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Original Article

The early effects of isokinetic muscle training on knee joint muscle strength after modified double-bundle anterior cruciate ligament reconstruction

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Abstract: This study aimed to determine whether adding isokinetic muscle training to a conventional rehabilitation program would improve muscle function and knee functional scores in patients receiving arthroscopic ACL reconstruction. Range of motion (ROM), knee muscle torque, visual analogue scale (VAS) pain score, and Lysholm functional score were determined at 6 and 10 weeks postoperatively. Patients who received isokinetic training had significantly greater changes in knee flexion (32.00 ± 20.30° vs. 14.58 ± 13.56°, P = 0.026) and knee extension (-4.58 ± -5.82° vs. -0.50 ± -1.58°, P = 0.044) from 6 to 10 weeks postoperatively compared to controls receiving conventional training only. Significant improvements were shown in 10-week postoperative scores in both groups compared to their 6-week postoperative scores, including VAS pain scores. In accordance with Editor's request, we highlight the changes by using colored text within the manuscript. ental group 30.0 ± 19.6 vs. 46.2 ± 31.2; controls 40.9 ± 18.7 vs. 63.6 ± 24.2); Lysholm functional scores (experimental group; 70.00 ± 17.99 vs. 52.46 ± 18.09; controls 66.00 ± 16.56 vs. 51.00 ± 15.90) and knee ROM (experimental group 103.50 ± 17.65 vs. 72.73 ± 30.93; controls 102.50 ± 22.11 vs. 90.36 ± 28.32) (all P<0.05). At 10 weeks postoperatively, the isokinetic training group had significantly higher knee extension peak torque (88.68 ± 35.79 Nm/kg vs. 52.96 ± 29.77 Nm/kg, P = 0.014) and knee flexion peak torque (130.03 ± 35.02 Nm/kg vs. 94.51 ± 16.24 Nm/kg, P = 0.004) at the angle of 30°. Isokinetic training added to conventional physiotherapy rehabilitation after arthroscopic ACL reconstruction may help to improve knee function.

Keywords: Isokinetic muscle training, physiotherapy, rehabilitation, anterior cruciate ligament reconstruction, biodex dynamometer

Introduction

Anterior cruciate ligament (ACL) injuries are not uncommon in active individuals, and can result in functional impairment and eventual degeneration of the knee joint [1-3]. Injuries typically occur in young and active individuals and can lead to loss of their ability to participate in the activities of daily life and sports. The goal of treating patients with ACL injuries is to restore functional stability in order to allow maximum performance and minimize long-term morbidity.

During the past decade, arthroscopic ACL reconstruction became popular due to improvements in arthroscopic techniques and a greater understanding of ACL anatomy and function. The arthroscopic approach to reconstruction has the advantages of better visualization for tunnel placement, less chance of arthrofibrosis, and improved appearance compared to traditional open techniques [4]. Many different techniques and grafts are available for arthroscopic ACL reconstruction [5-8]. Although study results have shown that double-bundle ACL reconstruction restores the native anatomy of the ACL more accurately than other techniques [9], functional recovery has been reported to be similar between single-bundle and double-bundle reconstruction techniques [10].

Regardless of the repair technique, rehabilitation after ACL reconstruction is critical to re-

Figure 1. Modified Y-shape 2-bundle tendon graft composed of gracilis and semitendinosus tendon grafts.

store patients' locomotor function [11]. In patients who have undergone ACL reconstruction, the main functional impairments are quadriceps weakness and impaired neuromuscular control [12, 13]. A primary goal of physiotherapy after ACL reconstruction is to normalize the antagonist strength ratio of the knee muscle groups [12-15]. Many rehabilitation programs have been proposed for patients who have received ACL reconstruction, but no consensus been reached on which program is the most effective [12, 16]. Results of some studies have shown that the accelerated program administered after ACL reconstruction may improve thigh muscle strength and knee stability at short-term follow-up [17, 18]. However, investigators in these studies do not seem to design and implement regular short-term rehabilitation programs after surgery. Most investigators have selected the isokinetic dynamometer as a measuring device. While isokinetic testing has only been used as an evaluation tool in previous studies, few researchers have included isokinetic muscle training in rehabilitation programs. Nevertheless, studies in which isokinetic training was incorporated into postoperative rehabilitation programs after ACL reconstruction demonstrated good to excellent results [11, 15, 19]. Also, results of our previous study [20] showed that early Accelerated Rehabilitation Exercise improved muscle function and promoted patients' early recovery to daily activities. In that study, the isokinetic dynamometer served only as a measuring device, while in the present study we explored whether the isokinetic dynamometer could be a useful training tool rather than just a measuring device.

