Original Article

Self-Rehabilitation Guided by a Mobile Application After Anterior Cruciate Ligament Reconstruction Leads to Improved Early Motion and Less Pain

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Purpose: To evaluate the adherence rate and the contribution of self-rehabilitation (SR) guided by a mobile application after anterior cruciate ligament reconstruction (ACLR) in combination with physical therapy sessions on early knee function. **Methods:** This study was a retrospective analysis of prospectively collected data from a single health care facility. All patients who underwent ACLR by a single surgeon from December 2019 to September 2020 were included. Two groups were formed and compared based on use of the mobile app: users (>10 days of use) and nonusers (≤10 days of use). Outcomes included physical examination at 3 and 6 weeks postoperatively. **Results:** A total of 65 patients were analyzed: 19 in the nonuser group and 46 in the user group. Adherence rate was 91% at 10 days, 71% at 15 days, 62% at 21 days, and 44% at 45 days. At 3 weeks, the user group was 3.86 times [range 1.12 to 13.3] as likely to lock the quadriceps during gait with crutches and was 4.2 times [range 1.2 to 14.3] as likely to be pain free. There was a tendency to have less flexion contracture in the user group (17% versus 32%, $P = .32$). At 6 weeks, the differences leveled out, but the user group still had slightly better quadriceps locking during gait without crutches (87% versus 79%, $P = .46$). **Conclusions:** SR guided by a mobile app combined with a standard rehabilitation protocol is correlated with better knee function at initial follow-up. **Level of evidence:** IV, therapeutic case series.

Effective rehabilitation after anterior cruciate ligament reconstruction (ACLR) is one determinant of good clinical outcomes and faster return to sport. There is a higher risk of graft failure if rehabilitation is not carried out properly.[1-4] Numerous rehabilitation protocols have been described,[5] with the vast majority being under the supervision of a physical therapist. In 2020, Andrade et al.[6] published a systematic review on the quality and applicability of existing clinical practice guidelines after ACLR. They concluded that the programs were generally good but difficult to implement in daily clinical practice. Among their 3 highly recommended protocols, 2 (MOON[7] and APTA[8]) included a clearly defined home-based program.

The term self-rehabilitation (SR) includes all rehabilitation exercises performed autonomously at home without the supervision of a physical therapist. It has many advantages: it contributes to patient education by placing patients in the foreground of their health care, it allows the continuation of care when access to a physical therapist is not possible, and it can lower health care costs by spacing out physical therapy sessions. Hohmann et al.[9] compared physiotherapy-guided versus home-based unsupervised rehabilitation after ACLR and found no difference at 12 months between the 2 groups. This echoes the work of Grant et al.,[10] who found better results in range of motion (ROM) at 3 months after SR.

The main limit of SR is the patients' diligence.[11] Many factors that reduce patient adherence to home-based training have been identified. The lack of timely feedback and real-time supervision by a health care professional in an at-home setting are often cited as the most important factors. Also, because of lack of

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motivation and supervision, patients could perform exercises incorrectly, which increases the risk of reinjury. To counter that, many mobile applications for patient education have emerged over the past 5 years in all specialties combined[12-14]; however, few studies have really evaluated the adherence rate for those programs.[15]

The purpose of this study was to evaluate the adherence rate and contribution of SR guided by a mobile app after ACLR in combination with physical therapy sessions on early knee function. Our hypothesis was that increased app utilization would correlate with better early postoperative functional recovery.

Methods

The study was approved by our hospital's research and ethics committee and was performed in accordance with the Declaration of Helsinki's ethical standards. Informed consent was obtained from all participants before enrollment in the study.

A retrospective analysis of prospectively collected data from a single-center database was performed. All patients operated on from December 2019 to September 2020 by a single senior surgeon (J.M.F.) and reviewed in person by a single independent practitioner (L.B., nonsurgical sports medicine physician) at the 3- and 6-week follow-up examinations were included. In our center, patients are randomly reviewed by 4 different sports medicine physicians. Inclusion criteria were all patients undergoing primary ACLR with or without meniscus repair, meniscectomy, or lateral extra-articular reconstruction. Exclusion criteria were inability to use a mobile app or additional surgical procedures (osteotomy); lateral extra-articular reconstruction and meniscus repair were not excluded.

