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Functional recovery with perioperative asynchronous telerehabilitation in colorectal cancer: a randomized clinical trial

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Abstract

Purpose

To determine whether asynchronous digital monitoring, individualized progression, reminders, and physiotherapist support provide additional functional benefit over a content-matched perioperative home rehabilitation program after colorectal cancer surgery.

Methods

This single-center, assessor-masked randomized clinical trial assigned 80 adults 1:1 to telerehabilitation or booklet-based rehabilitation. Both groups received respiratory, aerobic, and progressive resistance exercise plus perioperative education. The primary outcome was 6-minute walk test (6MWT) at approximately 50 days after surgery (T4). Secondary outcomes included functional mobility, pulmonary function, physical activity, adherence, and satisfaction. Usability was assessed among telerehabilitation participants. Between-group clinical analyses were adjusted for baseline values and age.

Results

Eighty participants were randomized, 40 per group. The adjusted between-group difference in 6MWT distance at T4 was not significant (P = .180). No significant adjusted between-group differences were observed for functional mobility, pulmonary function, or physical activity. Overall recorded adherence was higher with telerehabilitation than with booklet-based rehabilitation (69.6% vs 52.8%; difference, 16.8 percentage points; P = .002). Satisfaction at T4 favored telerehabilitation (P = .044). Among telerehabilitation participants, total usability increased from 6.24 to 6.68 of 7 (P < .001).

Conclusion

In adults undergoing colorectal cancer surgery, both rehabilitation strategies were associated with functional recovery, while asynchronous telerehabilitation did not confer additional short-term functional benefit. The digital approach was associated with greater recorded adherence and end-of-program satisfaction, suggesting potential value in engagement and continuity of rehabilitation delivery. Trial registration: ClinicalTrials.gov NCT06593678; registered 29 August 2024.

Clinical trial registration

ClinicalTrials.gov NCT06593678. Registered 29 August 2024.

INTRODUCTION

Colorectal cancer remains a leading cause of cancer morbidity and mortality worldwide [1]. As survival improves, preserving postoperative physical function has become an important goal of perioperative cancer care, because patients may experience declines in exercise capacity, mobility, and independence [2, 3].

Exercise-based rehabilitation aims to increase preoperative physiological reserve, attenuate postoperative functional decline, and accelerate recovery after colorectal resection [4, 5]. Exercise during cancer treatment is recommended to preserve physical function, cardiorespiratory fitness, and strength [6], and higher physical activity after colorectal cancer diagnosis has been associated with favorable long-term outcomes [2, 7, 8].

Randomized trials have reported heterogeneous effects of perioperative rehabilitation on functional recovery [9–13]. Gillis et al. found greater 6-minute walk test (6MWT) improvement when multimodal rehabilitation began before rather than after surgery [9], and PREHAB reported improved postoperative functional recovery after 4 weeks of supervised multimodal prehabilitation [10]. Conversely, trials in frail or older populations reported smaller or less consistent functional effects [11, 12], and PHYSSURG-C, using brief home-based pre- and postoperative exercise similar to the present intervention, found no improvement in short-term self-reported physical recovery versus usual care [13]. Recent syntheses support a potential benefit of prehabilitation but highlight substantial heterogeneity in intervention composition, duration, comparator, outcome measures, and timing [14, 15]. Because most trials used usual care as comparator, it remains uncertain whether benefit derives from the exercise content or from its delivery and support.

Access to supervised rehabilitation remains uneven because of travel, scheduling constraints, postoperative mobility limitations, workforce capacity, and fragmented referral pathways [16], barriers that telehealth may help address. Telehealth-delivered exercise has shown potential to improve cardiorespiratory fitness and physical activity across cancer populations [17], and broader reviews suggest benefits for accessibility and continuity of care despite substantial heterogeneity in technologies, intervention components, and implementation outcomes [18, 19]. Digitally delivered exercise has also shown potential benefits in hematopoietic cell transplant and colorectal cancer survivors [20, 21], and American Society of Clinical Oncology (ASCO) telehealth standards explicitly address asynchronous interventions [22]. However, when both groups receive structured home-based rehabilitation, whether the digital component itself (monitoring and asynchronous physiotherapist support) adds functional benefit remains uncertain.

Therefore, this randomized clinical trial (RCT) evaluated whether asynchronous digital monitoring, individualized progression, reminders, and physiotherapist support improve perioperative functional recovery after colorectal cancer surgery compared with a booklet-based active comparator providing the same principal exercise and educational content, thereby isolating the incremental contribution of digital delivery.

METHODS

Study Design

This investigator-initiated, single-center, assessor-masked, parallel-group RCT was conducted at Hospital Royo Villanova (Zaragoza, Spain), with recruitment from August 30, 2024, to December 23, 2025. It was approved by the Clinical Research Ethics Committee of Aragón (CEICA; PI23/557), registered at ClinicalTrials.gov (NCT06593678: https://clinicaltrials.gov/study/NCT06593678), and conducted in accordance with the Declaration of Helsinki and CONSORT guidelines. The protocol has been published previously [23].