Complications after ACL reconstruction include arthrofibrosis and knee stiffness, which can be severe and disabling. Therefore, surgeons must try to prevent such complications. Improving range of motion (ROM) is an important goal of rehabilitation, but the main procedure in conventional rehabilitation programs usually consists of only passive ROM exercises. If patients respond slowly to this, it can result in arthrofibrosis. Few studies have addressed ROM improvement by isokinetic exercise, which prompted our team to consider isokinetic exercise as a component of our experimental rehabilitation program. We focused on the timing of the addition of isokinetic training, setting it at 6 weeks because the knee must be mobilized for about 4 weeks after ACL reconstruction with hamstring tendon graft, and when knee movement begins, it takes about 2 weeks to achieve 90 degree range of motion. We hypothesized that the addition of isokinetic training at 6-weeks postoperative would lead to an improvement of knee function. The purpose of this study was to determine if adding isokinetic muscle training to a traditional rehabilitation program would improve muscle function and knee functional scores in patients who had received arthroscopic ACL reconstruction.

Materials and methods

Patients

This prospective study included patients who had received primary endoscopic reconstruction of isolated ACL tears by a modified double-bundle (Y-shape) ACL reconstruction technique using semitendinosus and gracilis muscle autografts. All surgeries were performed by a single surgeon with 25 years of experience. The grafts were prepared from flexor tendons of the operated knee joint. Grafts were secured with Bioscrews under 90° flexion for the anteromedial (AM) bundle and 0° flexion for posterolateral (PL) bundle (**Figure 1**). Postoperatively, patients were randomly assigned to a conventional physiotherapy rehabilitation program or one that included isokinetic muscle training.

This study was approved by the Institutional Review Board (IRB no: 091102) of Changhua

Christian Hospital, Changhua, Taiwan, and all patients provided signed informed consent.

Physiotherapeutic program

A two-stage physiotherapeutic rehabilitation program was implemented postoperatively for all patients, as described previously [15]. The complete program is summarized in the Supplemental Table 1. In Stage I, all patients completed 6 weeks of a conventional physiotherapy rehabilitation program. In Stage II, patients were then randomized to one of 2 groups for continued physiotherapy rehabilitation. The control group continued with conventional rehabilitation for 4 additional weeks. The experimental group received isokinetic muscle training twice weekly, in addition to conventional rehabilitation, for 4 additional weeks. The speed of the isokinetic training was 180°/sec for 3 sets, 20 repetitions, and took approximately 30 minutes, as detailed below.

Isokinetic training

The target muscle groups receiving training and testing comprised the quadriceps and hamstring muscles. Patients in the experimental group received training using an isokinetic model with the speed set at 180°/sec. During training, when the quadriceps was the main muscle group being trained, the standard posture consisted of the hip joint flexed at 90° and the knee joint flexed at 90° and motion of the knee joint consisted of quickly kicking straight out (from 90° to 0°). When the hamstring is the main muscle group being trained, the knee then quickly flexed to the original position (from 90° to 0°). After completion of four weeks of training, the isometric model was used to perform muscle strength testing. At that time, the subjects sat in a Biodex chair, and the standard posture consisted of the hip joint flexed at 90° and the knee joint flexed first at 60°. The quadriceps and hamstring (Q & H) isometric contraction strength testing was performed (quadriceps first contracted five times, and hamstring then contracted five times). After completion of testing, the knee joint was flexed at 30°, and Q & H isometric contraction was performed to test muscle strength.

