

Effectiveness of an Exercise-Based Telerehabilitation on Cardiorespiratory Fitness, Gait Speed, and Symptoms in Individuals with Long COVID: A Randomized Controlled Trial

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Abstract

Background

Telerehabilitation has emerged as a promising intervention, with evidence indicating potential benefits for physical function, symptoms, and quality of life (QOL) in individuals with long COVID. However, current research remains limited and shows inconsistent results. This study evaluated the efficacy of a 12-week exercise-based telerehabilitation on primary outcomes, including cardiorespiratory fitness (CRF), gait speed, long COVID symptoms, as well as secondary outcomes, including body composition, sleep quality, and quality of life (QOL) in participants with long coronavirus disease 2019 (COVID-19).

Methods

This randomized controlled trial enrolled 120 participants aged 20–80 years with long COVID from a rehabilitation outpatient clinic at a medical center in northern Taiwan. Participants were assigned to either the telerehabilitation group (TG; $n = 57$) or active control group (ACG; $n = 63$). Both groups received a single in-person exercise counseling session delivered by a research nurse, while the TG additionally participated in a 12-week, physical therapist-supported exercise-based telerehabilitation program combining aerobic and resistance training. Primary outcomes included cardiorespiratory fitness (CRF), gait speed, and long COVID symptoms. Secondary outcomes included body composition, sleep quality assessed using the Pittsburgh Sleep Quality Index, and quality of life (QOL) assessed using the World Health Organization Quality of Life–BREF.

Results

Compared with the ACG, the TG demonstrated statistically significant improvements in CRF (peak oxygen consumption, $B = 2.12$, $p = 0.031$; anaerobic threshold, $B = 1.83$, $p = 0.005$), gait speed ($B = 0.07$, $p = 0.005$). No significant improvements were observed in sleep quality and QOL. Overall, 41 participants (71.9%) in the TG met the predefined adherence criterion. The intervention was well tolerated, with no serious adverse events or post-exertional symptom exacerbation reported.

Conclusions

A 12-week exercise-based telerehabilitation was associated with improvements in CRF and gait speed. The intervention was well tolerated and may represent a feasible approach for promoting physical recovery.

Trial registration

Contributions to the literature

- Exercise-based telerehabilitation improved cardiorespiratory fitness and gait performance in individuals with long COVID.
- Structured telerehabilitation provided additional benefits beyond exercise counseling and weekly remote reminders.
- Home-based telerehabilitation showed satisfactory adherence and was generally safe and well tolerated.
- These findings support telerehabilitation as a practical approach to improving access to long COVID rehabilitation.

BACKGROUND

Despite significant declines in severe coronavirus disease 2019 (COVID-19) cases following widespread vaccination[1], persistent vaccine hesitancy[2] and the risk for developing long COVID after initial infection or reinfections[3] remain substantial clinical concerns. Long COVID affects multiple organ systems[4], resulting in exercise intolerance[5, 6], decreased physical performance[7], impaired muscle health[8], poor sleep quality[9], and diminished quality of life (QOL)[9]. Exercise interventions, including respiratory, aerobic, and resistance training, can mitigate these adverse effects[10].

Telerehabilitation has emerged as a widely adopted form of virtual care during and after the COVID-19 pandemic. Recent systematic reviews suggest that telerehabilitation with exercise intervention for individuals after COVID infection may improve exercise capacity or physical function[11–15], muscle strength[11], QOL[11, 13, 15], and symptoms such as fatigue[12] and dyspnea[11, 14, 15]. Some studies have even reported non-inferiority compared to face-to-face rehabilitation[12, 13]. However, these reviews [11–14] included only a limited number of studies with some overlap, most of which involved small sample sizes and reported inconsistent findings regarding symptom improvement[11, 12, 14] and muscle strength[11, 12]. In addition, the optimal duration of intervention for long COVID has not been established[12–14]. Therefore, the current body of evidence remains insufficiently robust.

