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RESEARCH ARTICLE

Comparison of Early Outcomes of Video-Assisted Telerehabilitation and Traditional Exercise Program after Anterior Cruciate Ligament Surgery

Ön Çapraz Bağ Cerrahisi Sonrası Video Destekli Telerehabilitasyon ve Geleneksel Egzersiz Programının Erken Dönem Sonuçlarının Karşılaştırılması

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ABSTRACT

Objective: This prospective, randomized and controlled study aimed to determine the extent of changes in early-term outcomes following anterior cruciate ligament (ACL) reconstruction when tele-rehabilitation is applied optimally, comparing to traditional rehabilitation.

Materials and Methods: The study included 24 patients with anterior cruciate ligament rupture who presented to our clinic before having their first isolated ACL reconstruction on the affected extremity. Participants were randomly divided into two groups: a traditional rehabilitation group and a tele-rehabilitation group. Both groups followed the same rehabilitation program consisting of daily home exercises for four weeks. The tele-rehabilitation group received a written and illustrated rehabilitation program, which was also verbally explained and followed by online standard video access. The traditional group received the same written and illustrated program, which was explained verbally, but without video access. Tests were conducted at three different times. Exercise programs were administered on the first day post-surgery and following the mid-test at the second week post-surgery.

Results: Significant differences were observed between the two groups in outcomes of ACL Quality of Life Questionnaire, Tegner Activity Scale, satisfaction survey values, active flexion and extension range of motion measurements, walking parameters, hamstring average torque values, and proprioception at 15° ($p<0.05$). No significant differences were found in other measurement parameters ($p>0.05$).

Conclusion: To conclude, tele-rehabilitation yielded positive early-term results following ACL surgery. This suggests that tele-rehabilitation can be a valuable alternative for early-term rehabilitation in cases where in-clinic rehabilitation is not available or hospital access is restricted.

Keywords: Tele-rehabilitation, anterior cruciate ligament, gait analysis, proprioception, muscle strength

ÖZ

Amaç: Bu prospektif, randomize ve kontrollü çalışmada ön çapraz bağ (ÖÇB) rekonstrüksiyonu sonrası hasta uyumunun optimal olduğu şekilde uygulanması halinde telerehabilitasyonun geleneksel rehabilitasyona kıyasla erken dönem sonuçlarda ne düzeyde bir değişiklik meydana getirdiğini belirlemek amaçlandı.

Gereç ve Yöntem: Çalışmaya, ÖÇB rüptürü geçirip etkilenmiş ekstremiteden ilk kez izole rekonstrüksiyon yapılmadan önce kliniğimize başvuran 24 hasta alındı. Eşleştirilmiş randomizasyon yöntemi kullanılarak, katılımcılar geleneksel ve telerehabilitasyon gruplarına ayrıldı. Her iki grup da müdahale grubu olmak üzere dört hafta ve haftanın her günü evde aynı rehabilitasyon programını uyguladı. Telerehabilitasyon grubundaki hastalara rehabilitasyon programı yazılı, resimli olarak verildikten ve sözlü olarak anlatıldıktan sonra çekilen standart videoya internet erişimleri sağlandı. Geleneksel grup ise rehabilitasyon programını yazılı, resimli olarak aldı ve program sözlü olarak anlatıldı. Her iki grupta yer alan 24 hastaya cerrahi öncesi ikinci gün (pre-test), cerrahi sonrası ikinci hafta (mid-test) ve cerrahi sonrası dördüncü hafta (post-test) olmak üzere üç kez testler uygulandı. Cerrahi sonrası birinci gün yatak başında ve cerrahi sonrası ikinci hafta ölçümlerinin ardından egzersiz programına geçildi.

Bulgular: İki grubun opere ekstremite değerlerinin karşılaştırılmasında rehabilitasyon yönergelerinin etkisini değerlendiren grup*zaman incelemesi yapıldı. ÖÇBYK, TEGNER, memnuniyet anket değerleri, aktif fleksiyon ve ekstansiyon EHA ölçümleri, yürüyüş parametreleri, hamstring ortalama tork değeri ve 15°'de propriyosepsiyon ölçümlerinde anlamlı fark saptanırken ($p<0.05$), TAMPA ve LYSHOLM anket değerleri,

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pasif fleksiyon EHA ölçümleri, kuadriseps kuvvet değerleri, hamstring güç değerleri, denge ve 45°-75° propriyosepsiyon değerlerinde anlamlı fark gözlenmedi (p>0.05).

Sonuç: Kas-iskelet sistemi üzerine pozitif etkileri bildirilmiş telerehabilitasyonun, ÖÇB cerrahisi sonrası erken dönem sonuçlar üzerine olumlu gelişmeler sağladığı saptandı. Telerehabilitasyonun spor yaralanmaları sonrası cerrahi girişimin ardından klinikte rehabilitasyon alınamadığı ve/veya hastaneye erişimin sağlanamadığı durumlarda hastaların erken dönem rehabilitasyonlarına katkı sağlayabileceği gösterildi.