Outcome measures

Patients in both groups received knee function testing after completing 6 and 10 weeks of rehabilitation. Because knee pain, in some patients, will delay the recovery of ROM after ACL reconstruction, we evaluated variations in knee pain between the two groups using the visual analog scale (VAS) as described previously [21, 22]. In the present study, knee pain was assessed on a visual analogue scale (VAS) with 1 = no pain and 10 = severe pain. Although VAS is sometimes associated with bias because of self-reporting, a 33% decrease in pain is said to represent a reasonable standard for determining that changes in pain are meaningful based on the patient's perspective [22]. Evaluation of the performance of daily activities was made using the Lysholm functional score, as previously described [23]. Flexion and extension range of motion (ROM) of the knee was evaluated with the patient in the prone position using a Biodex instrument (Biodex 3 System 333-250 Dynamometer, Biodex Medical Systems, Shirley, NY, USA) and the results were recorded with 1° accuracy. A positive value with this instrument indicates lack of full knee extension, and decreases in value indicate values closer to full knee extension. One physical therapist with 10 years of experience using the Biodex instrument measured ROM three times for each ROM and reported the average of the three measurements as the final result. All tests using with the Biodex instrument were performed according to the manufacturer's directions [24].

Muscle torque (Nm/kg) of the extensor and flexor muscles of the operated knee were measured under maximal voluntary isokinetic contraction (MVIC), using the Biodex 3 System (Model 333-250; Biodex Medical Systems, Shirley, NY, USA) and using the Biodex Advantage software incorporated within the instrument [24]. Measurements were made at 6 weeks and 10 weeks postoperatively. Prior to measurement, patients underwent a 12-minute warm up on a stationary bicycle at a frequency of 60 rpm and 60 watts for 6 minutes, after which the power was increased every 2 minutes by 5-10 watts. After a total of 12 minutes, the patients rested for 8-10 minutes before torque measurements were obtained. For all measurements, the trunk, pelvis, and thighs were stabilized with stabilizing belts. The dynamometer head axis overlapped the axis of the examined joint, and the lever arm leaning against the shank was placed at 40 cm from the knee joint axis, as previously described [25].

Measurements of maximal muscle torque of the knee joint extensor and flexor muscles under MVIC were performed twice, and the better result was selected for further analysis. All measurements were performed first on the uninvolved limb and then repeated on the involved limb. Applying the procedure on the uninvolved leg provided procedural training for the involved leg and helped to familiarize patients with the operation of the Biodex instrument. The patient assumed a seated position in the measuring chair, with the hip joint at the angle of 80° and the knee joint at 70° for extensor muscles and 30° for flexor muscles. The measurement was initiated with the 'start' command, and the result was recorded in the memory of the device. The extensor muscles of the uninvolved knee were measured first. This was followed by a 1-minute break, and then by measurement of the maximal muscle torque of flexor muscles of the uninvolved knee. After finishing, and then a subsequent 1-minute break, the second measurement was performed, first for the extensor muscles, and after a 1-minute break, for the flexor muscles of the uninvolved knee. The last measurement was followed by a 3-minute break to prepare the stand for measurements of the operated leg. Measurements of the maximal torque of the extensor and flexor muscles of the operated knee were then performed as described above.

The measurements of peak torque for knee joint extensor and flexor muscles under isokinetic conditions were performed with the patient in a seated position with a hip joint angle of 80°. Evaluation included torque of flexion, extension, time to peak flexion torque, and peak extension torque at 30 degrees and 60 degrees of the knee flexion position. The isokinetic training was concentric only, and was performed at angular velocities of 180 degrees per second (fast mode) prior to measuring torque of knee flexion/extension. First, extension and flexion of the knee of the uninvolved leg was performed at the angular velocity of 180°/s. After a 3-minute rest, the measurement of peak muscle torque was performed during a 5-repetition set of extension and flexion of the knee of the uninvolved leg. This was followed by a 3-minute rest to prepare the stand for the measurements of the operated leg and to allow the patient to rest. Measurements for the operated leg were then performed as described above and only data of the involved leg were entered into analysis. We also recorded the time from start to peak torque, which is shown in the results and **Table 3**. Time from start to maximum extension force (T Ext; ms) indicates time to arrive at peak extension torque; and time needed from start to maximum flexion (T Flx; ms) indicates time to arrive at peak flexion torque. All torque values were normalized to body weight, and the highest peak torques for the extensor and flexor muscles were selected for further analysis. We calculated the ratio of flexor to extensor torque under static conditions, that is the ratio between maximum torque of knee flexion (Mfl), mainly the hamstring muscle, versus maximum torque of knee flexion (Mext), mainly the quadriceps muscle, expressed as H/Q ratio: Mfl/Mext x 100%. This ratio is calculated to control the restoration process of muscle strength distribution during physiotherapeutic procedures. The ratio at 60 degrees is generally greater than that at 30 degrees.