Participants

Consecutive adults scheduled for elective colon or rectal cancer resection were screened preoperatively. Eligibility criteria were age 18 to 80 years, American Society of Anesthesiologists (ASA) physical status I to III, functional independence, ability to complete walking and pulmonary assessments, and access to an internet-enabled device. Principal exclusions were ASA IV; unstable cardiovascular disease; musculoskeletal, neurologic, or medical conditions contraindicating walking or moderate exercise; and cognitive or psychiatric conditions preventing informed participation or reliable assessment. Complete criteria are reported in the protocol [23].

Randomization and Masking

Participants were randomized 1:1 to telerehabilitation or booklet-based rehabilitation using a computer-generated blocked sequence (permuted blocks of variable size, 4 and 6) stratified by sex and prespecified age category, generated by an investigator not involved in recruitment or outcome assessment. Allocation was concealed in sequentially numbered, opaque, sealed envelopes, and the clinician who enrolled participants had no access to the sequence. Participants and the treating physiotherapist could not be masked; physical and pulmonary outcomes were assessed with standardized procedures by a physiotherapist with 20 years of clinical experience, uninvolved in treatment and blinded to allocation. Participants were asked not to disclose their group assignment. Data analysts were masked to group allocation.

Intervention

Both groups received routine surgical and medical care and the same core rehabilitation components: respiratory exercise, aerobic training, progressive resistance exercise, and perioperative education. They differed primarily in delivery, monitoring, reminders, progression support, and communication between assessments. Both interventions were delivered by physiotherapists with 10 years of experience in oncologic or perioperative rehabilitation.

Prehabilitation began after baseline assessment and continued until the day before surgery, with duration determined by surgical scheduling. Structured postoperative rehabilitation began after clinical review and suture removal, approximately 21 days after surgery, and continued for 4 weeks, without replacing routine in-hospital mobilization or perioperative care. Full specifications and progression rules are provided in the protocol [23].

Telerehabilitation Group

Participants accessed the HEFORA telerehabilitation platform through a mobile application or web interface and completed 5 structured sessions per week combining respiratory, aerobic, and resistance exercise. Respiratory exercises were prescribed daily. Aerobic exercise was individualized and progressed toward approximately 150 to 300 minutes per week when clinically appropriate. Resistance exercise targeting major muscle groups was prescribed at least 4 times weekly, progressing from 2 to 3 sets of 8 repetitions to 3 sets of 15 repetitions as tolerated.

Intensity was guided by a modified Borg rating of perceived exertion of 3 to 7. Initial basic, intermediate, or advanced levels were assigned according to baseline physical performance, comorbidities, and symptoms. The physiotherapist reviewed symptoms, perceived exertion, missed sessions, and postoperative recovery, adapting exercise type, volume, intensity, or progression when clinically indicated. The platform recorded completed, partially completed, modified, and missed activities, fatigue, reasons for noncompletion, and symptoms; enabled asynchronous messaging; and generated reminders after at least 48 hours without recorded activity.

Booklet-Based Rehabilitation Group

Participants received the same exercise components (active comparator), frequency guidance, progression levels, and educational content in a printed booklet with written instructions and photographs. A physiotherapist provided initial face-to-face instruction on exercise performance, progression, symptom monitoring, and paper-diary completion. Participants then exercised independently at home according to predefined guidance, with progression reviewed during scheduled assessments, without platform-based monitoring, automated reminders, or asynchronous physiotherapist communication.

Outcomes

Assessments were performed before prehabilitation (T1), the day before surgery (T2), approximately 21 days after surgery before structured rehabilitation (T3), and after 4 weeks of postoperative rehabilitation, approximately 50 days after surgery (T4).

The primary outcome was 6MWT distance at T4, measured over a 30-m corridor using standardized procedures [24]. Secondary outcomes were Timed Up and Go (TUG) [25], forced vital capacity (FVC) and

forced expiratory volume in 1 second (FEV1) [26], and physical activity and sitting time measured with the International Physical Activity Questionnaire-Short Form (IPAQ-SF) [27].

Adherence was recorded daily using HEFORA activity records (telerehabilitation) or paper diaries (booklet). Each intervention day was classified as complete (all scheduled activities performed), partial (some performed), or not completed (none performed). Adherence was calculated as complete or partial days divided by total intervention days, summarized for prehabilitation (T1-T2), postoperative rehabilitation (T3-T4), and the overall period, and categorized as level 0 (< 20%), 1 (20% to < 50%), 2 (50% to < 80%), or 3 (≥ 80%). Satisfaction was assessed at T2 and T4 using an *ad hoc* questionnaire with items scored from 0 (very dissatisfied) to 4 (very satisfied).