According to the recent statements from the American Thoracic Society[16], the most commonly prescribed rehabilitation programs last 8–12 weeks and typically include both aerobic and resistance training. Therefore, the present study aimed to implement a 12-week exercise-based telerehabilitation with aerobic and resistance training for individuals with long COVID and evaluate its efficacy on primary outcomes, including cardiorespiratory fitness (CRF), gait parameters, and long COVID symptoms, as well as secondary outcomes, including body composition, sleep quality, and quality of life (QOL). We hypothesized that the telerehabilitation group (TG) would demonstrate greater improvements in all outcomes compared with the active control group (ACG) after the 12-week intervention.

METHODS

Design

A parallel-group randomized controlled trial was conducted in participants with long COVID to compare the effectiveness of the intervention between the TG and ACG. This study was reported following the Consolidated Standards of Reporting Trials (CONSORT) guidelines[17].

Participants and settings

Between July 2023 and December 2023, potential outpatients with long COVID who attended the rehabilitation outpatient clinic at a medical center in northern Taiwan were invited to participate in the study, with follow-up through March 2024. During recruitment, participants were informed about random assignment and provided with a detailed explanation of the study procedures, potential risks, and their rights.

Participants were eligible for inclusion if they: (1) were aged 20–80 years; (2) tested negative for COVID-19 via rapid antigen testing following isolation and treatment, but continued to self-report symptoms consistent with long COVID for at least 4 weeks after the negative result[4, 18]; and (3) owned a mobile phone and had reliable internet access. Participants were excluded if they: (1) had acute or unstable chronic medical conditions or had undergone major surgery within the past 6 months; (2) were unable to perform cardiopulmonary exercise testing (CPET) owing to neurological or orthopedic disorders resulting in moderate to severe physical impairment; (3) were hospitalized during the intervention period or experienced aggravated symptoms due to COVID-19 reinfection; or (4) underwent CPET and were identified as high-risk for exercise participation[19].

Participants were randomly assigned in a 1:1 ratio to either the 12-week telerehabilitation group (TG, n = 57) or the active control group (ACG, n = 63) using a computer-generated simple randomization sequence. Allocation concealment was achieved using sequentially numbered, sealed, opaque envelopes prepared by a research assistant independent of recruitment, assessment, intervention delivery, and data analysis. Baseline characteristics were collected before the intervention by a separate research nurse blinded to group allocation.

Sample size was calculated using G*Power (version 3.1.9) based on repeated-measures ANOVA (within-between interaction). Because cardiorespiratory fitness (VO_{2peak}), gait parameters, and long COVID symptom burden were prespecified as co-primary outcomes, sample size was estimated separately for each outcome, and the largest required sample size was adopted to ensure adequate statistical power across all primary endpoints. For VO_{2peak} , the expected effect size was estimated based on a previous study ($f = 0.3$)[20]. With $\alpha = 0.05$, power = 0.80, two groups, and two measurement points, the required sample size was 24 participants. For gait parameters, assuming an effect size of $f = 0.227$ based on Daynes et al. [21], the required sample size was 42 participants. For long COVID symptoms, the expected

effect size was estimated at $f = 0.547$ based on the Chalder Fatigue Questionnaire (CFQ-11; bimodal scoring) and $f = 0.420$ based on the CFQ-11 (Likert scoring), corresponding to required sample sizes of 10 and 14 participants, respectively[22]. The largest of these estimates (42 participants) was therefore adopted as the target enrollment. To account for an anticipated attrition rate of 30%, the sample size was inflated using the formula $N / (1 - \text{dropout rate})$, yielding a target sample size of 60 participants, with a minimum of 30 participants per group.

Intervention

A well-trained research nurse with 5 years of experience provided a face-to-face counseling session to promote regular exercise participation (15–20 min) once for both the TG and ACG, based on American College of Sports Medicine guidelines[19] and the initial results of CPET, which was conducted by a physiatrist.