Statistical analysis

Age, weight, height, VAS, Lysholm functional scores, angle of knee flexion/extension, and peak torque (tested in flexion 30 degrees and flexion 60 degrees), peak time, torque variance of isometric knee extension/flexion at angles of 30/60 degrees, and ratio of knee flexion to extension (quadriceps/hamstring, H/Q ratio) under static conditions, are summarized as means ± standard deviations (SD). Changes in scores of VAS, maximum knee flexion, maximum knee extension and Lysholm functional score were derived by measurements at week 10 minus measurements at week 6. Group comparisons of two separate time points (6-weeks and 10-weeks) and changes in primary outcomes from week 6 to week 10 were performed using the independent sample t-test. Within-group comparisons were made utilizing paired samples t-test to assess differences between 6-week and 10-week measurements of primary outcomes (VAS, ROM, Lysholm score, torque extension and flexion) in each group. Statistical analyses were performed using only data of the involved limb. All statistical analyses were performed using SPSS statistical software (version 13.0, SPSS Inc., Chicago, IL). A 2-sided value of $P<0.05$ was considered to indicate statistical significance.

Table 1. Baseline characteristics of study subjects

Characteristics	Total (n = 46)	Control (n = 20)	Experimental (n = 26)	*P*-value†
Age (y)	30.9 ± 9.3	32.8 ± 7.7	33.6 ± 11.4	0.844
Body weight (kg)	71.7 ± 8.1	72.8 ± 12.4	70.8 ± 13.9	0.729
Body height (cm)	168.3 ± 5.8	175.1 ± 9.3	174.1 ± 3.6	0.756

Data are presented as mean ± standard deviation. †Determined by independent t-test.

Table 2. Comparisons of primary outcomes between the control group and experimental group

Primary outcomes	Control (n = 20)	Experimental (n = 26)	*P*-value†
Visual analogue scale (mm)			
6 Weeks postoperatively	63.6 ± 24.2	46.2 ± 31.2	0.145
10 Weeks postoperatively	40.9 ± 18.7‡	30.0 ± 19.6‡	0.179
4-week Change	-20.8 ± 15.1	-12.4 ± 18.2	0.197
Maximum knee flexion (°)			
6 Weeks postoperatively	90.36 ± 28.32	72.73 ± 30.93	0.151
10 Weeks postoperatively	102.50 ± 22.11‡	103.50 ± 17.65‡	0.909
4-week Change	14.58 ± 13.56	32.00 ± 20.30	0.026
Maximum knee extension (°)			
6 Weeks postoperatively	1.82 ± 4.62	6.79 ± 8.68	0.101
10 Weeks postoperatively	1.00 ± 3.16	3.33 ± 3.89‡	0.144
4-week Change	-0.50 ± -1.58	-4.58 ± -5.82	0.044
Lysholm functional score			
6 Weeks postoperatively	51.00 ± 15.90	52.46 ± 18.09	0.853
10 Weeks postoperatively	66.00 ± 16.56‡	70.00 ± 17.99‡	0.655
4-week Change	14.86 ± 13.70	19.00 ± 11.25	0.517

Data are presented as mean ± standard deviation. †Determined by independent t-test. ‡P<0.05 compared to 6 weeks postoperatively; determined by paired t-test.

Results

Baseline characteristics

A total of 46 patients who received ACL reconstruction were included in the study with 20 patients in the control group and 26 in the experimental group. The two groups were similar in age, body weight, and body height (all P>0.05). Patients' mean age was 30.9 ± 9.3 years (range, 16 to 55 years) (**Table 1**).

Primary outcomes: VAS pain scores, Lysholm functional scores, and knee ROM

At 6 weeks after surgery, no significant differences were found between groups in VAS pain scores, Lysholm functional scores, and knee ROM (**Table 2**). However, at 10 weeks after surgery, these scores were significantly improved in both groups compared with scores at 6 weeks (VAS pain score P<0.001 for control group, p = 0.011 for experimental group; Lysholm functional score P = 0.028 for control group, P = 0.001 for experimental group; and knee ROM P =0.001 for control group, P = 0.008 for experimental group). The exception was the angle of knee extension in the experimental group, which decreased significantly compared to that at 6 weeks (P = 0.02). Patients who received isokinetic training had significantly greater changes in knee flexion (32.00 ± 20.30° vs. 14.58 ± 13.56°, P = 0.026) and knee extension (-4.58 ± -5.82° vs. -0.50 ± -1.58°, P = 0.044) from 6 to 10 weeks postoperatively as compared to those who received traditional training. No statistically significant changes in VAS pain scores and Lysholm functional scores were found between the control group and experimental group (**Table 2**).