Telerehabilitation participants completed the validated Spanish 12-item abbreviated Telehealth Usability Questionnaire (TUQ) at T2 and T4 [28, 29], with items scored from 1 (strongly disagree) to 7 (strongly agree) and a not-applicable option. The prespecified primary usability measure was the mean total score. Validated factors were effectiveness (items 1, 2, 10, 11) and ease of use (items 3–9, 12); total and factor scores were calculated as the mean of completed items, with higher scores indicating more favorable usability.

Safety was monitored throughout the intervention for adverse events potentially related to exercise. Participants were instructed to report new or worsening symptoms through HEFORA or the paper diary. The treating physiotherapist could modify, temporarily suspend, or discontinue exercise for pain, fever, dyspnea, palpitations, dizziness, marked fatigue, or clinical deterioration without discontinuing follow-up.

Sample size

The sample size was based on 6MWT. Assuming a two-sided α of .05, 80% power, a 60-m between-group difference, an SD of 80 m, and 20% attrition, the protocol specified 56 participants (28 per group) [23]. The enrollment target of 80 participants (40 per group), calculated for postoperative complications (Clavien–Dindo) as the initially planned primary outcome, was retained after an ethics-approved amendment changed the primary outcome to 6MWT (see Limitations). No other changes to outcomes or analyses were made, and no interim analyses or stopping guidelines were planned.

Statistical Analysis

Analyses used IBM SPSS Statistics version 30.0 (IBM Corp., Armonk, NY), with two-sided α = .05. The trial evaluated between-group effectiveness rather than equivalence or noninferiority.

Continuous variables are reported as means (SDs) and categorical variables as frequencies (percentages). Normality was assessed with Shapiro-Wilk tests. Baseline comparisons used independent-samples t or Mann-Whitney U tests for continuous variables and χ^2 or Fisher exact tests for categorical variables.

Analyses followed the intention-to-treat (ITT) principle, with missing data imputed using the last observation carried forward (LOCF) approach.

Adherence analyses were restricted to participants with monitoring data. Because age differed at baseline, primary continuous outcomes were compared by ANCOVA adjusted for baseline value and age, with partial η^2 as effect size. Sensitivity analyses used linear mixed-effects models with fixed effects for group, time, group-by-time interaction, and age, followed by exploratory pairwise comparisons when appropriate. Within-group changes were assessed with repeated-measures ANOVA or Friedman tests with Bonferroni-adjusted pairwise comparisons, using Cohen d or r as effect sizes. Categorical outcomes used χ^2 or Fisher exact tests with Cramér V, and adherence and satisfaction were compared using Mann-Whitney U tests with r. Longitudinal changes are reported as mean differences (Δ) with 95% CIs. Adverse events were summarized descriptively by group.

RESULTS

Participant Flow and Baseline Characteristics

Eighty participants were randomized (40 per group) and all were included in ITT analyses. Fourteen had no observed post-rehabilitation assessment because of voluntary withdrawal (n = 12), loss to follow-up (n = 1), or postoperative death (n = 1) (Fig. 1). The telerehabilitation group was younger than the booklet group (60.88 ± 9.63 vs 68.95 ± 9.33 years; P < .001) and differed in educational level (P < .001) and employment status (P = .025); other baseline characteristics did not differ significantly (Table 1).

Table 1
Baseline Demographic and Clinical Characteristics

Characteristic	Overall (N = 80)	Booklet-Based Rehabilitation (n = 40)	Telerehabilitation (n = 40)	P
Demographic factors				
Age, years, mean (SD)	64.92 (10.26)	68.95 (9.33)	60.88 (9.63)	< .001
Height, cm, mean (SD)	168.72 (9.78)	166.81 (9.39)	170.64 (9.91)	.080
Weight, kg, mean (SD)	76.49 (15.24)	74.95 (13.51)	78.03 (16.82)	.369
Body mass index, kg/m², mean (SD)	26.59 (3.90)	26.77 (3.77)	26.40 (4.06)	.674
Sex, No. (%)				.816
Female	29 (36.3)	14 (35.0)	15 (37.5)	
Male	51 (63.8)	26 (65.0)	25 (62.5)	
Has children, No. (%)	66 (82.5)	36 (90.0)	30 (75.0)	.077
Educational level, No. (%)				< .001
Primary education	30 (37.5)	24 (60.0)	6 (15.0)	
Secondary education	36 (45.0)	12 (30.0)	24 (60.0)	
University education	14 (17.5)	4 (10.0)	10 (25.0)	
Employment status, No. (%)				.025
Employed	27 (33.8)	8 (20.0)	19 (47.5)	
Retired	45 (56.3)	28 (70.0)	17 (42.5)	
Unemployed	8 (10.0)	4 (10.0)	4 (10.0)	
Married, No. (%)	58 (72.5)	32 (80.0)	26 (65.0)	.133
Clinical factors				
Surgical risk, No. (%)				.107
Low	24 (30.0)	8 (20.0)	16 (40.0)	
Normal	36 (45.0)	18 (45.0)	18 (45.0)	
High	20 (25.0)	14 (35.0)	6 (15.0)	

