Randomised Controlled Trial

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Efficacy of a smartphone application assisting home-based rehabilitation and symptom management for patients with lung cancer undergoing video-assisted thoracoscopic lobectomy: a prospective, single-blinded, randomised control trial (POPPER study)

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Background: Video-assisted thoracoscopic (VATS) lobectomy can affect patients' pulmonary function and quality of life significantly. No optimal protocol combining patient-reported outcome-based symptom management and postdischarge rehabilitation programme has yet been established. This study aimed to assess the efficacy of a novel smartphone app designed for home-based symptom management and rehabilitation.

Methods: The app was developed based on three modules: a symptom reporting system with alerts, aerobic and respiratory training exercises, and educational material. Four core symptoms were selected based on a questionnaire survey of 201 patients and three rounds of Delphi voting by 30 experts. The authors screened 265 patients and randomly assigned 136 equally to the app group and usual care group. The primary outcome was pulmonary function recovery at 30 days postoperatively. Secondary outcomes included symptom burden and interference with daily living (both rated using the MD Anderson Symptom Inventory for Lung Cancer), aerobic exercise intensity, emergency department visits, app-related safety, and satisfaction with the app.

Findings: Of the 136 participants, 56.6% were women and their mean age was 61 years. The pulmonary function recovery ratio 1 month after surgery in the app group was significantly higher than that in the usual care group (79.32 vs. 75.73%; $P = 0.040$). The app group also recorded significantly lower symptom burden and interference with daily living scores and higher aerobic exercise intensity after surgery than the usual care group. Thirty-two alerts were triggered in the app group. The highest pulmonary function recovery ratio and aerobic exercise intensity were recorded in those patients who triggered alerts in both groups.

Interpretation: Using a smartphone app is an effective approach to accelerate home-based rehabilitation after VATS lobectomy. The symptom alert mechanism of this app could optimise recovery outcomes, possibly driven by patients' increased self-awareness.

Keywords: postoperative rehabilitation, pulmonary function, smartphone app, symptoms, VATS lobectomy

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Introduction

Lung cancer is the leading cause of cancer-related deaths worldwide. With the aid of low-dose computed tomography screening, more patients can be identified at the early stage[1,2], for which surgery remains the only curative treatment modality[3]. However, they usually undergo considerable functional deterioration and severe quality of life (QoL) impairment during the first few months immediately after pulmonary resection, even when accomplished via minimally invasive surgery[4–8]. Therefore, restoring function and physical activity during this key time window remains challenging for the thoracic service community.

The enhanced recovery after surgery (ERAS) model is widely adopted in current clinical practice, along with advancements in minimally invasive surgical techniques [e.g. video-assisted thoracoscopy (VATS)] to achieve better clinical outcomes (shorter length of stay and reduced postsurgery complications)[9–11]. However, shortening hospital stays and revisits to care providers after surgery based on the ERAS model may not guarantee a uniform recovery process. After discharge, the primary goal for patients is to participate in a pulmonary rehabilitation (PR) procedure, which is essential to improving pulmonary function within a given period[12,13], and manage postoperative patient-reported outcome (PRO)-based symptoms. However, in the real-world, heterogeneity in community services and patient compliance in recovery may affect functional optimisation at the physical and psychological levels.

Several major factors may discourage rehabilitation. First, patients' lack of rehabilitation knowledge or awareness will lower the true efficacy of functional restoration. Second, systematic guidance on exercise planning or real-time assistance for symptom evaluation and management may be unavailable for discharged patients. Third, patients tend to be unwilling to undergo early mobilisation owing to functional decline and symptomatic disturbances[14,15].

With the rapid development of digital technology over the past decade, smartphone-based interventions have demonstrated the potential to improve healthcare delivery in the postdischarge period[16–18]. Studies have reported the implementation of mobile apps for the postoperative management of patients with lung cancer, focusing on education, and rehabilitation programmes after discharge, which effectively recorded postoperative PROs and improved well-being and QoL[19,20]. The latest evidence suggests that PRO-based symptom management via mobile device platforms improves surgical outcomes with a lower symptom burden and fewer complications[21]. However, evidence is lacking about how mobile health may promote functional rehabilitation after lung cancer surgery, such as pulmonary function recovery. In addition, whether functional rehabilitation could be improved by symptom management via a single digital platform is unknown.

As an optimal protocol combining PRO-based symptom management and rehabilitation after discharging post-thoracic surgery has not been established, we hypothesised that a smartphone app customised for PRO-based symptom management with symptom alerts, training exercises, and educational material may help improve the pulmonary functional rehabilitation and reduce the symptom burden for patients undergoing lung resection. In this POPPER study, we conducted a prospective randomised controlled trial (RCT) among patients with lung cancer undergoing VATS lobectomy and evaluated the efficacy of a smartphone rehabilitation app compared with usual care after discharge.

HIGHLIGHTS

- This study evaluated the efficacy of a smartphone rehabilitation app among lung cancer patients after lobectomy. The app integrated three major functional modules: PROs with real-time alerts, exercise training, and educational reading material.
- One hundred thirty-six participants were enroled and analysed in this study. Compared with usual care group, the app group had significantly higher FEV1% pred recovery ratio in the first month after surgery.
- The app group also recorded significantly less symptom burden, less life interference, and a higher Borg score for aerobic exercise after surgery compared with the control group.
- Using a smartphone app may serve to help patients accelerate home-based rehabilitation after video-assisted thoracoscopy lobectomy.

Methods

Study design and participants

POPPER was a single-blind RCT conducted at Peking University Cancer Hospital. The study protocol was approved by the institutional review board of the hospital (number: 2021KT92) and registered on the Chinese Clinical Trial Registry website (identifier: ChiCTR2100049674). The trial adhered to CONSORT guidelines[22]. All patients provided written informed consent before enrolment.

Eligible patients were: (1) aged 18–75 years and diagnosed with clinical stage I–II nonsmall cell lung cancer, according to the eighth edition of the TNM Classification of Malignant Tumours, and scheduled to undergo thoracoscopic VATS lobectomy; (2) able to complete follow-up and a spirometry test; and (3) willing to complete the electronic questionnaire and communicate with the investigators.

Patients were excluded if they met any of the following criteria: (1) previously received neoadjuvant therapy; (2) unable to perform the spirometry test for personal reasons; (3) had a locomotor system issue that prevented them from completing the PR exercise; or (4) had simultaneous or metachronous diseases that the investigator considered ineligible for the study.

Randomisation and masking

When admitted to the hospital, patients who met all the inclusion and exclusion criteria were randomly assigned (1:1) to an app group or a usual care group (control group). Considering the necessity of introducing detailed app instructions to patients in the app group, clinicians, and nurses delivering the interventions were not masked. During the entire study process, all participants, outcome analysers, statisticians, and staff who performed the spirometry test and collected data were blinded to the group allocation.

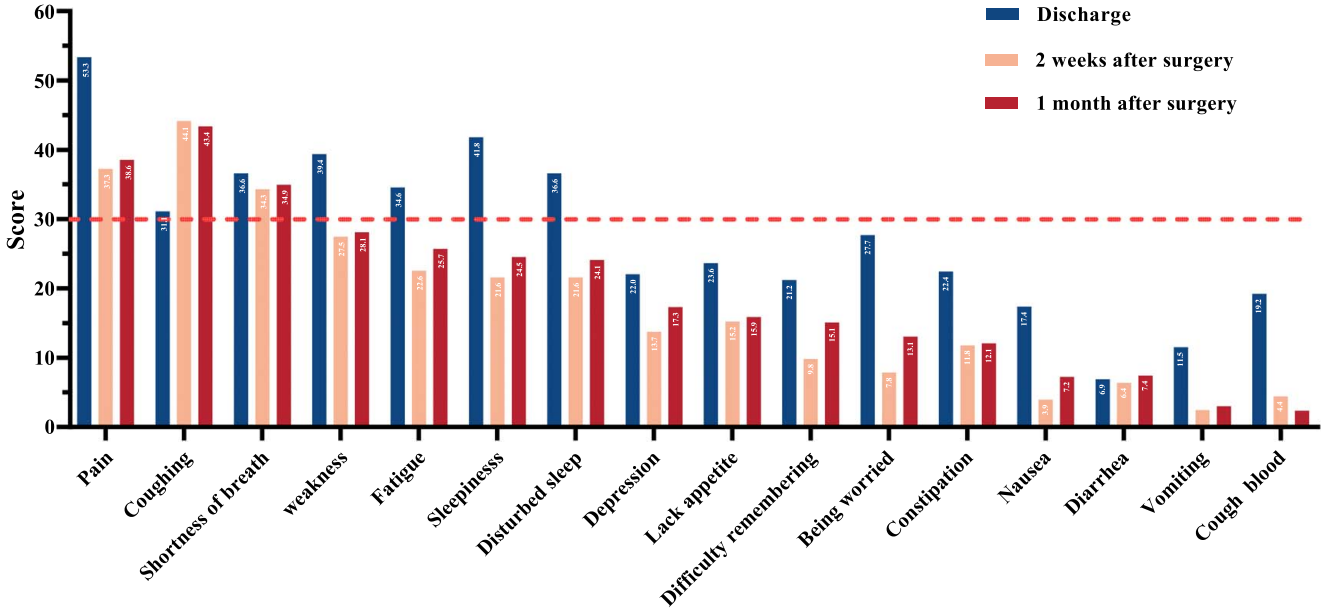

Figure 1. Mean scores of each symptom at the different time points after surgery.