Standard Rehabilitation

Patients were asked to mobilize their knee without a brace, bearing weight with crutches immediately after surgery; active and passive ROM were limited from 0° to 90° in the first 3 weeks. Physical therapy sessions were started 10 days after surgery to reduce the risk of hematoma and avoid excessive walking. Rehabilitation aims, content, and progression followed current clinical guidelines. The rehabilitation protocol was not different in case of meniscal repair or lateral extra-articular reconstruction. Our national health insurance reimburses 40 sessions of 30 minutes maximum for every patient who undergoes ACL reconstruction. The choice of specific exercises and therapeutic modalities was at the discretion of the physical therapist, guided by a cover letter written by our department, in which each exercise was explained based on the time after surgery. Physical therapists were free to give their own SR protocol.

Mobile Application

The mobile app DoctUp® (Healing SAS, Chassieu, France) (Fig. 1) was presented to patients during the preoperative consultation as a support to use in addition to the physical therapy sessions. This app was designed by the participating surgeons, with home-based exercises progressing over the course of the rehabilitation from day 1 to day 90. It is available freely on the Google Play Store and Apple App Store. Each exercise is accompanied by a short video with instructions, aims, and potential errors.

Clinical Evaluation

Routine follow-up was performed by an independent, blinded, nonsurgical sports medicine physician (L.B.) 3 and 6 weeks after surgery. Pain (visual analog scale [VAS]), swelling, ROM, quadriceps isometric activation, and quadriceps locking during gait (with and without crutches) were evaluated first (Fig. 2). Significant flexion contracture was defined as a loss of extension $\geq 5°$ measured by a goniometer (Fig. 2A). Then information about the visits with the physical therapist and the use of the mobile app was collected based on the patients' own reports. If the recovery was not as expected after 3 weeks, tips were given to the patient to improve it.

Statistical Analysis

Two groups were formed based on utilization of the app. Days of use are expressed by taking day 1 after surgery as the starting point; patients starting the app after day 10 were considered nonusers. App use was considered satisfactory after >10 days of consecutive use. This threshold was used because it corresponds to the usual start of physical therapy sessions in our practice. Thus, we compared those performing standard SR following their surgeon's recommendation to those performing SR guided by a mobile app.

The continuous variables were averaged and reported with standard deviation and range. Comparisons were made using independent t tests for normally distributed variables and the Mann-Whitney U test for non—normally distributed variables. Categorical variables were summarized by their percentages; comparisons were done using chi-square or Fisher's exact test. Significant results after univariate analysis were assessed by a binomial logistic regression model including all the confounding factors. Significance was set at $\alpha = 0.05$; P values <0.05 were considered statistically significant. The statistical analyses were performed with XLstat (version 2015.1, Addinsoft, Paris, France). VAS for pain was interpreted according to the patient acceptable symptom state (PASS) with a threshold of 2[16]; there was no PASS fixed for flexion contracture, as its mere presence is unacceptable.