Characteristic	Overall (N = 80)	Booklet-Based Rehabilitation (n = 40)	Telerehabilitation (n = 40)	P
Demographic factors				
Tumor location, No. (%)				.660
Rectum	22 (27.5)	9 (22.5)	13 (32.5)	
Right colon	36 (45.0)	20 (50.0)	16 (40.0)	
Left colon	16 (20.0)	7 (17.5)	9 (22.5)	
Other	6 (7.5)	4 (10.0)	2 (5.0)	
Study timing				
Days between assessments, mean (SD)	16.24 (7.61)	16.00 (6.63)	16.48 (8.56)	.830

Table 2
Clinical Outcomes by Group and Assessment Time, With Adjusted Between-Group Effects

Outcome / Assessment	Booklet-Based Rehabilitation (n = 40)	Telerehabilitation (n = 40)	Adjusted P[a]	Effect Size[b]
Functional capacity				
6MWT, m			.180	.02
T1	497.88 (67.72)	531.33 (68.02)		
T2	528.85 (77.99)	575.70 (72.66)		
T3	508.88 (67.55)	545.27 (65.37)		
T4	542.55 (71.67)	592.15 (67.23)		
Functional mobility				
TUG, s			.807	< .01
T1	8.52 (1.79)	7.41 (1.73)		
T2	7.88 (1.58)	6.77 (1.53)		
T3	8.20 (1.71)	7.61 (1.67)		
T4	7.48 (1.56)	6.59 (1.48)		
Pulmonary function				
FVC, L			.239	.02
T1	2.89 (1.08)	3.43 (1.05)		
T2	2.84 (1.05)	3.48 (0.97)		
T3	2.76 (1.02)	3.46 (0.99)		
T4	2.91 (1.08)	3.45 (1.02)		
FEV_1, L			.452	.01
T1	2.07 (0.90)	2.52 (0.76)		
T2	2.10 (0.83)	2.53 (0.88)		
T3	1.99 (0.76)	2.65 (0.93)		
T4	2.11 (0.90)	2.64 (0.93)		
Physical activity				

Outcome / Assessment	Booklet-Based Rehabilitation (n = 40)	Telerehabilitation (n = 40)	Adjusted P[a]	Effect Size[b]
Functional capacity				
IPAQ-SF total, MET-min/week			.446	.01
T1	1751.05 (1344.04)	1944.54 (1642.33)		
T2	1677.31 (1460.11)	1807.34 (1356.75)		
T3	1285.79 (981.07)	1475.25 (1011.78)		
T4	1445.97 (1122.73)	1883.60 (1369.06)		
Sitting time, min/day			.141	.03
T1	336.63 (142.58)	289.13 (127.44)		
T2	354.13 (159.30)	277.13 (118.38)		
T3	353.88 (149.90)	324.88 (122.36)		
T4	340.50 (137.66)	280.88 (126.88)		

Abbreviations: 6MWT, 6-minute walk test; FEV_1, forced expiratory volume in 1 second; FVC, forced vital capacity; IPAQ-SF, International Physical Activity Questionnaire-Short Form; MET, metabolic equivalent task; TUG, Timed Up and Go. T1, baseline before prehabilitation; T2, post-prehabilitation; T3, pre-rehabilitation; T4, post-rehabilitation. Data are mean (SD).

[a]Adjusted **P** values and effect sizes are from analysis of covariance models comparing groups at T4, adjusted for the corresponding baseline (T1) value and age.

[b]**Effect sizes** are expressed as partial eta squared (ηp^2).

Table 3
Adherence Outcomes

Outcome	Booklet-Based Rehabilitation	Telerehabilitation	P	Effect Size[a,b]
Adherence (n = 33 per group)				
Prehabilitation period (T1-T2)				
Days available	16.06 (7.54)	16.06 (8.83)	.611	.06[a]
Days completed	8.27 (5.33)	11.27 (8.36)	.266	.14[a]
Available days completed, %	52 (30)	70 (29)	.003	.36[a]
Adherence level			.218	.26[b]
Level 0, No. (%)	6 (18.2)	3 (9.1)		
Level 1, No. (%)	10 (30.3)	5 (15.2)		
Level 2, No. (%)	6 (18.2)	7 (21.2)		
Level 3, No. (%)	11 (33.3)	18 (54.5)		
Postoperative rehabilitation period (T3-T4)				
Days available	29.36 (2.64)	31.24 (3.46)	.050	—
Days completed	15.80 (9.38)	21.61 (9.12)	.007	.33[a]
Available days completed, %	53.2 (29.9)	69.5 (29.1)	.006	.34[a]
Adherence level			.187	.27[b]
Level 0, No. (%)	6 (18.2)	3 (9.1)		
Level 1, No. (%)	10 (30.3)	5 (15.2)		
Level 2, No. (%)	6 (18.2)	6 (18.2)		
Level 3, No. (%)	11 (33.3)	19 (57.6)		
Overall adherence				
Total completed days	24.06 (13.49)	32.88 (15.71)	.028	.27[a]
Overall adherence, %	52.8 (29.4)	69.6 (29.2)	.002	.37[a]
Overall adherence level			.218	.26[b]