Components of the app

Symptom reporting component with real-time alerts

Questionnaire survey for selecting symptoms

After lung surgery, the specific symptoms that should be recorded for home-based monitoring remain unclear. Therefore, to design the app components, we began with a questionnaire survey to determine symptoms that need to be reported after lung cancer surgery. Data were extracted from a prospective study conducted to observe postoperative pulmonary function recovery after lung cancer resection; QoL data were supplements to this study (ChiCTR**). We collected data from 201 patients with lung cancer who underwent VATS lobectomy between January and July 2021 at our hospital and completed a questionnaire based on the European Organisation for Research and Treatment of Cancer (EORTC) QLQ-C30 and LC13[23] to investigate patients' symptoms within 30 days of surgery. In the questionnaire survey, each symptom was scored on a four-point categorical scale. To standardise the analysis, these scores were linearly transformed to a scale ranging from 0 to 100, with higher scores indicating worse symptoms[24]. A 10-point change or more from the baseline was considered clinically significant[25]. Those with a mean score ≥ 30 were deemed as having the most severe symptoms[26].

Based on the results, the most severe symptoms after discharge (2 weeks and 1 month after surgery) were pain, coughing, and shortness of breath, which were considered the core symptoms for reporting in this app component (Fig. 1 and Supplementary Tables 1–4, Supplemental Digital Content 1, http://links.lww.com/JS9/C853). To confirm this result, we used K-means consensus clustering analysis to select symptoms. These symptoms were robustly segregated into three clusters, in which pain, coughing, and shortness of breath were grouped in the same cluster at 2 weeks and 1 month after surgery (Supplementary Figure 1, Supplemental Digital Content 1, http://links.lww.com/JS9/C853).

Delphi voting for selecting the core symptoms

As the EORTC QLQ-C30 and LC13 were not designed for lung cancer surgery, surgery-specific symptoms may not have been included in the questionnaire. To solve this problem, we used Delphi expert voting to select further core symptoms observed after VATS lobectomy. Twenty experienced thoracic surgeons and 10 registered nurses from 10 high-volume medical centres in Beijing, who had more than ten years of professional experience and held the titles of chief physician or associate chief physician, participated in three rounds of voting to select the most important symptoms from the QLQ-C30 and LC13 questionnaires. The participants in each voting round could add new symptom items based on their clinical practice experience.

The three most severe symptoms from the questionnaire survey (pain, coughing, and shortness of breath) also had the highest ratings in the results of the three rounds of voting. In addition, postoperative fever (new item) and coughing blood were regarded as high-priority surgically related symptoms (Supplementary Table 5, Supplemental Digital Content 1, http://links.lww.com/JS9/C853). For convenience, we combined coughing blood with coughing as one item with different alert thresholds (Supplementary Table 6). Finally, four symptoms were determined for the reporting component: pain, coughing, shortness of breath, and fever. The details of the process and results of selecting the core symptoms are listed in the Supplementary Material (Supplemental Digital Content 1, http://links.lww.com/JS9/C853).

Symptom alert

In the app module, two types of symptom alerts (yellow and red) could be triggered when patients answered questions about these four symptoms if their extent was moderate or severe according to CTCAE 5.0 grading (Supplementary Table 6, Supplemental Digital Content 1, http://links.lww.com/JS9/C853). The medical team received alert notifications automatically through this app

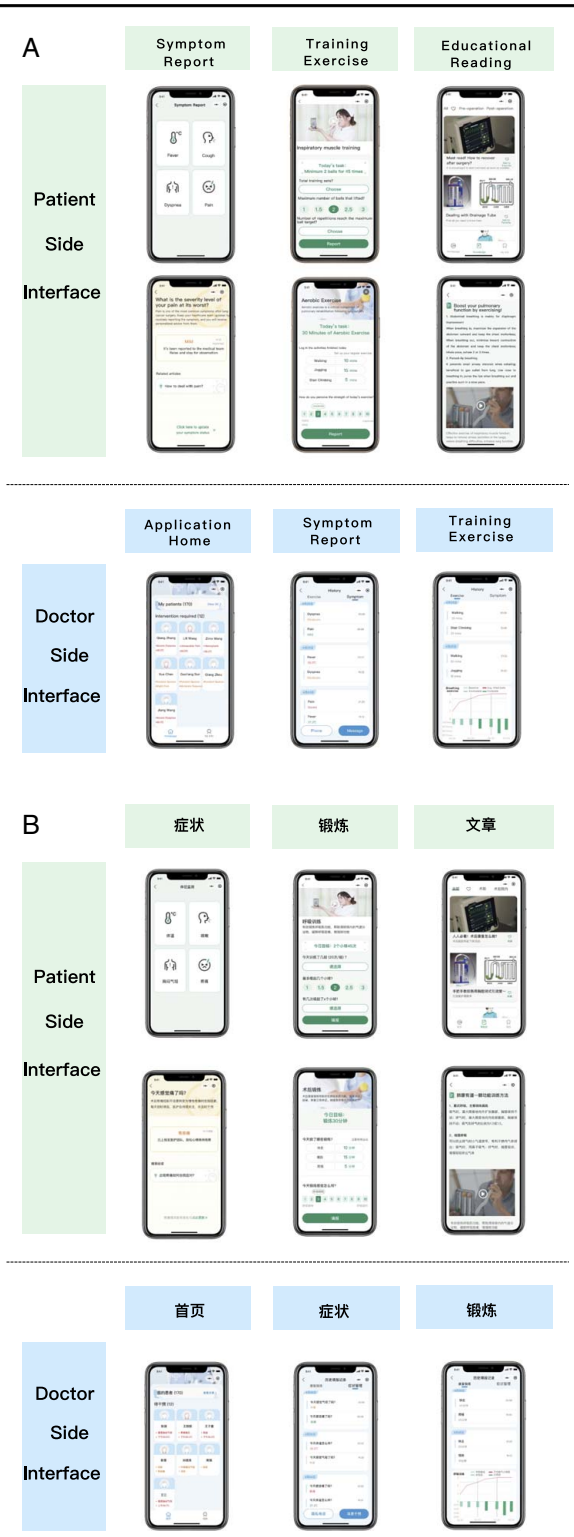

Figure 2. Screenshots of the app component functions. (A) English version; (B) Chinese version.

on a smartphone and connected with patients directly via the app. Telephonic intervention was completed within 4 h of a yellow alert being triggered, whereas immediate intervention was provided when a red alert was received for such symptoms as severe dyspnoea and high fever.

Training exercise component

Respiratory exercise

Respiratory exercise was performed using abdominal breathing methods with deep inspiration in a sitting position, holding the breath for 5 s, then exhaling slowly, and repeating the process three to five times/min. The incentive spirometer was a tri-balls device (UTRI4311, GaleMed Co., Ltd) (Supplementary Figure 2, Supplemental Digital Content 1, http://links.lww.com/JS9/C853) comprising an inhaling tube and three balls with different weights. Every time patients inhaled through the tube, the balls rose according to the volume of inspiration; thus, they tried their best to raise as many of the balls as possible in one inhaling process. A maximal inspiratory pressure (PI max) was recorded as one count. The app module provided videos showing the instructions and examples of the exercise methods and set up a training plan for patients as a daily task reminder.

Aerobic exercise

As the first option for aerobic exercise, patients with sufficient physical capacity were encouraged to climb stairs[27]. Other exercises, such as walking outdoors, jogging, cycling, and even traditional Chinese exercises, were also allowed[28,29]. Given that patients had different ages, education levels, comorbidities, and physical conditions after surgery, the type of aerobic exercise was based on their preferences. This component also set up a daily task and reminded patients to complete it as well as recorded data for each exercise type and duration.