Secondary outcomes: knee muscle torque and flexion/extension ratio

At 6 weeks postoperatively, no significant differences were found between groups in all measurements of knee muscle torque at angles of 30° and 60° (**Tables 3** and **4**). At 10 weeks postoperatively, patients who received isokinetic training had significantly higher knee extension peak torque (88.68 ± 35.79 Nm/kg vs. 52.96 ± 29.77 Nm/kg, P = 0.014) and knee flexion peak torque (130.03 ± 35.02 Nm/kg vs. 94.51 ± 16.24 Nm/kg, P = 0.004) compared to those who had received traditional rehabilitation at an angle of 30°. Results of extension/flexion torque at week 6, time to peak extension/flexion torque, and torque variance were similar between the two groups. From week 6 to week 10, no significant changes in knee

Table 3. Comparison of secondary outcomes measured for 30°-movement on flexor and extensor muscles between the control group and experimental group

Secondary outcomes	Control (n = 20)	Experimental (n = 26)	*P*-value†
Ext. torq (Nm/kgw)			
6 Weeks postoperatively	51.00 ± 15.90	53.84 ± 32.20	0.705
10 Weeks postoperatively	52.96 ± 29.77	88.68 ± 35.79‡	0.014
4-week Change	3.82 ± 30.31	34.84 ± 33.76	0.027
Flex. torq (Nm/kgw)			
6 Weeks postoperatively	84.33 ± 27.93	106.19 ± 38.57	0.126
10 Weeks postoperatively	94.51 ± 16.24	130.03 ± 35.02‡	0.004
4-week Change	10.18 ± 29.24	23.84 ± 24.85	0.231
Peak T Ext (ms)			
6 Weeks postoperatively	2846.67 ± 1584.10	3152.50 ± 1633.37	0.646
10 Weeks postoperatively	2305.00 ± 1537.89	2840.83 ± 1342.61	0.373
4-week Change	-541.67 ± 948.15	-311.67 ± 1463.03	0.652
Peak T Flx (ms)			
6 Weeks postoperatively	2792.50 ± 1553.55	3300.00 ± 1232.43	0.385
10 Weeks postoperatively	2992.50 ± 1655.89	3011.67 ± 1283.30	0.975
4-week Change	200.00 ± 1900.97	-288.33 ± 1503.11	0.492
Var. Ext			
6 Weeks postoperatively	26.26 ± 46.58	16.59 ± 10.12	0.489
10 Weeks postoperatively	10.07 ± 9.33	6.17 ± 2.85‡	0.180
4-week Change	-16.19 ± 50.18	-10.42 ± 9.18	0.699
Var. Flx			
6 Weeks postoperatively	6.75 ± 2.66	5.83 ± 3.90	0.508
10 Weeks postoperatively	6.37 ± 2.58	5.92 ± 3.08	0.704
4-week Change	-0.38 ± 3.02	0.09 ± 4.17	0.754
H/Q ratio (%)			
6 Weeks postoperatively	224.12 ± 127.63	230.02 ± 85.04	0.895
10 Weeks postoperatively	239.91 ± 153.92	157.08 ± 38.05‡	0.084
4-week Change	15.79 ± 124.73	-72.94 ± 83.69	0.053

Data are presented as mean ± standard deviation. †Determined by independent t-test. ‡P<0.05 compared to 6 weeks postoperatively; determined by paired t-test. Abbreviations: Ext. torq: Knee extension peak torque/body weight. Flex. torq: Knee flexion peak torque/body weight. Peak T Ext: Time to peak extension torque (millisecond). Peak T Flx: Time to peak flexion torque (millisecond). Var. Ext: Torque variance between every test during extension. Var. Flx: Torque variance between every test during flexion. H/Q ratio: Flexion/extension ratio, the ratio of flexor to extensor torque under static conditions.

torque were found in the control group. However, in the experimental group, significant increases were found in extension (P = 0.004) and flexion torque (P = 0.007) as well as significant decreases in torque variance during extension (P = 0.002), and a significant reduction of H/Q ratio (P = 0.012) at the angle of 30° (**Table 3**).