The ACG was instructed to perform unsupervised, self-directed exercise for 12 weeks. The TG participated in a 12-week exercise-based telerehabilitation program using the KNEESUP Compact (Conzian Ltd., Taipei, Taiwan) rehabilitation system (Fig. 1). Participants in the TG received instructions at the hospital on proper use of the knee brace (applied to one leg) and operation of the KNEESUP Care application by the research nurse. All devices were tested for functionality, and participants were provided with the equipment to complete the rehabilitation at home. Participants in both groups received weekly remote reminders from the research nurse via the LINE phone application.

KNEESUP Compact Rehabilitation System

The KNEESUP Compact rehabilitation system comprises a Smart Core motion tracker, a mobile application, and a web portal. The KNEESUP Care application, which can be installed on mobile devices and is available on both Google Play[23] and the Apple App Store[24], connects via Bluetooth to the Smart Core motion tracker attached to a knee brace. The Smart Core motion tracker provides three-dimensional motion tracking and real-time monitoring to improve movement accuracy and reduce exercise-related injuries.

Participants registered in the system and received an individualized rehabilitation program from a medical staff via the mobile application. Before each session, the application displayed safety notifications and target exercise intensity based on the rating of perceived exertion (RPE) or Borg Category-Ratio 10 (CR10) scale. After each session, exercise data were automatically uploaded to a secure server for monitoring of adherence, performance, and symptoms.

Exercise prescription in the telerehabilitation group

A physiatrist developed an initial 12-week individualized rehabilitation program, which was subsequently adjusted by a physical therapist via the web portal throughout the intervention period. More comprehensive descriptions of the KNEESUP Compact rehabilitation system and the exercise prescription are provided in Table 1 and Supplementary Material 1.

Table 1
Exercise-based telerehabilitation program

Component	Aerobic training	Resistance training
Frequency	3 sessions/week	2 sessions/week
Exercise	High-knee running in place (30–60 s), front and back jumps (30 s), and running in place (120 s)	Selected according to participants' condition from glute bridges, squats, planks, lunges, side leg raises, and wall sits
Intensity	Self-paced, as fast as tolerated; target RPE 12–14	CR10 = 4–6
Volume	Standardized circuit	Dynamic exercises: 8–12 repetitions/set; Isometric exercises: 30–60 s/set; 2–3 sets/exercise
Progression	Exercise duration and composition were individually adjusted according to functional capacity and tolerance.	Repetitions or isometric holding duration were gradually increased according to participants' tolerance and performance.
Session structure	Exercise prescriptions were individualized with variations in aerobic and resistance training; however, the overall session duration was standardized to approximately 30 min. Rest intervals were standardized to 30 s between sets and 1 min between exercises.	
Monitoring	A physical therapist monitored adherence through the web portal, reviewed completed exercise time, completed sets, post-exercise feedback, reported concerns, and exercise-related adverse events, and provided asynchronous counseling. Progression to subsequent phases was individualized and implemented after participants achieved the prescribed exercise volume, typically every 2–3 weeks.	

Measures

Sociodemographic information including sex, age, body mass index, duration of diagnosed COVID, comorbidity, was collected at baseline. Following the commencement of the trial, additional CRF measures (heart rate recovery [HRR]) and long COVID symptom assessments were incorporated to enable a more comprehensive evaluation of telerehabilitation effectiveness. Primary outcomes, including CRF, gait parameters, and long COVID symptoms, as well as secondary outcomes, including body composition, sleep quality, and QOL were collected at baseline and at 12 weeks by the research nurse, who was a blinded assessor and was independent of the research nurse delivering the exercise promotion counseling. Feasibility outcomes, including dropout, adherence, and adverse events, were collected to evaluate the intervention's acceptability and safety.

Detailed descriptions of the outcome measures, including their assessment procedures and measurement properties, are presented in Supplementary Table S1.

Primary outcomes

CRF was assessed using CPET on a cycling ergometer (MGC Ultima CardiO2) with a ramp protocol, increasing the workload by 10 W/min. Outcomes included $\text{VO}_{2\text{peak}}$ (mL/kg/min), anaerobic threshold (AT) (mL/kg/min), oxygen pulse (O_2 pulse) (mL/beat), and HRR at 1 and 2 min.