Outcome	Booklet-Based Rehabilitation	Telerehabilitation	P	Effect Size[a,b]
Adherence (n = 33 per group)				
Prehabilitation period (T1-T2)				
Level 0, No. (%)	6 (18.2)	3 (9.1)		
Level 1, No. (%)	10 (30.3)	5 (15.2)		
Level 2, No. (%)	6 (18.2)	7 (21.2)		
Level 3, No. (%)	11 (33.3)	18 (54.5)		

Abbreviations: Data are mean (SD) or No. (%), as indicated. [a] Effect sizes are r for rank-based comparisons. [b] Effect sizes are Cramér's V for categorical adherence-level comparisons.

Primary Outcome

Age- and baseline-adjusted ANCOVA showed no significant between-group difference in 6MWT distance at T4 (F = 1.83; P = .180; partial η^2 = 0.02), and the sensitivity mixed-effects model showed no significant group-by-time interaction (P = .070). An exploratory age-adjusted comparison at T4 favored telerehabilitation (P = .046).

In the telerehabilitation group, 6MWT distance increased by 44.4 m (95% CI, 31.4 to 57.3; P < .001; d = 1.47) during prehabilitation, 46.9 m (95% CI, 35.2 to 58.6; P < .001; d = 1.71) during postoperative rehabilitation, and 60.8 m (95% CI, 44.1 to 77.6; P < .001; d = 1.55) from baseline to the end of rehabilitation. Corresponding increases in the booklet group were 31.0 m (95% CI, 18.0 to 43.9; P < .001; d = 1.02), 33.7 m (95% CI, 22.0 to 45.4; P < .001; d = 1.23), and 44.7 m (95% CI, 27.9 to 61.5; P < .001; d = 1.14).

Secondary Clinical Outcomes

Functional mobility. Adjusted ANCOVA showed no between-group difference in TUG (F = 0.06; P = .807; partial η^2 < 0.01). In the mixed-effects model, time was significant (F = 29.82; P < .001), but group (F = 2.92; P = .091) and group-by-time interaction (F = 1.90; P = .137) were not. An exploratory comparison favored telerehabilitation at T2 (P = .034). TUG improved within both groups, by 0.82 seconds (95% CI, 0.33 to 1.30; P < .001; d = 0.72) with telerehabilitation and 1.04 seconds (95% CI, 0.56 to 1.53; P < .001; d = 0.92) with the booklet.

Pulmonary function. FVC and FEV1 remained stable, with no significant between-group differences (FVC: P = .239, partial η^2 = 0.02; FEV1: P = .452, partial η^2 = 0.01) and no significant group, time, or group-by-time effects in mixed-effects models (all P > .05). An exploratory comparison showed higher FEV1 with telerehabilitation at T3 only (P = .048). Age was associated with both outcomes (P < .001), and within-group changes were not significant (P > .05).

Physical activity. No significant between-group differences were observed in weekly physical activity (P = .446; partial η^2 = 0.01), sitting time (P = .141; partial η^2 = 0.03), or physical activity categories at any assessment (all P > .05). Within the telerehabilitation group, physical activity increased by 408.4 MET-min/week during postoperative rehabilitation (95% CI, 111.7 to 705.0; P = .002; r = 0.55) and sitting time decreased by 44.0 min/day (95% CI, − 70.6 to − 17.4; P < .001; d = 0.36), with no significant changes in the booklet group.

Adherence. Analyses included 66 participants with monitoring data. During prehabilitation, whose duration was similar between groups, the telerehabilitation group completed a higher percentage of prescribed days (70% ± 29% vs 52% ± 30%; P = .003; r = 0.36), although the number of completed days did not differ significantly (11.27 ± 8.36 vs 8.27 ± 5.33; P = .266). During postoperative rehabilitation, telerehabilitation participants completed more days (21.61 ± 9.12 vs 15.80 ± 9.38; P = .007; r = 0.33) and had higher adherence (69.5% ± 29.1% vs 53.2% ± 29.9%; P = .006; r = 0.34). Across the intervention, they accumulated more monitored days (32.88 ± 15.71 vs 24.06 ± 13.49; mean difference, 8.82 days; 95% CI, 1.61 to 16.02; P = .028) and had higher overall adherence (69.6% ± 29.2% vs 52.8% ± 29.4%; mean difference, 16.8 percentage points; 95% CI, 2.4 to 31.2; P = .002; r = 0.37). Adherence-category distributions did not differ significantly, although high adherence was more frequent (54.5% vs 33.3%) and nonadherence less frequent (9.1% vs 18.2%) with telerehabilitation.