Anahtar Sözcükler: Telerehabilitasyon, ön çapraz bağ, yürüyüş analizi, propriyosepsiyon, kas kuvveti

INTRODUCTION

Rehabilitation following anterior cruciate ligament (ACL) reconstruction focuses on reducing pain, controlling edema, achieving full knee extension, increasing knee flexion, regaining quadriceps control, and restoring patellar mobilization. Early-stage exercises and biofeedback are used to combat quadriceps muscle inhibition. Strengthening exercises are performed to enhance motor control of the muscles around the knee. Exercises are carefully monitored to protect the graft. Weight-bearing exercises increase stability while reducing pain and providing satisfactory results. As the rehabilitation progresses, the goal is to improve knee stability and strength through proprioceptive training and functional activities [1-4].

Rehabilitation has evolved with innovative solutions like telerehabilitation, which enables patients to participate in rehabilitation from their homes, reducing hospital stays and costs. It offers an effective alternative during access challenges in remote areas and pandemic periods. Telerehabilitation provides a personalized approach and information about various strategies [5-7]. Research on the musculoskeletal system has demonstrated the benefits of telerehabilitation [8]. However, studies focusing on young patients and rehabilitation following sports surgery are limited, and a review of the literature reveals that very few studies have specifically addressed early-phase isokinetic evaluations and gait analysis. In this regard, the most distinctive feature of the present study is the quantitative assessment of both isokinetic muscle performance and gait patterns in young and active individuals during the early rehabilitation period following ACL reconstruction. Thus, the aim of this study is to evaluate the effectiveness of telerehabilitation not only through subjective outcomes but also with objective data. In this study, the early outcomes of telerehabilitation were comprehensively analyzed in comparison to traditional rehabilitation, expecting to provde a methodological contribution to the literature on telerehabilitation following sports surgery.

The hypothesis of the study is that a telerehabilitation program applied following ACL would be as effective as or more effective than a traditional face-to-face rehabilitation program in the early period.

MATERIAL AND METHODS

Study group: Patients presenting with an isolated anterior ACL rupture between February 2022 and December 2023, prior to their first isolated ACL reconstruction, were included. Ethical approval was obtained from the Ethics Committee of the Faculty of Medicine, Süleyman Demirel University (decision number 44, dated 11.02.2022).

Sample size calculation before the study: Using GPower v3.1.9.4 software and referencing a similar study, the minimum required sample size was determined as 20 patients (10 per group) with 90% power and a 5% type-1 error. To account for an anticipated 10% dropout rate, a total of 22 patients were planned for inclusion.

Inclusion and exclusion criteria: Eligible participants were aged between 18 and 40 years, and undergoing their first ACL reconstruction. Exclusion criteria included individuals under 18 or over 40 years of age, those who were requiring revision surgery, those with meniscal lesions or who had undergone meniscal surgery, and individuals with communication impairments that could affect their ability to complete survey responses.

Intervention groups and group determination: According to the study plan, 24 patients who underwent ACL surgery and did not meet the exclusion criteria were divided into two groups using a matched randomization method, namely the traditional group and the video group. Both groups performed home exercises every day for four weeks. The same rehabilitation program was applied to both groups during this period (Appendix 1). In the video group, patients received the rehabilitation program in written and illustrated form, which was verbally explained. Following this, they were granted access to standardized video recordings(https://www.youtube.com/watch?v=819c-EWk_6Ts,https://www.youtube.com/watch?v=TgbT-G8LN-sU).

The telerehabilitation protocol did not include any interactive feedback or live supervision. Instead, it was designed solely based on pre-recorded instructional videos. Patients were expected to perform the exercises independently by following the content provided in the videos, with no individualized adjustments or real-time monitoring throughout the program. The traditional group received the same written and illustrated program, which was explained verbally, but without video access. All 24 patients were given the exercise program on the first day postoperatively at bedside, and after measurements in the second week.

Applied assessment methods and timing: Evaluations were conducted at three time points: preoperatively (pre-test), postoperative week 2 (mid-test) and week 4 (post-test). The pre-test included the ACL Quality of Life Questionnaire, Tegner Activity Scale, Lysholm Knee Score, Tampa Scale of Kinesiophobia, range of motion (ROM) measurement, gait assessment, isometric strength evaluation, proprioception, and balance tests. The mid-test assessed ROM and gait. The post-test included a satisfaction questionnaire alongside all other assessments. Compliance was monitored through an 'Exercise Compliance Chart,' and data from patients who completed at least 220 of the 266 prescribed sessions were included in the analysis.

Tests and measurements used

ACL quality of life questionnaire (ACL-QOL): Assesses quality of life using 32 questions scored on a Visual Analog Scale (VAS), with higher scores indicating better outcomes [9,10].

Tegner activity scale: Rates activity level on a scale of 0-10, considering job performance and sports participation [11].

Lysholm knee score: Evaluates pain, instability, and function following ACL injury [12].