Gait parameters were assessed using the Timed Up and Go test. Participants wore bilateral KNEESUP Compact knee braces with Smart Core motion trackers. Gait speed (m/s) and cadence (steps/min) were analyzed using METASENS software.

Long COVID symptoms were assessed using a structured checklist based on the Centers for Disease Control and Prevention description of post-COVID conditions[25, 26].

Secondary outcomes

Body composition was assessed using the InBody 120 analyzer, which uses multi-frequency bioelectrical impedance analysis[27]. Body fat mass (%), and lean mass (kg) were collected.

Sleep quality was assessed using the Pittsburgh Sleep Quality Index (PSQI)[28]. The PSQI yields a global score (0–21), with a global score > 5 indicating poor sleep quality.

QOL was assessed using the Taiwanese version of the World Health Organization Quality of Life–BREF (WHOQOL–BREF), comprising 28 items across four domains[29]. Higher scores indicate better QOL[30].

Feasibility

Feasibility was evaluated according to three indicators: dropout rate, defined as the proportion of participants who withdrew from the study or did not complete the post-intervention assessment; adherence, defined as completion of at least 70% of the prescribed exercise dose ($\geq 1,260$ of 1,800 minutes) during the 12-week telerehabilitation program in the TG, comprising 36 aerobic and 24 resistance exercise sessions (30 minutes per session)[31]; and adverse events, defined as any unfavorable signs, symptoms, or health-related events occurring during the intervention period, including discomfort, injury, or unexpected symptoms reported after each exercise session through the KNEESUP Care application.

Ethical consideration

The study protocol was approved by the Institutional Review Board of our Hospital (Approval No. redacted for review), and all participants provided written informed consent before enrollment.

Data analysis

All analyses were performed using SPSS (version 24.0; IBM Corp., Armonk, NY, USA). Continuous variables are presented as mean $\pm$ SD or median (interquartile range), and categorical variables as number (%). Normality was assessed using the Shapiro–Wilk test with visual inspection of histograms and Q–Q plots. Within-group comparisons used paired t-tests or Wilcoxon signed-rank tests, and between-group comparisons used the chi-square, independent t-, or Mann–Whitney U tests, as appropriate. Intervention effects were examined using generalized estimating equations (GEEs) with group $\times$ time interaction[32]. Analyses followed the intention-to-treat principle with missing data handled using GEEs, which account for within-subject correlation across repeated measures and accommodate unbalanced or incomplete data by using all available observations under the missing-at-random assumption. To account for multiple comparisons across all primary and secondary outcomes, the Benjamini–Hochberg procedure was applied to control the false discovery rate, yielding adjusted p-values[33]. This approach was chosen over family-wise error rate control to adequately balance the risk of false positives with the ability to detect potential treatment effects across a broad set of endpoints. Statistical significance was set at a two-sided $p < 0.05$.

RESULTS

Participant characteristics

A total of 162 participants were initially assessed for eligibility; however, 22 participants declined to participate, and 20 did not meet the inclusion criteria. Consequently, 120 participants were enrolled. Of those enrolled, 92 (76.7%) completed the full data collection process, whereas 28 did not complete the post-test evaluation (Figure 2).

Table 2 summarizes the baseline characteristics of the 120 participants. No statistically significant between-group differences were observed.

Outcome evaluation

Primary outcomes

CRF

Baseline and 12-week CRF outcomes are presented in Table 3. At baseline, groups differed significantly in VO_{2peak} ($t=2.07$, $p=0.041$) and AT ($t=2.51$, $p=0.013$). Based on GEE analyses, the TG demonstrated greater improvements than the ACG in VO_{2peak} ($B=2.12$, $p=0.010$), AT ($B=1.83$, $p<0.001$), O_2 pulse ($B=0.47$, $p=0.009$), and 2-min HRR ($B=3.92$, $p=0.006$). These findings remained significant after BH correction (VO_{2peak} , $p=0.031$; AT, $p=0.005$; O_2 pulse, $p=0.031$; 2-min HRR, $p=0.025$) (Table 4).