Satisfaction and usability. Satisfaction was higher with telerehabilitation at T4 (P = .044; r = 0.23) but not at T2 (P = .308; r = 0.11), and did not change significantly between T2 and T4 in either group (telerehabilitation: P = .564, r = 0.09; booklet: P = .058, r = 0.30). Among 33 telerehabilitation participants with usability data, total TUQ scores increased from 6.24 ± 0.18 at T2 to 6.68 ± 0.14 at T4 (P < .001; d = 2.73), effectiveness from 6.24 ± 0.27 to 6.66 ± 0.23 (P < .001; d = 1.66), and ease of use from 6.30 ± 0.53 to 6.97 ± 0.17 (P < .001; d = 1.70).

Safety. No exercise-related adverse events were reported in either group.

DISCUSSION

In this RCT, asynchronous telerehabilitation did not produce a significant incremental improvement in 6MWT distance compared with booklet-based active rehabilitation providing the same principal exercise and educational content, and no significant between-group effects were observed for TUG, pulmonary function, or self-reported physical activity. Both groups nevertheless demonstrated substantial functional improvement across the perioperative period. Telerehabilitation was associated with higher recorded adherence, greater end-of-program satisfaction, and favorable usability among platform users.

The active comparator is central to interpreting these findings. Most colorectal cancer trials compared perioperative rehabilitation with usual care or with rehabilitation delivered at different perioperative stages [9–13], and syntheses highlight substantial heterogeneity in intervention composition, supervision, duration, patient characteristics, and outcome timing [14, 15]. Evidence for home-based prehabilitation is particularly uncertain: a recent meta-analysis found a 6MWT benefit that lost

significance in sensitivity analysis [31], although pilot trials have reported functional gains [32]. In contrast, both groups in the present trial received structured exercise, respiratory training, and perioperative education. This content-matched design therefore addressed a different question: whether digital monitoring, reminders, individualized progression, and asynchronous physiotherapist support add benefit beyond the rehabilitation content itself. The absence of a between-group effect should consequently be interpreted in the context of two active rehabilitation strategies rather than as evidence against perioperative rehabilitation.

Participants were functionally independent with relatively preserved walking capacity at enrollment, and within-group changes describe recovery under structured rehabilitation but do not establish comparative efficacy. Because neither the prespecified adjusted comparison nor the sensitivity analysis was significant, the exploratory T4 comparison favoring telerehabilitation should be interpreted cautiously, even though differences greater than approximately 19 m are considered clinically relevant after colorectal resection [5]. As a superiority trial, the nonsignificant primary result does not establish equivalence or noninferiority.

Secondary outcomes were generally consistent with the primary finding. TUG improved in both groups without significant between-group or group-by-time effects, and FVC and FEV1 remained stable. Preserved baseline functional and respiratory status may have limited detectable improvement, and perioperative rehabilitation studies have generally reported more consistent effects on functional performance than on physiologic measures [4, 30]; the isolated exploratory FEV1 difference at T3 does not modify these findings. Similarly, within-group increases in physical activity and reductions in sitting time with telerehabilitation were not supported by between-group differences and should be considered exploratory. Surgical recovery, temporary activity restrictions, altered routines, and the short intervention period may constrain habitual free-living activity, and the IPAQ-SF, which captures activity beyond prescribed rehabilitation, may be relatively insensitive to differences in intervention delivery.

Adherence was the clearest implementation-related difference, being higher with telerehabilitation during both prehabilitation and postoperative rehabilitation. Digital monitoring, reminders, activity tracking, and asynchronous professional communication may facilitate engagement by increasing the visibility of prescribed activities and providing continuous support [17–19], consistent with ASCO guidance supporting individualized asynchronous interventions, including automated reminders [22]. Qualitative evidence from cancer telerehabilitation identifies connection with physiotherapists and accountability to a routine as drivers of engagement [33], consistent with patient-reported determinants of prehabilitation adherence [34]. However, adherence was recorded electronically in one group and with paper diaries in the other; differences in recall, missing entries, completeness, and recording behavior may have contributed, and digital monitoring itself may influence behavior. Recorded adherence should therefore be regarded primarily as an implementation outcome rather than a fully objective or interchangeable measure of exercise exposure, and the absence of a corresponding 6MWT benefit illustrates that greater engagement does not necessarily translate into superior functional recovery.

Satisfaction favored telerehabilitation at the end of postoperative rehabilitation but not at T2, suggesting that digital support may become more relevant during postoperative recovery, when independent home rehabilitation may be more demanding. These findings remain exploratory, and high TUQ scores describe perceived usability among enrolled digital users without establishing comparative acceptability or generalizability to patients with limited digital literacy or technology access [18, 19].