Educational material component

The app provided reading material on four aspects: (1) general knowledge of lung cancer, including pathogenesis, symptoms, and treatment; (2) lung cancer surgery and perioperative matters requiring attention; (3) the importance and methods of post-operative rehabilitation; and (4) information on nutritional and psychological support. Patients read these materials according to their needs and all reading behaviours were recorded by the app.

The functions of these app components, including the patient and doctor sides, were captured in screenshots (Fig. 2).

Procedures

Before surgery, all participants routinely received 5 min face-to-face training from a nurse to provide the standard ERAS procedures. Training focused on relieving patients' anxiety and familiarising them with the PR programme, including performing the respiratory exercise and using the tri-ball spirometer device. Patients were required to continue practising during the pre-operative period until their performance met the standard. All patients underwent thoracoscopic lobectomy by the same surgical team with uniform operating procedures. After surgery, the in-hospital PR programme was provided for all patients, including active coughing to reduce sputum retention and performing the respiratory exercise (i.e. tri-ball incentive spirometry 100 times per day divided into five sets) and aerobic exercise (30 min per day) according to patients' exercise capacity and recovery condition. Patients were withdrawn from the study if they did not undergo VATS lobectomy, experienced severe postoperative complications that prevented them from

Table 1

Participants' characteristics.

	App group $N=68$	Usual care group $N=68$	*P*
Age, years	62.50 (56.00–67.75)	64.00 (56.25–66.00)	0.64
BMI, kg/m^2	24.30 (22.53–26.35)	24.60 (22.10–26.48)	0.78
Sex, no. (%)			0.12
Male	34 (50.00)	25 (36.80)	
Female	34 (50.00)	43 (63.20)	
Charlson comorbidity score, no. (%)			0.39
0	53 (77.90)	48 (70.60)	
1	11 (16.20)	15 (22.10)	
2	4 (5.90)	5 (7.40)	
COPD, no. (%)			0.09
Yes	10 (14.70)	4 (5.90)	
No	58 (85.30)	64 (94.10)	
Education, no. (%)			0.72
Primary or less	44 (64.70)	42 (61.80)	
Secondary or more	24 (35.30)	26 (38.20)	
Smoking history, no. (%)			0.80
Yes	26 (38.20)	22 (32.40)	
No	42 (61.80)	46 (67.60)	
Tumour family history, no. (%)			0.23
Yes	4 (5.90)	8 (11.80)	
No	64 (94.10)	60 (88.20)	
ECOG performance score, no. (%)			1.00
0	66 (97.10)	66 (97.10)	
1	2 (2.90)	2 (2.90)	
Tumour location, no. (%)			0.79
Right upper lobe	21 (30.90)	22 (32.40)	
Right middle lobe	9 (13.20)	7 (10.30)	
Right lower lobe	12 (17.60)	10 (14.70)	
Left upper lobe	12 (17.60)	13 (19.10)	
Left lower lobe	14 (20.60)	16 (23.50)	
Pathology, no. (%)			0.41
Squamous cell carcinoma	3 (4.40)	2 (2.90)	
Adenocarcinoma	65 (95.60)	66 (97.10)	
Clinical TNM staging (8th), no. (%)			0.82
cIA	56 (82.40)	57 (83.80)	
cIB	12 (17.60)	11 (16.20)	
Operation time, minutes, median (IQR)	120.00 (102.00–135.00)	120.00 (109.25–125.00)	0.94
Drainage volume, mL, median (IQR)	605.00 (415.00–818.75)	547.50 (400.00–765.00)	0.33
Extubation time, days, median (IQR)	3.00 (2.00–3.00)	3.00 (2.00–3.00)	0.15
Length of postoperative hospital stay, median (IQR)	4.00 (4.00–5.00)	4.00 (4.00–5.00)	0.11
Follow-up, median (IQR)	28.00 (27.00–32.00)	28.00 (27.00–32.00)	0.85

COPD, chronic obstructive pulmonary disease; ECOG, Eastern Cooperative Oncology Group; IQR, interquartile range; TNM, tumour, node, metastasis.

performing the spirometry test, or were hospitalised for more than 14 days.

From admission to the postoperative period in the hospital, participants in both the app and the usual care groups were treated using the same protocol. When they were ready to be discharged, the clinicians and nurses delivered different apps to the groups: in the app group, participants downloaded the app on their smartphone and started using all three components until 1 month after surgery: (1) daily symptom reporting in the resting state for the four core symptoms and triggering alerts to the medical team if the extent was severe; (2) completing the daily aerobic and respiratory exercises in the app programme; and (3) reading all four aspects of the educational material as a supplement. In the usual care group, participants could also download an app on their smartphones, which only had a document to provide them with regular instructions after discharge and encourage them to continue the respiratory and aerobic exercises based on their physical status and willingness. By contrast, the three app components (i.e. symptom reporting system with alerts, training exercises, and educational material) could not be used. Thirty days after surgery, participants were required to return to the hospital to complete the follow-up. Those who returned later than postoperative day (POD) 37 (exceeding 1 week) were regarded as having a delayed return.

Measures and outcomes

We collected clinical and demographic data, including age, sex, BMI, education level, smoking history, comorbidities, chronic obstructive pulmonary disease history, resected lobe, and length of hospital stay. We also collected participants' data after discharge, such as the emergency department (ED) visit rate, the readmission rate, severe complications within 30 days (Clavien–Dindo grade IIIb or above), and mortality.

The primary outcome of this study was the difference in the pulmonary function recovery ratio (PFRR) 1 month after surgery between the two groups. Participants in both groups (excluding those withdrawn) completed the spirometry test at three time points: before surgery, on the day of discharge, and after 1 month. The detailed process of taking the spirometry test is listed in the Supplementary Material (Supplemental Digital Content 1, http://links.lww.com/JS9/C853). The PFRR was calculated using the formula: (return %pred) / (preoperative %pred) × 100(%).

The secondary outcomes included the postoperative symptom burden and interference with daily living, both of which were measured using the MD Anderson Symptom Inventory for Lung Cancer (MDASI-LC) on a scale from zero (not present) to ten (as bad as you can imagine). The MDASI-LC includes 16 items for symptom burden and six items for interference with daily living (i.e. performing general activities, working, walking, mood, relations with others, and enjoyment of life). The interference with daily living score for all participants in both groups (excluding those withdrawn) was longitudinally assessed via a mini app at four time points: before surgery, 1 week after discharge, 2 weeks after discharge, and 30 days later at follow-up. The symptom burden score was assessed at three-time points: before surgery, 1 week after discharge, and 30 days later at follow-up.

The other secondary outcomes for both groups included exercise intensity (measured using the 10-point Borg scale of shortness of breath) and the ED visit and readmission rates, while they additionally included app-related safety and the satisfaction score for the app group. Data on symptom reporting by the app group were also collected and assessed according to the alert results as a subgroup analysis. Patients' Borg scores were assessed before surgery and every week thereafter by telephone interview