At the angle of 60°, only knee flexion peak torque was significantly higher in the experimental group compared to the control group (104.80 ± 32.61 Nm/kg vs. 79.40 ± 18.20 Nm/kg, respectively, P = 0.028) at 10 weeks postoperatively; no differences were found between groups in other measurements of knee muscle torque (i.e., flexion torque at week 6, extension torque, time to peak extension/flexion, torque variance and H/Q ratio) at either week 6 or week 10. However, a significant reduction in H/Q ratio was noted from week 6 to week 10 in the experimental group at the angle of 30 degrees (P<0.05). At the angle of 60°, higher extension (P = 0.011) and flexion torque (P = 0.003), with less torque variance during extension (P = 0.019) was observed at 10 weeks after the operation when compared to week 6 (**Table 4**). In addition, no significant differences in time to peak flexion torque or peak extension torque were found between the experimental and control groups, indicating that isokinetic training did not promote muscle activity.

Discussion

The results of this study included significant differences in the primary outcome measures of VAS, Lysholm scores and ROM between experimental group patients and controls, including decreases in knee extension ROM in the experimental group. Results demonstrated that iso-

Table 4. Comparison of secondary outcomes measured for 60°-movement on flexor and extensor muscles between the control group and experimental group

Secondary outcomes	Control (n = 20)	Experimental (n = 26)	*P*-value
Ext. torq (Nm/kgw)			
6 Weeks postoperatively	95.34 ± 51.97	101.46 ± 60.00	0.792
10 Weeks postoperatively	112.69 ± 46.90	169.62 ± 85.26‡	0.055
4-week Change	17.35 ± 39.10	68.16 ± 77.40	0.055
Flex. torq (Nm/kgw)			
6 Weeks postoperatively	67.25 ± 18.63	77.34 ± 35.02	0.388
10 Weeks postoperatively	79.40 ± 18.20‡	104.80 ± 32.61‡	0.028
4-week Change	12.14 ± 18.33	27.46 ± 25.70	0.107
Peak T Ext (ms)			
6 Weeks postoperatively	3427.50 ± 1190.75	3843.33 ± 1090.79	0.382
10 Weeks postoperatively	3322.50 ± 1366.53	3480.83 ± 1180.11	0.764
4-week Change	-105.00 ± 1241.63	-362.50 ± 1018.68	0.584
Peak T Flx (ms)			
6 Weeks postoperatively	2800.00 ± 1648.52	3343.33 ± 1140.62	0.358
10 Weeks postoperatively	2574.17 ± 1019.07	2900.00 ± 1226.47	0.486
4-week Change	-225.83 ± 1529.93	-443.33 ± 1616.53	0.738
Var. Ext			
6 Weeks postoperatively	11.94 ± 13.25	16.59 ± 13.76	0.408
10 Weeks postoperatively	8.13 ± 4.23	5.83 ± 3.25‡	0.149
4-week Change	-3.81 ± 14.32	-10.77 ± 13.64	0.236
Var. Flx			
6 Weeks postoperatively	6.44 ± 2.65	7.49 ± 3.53	0.418
10 Weeks postoperatively	6.69 ± 4.33	7.39 ± 4.39	0.697
4-week Change	0.25 ± 4.09	-0.10 ± 5.04	0.854
H/Q ratio (%)			
6 Weeks postoperatively	86.34 ± 38.21	90.80 ± 38.34	0.778
10 Weeks postoperatively	75.82 ± 18.14	70.67 ± 21.12	0.528
4-week Change	-10.52 ± 28.78	-20.13 ± 31.87	0.446

Data are presented as mean ± standard deviation. †Determined by independent t-test. ‡P<0.05 compared to 6 weeks postoperatively; determined by paired t-test. Abbreviations: Ext. torq: Knee extension peak torque/body weight. Flex. torq: Knee flexion peak torque/body weight. Peak T Ext: Time to peak extension torque (millisecond). Peak T Flx: Time to peak flexion torque (millisecond). Var. Ext: Torque variance between every test duringextension. Var. Flx: Torque variance between every test during flexion. H/Q ratio: Flexion/extension ratio, the ratio of flexor to extensor torque under static conditions.