Tampa scale of kinesiophobia: A 17-item questionnaire assessing kinesiophobia, with higher scores indicating greater fear [13].

Satisfaction survey: A 5-item, 5-point Likert scale-based assessment measuring rehabilitation satisfaction (score range: 0-50).

Range of motion (ROM) measurement: Measured using a Universal Goniometer in the prone position [14].

Gait evaluation: Gait was evaluated using video recording and observational gait analysis. Video recording was chosen for its ease of application and the ability for repeated assessments in the clinic. Four-directional video recordings (front, back, left, right) were obtained using an iPhone 11 (Figure 1A). It was analyzed via Kinovea software using a 21-parameter scoring system for *Observational Gait Analysis* [15].

Isometric muscle strength test: As recommended in the literature, it was conducted at 60º knee flexion using an Isoforce isokinetic dynamometer [16] (Figure 1B).

Proprioception measurements: Evaluated via an isokinetic dynamometer at 15°, 45° and 75° knee angles [17] (Figure 1C).

Balance evaluation: Measured using the Flamingo Balance test, which required patients maintain a one-leg stance [18] (Figure 1D).

Flowchart of study participants: Out of 56 initially screened patients, exclusions included 20 patients who underwent additional procedures, four with different graft selections, one being underage, three being unfit for early rehabilitation, two lost in follow-up, and two with comorbidities. Ultimately, the study included 24 patients.

Statistical analysis

Data analysis was performed using IBM SPSS v26.0. Categorical variables were presented as counts and percentages, while numerical data were expressed as mean±SD or median (25^{th} -75^{th} percentile) based on normality assessment using Skewness-Kurtosis values and the Shapiro-Wilk test. Group comparisons were conducted using the Chi-Square test for categorical data, one-way ANOVA for parametric numerical data, and the Kruskal-Wallis test for non-parametric numerical data. A two-way Repeated Measures Mixed-Design ANOVA was employed to compare numerical data across test phases, with Bonferroni-corrected Tukey post-hoc analysis for subgroup comparisons. Statistical significance was set at p<0.05.

RESULTS

Participants' characteristics

Data of the 24 patients included in the study (Table 1) were analyzed, revealing no statistically significant differences between the study groups (p>0.05).

Table 1. Comparison of participants' data

Parmeter	Telehabilitation (T)	Traditional rehab (TR)	p
Age (yrs)$^{+}$	31.2±9.1	29.8±9.1	0.706
Height (cm)$^{+}$	179.4±7.4	176.5±7.1	0.333
BW (kg)$^{+}$	80.6±11.6	82.4±10.5	0.688
BMI (kg/m^2)$^{+}$	25.1±3.3	26.4±2.6	0.273
Gender M/F (% (n))*	75 (9) / 25 (3)	83.3 (10) / 16.7 (2)	1
Dominant side R/L (% (n))*	100 (12) / 0 (0)	91.7 (11) / 8.3 (1)	1
Affected side R/L (% (n))*	58.3 (7) / 41.7 (5)	58.3 (7) / 41.7 (5)	1
ACL injury time (mo)$^{\#}$	33.3±40.9	34.6±51.1	0.729

Data as $\bar{X}$±SS. Chi-square test, $^{+}$: independent samples T-test, $^{\#}$: Mann Whitney U test; BW: body weight, BMI: body mass index, rehab.: rehabilitation, n: sample size, p≤0.05 is statistically significant.

Comparison of survey results

The results from the initial (T-I) and final (F) tests of the following surveys were evaluated: ACL-QOL (T-I: 34.2±12.4, F: 53.5±15.5 vs. TR-I: 39.8±15.1, F: 38.4±13.1);

TAMPA (T-I: 42.4±6.1, F: 37.3±6.3 vs. TR-I: 42.3±8.6, F: 37.5±6.9);

LYSHOLM (T-I: 73.5±10.7, F: 81.3±9.9 vs. TR-I: 59.2±16.9, F: 72.3±12.3);

TEGNER (T-I: 4.08±0.99, F: 5.33±1.87 vs. TR-I: 4.16±0.38, F: 2.83±1.99).

When examining the impact of surgical intervention and regular rehabilitation over a 4-week period, regardless of group allocation, statistically significant differences were found in ACL-QOL, TAMPA, and LYSHOLM scores between the initial and final tests (F(1-22)= 6.650, p<0.05, ηp^2=0.232; F(1-22)= 33.486, p<0.05, ηp^2=0.604; and F(1-22)= 7.852, p<0.05, ηp^2=0.263, respectively). However, TEGNER scores did not reveal a significant difference (F(1-22)= 0.016, p>0.05, ηp^2=0.001).

Furthermore, when evaluating the effects of the applied rehabilitation protocols, ACL-QOL and TEGNER values were statistically significantly different (F(1-22)= 8.908, p<0.05, ηp^2=0.288 and F(1-22)= 15.477, p<0.05, ηp^2=0.413). Conversely, TAMPA and LYSHOLM results did not present significant differences (F(1-22)= 0.038, p>0.05, ηp^2=0.002 and F(1-22)= 0.506, p>0.05, ηp^2=0.023). When comparing satisfaction survey results between both groups, the T group had scores of 48.3±1.6, while the TR group had scores of 40.1±3.3. The difference between the groups was statistically significant (p<0.05).