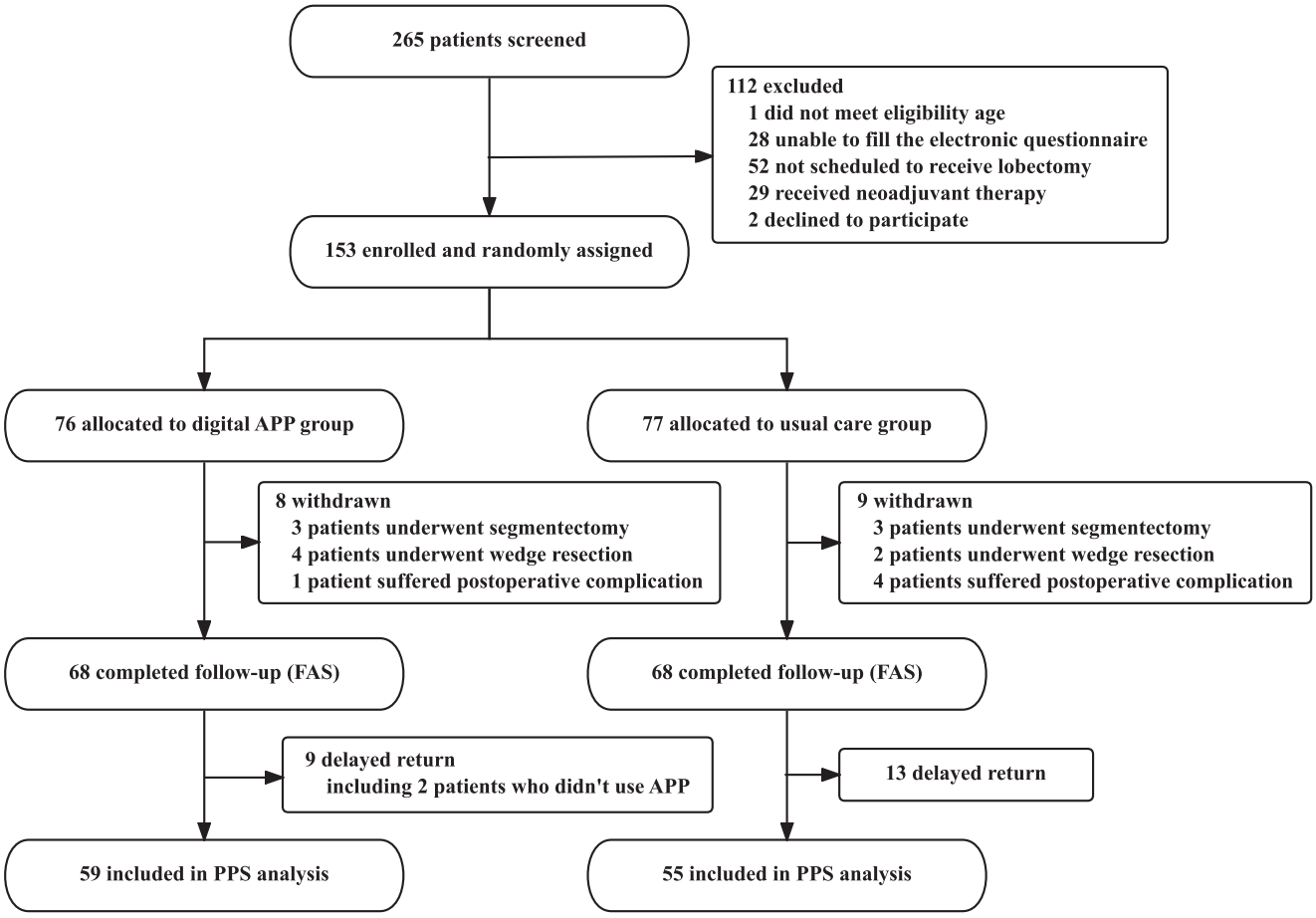

Figure 3. Flowchart of the study participants.

until the 1-month visit (POD 7, 14, 21, 28). The satisfaction scores, rated from 0 (not satisfied) to 5 (very satisfied), were given by the participants in the app group 1 month after using it, including the difficulty of using the app and usefulness for their postoperative rehabilitation.

Statistical analysis

Based on previous results[27,29–31], the PFRR at the 1-month follow-up in the usual care group was estimated as 75.0% ± 10.0%. As a 5.7% point increase in the PFRR was observed in stair-climbing patients compared with routine exercise in a previous study (77.8% ± 7.1% vs. 72.1% ± 6.7%, $P = 0.043$)[27], a mean improvement of 5% points in the PFRR in the app group was considered clinically meaningful. We calculated a sample size of 126 patients using PASS software version 15.0.5 (NCSS, LLC.), with a significance level of $\alpha = 5\%$ and 80% power (two-tailed) for the primary outcome. Assuming 10% attrition at follow-up, a sample of 138 patients (69 per group) was required.

We checked the data for normality. Normally distributed (non-normally distributed) data were summarised using differences in the mean (median), with a 95% CI for both groups at each time point. We analysed the outcomes of the pulmonary function parameters (FEV1), forced vital capacity (FVC), and maximal voluntary ventilation (MVV) at 1 month postoperatively in the two groups using the Student's *t*-test. The MDASI-LC score, Borg score, ED visit rate, and readmission rate were analysed using the χ^2 test, two-tailed Fisher's exact test, or descriptive statistics, as appropriate.

After excluding withdrawn patients, randomised patients who met all the inclusion and exclusion criteria were determined as the full analysis set (FAS), whereas those who followed all the protocols were regarded as the per-protocol set (PPS). Both the primary and secondary outcomes were investigated in the FAS population. Sensitivity analyses of the primary outcome were also performed in the PPS population to confirm the consistency of the results. All the analyses considered two-sided *P*-values of 5% as statistically significant and were conducted using SPSS version 23 (SPSS Inc.).

Results

Patients' characteristics

Between 1 December 2021 and 30 June 2022, 265 patients were screened; of these, 153 were randomly assigned to the app group or the usual care group when they were admitted to the hospital ($n = 76$ and $n = 77$, respectively). After surgery, 17 patients were determined to be ineligible and withdrawn (six wedge resections, six segmentectomy, and five postoperative complications). The remaining 136 patients were analysed as the FAS population (68 in each group). Table 1 lists the patients' demographics and

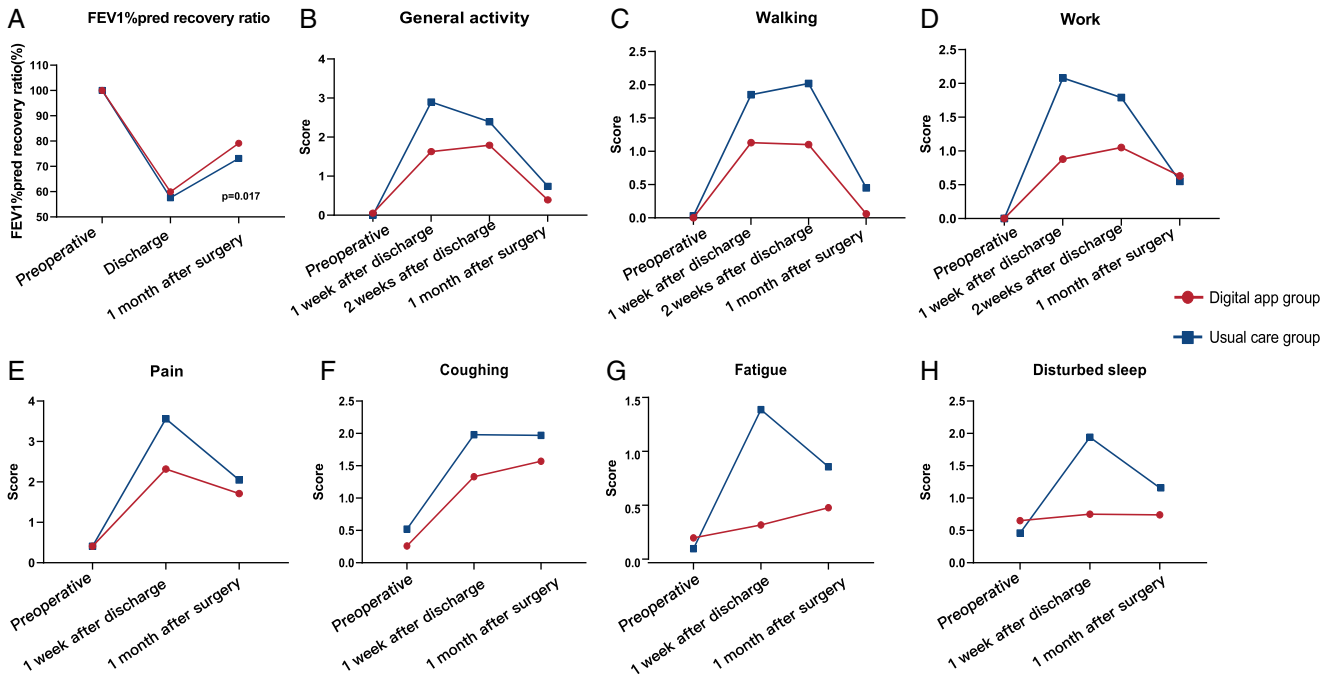

Figure 4. Pulmonary function recovery and changes in quality of life in the two groups. (A) PFRR; (B) Interference in performing general activities; (C) Interference in working; (D) Interference in walking; (E) Pain; (F) Coughing; (G) Fatigue; (H) Disturbed sleep.

clinical characteristics. The baseline characteristics were well-balanced between the two groups. The mean age was 61 years, 56.6% were women, and 36.8% had graduated from senior high school or above. The mean operative time was 122 min and the median length of postoperative hospital stay was 4 days (range: 2–9 days).

Of these 136 patients, 22 had a delayed 1-month follow-up (later than POD 37) due to the COVID-19 pandemic or other personal reasons (median delay of 15 days in the app group and 14 days in the usual care group). In addition, among the delayed-return patients, two in the app group did not use the app for personal reasons. After excluding these 22 delayed-return patients, 114 patients were included in the PPS population, including 59 in the app group and 55 in the usual care group (Fig. 3).