kinetic training effectively promotes flexor and extensor muscle strength recovery after ACL reconstruction, and patients who received isokinetic training in addition to conventional physiotherapy rehabilitation had a significantly greater change in knee flexion and knee extension from 6 to 10 weeks postoperatively. Full knee extension following ACL reconstruction is an especially critical parameter in evaluating any recovery of muscle strength. At 10 weeks postoperatively, patients had significantly higher knee extension peak torque and knee flexion peak torque at the angle of 30°. The good early effects of rehabilitation combining isokinetic muscle training with a conventional rehabilitation program suggest that patients may be able to achieve earlier recovery, allowing them to return to daily activities and sports training sooner. However, additional study with longer follow-up is needed to ascertain this possibility.

A physiotherapy rehabilitation program is essential for restoring function after ACL reconstruction. However, many different types of programs exist and there is no consensus on which program is the most effective [11, 26-28]. A recent review of the literature by Gokeler et al. [16] examined quadriceps function after ACL reconstruction and rehabilitation and found that only 10 of 645 identified studies met their inclusion criteria of reporting a detailed muscle strengthening protocol and the timeframes of all measurements. Of the 10 studies, seven reported an increase in quadriceps strength regardless of the type of training, and an eccentric exercise program was associated with significantly better isometric quadriceps strength than a concentric program. Overall, the authors concluded that eccentric training may be the most effective in restoring quadriceps strength, while neuromuscular training should be added to strength training to optimize outcomes, and that full recovery may not be achieved using current rehabilitation methods. However, the present study applied a concentric rather than eccentric exercise program and added isokinetic training to conventional training, finding that this concentric rehabilitation method showed significant improvement in knee muscle strength in patients undergoing the combined training. Of the few reports that have examined isokinetic training, Sekir et al. [19] studied early vs. late initiation of isokinetic hamstring strengthening exercises after ACL reconstruction and found that early initiation improved hamstring as well as quadriceps strength without negatively impacting knee function according to results of the Cincinnati Knee Rating Scale. "Early" was defined as postoperative 3 weeks, and "late" as 6 weeks, which is the same timeframe applied in the present study. Improvements in knee function parameters were also comparable to those observed in the present study.

In the present study, at 10 weeks postoperatively, the experimental group had significantly greater peak torque compared to that in the control group. At 10 weeks postoperatively, extensor and flexor muscle torque of the experimental group at 30° angle, and flexion torque at 60° angle at angular velocities of 180 and 60 degrees were significantly higher than measurements of the control group. These data suggest that isokinetic training can promote flexor and extensor muscle strength recovery. The isokinetic training period of this study, however, was short. Similar to the present study, Czamara et al. [15] reported that 6 months of physiotherapy after ACL reconstruction favorably affected muscle strength of operated and non-operated knees under static and isokinetic conditions; however, those authors observed a 9% deficit in extensor muscle strength measured under isokinetic conditions of the involved knees compared with the uninvolved knees. Urabe et al. [14] reported that after 12 months of rehabilitation after ACL reconstruction, the strength of the operated leg was 8% to 10% less than that of the non-operative leg. Rebeyrotte-Boulegue et al. [29] noted a deficit in extensor muscle strength of the operated knees compared to the uninvolved ones at 2.5 years after ACL reconstruction under isokinetic conditions (15.3% for an angular velocity 60°/sec and 11.3% for the angular velocity 180°/sec).

Because the uninvolved leg also loses strength due to limited physical activity after surgery, physiotherapy programs typically include load to the uninvolved leg [20]. This results in an increase in muscle strength in both the affected and the unaffected limbs. The strength ratio of flexor to extensor muscles (H/Q ratio) is frequently used to monitor progress in physiotherapy such that the gain in strength is the same in the operated and non-operated limbs in the sagittal plane [29]. In the present study, the H/Q ratio of the experimental group at the angle of 30° was significantly less at 10 weeks postoperatively as compared to 6 weeks postoperatively, while that at the angle of 60° did not reach statistical significance. Morrissey et al. [30] studied whether knee anterior laxity changes after ACL surgery are related to aspects of thigh muscle resistance training during rehabilitation, and found that the only factor significantly related ($r = -0.347$) to anterior knee laxity change was average absolute load used in training the knee extensors.