Gait parameters

Baseline and 12-week gait parameters are presented in Table 3. No significant baseline differences were observed. After 12 weeks, the TG exhibited greater improvements in gait speed ($B=0.07$, $p<0.001$) and cadence ($B=4.96$, $p<0.001$) than the ACG, based on GEE analyses. These findings remained significant after BH correction (gait speed, $p=0.005$; cadence, $p=0.005$) (Table 4).

Long COVID symptoms

The number of participants reporting long COVID symptoms at baseline and 12 weeks is listed in Table 3. After 12 weeks, the TG reported significantly lower fatigue than the ACG ($OR=0.20$, $p<0.001$) based on GEE analyses. This finding remained significant after BH correction ($p=0.005$). (Table 4).

Secondary outcomes

Body composition

Baseline and 12-week body composition data are listed in Table 3. Baseline body weight significantly differed between the groups ($t=-2.18$, $p=0.031$). After 12 weeks, the TG exhibited a greater increase in lean mass than the ACG ($B=1.32$, $p<0.001$) based on GEE analyses. This finding remained significant after BH correction ($p=0.005$) (Table 4).

Sleep quality

PSQI scores at baseline and 12 weeks are presented in Table 3. The TG had poorer baseline sleep quality than the ACG ($t=-2.42$, $p=0.017$). After 12 weeks, the TG demonstrated greater improvement, with a larger reduction in PSQI scores ($B=-0.58$, $p=0.034$) than the ACG based on GEE analyses. This finding was no longer significant after BH correction (Table 4).

QOL

Baseline and 12-week domain scores of the Taiwanese WHOQOL-BREF are depicted in Table 3. At baseline, the TG had lower physical domain scores than the ACG ($p=0.02$). Based on GEE analyses, the TG demonstrated greater improvements in the physical ($B=0.97$, $p=0.033$) and social ($B=0.77$, $p=0.049$) domains than the ACG. However, neither finding remained significant after BH correction (Table 4).

Overall, 49 participants (86.0%) in the TG and 43 (68.3%) in the ACG completed the intervention, yielding dropout rates of 14.0% and 31.7%, respectively. Dropout reasons are shown in Figure 2. In the TG, 41 participants (71.9%) completed at least 70% of the prescribed exercise time and were therefore considered adherent, including 29 (50.8%) who completed the full prescribed exercise program. A total of 3 adverse events occurred in the TG: one ankle sprain, one exercise-related knee discomfort, and one fall unrelated to the intervention. Twelve participants reported mild post-exercise muscle soreness or fatigue that resolved within days. No post-exertional symptom exacerbation occurred.

DISCUSSION

The present study demonstrated that a 12-week exercise-based telerehabilitation conferred significant benefits for participants with long COVID. The findings were further supported by the per-protocol and sensitivity analyses using multiple imputation, which yielded results generally consistent with those of the primary intention-to-treat analysis (Supplementary Tables S2 and S3). Although the magnitude and statistical significance of several individual outcomes varied across analytic approaches, the overall interpretation of the intervention effects remained unchanged, supporting the robustness of our main conclusions. Improvements were primarily observed in exercise capacity and tolerance (VO_{2peak} , AT), as well as gait speed, with additional favorable changes in O_2 pulse, 2-min HRR, lean mass, and fatigue in the primary intention-to-treat analysis. Furthermore, because the ACG received once face-to-face exercise counseling with weekly remote reminders rather than no intervention, our findings may indicate the added value of a structured, device-supported, therapist-guided telerehabilitation program, as most outcomes in the ACG showed no improvement after 12 weeks.