Primary outcome

Pulmonary function recovery ratio

In the FAS population, the PFRR decreased significantly at discharge and increased at follow-up in both groups. The PFRR in the app group was significantly higher than that in the usual care group (79.32 vs. 75.73%; $P = 0.04$). FVC and MVV exhibited a similar trend of recovery and the difference between the groups was not significant. In the PPS population, the PFRR in the app group was significantly higher than that in the usual care group (79.14 vs. 73.12%, $P = 0.017$) (Fig. 4A and Table 2).

Secondary outcomes

Interference with daily living

In the FAS population, the mean interference with daily living score significantly increased after discharge and decreased close to the presurgery level at follow-up. The app group demonstrated significantly less interference in performing general activities and working from 1 week to 2 weeks after discharge and in walking from 1 week after discharge to follow-up than the usual care group (all $P < 0.05$) (Fig. 4B–D, Table 3). The other interference with daily living scores, including enjoyment of life, relationships with others, and mood, were similar between the two groups (Supplementary Table 7, Supplemental Digital Content 1, http://links.lww.com/JS9/C853).

Symptom burden

In the FAS population, the symptom burden scores increased rapidly after surgery. The five symptom burden scores (pain, coughing, fatigue, disturbed sleep, and shortness of breath) significantly increased in the first month after surgery (all $P < 0.05$). The app group had significantly lower symptom burden scores for pain, coughing, fatigue, and disturbed sleep 1 week after discharge than the usual care group (all $P < 0.05$) as well as at follow-up (n.s.; Fig. 4E–H, Table 3). The other symptom burden scores were similar between the two groups (Supplementary Table 7, Supplemental Digital Content 1, http://links.lww.com/JS9/C853).

Aerobic exercise intensity

In both groups, the Borg score decreased markedly after surgery and recovered weekly from POD 7–28. We observed a significantly higher Borg score in the app group than in the usual care group on POD 21 (2.84 vs. 1.65, $P < 0.001$) and POD 28 (2.83 vs. 1.15, $P < 0.001$) (Fig. 5A).

Table 2

Pulmonary function parameters in the two groups (FAS and PPS populations).

	FAS			PPS		
	App group *N* = 68	Usual care group *N* = 68	*P*	App group *N* = 59	Usual care group *N* = 55	*P*
FEV1%pred, %						
Before surgery	90.05 (82.68–102.38)	93.95 (86.40–101.83)	0.46	90.10 (82.60–103.00)	93.90 (85.80–101.90)	0.68
Discharge	56.40 (42.10–67.20)	53.85 (47.48–62.93)	0.89	56.00 (42.00–67.20)	52.80 (46.80–61.50)	0.84
Follow-up	71.40 (64.63–86.18)	71.75 (61.35–79.98)	0.22	72.00 (64.70–86.20)	70.30 (59.10–77.30)	0.07
Recovery ratio	79.32 (73.13–84.97)	75.73 (68.35–82.48)	0.04	79.14 (73.03–84.14)	73.12 (66.71–80.28)	0.02
FEV1, L						
Before surgery	2.40 (2.07–2.96)	2.35 (2.06–2.76)	0.25	2.42 (2.09–2.99)	2.35 (2.00–2.67)	0.02
Discharge	1.43 (1.10–1.78)	1.38 (1.13–1.69)	0.24	1.43 (1.05–1.78)	1.35 (1.14–1.70)	0.11
Follow-up	1.95 (1.54–2.32)	1.77 (1.48–2.03)	0.048	2.03 (1.54–2.33)	1.75 (1.42–1.95)	0.11
FVC%pred, %						
Before surgery	93.50 (86.53–104.45)	93.00 (88.43–101.03)	0.94	93.60 (86.40–105.40)	92.00 (88.00–99.00)	0.008
Discharge	58.30 (46.05–68.95)	56.35 (49.63–85.30)	0.74	57.95 (45.55–68.95)	55.20 (48.70–62.40)	0.44
Follow-up	77.20 (67.85–85.15)	75.40 (68.23–85.30)	0.76	77.20 (67.80–83.50)	73.50 (66.40–82.30)	0.38
Recovery ratio	79.79 (73.21–89.22)	80.22 (73.35–87.64)	0.68	79.70 (72.94–89.30)	79.00 (72.23–87.27)	0.71
FVC, L						
Before surgery	3.15 (2.67–3.92)	3.04 (2.63–3.57)	0.15	3.19 (2.69–3.98)	3.03 (2.54–3.55)	0.04
Discharge	1.96 (1.60–2.57)	1.83 (1.54–2.23)	0.20	2.12 (1.65–2.57)	1.74 (1.55–2.17)	0.19
Follow-up	2.71 (2.04–3.21)	2.42 (2.03–2.87)	0.15	2.76 (2.03–3.21)	2.36 (1.97–2.81)	0.04
MVV%pred, %						
Before surgery	92.70 (83.50–101.75)	89.70 (84.05–100.63)	0.65	93.00 (83.30–106.00)	89.00 (84.20–100.90)	0.81
Discharge	64.00 (54.20–80.10)	62.05 (56.15–79.98)	0.96	64.00 (54.60–78.20)	61.20 (55.50–70.10)	0.68
Follow-up	85.35 (70.95–95.38)	83.75 (74.38–91.13)	0.76	86.30 (68.70–98.10)	83.70 (71.40–90.50)	0.56
Recovery ratio	89.24 (81.70–96.17)	88.88 (80.49–94.89)	0.36	89.84 (81.82–96.23)	88.53 (77.80–92.97)	0.25
MVV, L						
Before surgery	97.00 (77.80–113.73)	93.40 (77.63–105.90)	0.34	100.20 (77.80–114.00)	93.90 (78.20–104.10)	0.24
Discharge	65.30 (54.70–81.60)	64.85 (53.40–74.73)	0.35	65.50 (55.00–83.60)	62.40 (51.70–72.20)	0.13
Follow-up	83.55 (67.68–109.05)	76.85 (68.95–91.40)	0.13	81.70 (68.50–111.10)	77.90 (66.40–90.30)	0.053

FEV1, forced expiratory volume in 1 s; FVC, forced vital capacity; MVV, maximal voluntary ventilation.

Alerts in symptom reporting

In the subgroup analysis, 39.7% of the participants (27/68) in the app group triggered at least one symptom alert. Of the 32 alerts recorded by the app, 78.1% were yellow and 21.9% were red. The most common symptom alerts were for pain (40.6%) and shortness of breath (28.1%) (Fig. 5B). Furthermore, the patients who triggered symptom alerts were more motivated in their rehabilitation than those who did not. The patients who triggered alerts read the educational material more frequently and exercised for significantly longer and at higher intensity than those who did not trigger alerts (Fig. 5C–F, Supplementary Table 8, Supplemental Digital Content 1, http://links.lww.com/JS9/C853). Accordingly, both the highest Borg score for aerobic exercise and the highest PFRR were observed among those patients who had triggered symptom alerts than those who had not in the app group and patients in the usual care group (PFRR: 81.08 vs. 78.35% vs. 73.12, $P = 0.049$) (Fig. 5G and H).

ED visit and 30-day readmission rates

After discharge, eight patients visited the ED. The app group ($n = 6$) presented a higher ED visit rate than the usual care group ($n = 2$); however, the difference was not significant (8.8 vs. 2.9%, $P = 0.147$). Common reasons for ED visits included shortness of breath and fever. Among these patients, three in the app group and one in the usual care group were ultimately readmitted within 30 days of surgery (4.4 vs. 1.5%, $P = 0.314$), including two with pleural effusion, one with hypertension, and one with cerebral infarction. No severe 30-day postoperative complications or deaths occurred.

App-related safety

In the app-related safety analysis, accidents related to PR exercises (e.g. falls or excessive exercise) were recorded as zero. No eye injuries or other physical injuries were reported when using the smartphone within 1 month of surgery.

Satisfaction with the app

After excluding the two patients who did not use the app, 66 participants completed the satisfaction survey, of which 95.5% (63/66) had a score of 3 (basically satisfied) or above; 90.9% (60/66) reported no difficulty in using the app and 93.9% (62/66) reported that the app did not interfere with their daily lives. In addition, 95.5% (63/66) found the app helpful for symptom management and 71.2% (47/66) found the app's training exercises helpful, with 75.8% (50/66) adhering to the postoperative rehabilitation tasks. A total of 71.2% (47/66) intended to continue using the app until 3 months after surgery.