Taken together, the principal value of asynchronous telerehabilitation may concern delivery rather than exercise content. For functional capacity, access to structured and appropriately progressed exercise may matter more than delivery technology, whereas asynchronous digital delivery may add value for monitoring, adherence, continuity, and potentially accessibility. Clinically, these findings support a pragmatic rather than technology-centered approach: where supervised services are difficult to access, asynchronous telerehabilitation may extend professional support into the home while preserving structured exercise prescription, but digital delivery alone should not be assumed to improve functional recovery. Future trials should determine which patients benefit most from digital monitoring, whether adherence gains are sustained beyond the intervention, and whether objective activity monitoring, earlier postoperative support, or integrated nutritional support [35] can convert implementation advantages into clinically meaningful functional outcomes.

Limitations

First, this single-center trial may limit generalizability across surgical pathways, health care systems, and patient populations. Second, eligibility required functional independence and an internet-enabled device, limiting applicability to frailer, more functionally impaired, or digitally underserved patients. Third, prehabilitation duration depended on surgical scheduling, and short preoperative windows constrain prehabilitation delivery in routine pathways [35, 36]; moreover, structured postoperative rehabilitation began approximately 21 days after surgery, following clinical review and suture removal. Although this reflected the predefined pathway and did not replace routine early mobilization or other perioperative care, it may have limited the intervention's influence on early postoperative functional decline, and outcome timing may affect detectable effects [15]. Fourth, adherence was measured with different methods across groups, creating potential differential ascertainment, and adherence analyses were restricted to participants with monitoring data and should be distinguished from ITT effectiveness analyses. Fifth, groups differed at baseline in age, educational level, and employment status; only age was included in adjusted models, so residual confounding is possible, particularly for adherence and patient-experience outcomes. Sixth, the amendment changing the primary outcome was submitted to the ethics committee before recruitment began but was approved on 11 September 2024, shortly after enrollment started and before any outcome data were available; postoperative complications (Clavien–Dindo) have not yet been analyzed and will be reported separately. Finally, participants and the treating physiotherapist could not be masked, maintenance of assessor masking was not formally tested, and patient-reported outcomes may reflect expectations. Follow-up was limited to the perioperative period, precluding conclusions about longer-term outcomes.

CONCLUSION

In adults undergoing colorectal cancer surgery, asynchronous telerehabilitation did not provide a significant incremental benefit in short-term functional recovery compared with booklet-based active rehabilitation containing the same principal exercise and educational content. Telerehabilitation was associated with higher recorded adherence, greater end-of-program satisfaction, and favorable usability among platform users, suggesting that asynchronous digital support may enhance engagement with structured home rehabilitation without necessarily improving short-term functional outcomes. Multicenter studies with longer follow-up are needed to determine whether improved monitoring, adherence, and accessibility translate into clinically meaningful functional or longer-term benefits.

Abbreviations

• **6MWT**
6-minute walk test
• **ASCO**
American Society of Clinical Oncology
• **RCT**
randomized clinical trial
• **CEICA**
Clinical Research Ethics Committee of Aragón
• **CONSORT**
Consolidated Standards of Reporting Trials
• **ASA**
American Society of Anesthesiologists
• **T1**
baseline assessment before prehabilitation
• **T2**
assessment on the day before surgery after prehabilitation
• **T3**
postoperative assessment before rehabilitation
• **T4**
assessment after postoperative rehabilitation
• **TUG**
Timed Up and Go
• **FVC**
forced vital capacity
• **FEV1**
forced expiratory volume in 1 second
• **IPAQ-SF**
International Physical Activity Questionnaire-Short Form

• **TUQ**
Telehealth Usability Questionnaire
• **SD**
standard deviation
• **ITT**
intention-to-treat
• **LOCF**
last observation carried forward
• **ANCOVA**
analysis of covariance
• **ANOVA**
analysis of variance
• **CI**
confidence interval
• **MET**
metabolic equivalent task

STATEMENTS AND DECLARATIONS

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Competing interests

Sandra Calvo participated as a researcher in the European project in which the HEFORA platform was developed. She holds no financial or intellectual property interest in the platform. The remaining authors have no relevant financial or non-financial interests to disclose.

Author contributions

Conceptualization: JMB-B, CJ-S, SC; Methodology: JMB-B, CJ-S, BC-P, JLB-L, SC; Investigation: JMB-B, NB-dlC, LLR-E, JLB-L; Formal analysis: CJ-S; Data curation: CJ-S, SC; Project administration: CJ-S, SC; Funding acquisition: CJ-S, SC; Supervision: CJ-S, SC; Writing – original draft: JMB-B, CJ-S, SC; Writing – review and editing: all authors. All authors read and approved the final manuscript and agree to be accountable for the work.

Data availability

Deidentified participant-level data, the data dictionary, the study protocol, and the SPSS analysis syntax are available from the corresponding author upon reasonable request, subject to participant consent and applicable ethical, institutional, and data-protection requirements.