A key strength of this study was the use of CPET, the gold standard for evaluating exercise capacity. Although reduced VO_{2peak} due to deconditioning and peripheral limitations has been reported in individuals with long COVID[6], few randomized controlled trials have assessed telerehabilitation effects using CPET[18, 34]. Most systematic reviews[11–14] have relied on submaximal measures, primarily the 6-min walk test. Consistent with these findings, our study demonstrated improved physical function following telerehabilitation. In addition, CPET may provide further physiological insight into these improvements by indirectly suggesting favorable adaptations in cardiovascular performance and autonomic regulation. An increase of 1 metabolic equivalent, equivalent to approximately 3.5 mL/kg/min in oxygen consumption, has been associated with a 13% reduction in all-cause mortality[35]. Late dysautonomia has been reported in approximately 2.5% of patients with long COVID[36]. In our study, HRR may serve as an indirect marker of autonomic regulation and may assist in the early identification and follow-up of changes in autonomic regulation following the intervention. A decrease of < 12 beats/min in 1-min HRR or < 22 beats/min in 2-min HRR suggests an increased mortality risk[37]. The observed increases in O_2 pulse and AT may reflect improved oxygen utilization and recovery from non-cardiac circulatory impairments, including endothelial dysfunction[38], impaired peripheral oxygen delivery at the microcirculatory level[39], and reduced muscle mass and function[40]. Improvements in

gait speed and lean mass further support this interpretation, although gait speed did not reach the suggested clinically important change (0.10–0.20 m/s)[41]. During recruitment, CPET identified three high-risk patients (two with an inadequate blood pressure response and one with silent ischemia), who were excluded. This highlights its value in identifying high-risk patients and improving telerehabilitation safety.

Our participants had a mean disease duration of 34 weeks (median, 30 weeks; range, 4-106 weeks), indicating that most had prolonged symptoms despite a small proportion in the early post-acute stage. This reduces the likelihood that the observed improvements were solely attributable to spontaneous recovery and supports the potential contribution of the intervention.

The reduction in the presence of fatigue was consistent with the findings of a previous systematic review[12]. Although the presence of dyspnea (shortness of breath) decreased in the TG, this effect became nonsignificant after adjusting for covariates. It diverges from most prior systematic reviews[11, 14, 15, 42, 43] except that by Oliveira et al.[12], potentially owing to low baseline dyspnea scores. Moreover, binary assessment of dyspnea and other symptoms, rather than severity-based evaluation, could detect reductions in symptom presence but not changes in symptom burden or severity. The absence of validated symptom severity scales limited interpretation of the clinical magnitude of improvement. Future studies should incorporate validated severity instruments to better characterize changes in long COVID symptom burden.

Sleep quality and physical domain in QOL showed improvements in the covariate-adjusted analysis; however, these associations did not remain significant after BH correction. Given the limited evidence for exercise alone in treating insomnia[44], and exercise-based telerehabilitation for sleep quality in individuals with long COVID[18], further research is warranted because sleep disorders remain a substantial burden in this population[9]. Although the physical QOL domain did not parallel the observed physical gains or the findings of previous systematic reviews[11, 13, 15], improvements were still observed in within-group comparisons. In addition, previous evidence suggests that small changes in WHOQOL-BREF domain scores may reflect clinically relevant improvements[45]. Therefore, telerehabilitation may improve the physical QOL domain, although this was not fully demonstrated in our study.

Several factors may explain the high dropout rate in the ACG. Although weekly exercise reminders were sent via LINE, participant engagement could not be confirmed. The ACG received only one face-to-face exercise counseling session with limited ongoing support, which may have reduced motivation for continued participation. In addition, work-related time constraints caused dropout and prevented some participants from completing the post-intervention CPET assessment. The TG showed a low dropout rate and satisfactory adherence according to our predefined criterion. However, exercise intensity was based on self-reported ratings of perceived exertion, so actual training stimulus may have varied. There is currently no clear consensus regarding the optimal definition of adherence in exercise-based clinical trials[46], and different adherence thresholds may influence the interpretation of intervention

effectiveness. Future studies should adopt standardized adherence criteria and investigate dose–response relationships to better clarify how exercise adherence and training intensity influence clinical outcomes.

Study limitations

This study had certain limitations. First, participants were not blinded, introducing potential expectation bias. Second, long COVID symptoms were assessed as binary variables rather than using validated severity scales, reflecting symptom presence rather than severity or burden. Third, simple randomization resulted in baseline group imbalances, which were addressed using GEEs and the BH procedure. Finally, although adherence was monitored, its association with treatment response was not examined.