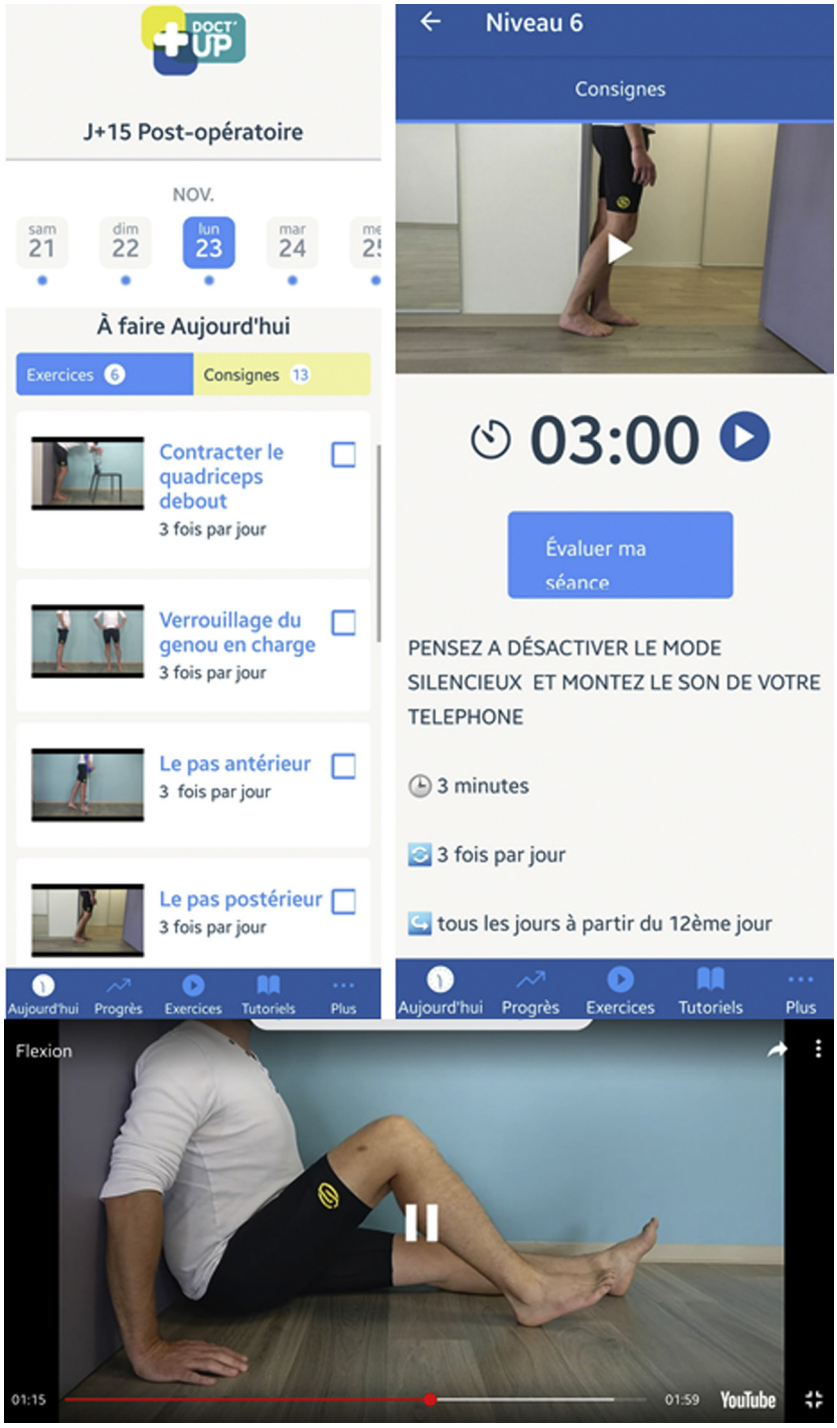

Fig 1. Mobile application Doctup®. Each exercise is accompanied by a short video with instructions, aims, and potential errors.

Results

Sixty-five patients met the inclusion criteria; no patients were excluded. No patients were lost to follow-up at 3 and 6 weeks. Nineteen patients used the mobile app for ≤10 days, whereas 46 used it for >10 days. Patient demographics, details about the operation, and the physical therapist's care are summarized in Table 1. There were no significant differences between the 2 groups in these parameters.

Use of the Mobile Application

Six patients did not use the app at all (91% use at 10 days), 13 stopped at day 10 (71% use at 15 days), 6 stopped at day 15 (62% use at 21 days), and 12 stopped at day 21 (44% use at 45 days) (Fig. 3). Among the patients who did not use it at all, 5 forgot to use it from the very start and 1 had a connection problem. Among the patients who gave up before 10 days, 11 stopped at the beginning of the physical therapy sessions, 1 felt

Fig 2. Clinical assessment. (A) Presence of a flexion contracture ≥5°. (B) Good quadriceps isometric activation assessed by ascension of the patella. (C) Good quadriceps locking with no flexion contracture at the maximum extension phase during gait with crutches. (D) Good quadriceps locking with no flexion contracture at the maximum extension phase during gait without crutches.

that he had mastered the movements, and I felt the app was not diversified enough.

Clinical Outcome

Clinical outcomes are summarized in Table 2. No complications were reported during the entire follow-up period.