Comparison of range of motion measurements

The results for active flexion, passive flexion, and extension, independent of the groups to which patients belonged, revealed statistically significant differences (F(2-44)= 89.121, p<0.05, ηp^2=0.802; F(2-44)= 39.148, p<0.05, ηp^2=0.640 and F(2-44)= 26.501, p<0.05, ηp^2=0.546, respectively) (Table 2).

Table 2. Comparison of joint range of motion measurements among participants

Parameter		Telehabilitation (T)	Traditional rehab (TR)	p
Active flexion	Initial test	130.6±7.5	127.7±5.8	$0.001^{\dagger}$
	Mid test	108.5±10.3	67.1±22.6	
	Final test	133.8±7.4	108.8±8.8	
		p: $0.001^{\ddagger}$		
Passive flexion	Initial test	148.3±9.4	133.1±28.9	$0.073^{\dagger}$
	Mid test	121.3±12.3	85.4±18.9	
	Final test	151.3±8.6	120.0±9.3	
		p: $0.001^{\ddagger}$		
Extension	Initial test	1.25±1.54	0.66±1.49	$0.001^{\dagger}$
	Mid test	1.75±0.96	8.25±3.64	
	Final test	0.33±0.88	6.58±3.14	
		p: $0.001^{\ddagger}$		

Data as X̄±SS, rehab: rehabilitation, †: test x group p-value, ‡: intra-group p-value., p≤0.05 is considered statistically significant.

Table 3. Comparison of hip parameters in participants

Parameter		Telehabilitation (T)	Traditional rehab (TR)	p
HFMP	Initial test	-0.25±0.45	0±0	$0.165^{\dagger}$
	Mid test	-0.25±0.45	-0.33±0.88	
	Final test	0±0	-0.16±0.57	
		p: $0.168^{\ddagger}$		
HETSP	Initial test	0±0	0.16±0.38	$0.007^{\dagger}$
	Mid test	-0.08±0.28	-0.66±0.88	
	Final test	0±0	0.00±0.42	
		p: $0.001^{\ddagger}$		
HALRP	Initial test	-0.50±0.52	-0.50±0.67	$0.007^{\dagger}$
	Mid test	-0.41±0.51	-1.41±0.66	
	Final test	-0.25±0.45	-0.66±0.77	
		p: $0.006^{\ddagger}$		

Data as X̄±SS, rehab: rehabilitation, †: test x group p-value, ‡: within-group p-value, HFMP: hip flexion at the midswing phase, HETSP: hip extension at the terminal stance phase, HALRP: hip adduction at the loading response phase. p≤0.05 is considered statistically significant.

Additionally, when examining the overall effect, significant statistical differences were found between the results of active flexion and extension (F(2-44)= 17.265, p<0.05, ηp^2=0.440 and F(2-44)= 25.727, p<0.05, ηp^2=0.539). On the other hand, the results for passive flexion did not present a significant difference (F(2-44)= 2.781, p>0.05, ηp^2=0.112) (Table 2).

Comparison of gait parameters

Comparison of hip parameters: The results for hip flexion at the midswing phase, hip extension at the terminal stance phase, and hip adduction at the loading response phase were evaluated for each of the three tests. The values for hip extension at the terminal stance phase and hip adduction at the loading response phase displayed statistically significant differences, independent of the groups to which the patients belonged (F(2-44)= 8.649, p<0.05, ηp^2=0.282 and F(2-44)= 6.426, p<0.05, ηp^2=0.226). However, the value for hip flexion at the midswing phase did not reveal a significant difference (F(2-44)= 1.878, p>0.05, ηp^2=0.079) (Table 3).

Additionally, when examining the overall effect of measurements obtained at different times from participants across different groups, statistically significant differences were found for hip extension at the terminal stance phase and hip adduction at the loading response phase (F(2-44)= 5.626, p<0.05, ηp^2=0.204 and F(2-44)= 6.311, p<0.05, ηp^2=0.223). In contrast, the value for hip flexion at the midswing phase did not present a significant difference (F(2-44)= 1.878, p>0.05, ηp^2=0.079) (Table 3).

Comparison of knee parameters: The results for knee flexion at the initial contact phase, knee flexion at the loading response phase, knee flexion at the terminal stance phase, and knee flexion at the pre-swing phase were evaluated for each of the three tests. The values for knee flexion at the initial contact phase, knee flexion at the terminal stance phase, and knee flexion at the pre-swing phase displayed statistically significant differences, independent of the patient groups (F(2-44)= 13.369, p<0.05, ηp^2=0.378; F(2-44)= 42.838, p<0.05, ηp^2=0.661; and F(2-44)= 20.994, p<0.05, ηp^2=0.488, respecively). However, the value for knee flexion at the loading response phase did not reveal a significant difference (F(2-44)= 2.063, p>0.05, ηp^2=0.086) (Table 4).