Ethics approval

The study was conducted in accordance with the Declaration of Helsinki and approved by the Clinical Research Ethics Committee of Aragón (CEICA; PI23/557) on 20 December 2023.

Consent to participate

Written informed consent was obtained from all individual participants included in the study.

Consent to publish

Not applicable. The manuscript contains no identifiable individual data.

Clinical trial registration

ClinicalTrials.gov NCT06593678. Registered 29 August 2024.

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Figures

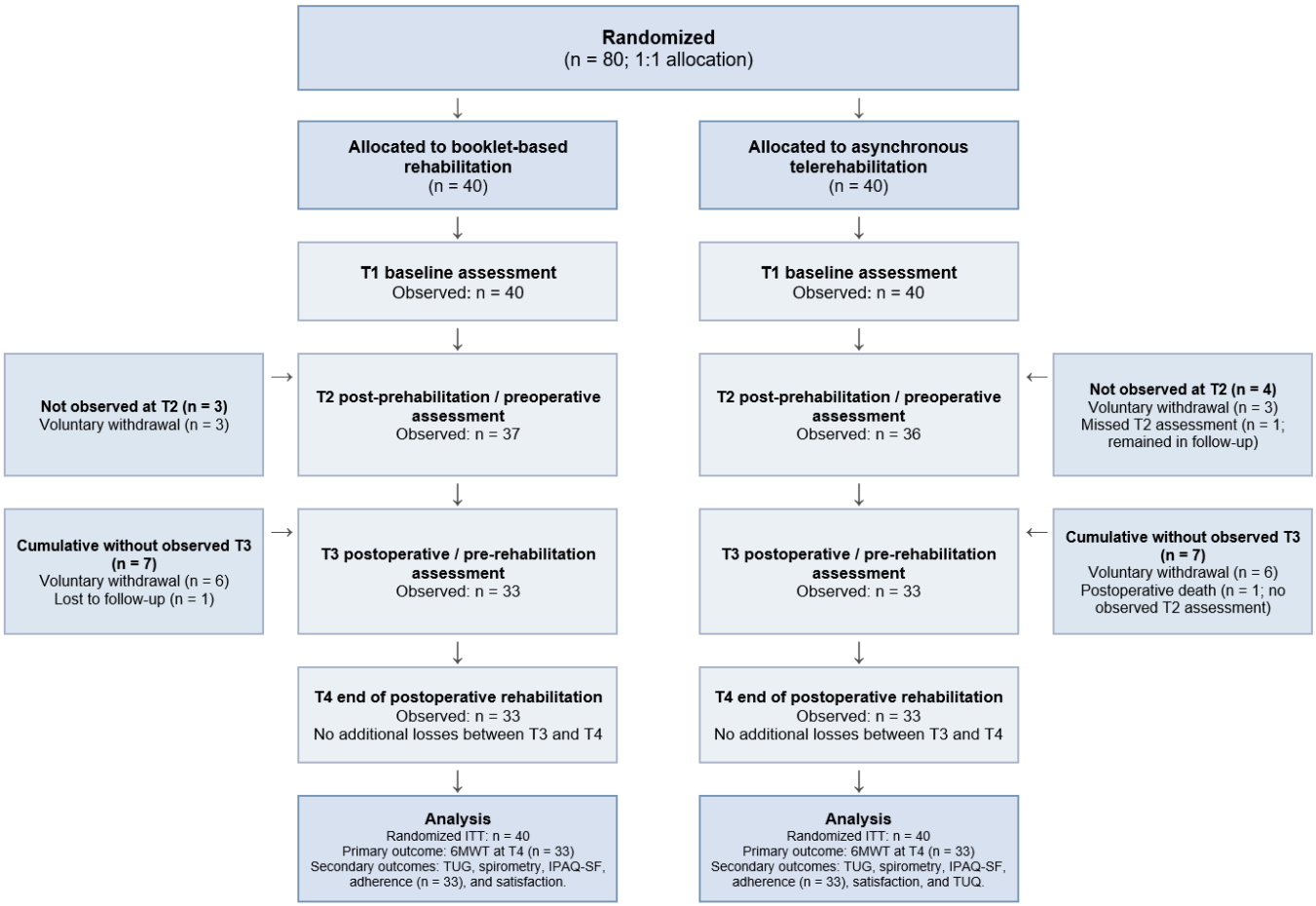


Figure 1

CONSORT participant flow. T1, baseline before prehabilitation; T2, post-prehabilitation / preoperative assessment; T3, approximately 21 days after surgery before structured postoperative rehabilitation; T4, after 4 weeks of postoperative rehabilitation; 6MWT, 6-minute walk test; TUG, Timed Up and Go; IPAQ-SF, International Physical Activity Questionnaire-Short Form; TUQ, Telehealth Usability Questionnaire; ITT, intention-to-treat.