Conclusions

This study demonstrated that a 12-week exercise-based telerehabilitation program was associated with improved CRF and gait speed in individuals with long COVID. The observed adherence and favorable safety profile further support the feasibility of exercise-based telerehabilitation as a valuable strategy for promoting physical recovery in this population.

Abbreviations

ACG

active control group

AT

anaerobic threshold

BH

Benjamini–Hochberg

BMI

body mass index

CONSORT

Consolidated Standards of Reporting Trials

CPET

cardiopulmonary exercise testing

CR10

Category-Ratio 10

CRF

cardiorespiratory fitness

GEE

generalized estimating equation

HRR

heart rate recovery

O₂ pulse
oxygen pulse
OR
odds ratio
PSQI
Pittsburgh Sleep Quality Index
QOL
quality of life
RPE
rating of perceived exertion
SPSS
Statistical Package for the Social Sciences
TG
telerehabilitation group
VO₂peak
peak oxygen consumption
WHOQOL–BREF
World Health Organization Quality of Life–BREF.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the Institutional Review Board of Tri-Service General Hospital (Approval No. A202305058) and written informed consent was obtained from all participants before enrollment.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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Author Contribution

C.H.L. and S.L.C. contributed to conceptualization. T.C.C. contributed to data curation. C.Y.S., C.H.L., and H.B.H. contributed to formal analysis. S.L.C. acquired funding. W.Y.C., C.Y.H., and J.W.J. contributed to investigation. C.Y.S. contributed to methodology. W.Y.C. and T.C.C. contributed to project administration. C.H.L. provided resources. C.C.C. and S.L.C. supervised the study. C.Y.H. and H.B.H. contributed to validation. C.H.L. contributed to visualization. C.Y.L. and C.H.L. wrote the original draft. C.Y.L., C.H.L., and S.L.C. reviewed and edited the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

Data are available from the corresponding author upon reasonable request, due to ethical restrictions on participant information.

Tables

Table 2-4 are available in the Supplementary Files section.

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Figures

Web Portal for medical professional

Mobile App and Knee Brace for patient

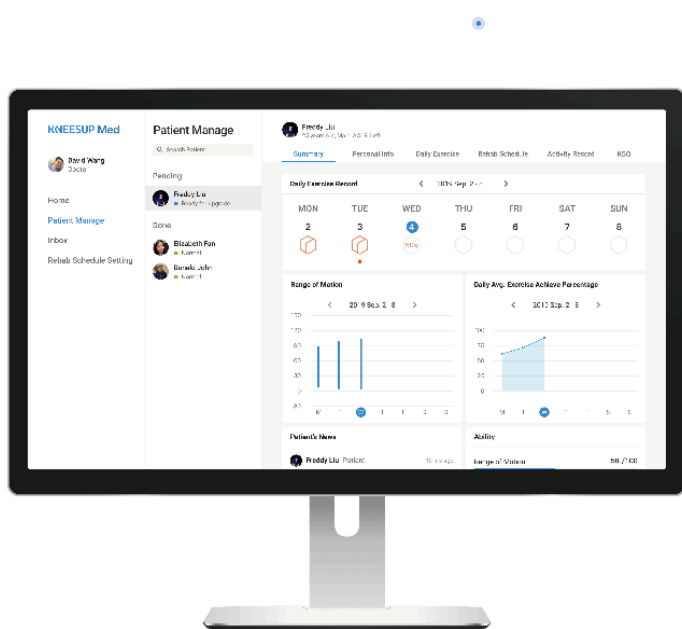


Figure 1

KNEESUP Compact rehabilitation system. The system consists of a knee brace with a smart core motion tracker, mobile application, and web portal. Reproduced with permission from Conzian Ltd., Taipei, Taiwan.