Table 3

MDASI-LC items for interference with daily living and symptom burden in the two groups (FAS population).

	Time relative effect		Therapeutic effect		
	B (95% CI)	*P*	App	Usual care	*P*
Interference with daily living scores					
General activities					
Before surgery	Ref.		0.05 ± 0.27	0.00 ± 0.00	0.19
1 week after discharge	2.23 (1.92–2.55)	< 0.001	1.63 ± 1.68	2.90 ± 1.65	< 0.001
2 week after discharge	2.06 (1.74–2.38)	< 0.001	1.78 ± 1.63	2.39 ± 1.45	0.03
Follow-up	0.54 (0.22–0.85)	< 0.001	0.39 ± 0.97	0.74 ± 1.33	0.09
Walking					
Before surgery	Ref.		0.00 ± 0.00	0.03 ± 0.25	0.31
1 week after discharge	1.47 (1.18–1.76)	< 0.001	1.13 ± 1.45	1.85 ± 1.72	0.01
2 week after discharge	1.54 (1.24–1.83)	< 0.001	1.10 ± 1.26	2.02 ± 1.84	0.002
Follow-up	0.23 (–0.06–0.53)	0.11	0.63 ± 0.39	0.45 ± 1.12	0.01
Working					
Before surgery	Ref.		0.00 ± 0.00	0.00 ± 0.00	–
1 week after discharge	1.47 (1.11–1.82)	< 0.001	0.88 ± 1.89	2.08 ± 1.85	< 0.001
2 wk after discharge	1.41 (1.05–1.77)	< 0.001	1.05 ± 1.74	1.79 ± 1.85	0.03
Follow-up	0.58 (0.23–0.94)	< 0.001	0.63 ± 1.54	0.55 ± 1.03	0.76
Symptom burden scores					
Pain					
Before surgery	Ref.		0.41 ± 1.08	0.41 ± 1.23	0.99
1 week after discharge	2.53 (2.15–2.91)	< 0.001	2.31 ± 1.68	3.56 ± 1.91	< 0.001
Follow-up	1.47 (1.08–1.85)	< 0.001	1.71 ± 1.81	2.05 ± 1.45	0.25
Coughing					
Before surgery	Ref.		0.26 ± 0.83	0.52 ± 1.20	0.15
1 week after discharge	1.28 (0.94–1.62)	< 0.001	1.35 ± 1.32	1.98 ± 1.67	0.02
Return	1.38 (1.04–1.73)	< 0.001	1.57 ± 1.43	1.97 ± 1.82	0.17
Fatigue					
Before surgery	Ref.		0.23 ± 1.16	0.13 ± 0.65	0.54
1 week after discharge	0.71 (0.41–1)	< 0.001	0.35 ± 0.92	1.42 ± 1.39	< 0.001
Follow-up	0.52 (0.22–0.82)	< 0.001	0.51 ± 1.16	0.89 ± 1.63	0.13
Disturbed sleep					
Before surgery	Ref.		0.56 ± 1.04	0.59 ± 1.66	0.89
1 week after discharge	0.8 (0.4–1.21)	< 0.001	0.61 ± 1.41	2.17 ± 2.00	< 0.001
Follow-up	0.41 (0.01–0.82)	0.05	0.83 ± 1.24	1.17 ± 2.14	0.27

Discussion

To the best of our knowledge, this POPPER study is the first RCT to demonstrate the efficacy of a smartphone app that integrates three major functional modules (i.e. symptom reporting system with alerts, training exercises (aerobic and respiratory), and educational material) to facilitate the rehabilitation of patients after discharging post-VATS lobectomy. This app may help patients accelerate their home-based rehabilitation by significantly enhancing their postoperative pulmonary function, represented by the PFRR 1 month after surgery, as shown by the higher Borg scores for aerobic exercise intensity, which may have been driven by the app components. Additionally, the patients in the app group exhibited lower interference with daily living scores for performing general activities and walking and lower symptom burden scores for pain, coughing, fatigue, and disturbed sleep. These results suggest that using this app is an effective approach for home-based rehabilitation after lung cancer surgery.

The optimal symptom selection and management of PRO after lung surgery lack consensus. A systematic review of 54 articles summarised the most commonly studied symptoms in patients who undergo lung cancer surgery[32]. These symptoms negatively impact QoL and functional status, while symptom burden severity is also an independent predictor of postoperative healthcare needs[33,34]. PRO-based symptom monitoring and management has been proven to be an ideal and essential modality for delivering personalised postdischarge care and enhancing postoperative recovery[35–37]. Previous studies on PRO for thoracic surgery have reported the five most severe postoperative symptoms as fatigue, pain, shortness of breath, disturbed sleep, and drowsiness or coughing[38,39]. Yang *et al.*[40] assessed seven symptom items and two functional items.

In our study, we collected four core symptoms from the data of a prospective study based on the QLQ-C30 and LC13 questionnaire in 201 patients and Delphi expert survey among 30 thoracic surgeons and nurses. Among these four symptoms, pain was the most frequently observed among our patients. This result was consistent with those of previous studies and indicated that postoperative pain control is critical for symptom management after discharge[7,38,39]. The second was shortness of breath, which resulted in 3.7% of ED visits and 1.5% of readmissions in our study. Shortness of breath is associated with QoL, functional exercise capacity, and postoperative pulmonary complications in patients after lung cancer surgery[41,42]. Hence, the PRO-based symptom assessment of shortness of breath using threshold alerts

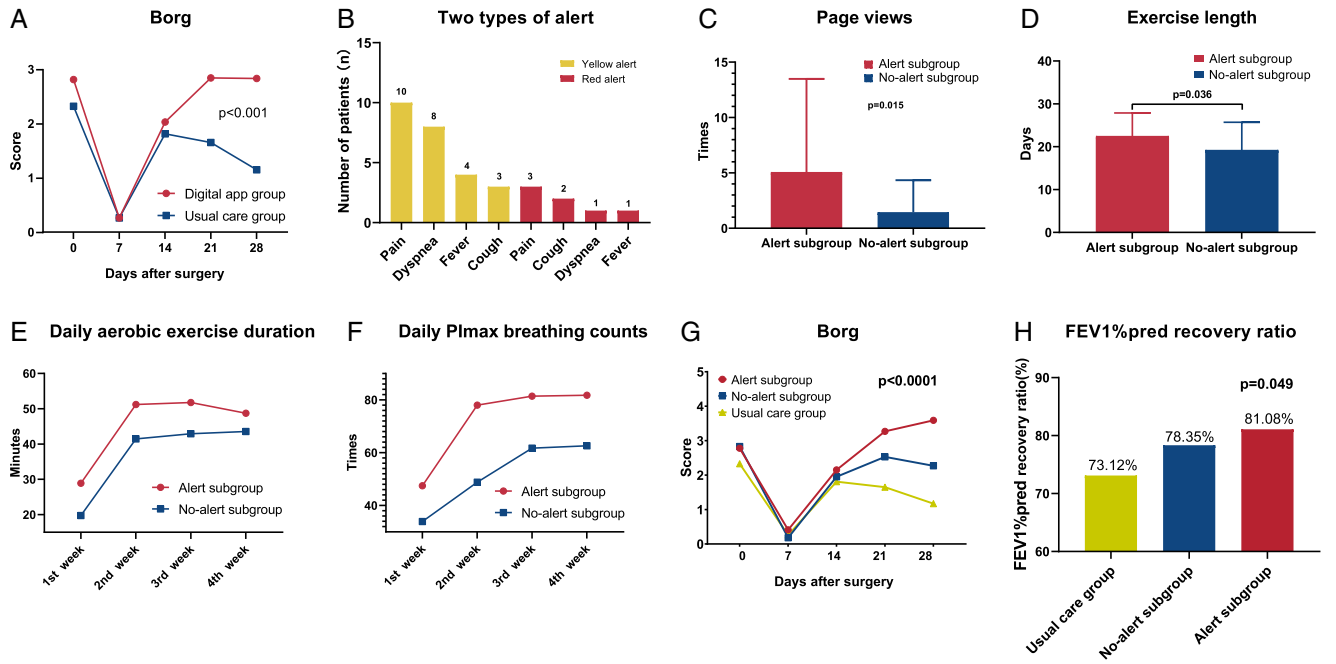

Figure 5. Borg scores and subgroup analysis of symptom reporting. (A) Borg scores of the two groups (FAS population); (B) Number of symptom alerts; (C) Page views for patients who did and did not trigger alerts; (D) Exercise length (days) among patients who did and did not trigger alerts; (E) Daily exercise duration (mins) among patients who did and did not trigger alerts; (F) PI max counts among patients who did and did not trigger alerts; (G) Borg scores among patients who did and did not trigger alerts and patients in the usual care group; (H) PFRR among patients who did and did not trigger alerts and patients in the usual care group.

is useful for monitoring and management. Third, 7.4% of the patients in the app group triggered fever alerts and 1.5% of the ED visits were caused by postoperative fever. Fever is a common postoperative symptom observed in patients who have undergone surgery, with incidence rates of 14–91%[43]. The reasons vary for thoracic surgery, including (1) response to injury caused by the release of pyrogenic cytokines; (2) atelectasis caused by sputum retention or pleural effusion; and 3) infection caused by pneumonia, wound infection, or even bronchopleural fistula[44–46].