At 3 weeks, the share of patients recording some pain was significantly lower in the users than in the nonusers (17% versus 49%, $P = .026$). Mean VAS among the patients in pain was low: 1.2 ± 0.4 [range 1 to 2] for the nonusers and 1.4 ± 0.7 [range 1 to 3] for the users ($P = .535$). The nonusers were twice as likely to have a flexion contracture (32% versus 17%, $P = .32$). Mean flexion contracture was 6.3° ± 2.5° [range 5 to 10] for the nonusers and 4.7° ± 0.7° [range 3 to 5] for the users, $P = .51$). As for quadriceps activation, there was a significant difference in favor of the app users in ability to lock the quadriceps during gait with crutches. Those 2 differences continued to be significant after the multivariate analysis (Tables 3 and 4); use of the mobile app reduced by 4.2 the risk of having pain and multiplied by 3.9 the chance of being able to lock the quadriceps during gait with crutches.

At 6 weeks, all those differences leveled out. There was satisfactory flexion and elimination of flexion contracture in both groups. There was a tendency for better quadriceps locking during gait without crutches in the user group (79% versus 87%, $P = .46$).

Table 1. Demographic, Intraoperative, and Postoperative Data Relative to Use of the Mobile Application

Characteristic	≤10 days of use (n = 19)	>10 days of use (n = 46)	*P* Value
Age (y)	29 ± 10 [14 to 44]	29 ± 12 [15 to 67]	.91
Female	7 (37)	21 (46)	.59
BMI (kg/cm^2)	25 ± 4 [18 to 31]	24 ± 4 [18 to 35]	.36
Time to surgery (mo)	4.5 ± 3 [1 to 12]	9.8 ± 17 [0.5 to 102]	.16
Type of graft			
Hamstring	18 (95)	42 (91)	1
Bone–patella tendon–bone	1 (5)	4 (9)	
Lateral extra-articular reconstruction	17 (89)	41 (89)	1
Meniscal lesions	13 (68)	26 (56)	.42
Suture	5 (26)	15 (32)	.77
Meniscectomy	5 (26)	9 (19)	.53
No treatment	3 (16)	2 (4)	.14
Osteochondral lesion	6 (32)	12 (26)	.76
ICRS grade of lesions	2 ± 0 [2 to 2]	2 ± 0 [2 to 2]	1
Beginning of physical therapy sessions (d)	10 ± 1.6 [7 to 15]	9 ± 2.3 [7 to 10]	.07
Physical therapy sessions			
3 weeks	5 ± 3 [0 to 10]	5 ± 2 [0 to 10]	.98
6 weeks	13 ± 7 [5 to 25]	12 ± 4 [3 to 25]	.85
Mobile app use (d)			
3 weeks	6 ± 4.6 [0 to 10]	20 ± 2 [14 to 21]	
6 weeks	6 ± 4.6 [0 to 10]	33 ± 13 [14 to 45]	

NOTE. Data are mean ± SD [range] or n (%).
BMI, body mass index; ICRS, International Cartilage Repair Society; SD, standard deviation.

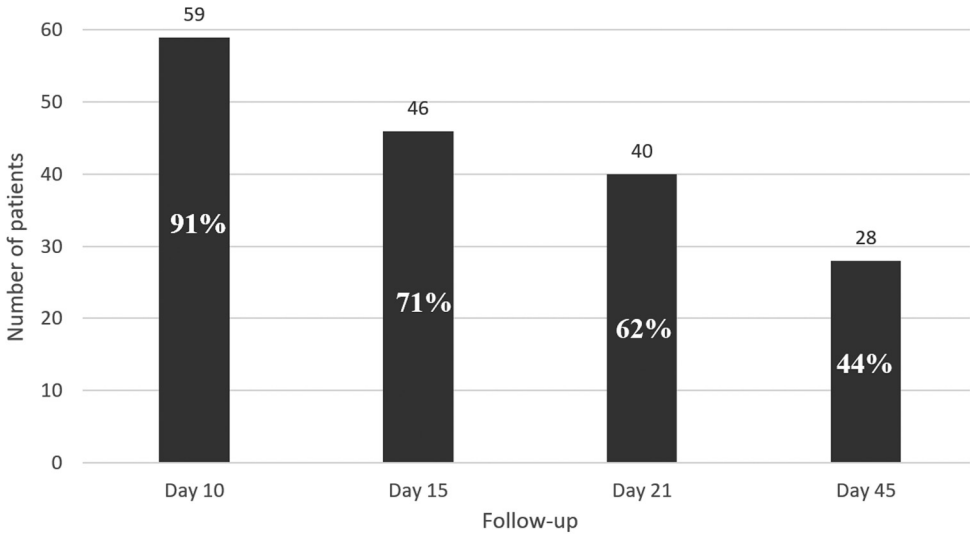

Fig 3. Adherence rate at days 10, 15, 21, and 45.