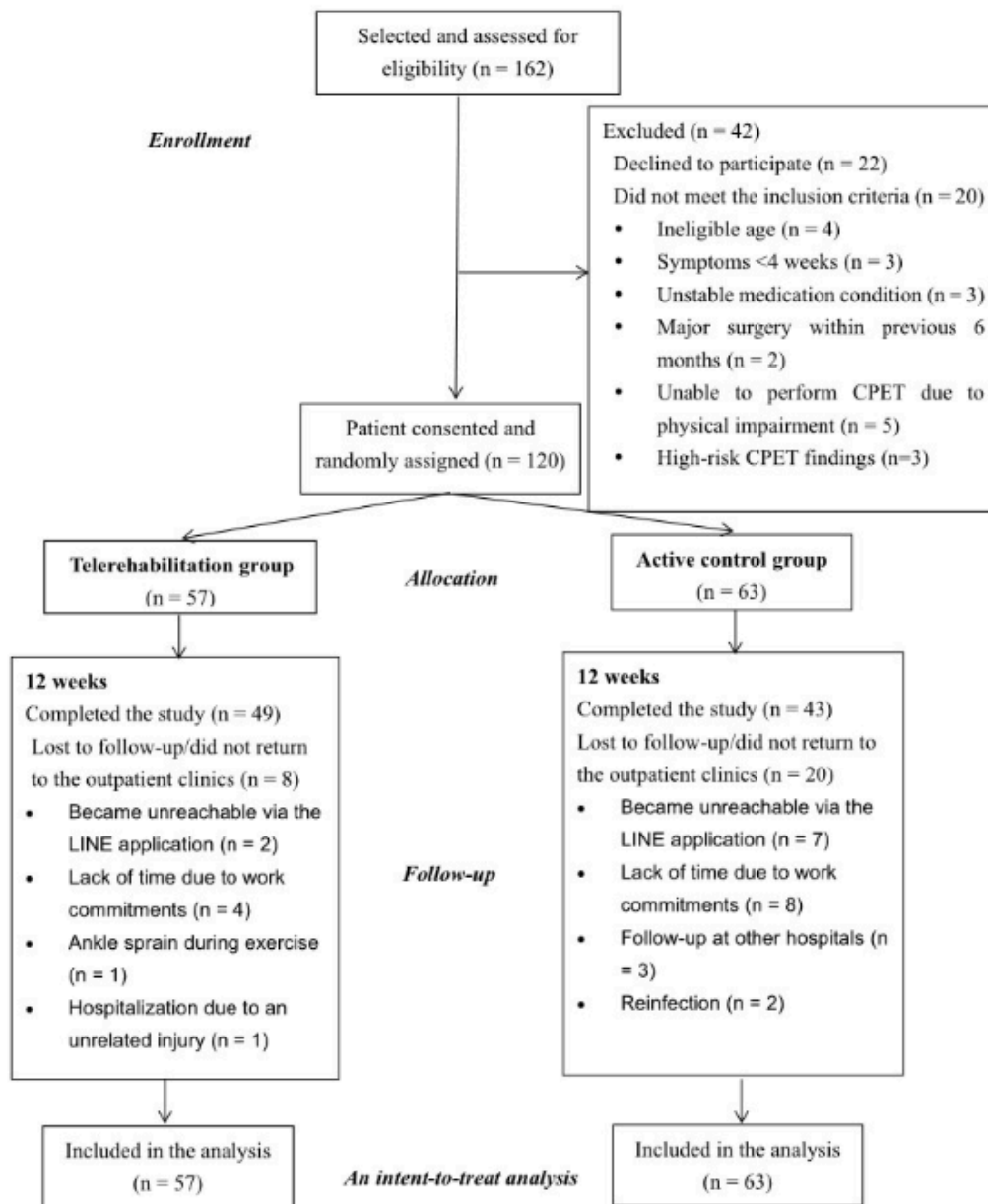


Figure 2

Consolidated Standards of Reporting Trials (CONSORT) diagram of participant flow through the trial. This flowchart outlines the participant recruitment process, reasons for exclusion, group randomization, and the number of participants who completed the post-intervention assessment.

Supplementary Files

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