Table 4. Comparison of knee parameters among participants

Parameters		Telehabilitation (T)	Traditional rehab (TR)	p
KFICP	Initial test	-0.41±0.51	-0.16±0.57	0.756†
	Mid test	0.33±0.65	0.83±1.02	
	Final test	-0.29±0.55	0.25±0.62	
		p: 0.001‡		
KFLRP	Initial test	-0.25±0.45	-0.08±0.66	0.001†
	Mid test	-0.08±0.28	-0.66±0.65	
	Final test	0±0	-0.66±0.65	
		p: 0.139‡		
KFTSP	Initial test	0.33±0.49	0.33±0.49	0.001†
	Mid test	0.91±0.51	2±0	
	Final test	0.33±0.49	1.25±0.62	
		p: 0.001‡		
KFPP	Initial test	-0.16±0.38	0±0	0.001†
	Mid test	-0.33±0.65	-1.41±0.99	
	Final test	-0.08±0.28	-0.33±0.49	
		p: 0.001‡		

Data as $\bar{X}$±SS, rehab: rehabilitation; †: test x group p-value, ‡: within-group p-value. KFICP: knee flexion at the initial contact phase, KFLRP: knee flexion at the loading response phase, KFTSP: knee flexion at the terminal stance phase, KFPP: knee flexion at the pre-swing phase. p≤0.05 is considered statistically significant.

Additionally, when examining the overall effect of measurements at different times from participants across different groups, statistically significant differences were found for knee flexion at the loading response phase, knee flexion at the terminal stance phase, and knee flexion at the pre-swing phase (F(2-44)= 8.938, p<0.05, ηp^2=0.289; F(2-44)= 11.387, p<0.05, ηp^2=0.341; and F(2-44)= 11.738,p<0.05, ηp^2=0.348, respectively). In contrast, the value for knee flexion at the initial contact phase did not display a significant difference (F(2-44)=0.281, p>0.05) (Table 4).

Comparison of foot and temporal parameters: The results for ankle plantarflexion at the pre-swing phase, ankle dorsiflexion at the initial contact phase, and various temporal parameters such as foot angle, step width, and velocity were evaluated for each of the three tests. The values for ankle plantarflexion at the pre-swing phase exhibited statistically significant differences, independent of the patient groups (F(2-44)= 16.500, p<0.05, ηp^2=0.429). In contrast, the values for ankle dorsiflexion at the initial contact phase and foot angle at the midstance phase did not reveal significant differences (F(2-44)= 0.688; p>0.05, ηp^2=0.030 and F(2-44)= 2.750, p>0.05, ηp^2=0.111). Additionally, when examining the overall effect of measurements at different times from participants across different groups, the value for ankle plantarflexion at the pre-swing phase remained statistically different (F(2-44)= 4.372, p<0.05, ηp^2=0.166). However, the values for ankle dorsiflexion at the initial contact phase and foot angle at the midstance phase did not display significant differences (F(2-44)= 2.062, p>0.05, ηp^2=0.086 and F(2-44)=0.001, p>0.05, ηp^2=0.001) (Table 5).

The values for step width and velocity displayed statistically significant differences, independent of the patient groups (F(2-44)= 14.889, p<0.05, ηp^2=0.348 and F(2-44)= 22.039, p<0.05, ηp^2=0.500). Furthermore, when examining the overall effect of measurements obtained at different times from participants across different groups, the value for step width revealed significant differences (F(2-44)= 5.117, p<0.05, ηp^2=0.189). However, the velocity value did not present significant differences (F(2-44)= 2.031, p>0.05, ηp^2=0.085) (Table 5).

Comparison of iisometric test results for quadriceps and hamstring muscles

The quadriceps values obtained, independent of the patient groups, revealed statistically significant differences (F(1-22)= 119.800, p<0.05, ηp^2=0.845; F(1-22)= 82.762, p<0.05, ηp^2=0.790; and F(1-22)= 100.428, p<0.05, ηp^2=0.820). Additionally, when examining the overall effect of measurements obtained at different times from participants across different groups, none of the quadriceps values revealed significant differences (F(1-22)= 0.062, p>0.05, ηp^2=0.003; F(1-22)= 1.365, p>0.05,

ηp^2=0.058; and F(1-22)= 0.030, p>0.05, ηp^2=0.001) (Table 6).