Discussion

The main finding of this study is the better early knee function after ACLR when the standard rehabilitation protocol is combined with SR guided by a mobile app. At 3 weeks, patients had a 4-fold lower risk of having pain and a 4-fold higher risk of having better quadriceps activation. The adherence rate was 91% at day 10, 71% at day 15, 62% at day 21, and 44% at day 45.

Quadriceps awakening is a major concern after knee surgery. Even the slightest improvement is valuable, since quadriceps deficiency may lead to extension deficit, cyclops syndrome,[17] quadriceps atrophy,[18] poor function,[18] dynamic instability,[19] gait abnormality,[20] persistent knee pain, and early osteoarthritis.[21] For these reasons, work on arthrogenic muscle inhibition (AMI) after knee surgery or trauma is vital. Sonnery-Cottet et al.[22] undertook a review on the interventions used to improve AMI and found that there was low-quality evidence for neuromuscular electrical stimulation and transcutaneous electrical nerve stimulation, and very low-quality evidence for ultrasound and vibration. Good compliance with SR is a simple option to control AMI; its use produces better quadriceps awakening, associated with a decrease in flexion contracture and less pain among frequent users. This effect of SR on muscular function is probably linked to repeated central neurological stimulation, as shown in the neurological field after stroke.[23-28]

Alasfour and Almarwani[15] studied the effect of a mobile app on adherence to a home-based exercise

Table 2. Clinical Outcomes Relative to Use of the Mobile Application

Outcome	≤10 d of use (n = 19)	>10 d of use (n = 46)	*P* Value
3-week follow-up			
Painful	9 (47)	8 (17)	.03*
≥PASS (VAS=2)	2 (10.5)	2 (4.3)	.57
Swelling	14 (74)	40 (87)	.28
Flexion contracture	6 (32)	8 (17)	.32
Flexion (°)	100 ± 10 [80 to 120]	97 ± 12 [60 to 120]	.26
Quadricep isometric activation	17 (89)	46 (100)	.08
Quadricep locking during gait (with crutches)	8 (42)	34 (74)	.02*
Quadricep locking during gait (without crutches)	5 (26)	12 (26)	1
6-week follow-up			
Painful	0	0	1
Swelling	3 (16)	8 (17)	.89
Flexion contracture	1 (5)	1 (2)	.50
Flexion (°)	126 ± 18 [80 to 140]	122 ± 11 [85 to 140]	.06
Quadricep isometric activation	19 (100)	46 (100)	1
Quadricep locking during gait (with crutches)	19 (100)	46 (100)	1
Quadricep locking during gait (without crutches)	15 (79)	40 (87)	.46

NOTE. Data are n (%) or mean ± SD [range].
PASS, patient acceptable symptom state; SD, standard deviation; VAS, visual analog scale.
*Statistically significant.

Table 3. Multivariate Analysis on Pain at 3 Weeks

Characteristic	Painful (n = 17)	Painless (n = 48)	Odds Ratio
Age (y)	30 ± 12 [17 to 53]	29 ± 12 [14 to 67]	1.01 [0.95 to 1.08]
Female	8 (47)	20 (42)	1.23 [0.30 to 4.98]
BMI (kg/cm^2)	24 ± 5 [19 to 31]	24 ± 4 [18 to 35]	0.96 [0.79 to 1.18]
Time to surgery (mo)	4.9 ± 5 [1 to 22]	9.4 ± 16 [0.5 to 102]	0.94 [0.84 to 1.06]
Meniscal lesions	9 (53)	30 (62.5)	0.48 [0.12 to 1.84]
Osteochondral lesions	5 (29)	13 (27)	1.57 [0.33 to 7.55]
Physical therapy sessions	5 ± 2 [1 to 10]	5 ± 2 [0 to 10]	1.06 [0.82 to 1.39]
>10 days of mobile app use	8 (47)	38 (79)	0.24 [0.07 to 0.85]*

