29) |
| **Pain scale** | |
| **Baseline** | 1.13 (2.09) |
| **Pre-surgery** | 0 (0); Unknown (n=29) |
| **Post-surgery** | 0.22 (0.67); Unknown (n=29) |
| **PGSGA** | |
| **Baseline** | 1.16 (0.43) |
| **Pre-surgery** | 1.2 (0.42); Unknown (n=28) |
| **Post-surgery** | 1 (0); Unknown (n=28) |

Data are presented as mean (median), standard deviation (interquartile range)

## Appendix 8.8

**Table 2: the distribution of the other outcome measures**

| Characteristic (n=22) | Mean (sd) |
|---|---|
| **EQ5D5L** | |
| **Baseline** | 63.2 (17.4) |
| **Pre-surgery** | 1 (0); Unknown (n=21) |
| **Post-surgery** | 55 (0); Unknown (n=21) |
| **HADS** | |
| **Baseline** | 1 (0); Unknown (n=1) |
| **Pre-surgery** | 1 (0); Unknown (n=2) |
| **Post-surgery** | 1 (0); Unknown (n=21) |
| **Pain scale** | |
| **Baseline** | 2.14 (3.03) |
| **Pre-surgery** | 2.5 (3.2); Unknown (n=4) |
| **Post-surgery** | 7 (0); Unknown (n=21) |
| **PGSGA** | |
| **Baseline** | 1.38 (0.66) |
| **Pre-surgery** | 1.36 (0.65); Unknown (n=2) |
| **Post-surgery** | 1 (0); Unknown (n=21) |

Data are presented as mean (median), standard deviation (interquartile range)

# Appendix 8.9: F4S Interview topic guide

**F4S Interview topic guide**

**This topic guide should be according to F4S protocol:**

- with reference to the literature on the use of pulmonary rehabilitation apps, apps used for rehabilitation for other long-term conditions, and previous experience of running the F4S feasibility study.
- The topic guide will also be informed by PPI groups and the PPI co-applicant, who is a lung cancer patient and also a public health researcher with extensive experience in the qualitative methodology.
- The topic guide will include core questions which will be asked of all patients covering the following topics: acceptability and compliance with F4S, including details of how and when F4S was used and not used; the influence of carers and family on exercise motivation; and barriers and facilitators to F4S use including how the quality of recovery scores captured their experience of surgery.
- Interviewees will also be encouraged, through the use of open-ended questioning, to reflect on the overall usefulness of F4S for themselves and other patients with similar conditions.
- Four pilot interviews will be undertaken to test and refine the topic guide.

**Introduction:**

- Thank you for seeing me today and offering to take part in this study.
- I would like first to outline the study so that you are able to decide whether you wish to proceed further (recap information sheet).
- Sign consent form × 2 (one for participant and information sheet, one for interviewer). I have a list of topics that I want to address.
- Feel free to ask questions at any stage during the interview.
- The interview will be audio-recorded and I might make a few notes in case I want to come back to something later.

**Topics/questions:**

**1- The Fit4surgery study:**

- I'd like to talk to you about the F4S programme running at hospital X.
- Have you previously had experience with a similar programme support?
- Some patients declined to take part in the F4S programme. What, if anything, would have to change for you to feel it is more worthwhile for patients to take up the offer of F4S programme before and after thoracic surgery? (2 Qs before and after surgery)
- (Prompts: What would have to change about the study? The location? The technological aspect of the support?)
- What was your overall experience of F4S programme?
- Did you find the F4S programme helpful? Why/why not?
- Did you find the training for F4S programme helpful? Why/ why not?

**2- Acceptability and compliance with F4S: (I'd now like to ask about your experience of the 'Fit 4 Surgery App' in particular:**

- Can you remember your first impression of the app? What did you think of it?
- After using the app, describe your experience in terms of the app usability?
- Was the app easy to use? Why/why not?
- Was the language used in the app appropriate? Why/why not?
- Was the app's design appealing to you? Why/why not?
- What motivated you to use the app?
- What was the impact of the app on your levels of fitness?
- And how do you describe your level of fitness before using the app?
- How do you describe your level of fitness after using the app?

**3- The influence of carers and family on exercise motivation:**

- How effective was staff communication and written communication on using the app?
- Were your family involved in you using the app?
- Were there any other factors that motivated you to use the app?

**4- Barriers and facilitators to F4S use:**

- What aspects of the app were particularly useful for you?
- Which parts of the app did you not find very useful?

**5- Recommendations for how its use could be improved:**

- Is there anything we could have added to the app that you would have found helpful?
- Based on the experience you had with the app, would you recommend it to other healthcare professionals delivering prehabilitation support to patients? Why/why not?