Table 5. Comparison of foot and temporal parameters among participants

Parameters		Telehabilitation (T)	Traditional rehab (TR)	p
APPP	Initial test	0.00±0.42	-0.25±0.45	0.019†
	Mid test	-0.41±0.51	-1.58±0.79	
	Final test	-0.08±0.28	-0.66±0.65	
		p: 0.001‡		
ADICP	Initial test	-0.08±0.28	0±0	0.139†
	Mid test	0±0	-0.25±0.62	
	Final test	0±0	-0.08±0.28	
		p: 0.508‡		
FAMP	Initial test	-0.08±0.28	0.00±0.42	1†
	Mid test	-0.25±0.45	-0.16±0.71	
	Final test	-0.08±0.28	0.00±0.42	
		p: 0.075‡		
Step width	Initial test	20.0±0.0	19.5±0.8	0.010†
	Mid test	19.5±1.2	17.0±2.4	
	Final test	19.6±0.8	17.6±1.7	
		p: 0.001‡		
Velocity	Initial test	63.3±6.9	66.4±13.0	0.143†
	Mid test	50.8±9.2	46.6±12.8	
	Final test	68.3±5.9	60.4±8.2	
		p: 0.001‡		

Data as X̄±SS, rehab: rehabilitation; †: test x group p-value, ‡: within-group p-value. APPP: ankle plantarflexion at pre-swing phase, ADICP: ankle dorsiflexion at initial contact phase, FAMP: foot angle at midstance phase, step width (cm), velocity (m/s). p≤0.05 is considered statistically significant.

The hamstring values obtained, independent of the patient groups, also displayed significant differences (F(1-22)= 34.986, p<0.05, ηp^2=0.614; F(1-22)= 34.744, p<0.05, ηp^2=0.612; and F(1-22)= 41.407, p<0.05, ηp^2=0.653). Additionally, when examining the overall effect of measurements at different times from participants across different groups, the mean hamstring torque values yielded significant differences (F(1-22)= 5.204, p<0.05, ηp^2=0.191). However, peak hamstring torque/BW and mean power/BW values did not reveal significant differences (F(1-22)= 0.620, p>0.05, ηp^2=0.027; and F(1-22)= 0.022, p>0.05, ηp^2=0.001) (Table 6).

Table 6. Comparison of isometric test results for quadriceps and hamstring

Parameters		Telehabilitation (T)	Traditional rehab (TR)	p
Quadriceps mean torque (Nm)	Initial test	165.1±27.7	156.5±44.3	0.806†
	Final test	88.2±19.9	76.0±27.4	
		p: 0.001‡		
Quadriceps peak torque/BW (Nm/kg)	Initial test	2.71±0.60	2.03±0.64	0.255†
	Final test	1.58±0.31	1.16±0.54	
		p: 0.001‡		
Quadriceps mean power/BW (W/kg)	Initial test	1.36±0.27	1.22±0.38	0.863†
	Final test	0.72±0.19	0.60±0.33	
		p: 0.001‡		
Hamstring mean torque< (Nm)	Initial test	54.7±15.5	64.9±19.4	0.033†
	Final test	41.4±13.5	34.9±11.9	
		p: 0.001‡		
Hamstring peak torque/BW (Nm/kg)	Initial test	0.98±0.29	0.89±0.36	0.439†
	Final test	0.66±0.21	0.47±0.21	
(Nm/kg)		p: 0.001‡		
Hamstring mean power/BW (W/kg)	Initial test	0.65±0.21	0.61±0.29	0.884†
	Final test	0.30±0.17	0.24±0.17	
		p: 0.001‡		

Data as X̄±SS, rehab: rehabilitation †: test x group p-value, ‡: within-group p-value. BW: body weight. p≤0.05 is considered statistically significant.

Comparison of balance and proprioception measurements

The results from the initial (I) and final (F) tests of the following assessments were evaluated: Modified Flamingo Balance test (T-I: 0.66±0.88, F: 0.16±0.38 vs. TR-I: 1.66±2.18, F: 1.50±2.02); Passive Proprioception at 15° (T-I: 5.31±2.16, F: 3.73±1.02 vs. TR-I: 4.75±1.50, F: 5.44±1.21); Passive Proprioception at 45° (T-I: 6.56±2.15, 4.87±2.71 vs. TR-I: 7.31±2.23, F: 7.29±3.62). Values obtained for each measure did not reveal significant differences, regardless of patient groups ($F(1-22)= 0.693$, $p>0.05$, $\eta p^2=0.031$; $F(1-22)= 0.934$, $p>0.05$, $\eta p^2=0.041$; $F(1-22)= 0.730$, $p>0.05$, $\eta p^2=0.032$; and $F(1-22)= 0.877$, $p>0.05$, $\eta p^2=0.038$, respectively). Additionally, when examining the overall effect of measurements obtained at different times from participants across different groups, proprioception at 15° was found to be significantly different ($F(1-22)= 6.086$, $p<0.05$, $\eta p^2=0.217$). However, values for balance, proprioception at 45° and at 75° did not display significant differences ($F(1-22)= 0.173$, $p>0.05$, $\eta p^2=0.008$; $F(1-22)= 1.056$, $p>0.05$, $\eta p^2=0.046$; and $F(1-22)= 0.836$, $p>0.05$, $\eta p^2=0.037$, respectively).

Comparison of compliance scores

When comparing compliance percentages to exercise between the two groups, the Telerehabilitation group had a value of 94.8±2.9, while the TR group had a value of 92.1±2.5, with a significant difference ($p<0.05$).