NOTE. Data are mean ± SD [range] or n (%).
BMI, body mass index; SD, standard deviation.
*Statistically significant.

program for patients with knee osteoarthritis and found encouraging results, with a 27% additional adherence rate in the group using the app versus the nonusers. Many protocols recommend SR[7,8] after ACLR. Some studies even found it to be similar alone over standard rehabilitation,[9,29,30] but none could answer this question, as they were prospective randomized studies. We opted for an evaluation that fits more with reality to assess the efficacy and adherence rate in a more suitable protocol. The mobile app indeed does not aim to replace physical therapy but rather to supplement it. Even though 71% of patients reached our threshold for a significant level of use, there is still progress to be made to enhance adherence. We foresee 3 windows of opportunity to impact adherence: introducing the app first at the start so patients use it at the very beginning; second, at the beginning of the physical therapy sessions at day 10; third, after the first consultation with the sports physician at 3 weeks.

Accessibility, low cost, and safety are the main advantages of a mobile app, mostly in our young and connected sports medicine population. In 2015, around 165,000 mobile health apps were available for purchase; in 2019, apps included 76 for orthopaedic sports medicine.[31,32] Although 65% of those apps are related to patient education or exercise programs, Wong et al.[32] were concerned about their content and evidence base, as the majority had no named medical professional involvement and none were scientifically evaluated. Fortunately, since 2015, more and more authors have assessed those mobile app.[15,33-35] Ardrern et al.[36] are launching a study evaluating the efficacy of their app delivering cognitive behavioral therapy to help athletes return to sport. Higgins et al.[37] recently studied a mobile app for postoperative home monitoring after ACLR that is projected to replace conventional follow-up visits with self-assessments directly sent to the surgeon. They found equal satisfaction and outcomes at 6 weeks, with noticeable cost savings for the patient and the health care system.[37] Our 2 apps could be complementary, allowing medical, cognitive-behavioral, and rehabilitation home monitoring.

Limitations

This study is not without limitations. First, there was a short period of data collection (6 weeks). We wanted to focus initially on the early effectiveness of the app, as this is the key point of the rehabilitation: to get through AMI as fast as possible.[6] Second, the small number of patients is a limitation. Despite this, we obtained significant results, but one might wonder whether differences such as the rate of flexion contracture at 3 weeks

Table 4. Multivariate Analysis on Quadriceps Locking with Crutches at 3 Weeks

	No Quadriceps Locking With Crutches (n = 14)	Quadriceps Locking With Crutches (n = 51)	Odds Ratio
Age (y)	28 ± 14 [17 to 67]	30 ± 11 [14 to 55]	1.03 [0.97 to 1.11]
Female	7 (50)	21 (41)	0.53 [0.14 to 1.95]
BMI (kg/cm^2)	22 ± 3 [19 to 27]	24 ± 4 [18 to 35]	0.90 [0.74 to 1.09]
Time to surgery (mo)	8 ± 9 [1 to 37]	8 ± 15 [0.5 to 102]	1.07 [0.94 to 1.22]
Meniscal lesions	9 (64)	30 (59)	0.64 [0.18 to 2.34]
Osteochondral lesions	15 (29)	3 (21)	1.10 [0.23 to 5.02]
Physical therapy sessions	5 ± 3 [0 to 10]	5 ± 2 [0 to 10]	1.23 [0.95 to 1.60]
>10 days of mobile app use	8 (57)	38 (74)	3.86 [1.12 to 13.3]*

NOTE. Data are mean ± SD [range] or n (%).
BMI, body mass index; SD, standard deviation.
*Statistically significant.

may have been significant with more patients. Third, patients who diligently use the mobile app may be the most conscientious patients, which constitutes selection bias, as they may have a better natural result without the app. The last limitation could be the retrospective and nonrandomized design of this study; this bias is reduced here by the prospective collection of data.

Conclusions

SR guided by a mobile app combined with standard rehabilitation is correlated with better knee function at initial follow-up.

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