The highest PFRR and Borg scores were obtained from patients in the app group who triggered an alert. Daily aerobic exercise duration and PI max breathing count were also higher for the patients who triggered alerts than those who did not. Our data strongly indicate a potential interaction between symptom management and functional rehabilitation using this alert mechanism. The frequency of viewing the educational material, exercise duration, and exercise intensity were all significantly higher among the patients who triggered alerts than those who did not. This finding implies that self-driven awareness invoked by an alert may encourage patients to follow rehabilitation guidance more actively and monitor their recovery more professionally via an app guide and instant feedback[47]. Therefore, self-driven rehabilitation combined with a professional guidance protocol may improve recovery after VATS lobectomy.

We selected 1 month after surgery as the primary endpoint to determine the efficacy of the app for two reasons. First, pulmonary function recovery in previous studies has shown a maximum function loss in terms of FEV1 and FVC from 2 weeks to 1 month after lung surgery[4,48,49], which indicates that patients need help to recover from the effects of surgery during this period. Second, POD 30 is a key time point to evaluate clinical outcomes related to lung surgery, such as postoperative pulmonary complications, mortality, and readmission[44,50–52], suggesting that assessing pulmonary function recovery within 30 days of surgery is important. Moreover, assessing the PFRR is better than measuring FVC, especially within 2 weeks to 1 month of lung surgery[29,49]. This may be because FEV1 is an indicator of airway resistance, which can recover more rapidly from postoperative aerobic exercise, whereas FVC is related to the residual lung volume, which is compensated gradually after lobectomy; therefore, recovery requires a longer period. Future studies could evaluate long-term pulmonary function recovery to assess changes in FEV1 and FVC.

This study had some limitations. First, it was conducted at a single centre with a relatively limited number of enroled patients. This treatment modality may depend on patients' education level and compliance with instructions. A phase III multicentre trial could confirm the results of this study. Second, the patients in the usual care group may have been indirectly induced and motivated when answering detailed questions about daily exercise, which would have influenced the results of the spirometry test; therefore, we only collected the Borg scores of the patients in the usual care group to reflect their exercise intensity. Hence, we did not compare the exercise type, frequency, duration, or amount of the two groups directly. Future research could introduce a more objective monitoring system (e.g. using wearable devices) to collect data on exercise intensity and duration as well as patients' vital sign measurements (e.g. heart rate and oxygen saturation). Third, we only evaluated the short term postsurgery benefits resulting from using the app and did not track long-term results or even survival outcomes due to the difficulty of following up caused by the COVID-19 pandemic. Surveying satisfaction with

the app 3–6 months after follow-up may be an important supplement to this study. Finally, we collected and selected four core symptoms and did not manage those not included in the app. The number of postoperative symptoms that must be reported and managed remains unknown. Balancing the number of symptoms and time required to report them using therapeutic equipment should be considered. Comprehensive outcomes from traditional parameters, novel rehabilitation indicators, and patient adherence should be adopted to determine the core symptoms and establish a PRO tool specific for lung surgery.

In conclusion, this POPPER study demonstrated the efficacy of a smartphone-based app for rehabilitation after discharge in patients with lung cancer who underwent VATS lobectomy. It guided the training programme and monitored symptoms using three related components, partly solving the problem of patient rehabilitation at home. A phase III study with more patients recruited from multiple centres is necessary to confirm these results. With the increasing number of users in real-world practice, patient management using apps would be further improved by accumulating adequate data and focusing on highly intelligent, accurate, and individualised algorithms in the future.

Ethical approval

The study protocol was approved by the Institutional Review Board of Peking University Cancer Hospital (number:2021KT92) and registered on the Chinese Clinical Trial Registry website (identifier: ChiCTR 2100049674). All patients provided written informed consent prior to enrolment.

Consent

All patients provided written informed consent prior to enrolment.

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Author contribution

N.W. and C.L.: conceived the study; N.W., C.L., F.L., X.Z., and X.L.: designed the experiments; C.L., F.L., and X.L.: performed the experiments; C.L., F.L., and X.L.: performed the data modelling; F.L., X.Z., W.Y., K.C., S.D., and C.H.: contributed to data acquisition; C.L., F.L., X.L., J.W., Y.W., S.L., L.W., Y.L., S.Z., M.H., D.S., D.Z., B.L., Y.W., X.C., Z.Z., and S.Y.: contributed to data visualisation; N.W., C.L., F.L., X.Z., and X.L.: wrote the original draft and reviewed and edited the manuscript; N.W., C.L., F.L., X.Z., and X.L.: contributed substantially to the development of this manuscript. All authors reviewed and approved the manuscript. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Conflicts of interest disclosure

The authors declare that they have no financial conflict of interest with regard to the content of this report.

Research registration unique identifying number (UIN)

The study protocol was registered on the Chinese Clinical Trial Registry website (identifier: ChiCTR 2100049674).

Guarantor

Professor Nan Wu and Professor Chao Lv.

Data availability statement

Access is provided after a proposal has been approved by an Independent Review Committee identified for this purpose and after the receipt of a signed Data Use Agreement. Source data, subject to intellectual property constraints, can be made available by contacting Nan Wu (nanwu@bjmu.edu.com).

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References

[1] Siegel RL, Miller KD, Fuchs HE, *et al*. Cancer statistics, 2021. CA Cancer J Clin 2021;71:7–33.
[2] Liu S, Chen Q, Guo L, *et al*. Incidence and mortality of lung cancer in China, 2008-2012. Chin J Cancer Res 2018;30:580–7.
[3] Howington JA, Blum MG, Chang AC, *et al*. Treatment of stage I and II non-small cell lung cancer: Diagnosis and management of lung cancer, 3rd ed: American College of Chest Physicians evidence-based clinical practice guidelines. *Chest* 2013;143(Suppl5):e278S–313S.
[4] Shin S, Kong S, Kang D, *et al*. Longitudinal changes in pulmonary function and patient-reported outcomes after lung cancer surgery. Respir Res 2022;23:224.
[5] Nomori H, Shiraishi A, Cong Y, *et al*. Differences in postoperative changes in pulmonary functions following segmentectomy compared with lobectomy. Eur J Cardiothorac Surg 2018;53:640–7.
[6] Chen J, Volpi S, Ali JM, *et al*. Comparison of post-operative pain and quality of life between uniportal subxiphoid and intercostal video-assisted thoracoscopic lobectomy. J Thorac Dis 2020;12:3582–90.
[7] Bendixen M, Jorgensen OD, Kronborg C, *et al*. Postoperative pain and quality of life after lobectomy via video-assisted thoracoscopic surgery or anterolateral thoracotomy for early stage lung cancer: a randomised controlled trial. Lancet Oncol 2016;17:836–44.
[8] Bayman EO, Parekh KR, Keech J, *et al*. A prospective study of chronic pain after thoracic surgery. Anesthesiology 2017;126:938–51.
[9] Zheng Y, Mao M, Li F, *et al*. Effects of enhanced recovery after surgery plus pulmonary rehabilitation on complications after video-assisted lung cancer surgery: a multicentre randomised controlled trial. Thorax 2023;78:574–86.