DISCUSSION

In this randomized, controlled, prospective study, the effects of two different rehabilitation guideline implementation methods on early-term outcomes were examined over a one-month period following ACL surgery. It was demonstrated that patients in the telerehabilitation group displayed significantly better early-term outcomes in most evaluated parameters compared with those in the traditional (TR) group.

The positive effects of early-term rehabilitation after ACL surgery have been proven [1]. With the advancement of technology, methods such as telerehabilitation have started to be used in rehabilitation. Telerehabilitation reduces healthcare costs and facilitates access for patients living in remote areas [7]. It is known that telerehabilitation provides positive effects in treating the acute phase of diseases as an alternative to traditional face-to-face approaches. In a study by Dunphy and Gardner [19], a web-based survey was conducted on 100 patients who had undergone ACL reconstruction, and the benefits of telerehabilitation, including resource savings, improved access, enhanced learning and increased exercise compliance were identified. Consequently, telerehabilitation was found to be acceptable and beneficial for patients.

In our study, the ACL-QOL, Lysholm, and Tegner questionnaires were used to evaluate knee parameters. Statistical analyses revealed significant changes between the initial and final tests in the ACL-QOL and Tegner questionnaires, while no such changes were observed in the Lysholm questionnaire. This discrepancy may be due to the Lysholm questionnaire's focus on long-term outcomes, whereas the ACL-QOL and Tegner questionnaires also encompass short-term results. Therefore, since we are assessing early-term outcomes, the Lysholm questionnaire might not reveal differences between the groups. Additionally, no significant changes were detected between the initial and final tests in the TAMPA questionnaire, which is used for assessing kinesiophobia. This finding could be attributed to the focus of our study on early-term postoperative results. However, significant differences were found between the groups in the Satisfaction Questionnaire results, which assessed patient satisfaction with the rehabilitation guidelines.

Liao et al. [20] compared telerehabilitation and hospital-based rehabilitation in 30 patients after ACL reconstruction. The telerehabilitation group had higher IKDC and KOOS scores at the 3^{rd} and 6^{th} months. However, no significant differences were found between the two groups at the end of the follow-up period. One year later, the telerehabilitation group displayed a higher TEGNER score. The authors noted that telerehabilitation was superior in short-term outcomes. Lee et al. [21] compared video-supported telerehabilitation with clinic-based rehabilitation in 50 patients with knee osteoarthritis and found no significant difference in quality of life measures. In the study by Özlü et al. [22], involving office workers with chronic neck pain, the telerehabilitation group yielded significant improvement in quality of life scores. Although our study involved a different muscurehabilitation group are consistent with the literature, displaying favorable outcomes.

Regarding kinesiophobia, Özden et al. [23] investigated the effectiveness of telerehabilitation in chronic low back pain and found that kinesiophobia was significantly reduced in the telerehabilitation group. Similar results were obtained in the study by Tore et al. [24] involving patients with moderate and mild osteoarthritis. However, Ünlü et al. [25] found no significant changes in kinesiophobia scores in patients with lumbar disc herniation undergoing telerehabilitation. Studies focusing on early-term outcomes related to kinesiophobia are limited, and the available studies presenting early- and mid-term outcomes are conflicting.

In studies examining satisfaction, Özden et al. [23] found that satisfaction with the rehabilitation protocol was higher in the telerehabilitation group in their study on the effectiveness of telerehabilitation in chronic low back pain. Similarly, Fahey et al. [26] in their review noted that telemedicine is a cost-effective method that provides good clinical outcomes and high patient satisfaction in orthopedic surgeries. The results of our study support these findings.

In the present study, while significant differences were found in active flexion and extension values for ROM, no significant differences were observed in passive flexion values. Özlü et al. [22] who studied office workers with chronic neck pain, ROM values of the telerehabilitation group were found to be better comparing to other groups. De Berardinis et al. [27] investigated telerehabilitation following unicondylar knee arthroplasty and found significant improvements in ROM values. In a study by An et al. [28] on female patients with total knee arthroplasty, significant differences in ROM values were observed in the telerehabilitation group. Wicks et al.'s [29] meta-analysis concluded that telerehabilitation provides significant improvements in ROM values. Data from our study are consistent with these findings.

In our study, significant improvements were observed in all walking parameters. In a study by Kalron et al. [30], telerehabilitation was found to yield better results in walking parameters compared with home-based traditional rehabilitation in patients who underwent hip surgery. Wicks et al.'s [29] meta-analysis concluded that physiotherapist-managed telerehabilitation significantly improves walking performance in adults. Piqueras et al. [31] noted that telerehabilitation after total knee arthroplasty is as effective as clinic-based rehabilitation. Hamouzová et al. [32] found that telerehabilitation after hip arthroplasty yielded similar results to face-to-face rehabilitation. Results from the literature suggest that telerehabilitation for walking is superior to home-based rehabilitation and as effective as clinic-based rehabilitation. However, the results primarily involve elderly populations and do not cover other walking patterns. While our study's results align with the literature, it is valuable for addressing various walking patterns.