This study has certain limitations. The number of patients studied was small, and the length of rehabilitation and follow-up were short. It is important to note that the length of rehabilitation treatment in our country is restricted by the national health insurance requirements, so when rehabilitation programs are longer than 2 months, which exceeds insurance coverage, patients tend to become less compliant. We also did not include the mechanism of injury, activity levels and duration of time from surgery in data analysis. We did use body weight to normalize flexion and extension torque (torque/body weight ratio) to reduce effects of age, activity levels, etc. However, we still cannot rule out that a very large age range as compared to injured populations. It may still influence the results. Also, regarding concerns about graft rupture or elongation associated with isokinetic training procedures, we recognize that the device exerts the force necessary to restrain the speed of movement, and so with stronger patients, greater force is needed to maintain the speed of concentric actions. Therefore, with either isometric or isokinetic concentric measures, the force will be the direct result of the patient's strength, which addresses any possible concerns about graft rupture/elongation, although further investigation of this issue is warranted. We also make certain that patients are able to tolerate traditional active ROM training before they begin isokinetic training. This reduces the possibility of injury during isokinetic training, and in our experience, no injuries have occurred. Finally, we had no good explanations why lack of full knee extension were seen more in experimental group than control group (**Table 2**); however, patients who received isokinetic training do have significantly greater changes in knee extension from 6 to 10 weeks postoperatively as compared to those who received traditional training.

Conclusions

Isokinetic training in addition to conventional physiotherapy rehabilitation after arthroscopic ACL reconstruction promotes flexor and extensor muscle strength recovery and may help lead to earlier recovery and an early return to normal activities and sports training. Further study with a longer isokinetic training period and longer follow-up is necessary to further evaluate the benefits of isokinetic training during rehabilitation after ACL reconstruction.

Disclosure of conflict of interest

None.

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Supplemental Table 1. Stages of the physiotherapy rehabilitation program

Rehabilitation Stages	Basic Rehabilitation Program	Special Muscle Strengthening Exercises
Stage I 1st-5th week after surgery	Local treatment with ice packs if necessary. Passive exercises on a CPM splint with gradual increase in the range of movement of the involved joint. Mobilization of the patellofemoral joint. Massage of the iliotibial band and the lateral head of the quadriceps. Gait training using 2 crutches. Electrostimulation of the quadriceps and posterior muscles of the thigh. Proprioceptive exercises in a closed kinematic chain. At the end of Stage I - learning to walk without crutches	Isometric tension of the quadriceps and flexor muscles of the involved knee joints and other large muscle groups. Isometric exercises with manually dosed resistance of muscle groups beyond the area of the operated knee joint, the uninvolved lower extremity, upper extremities, and the trunk. Exercises on an MTD platform. Gradual increase of the load on the involved leg from 20% to 100% of the body weight. Restrictive 2-legged squats on a stable surface
Stage II 6th-12th week after surgery	As above and additionally: Gradual increase in the range of movement until full extension and flexion of the knee joint is obtained. Gait training without crutches. Walking on a treadmill; level surface. Initial speed from 2.8 to 3.5 km/h. Gradual increase of speed to 5.5 to 6.5 km/h with total distance gradually increased. Exercises on a cycloergometer at the frequency of 60 rpm, without resistance for 1 week. During the subsequent week, the first 5 minutes at a power of 50 watts with an increase by 10 watt increments every 2 minutes. Initial time of 10 minutes with a gradual increase to 15 minutes. Every 2 weeks, the initial power value was increased by 5-10 watts. Walking up and down stairs without crutches. Proprioceptive exercises with assistance on a soft surface: trampoline, mattress, exercise mat, and practice balance beams. Attention focused on preserving a correct Q angle. Walking on a treadmill with an incline.	Concentric exercises with gradual increase of resistance for the ischiotibial muscles of the operated leg. Concentric exercises with physiotherapist's resistance of muscle groups of the lower and upper extremities and the trunk (does not apply to the quadriceps of the involved knee joint). Exercises on a stepper with gradual increase of resistance and gradual increase of lower extremity range of movement. Squats with both and 1 leg on an unstable surface. Gradual increase of squatting range.