[10] Rogers LJ, Bleetman D, Messenger DE, *et al*. The impact of enhanced recovery after surgery (ERAS) protocol compliance on morbidity from resection for primary lung cancer. J Thorac Cardiovasc Surg 2018;155: 1843–52.
[11] Fuzhi Y, Dongfang T, Wentao F, *et al*. Rapid recovery of postoperative pulmonary function in patients with lung cancer and influencing factors. Front Oncol 2022;12:927108.
[12] Vagvolgyi A, Rozgonyi Z, Kerti M, *et al*. Effectiveness of pulmonary rehabilitation and correlations in between functional parameters, extent of thoracic surgery and severity of post-operative complications: randomized clinical trial. J Thorac Dis 2018;10:3519–31.
[13] Choi J, Yang Z, Lee J, *et al*. Usefulness of pulmonary rehabilitation in non-small cell lung cancer patients based on pulmonary function tests and muscle analysis using computed tomography images. Cancer Res Treat 2022;54:793–802.
[14] Messaggi-Sartor M, Marco E, Martinez-Tellez E, *et al*. Combined aerobic exercise and high-intensity respiratory muscle training in patients surgically treated for non-small cell lung cancer: a pilot randomized clinical trial. Eur J Phys Rehabil Med 2019;55:113–22.
[15] Bradley A, Marshall A, Stonehewer L, *et al*. Pulmonary rehabilitation programme for patients undergoing curative lung cancer surgery. Eur J Cardiothorac Surg 2013;44:e266–71.
[16] van der Storm SL, Bektas M, Barsom EZ, *et al*. Mobile applications in gastrointestinal surgery: a systematic review. Surg Endosc 2023;37:4224–48.
[17] Patel B, Thind A. Usability of mobile health apps for postoperative care: systematic review. JMIR Perioper Med 2020;3:e19099.
[18] Greenberg JK, Javeed S, Zhang JK, *et al*. Current and future applications of mobile health technology for evaluating spine surgery patients: a review. J Neurosurg Spine 2023;38:617–26.
[19] Sui Y, Wang T, Wang X. The impact of WeChat app-based education and rehabilitation program on anxiety, depression, quality of life, loss of follow-up and survival in non-small cell lung cancer patients who underwent surgical resection. Eur J Oncol Nurs 2020;45:101707.
[20] Kneuertz PJ, Jagadesh N, Perkins A, *et al*. Improving patient engagement, adherence, and satisfaction in lung cancer surgery with implementation of a mobile device platform for patient reported outcomes. J Thorac Dis 2020;12:6883–91.
[21] Dai W, Feng W, Zhang Y, *et al*. Patient-reported outcome-based symptom management versus usual care after lung cancer surgery: a multicenter randomized controlled trial. J Clin Oncol 2022;40:988–96.
[22] Schulz KF, Altman DG, Moher D, *et al*. CONSORT 2010 Statement: updated guidelines for reporting parallel group randomised trials. BMC Med 2010;8:18.
[23] Bergman B, Aaronson NK, Ahmedzai S, *et al*. The EORTC QLQ-LC13: a modular supplement to the EORTC Core Quality of Life Questionnaire (QLQ-C30) for use in lung cancer clinical trials. EORTC Study Group on Quality of Life. Eur J Cancer 1994;30A:635–42.
[24] Fayers P, AN, Bjordal K, *et al*. TC QLQ-C30 scoring manual. European Organisation for Research and Treatment of Cancer; 2001.
[25] Osoba D, Rodrigues G, Myles J, *et al*. Interpreting the significance of changes in health-related quality-of-life scores. J Clin Oncol 1998;16:139–44.
[26] Goldman JW, Garassino MC, Chen Y, *et al*. Patient-reported outcomes with first-line durvalumab plus platinum-etoposide versus platinum-etoposide in extensive-stage small-cell lung cancer (CASPIAN): a randomized, controlled, open-label, phase III study. Lung Cancer 2020;149: 46–52.
[27] Wang YYS, Wang X, Li X, *et al*. Stair climbing exercise may ameliorate pulmonary function impairment in patients at one month after lung cancer resection. J Thorac Oncol 2018;13:1015.
[28] Chang NW, Lin KC, Lee SC, *et al*. Effects of an early postoperative walking exercise programme on health status in lung cancer patients recovering from lung lobectomy. J Clin Nurs 2014;23:3391–402.
[29] Brocki BC, Andreasen JJ, Langer D, *et al*. Postoperative inspiratory muscle training in addition to breathing exercises and early mobilization improves oxygenation in high-risk patients after lung cancer surgery: a randomized controlled trial. Eur J Cardiothorac Surg 2016;49:1483–91.
[30] Seok Y, Jheon S, Cho S. Serial changes in pulmonary function after video-assisted thoracic surgery lobectomy in lung cancer patients. *Thorac Cardiovasc Surg* 2014, 62:133–9.
[31] Kim HK, Lee YJ, Han KN, *et al*. Pulmonary function changes over 1 year after lobectomy in lung cancer. Respir Care 2016;61:376–82.
[32] Merlo A, Carlson R, Espey J III, *et al*. Postoperative symptom burden in patients undergoing lung cancer surgery. J Pain Symptom Manage 2022;64:254–67.
[33] Wang KY, Chang NW, Wu TH, *et al*. Post-discharge health care needs of patients after lung cancer resection. J Clin Nurs 2010;19:2471–80.
[34] Lin YY, Wu YC, Rau KM, *et al*. Effects of physical activity on the quality of life in Taiwanese lung cancer patients receiving active treatment or off treatment. Cancer Nurs 2013;36:E35–41.
[35] Shi Q, Wang XS, Vaporciyan AA, *et al*. Patient-reported symptom interference as a measure of postsurgery functional recovery in lung cancer. J Pain Sympt Manag 2016;52:822–31.
[36] Khullar OV, Fernandez FG. Patient-reported outcomes in thoracic surgery. Thorac Surg Clin 2017;27:279–90.
[37] Bouazza YB, Chiairi I, El Kharbouchi O, *et al*. Patient-reported outcome measures (PROMs) in the management of lung cancer: a systematic review. Lung Cancer 2017;113:140–51.
[38] Tang L, Yu H, Dai W, *et al*. Symptom trajectories informing patient care after lung cancer surgery: a longitudinal patient-reported outcome study. Ann Surg Oncol 2023;30:2607–17.
[39] Fagundes CP, Shi Q, Vaporciyan AA, *et al*. Symptom recovery after thoracic surgery: measuring patient-reported outcomes with the MD Anderson Symptom Inventory. J Thorac Cardiovasc Surg 2015;150:613–9 e2.
[40] Yang D, Hong Q, Zhao C, *et al*. Postoperative patient-reported outcomes after uniportal video-assisted thoracoscopic surgery using the perioperative symptom assessment for lung surgery scale. Curr Oncol 2022; 29:7645–54.
[41] Yu Q, Yu H, Xu W, *et al*. Shortness of breath on day 1 after surgery alerting the presence of early respiratory complications after surgery in lung cancer patients. Patient Prefer Adherence 2022;16:709–22.
[42] Ha D, Ries AL. Characterization of dyspnea in veteran lung cancer survivors following curative-intent therapy. J Cardiopulm Rehabil Prev 2020;40:120–7.
[43] EP D. Approach to the patient with postoperative fever In: Gorbach SL, Bartlett JG, Blacklow NR, eds. Infectious Diseases, 3rd ed. Lippincott Williams & Wilkins; 2004;817.
[44] Wei W, Zheng X, Zhou CW, *et al*. Protocol for the derivation and external validation of a 30-day postoperative pulmonary complications (PPCs) risk prediction model for elderly patients undergoing thoracic surgery: a cohort study in southern China. BMJ Open 2023;13:e066815.
[45] Maday KR, Hurt JB, Harrelson P, *et al*. Evaluating postoperative fever. JAAPA 2016;29:23–8.
[46] Clark JM, Cooke DT, Brown LM. Management of complications after lung resection: prolonged air leak and bronchopleural fistula. Thorac Surg Clin 2020;30:347–58.
[47] DeVito Dabbs A, Song MK, Myers BA, *et al*. A randomized controlled trial of a mobile health intervention to promote self-management after lung transplantation. Am J Transplant 2016;16:2172–80.
[48] Yokoba M, Ichikawa T, Harada S, *et al*. Postoperative pulmonary function changes according to the resected lobe: a 1-year follow-up study of lobectomized patients. J Thorac Dis 2018;10:6891–902.
[49] Kim SK, Ahn YH, Yoon JA, *et al*. Efficacy of systemic postoperative pulmonary rehabilitation after lung resection surgery. Ann Rehabil Med 2015;39:366–73.
[50] Strand TERH, Damhuis RA, Norstein J. Risk factors for 30-day mortality after resection of lung cancer and prediction of their magnitude. Thorax 2007;62:991–7.
[51] Quero-Valenzuela F, Piedra-Fernandez I, Martinez-Ceres M, *et al*. Predictors for 30-day readmission after pulmonary resection for lung cancer. J Surg Oncol 2018;117:1239–45.
[52] Pezzi CM, Mallin K, Mendez AS, *et al*. Ninety-day mortality after resection for lung cancer is nearly double 30-day mortality. J Thorac Cardiovasc Surg 2014;148:2269–77.