In the present study, only the average torque value of the hamstring for the operated limb was found to be significantly different, while other isometric strength values did not reveal significant differences. In a study by Russell et al. [33], comparing telerehabilitation and traditional rehabilitation groups with 65 total knee arthroplasty patients, similar results were obtained regarding quadriceps strength. An et al. [28] found positive effects of preoperative telerehabilitation on quadriceps strength in total knee arthroplasty patients. Nelson et al.'s study [34] comparing telerehabilitation with in-clinic face-to-face rehabilitation after total hip replacement found no significant differences in strength values. Piqueras et al. [31] also observed similar improvements in quadriceps and hamstring strength with clinic-based rehabilitation and telerehabilitation. While literature indicates that the effects of telerehabilitation on strength are similar to those of in-clinic face-to-face rehabilitation, results for home-based traditional rehabilitation are contradictory. The observed difference in hamstring strength in our study may be attributed to the higher active range of motion values in the telerehabilitation group. However, the lack of significant difference in quadriceps strength values could be due to low quadriceps control early after surgery.

We found no significant differences between the values obtained in balance measurements made with the modified flamingo test. In a study by Kalron et al. [30], home-based traditional rehabilitation and telerehabilitation methods were compared after total hip replacement, with no statistical differences observed in balance parameters between the groups. Nelson et al. [34] also found no difference in balance values between telerehabilitation and in-clinic face-to-face rehabilitation after total hip replacement. Tousignant et al.'s study [35], comparing telerehabilitation with home-based traditional rehabilitation after total knee arthroplasty, also found no significant difference in balance assessed by the Berg Balance Scale. Although different pathologies and age groups may use varying balance test methods, the results of our study are consistent with the literature.

In our study, among the passive proprioception figures compared, only the 15° data for the operated extremity was found to be significantly different. Tümtürk et al.'s study [36] compared home-based rehabilitation with telerehabilitation in patients with knee osteoarthritis and yielded significant improvements in proprioception in the left extremity of the telerehabilitation group. Gianola et al. [37] observed that virtual reality-based telerehabilitation provided significant improvements in proprioception comparing to traditional rehabilitation after total knee arthroplasty. On the other hand, Dighe et al. [38] found no significant differences in proprioception values between telerehabilitation and in-clinic rehabilitation in patients with knee osteoarthritis. The literature review indicates that, consistent with our findings, telerehabilitation is superior to home-based rehabilitation and as effective as in-clinic rehabilitation for proprioception.

When comparing exercise compliance results between the two groups, we found that the telerehabilitation group had significantly better compliance. In a study conducted by Campbell et al. [39], it was stated that in patients who underwent total knee arthroplasty surgery, the duration of participation in home-based exercises in the telerehabilitation group was significantly better than the control group, and their motivation for exercises was higher as well. Our study's results align with the literature in terms of exercise compliance.

Limitations of the study

The study's limitations include the fact that the surgeries were performed by different surgeons at the same clinic, and that exercise compliance charts were completed based on patients' self-reports. In revenge, the use of camera recordings for observational gait assessments, and the evaluation of strength and proprioception using an isokinetic dynamometer are notable strengths of the study.

CONCLUSION

The present study provides innovative and positive findings on the comparison between video-supported telerehabilitation and traditional exercise programs in the early postoperative period following ACL surgery -an area with limited research in the literature. In this study, video-supported telerehabilitation was compared with traditional rehabilitation programs delivered to patients in written and verbal form, and it was shown that telerehabilitation yielded more favorable outcomes in the early postoperative phase. Data obtained suggest that telerehabilitation may serve as a valuable tool for early rehabilitation, especially in extraordinary situations such as a pandemic, where clinical rehabilitation is not very feasible or access to hospitals is restricted. In this context, telerehabilitation can be considered a viable method for patients who have undergone or are scheduled to undergo ACL surgery, particularly in settings where access to healthcare facilities is limited. However, whether telerehabilitation can fully replace face-to-face clinical rehabilitation remains an area that requires further scientific investigation and expert consensus. Therefore, we believe that the telerehabilitation approach used in our study should be considered a promising option for appropriate patients in the future.

Ethics Committee Approval

The study was approved by the Ethics Committee of the Faculty of Medicine, Süleyman Demirel University (approval date 11.02.2022 and decision number 44) and was conducted in accordance with the principles of the Declaration of Helsinki.

Conflict of Interest

The authors declared no conflicts of interest with respect to authorship and/or publication of the article.

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Author Contributions

Consept: FHK,SE; design: FHK,SE; supervison: FHK,SE; materials: FHK,SE; data collection and/or processing: FHK; analysis and interpreta- tion: FHK; literature review: FHK; writing manuscript: FHK; critical reviews: FHK,SE. All authors contributed to the final version of the manuscript and discussed the results and contributed to the final manuscript.

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