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Quadriceps tendon autograft ACL reconstructed subjects overshoot target knee extension angle during active proprioception testing

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Abstract

Purpose To compare the active joint position sense (JPS), muscle strength, and knee functions in individuals who had anterior cruciate ligament (ACL) reconstruction with quadriceps tendon autograft, hamstring tendon autograft, tibialis anterior allograft and healthy individuals. It was hypothesized that when compared to an age and gender-matched healthy control group, subjects who were post-ACL reconstruction would display impaired active joint position sense, knee extensor and flexor strength symmetry and knee function at 1 year post-surgery. A secondary hypothesis was that differences would exist between the quadriceps tendon autograft, hamstring tendon autograft and tibialis anterior allograft groups.

Methods Sixty-seven patients with ACL reconstruction and 20 healthy individuals were included. Active JPS reproduction was measured at 15°, 45° and 75° of knee flexion. International Knee Documentation Committee (IKDC) subjective score and one-leg hop test were used to assess the functional status of the patients.

Results The JPS detection was different at the 15° target angle between groups ($F_{3.86} = 24.56$, $p < 0.001$). A significantly higher proportion of quadriceps tendon autograft group patients failed to identify the 15° active JPS assessment position compared to the other groups ($p < 0.0001$). The quadriceps index was lower in patients compared to healthy individuals ($p < 0.001$), while the hamstring index was similar (n.s.). The knee functional outcomes were similar between ACL reconstructed groups and healthy controls (n.s.).

Conclusion Knee proprioception deficits and impaired muscle strength were evident among patients at a mean 13.5 months post-ACL reconstruction compared with healthy controls. Patients who underwent ACL reconstruction using a quadriceps tendon autograft may be more likely to actively over-estimate knee position near terminal extension. Physiotherapists may need to focus greater attention on terminal knee extension proprioceptive awareness among this patient group.

Level of evidence III.

Keywords Anterior cruciate ligament · Quadriceps tendon autograft · Hamstring tendon autograft · Tibialis anterior tendon allograft · Proprioception

Introduction

Anterior cruciate ligament (ACL) reconstruction continues to be the primary treatment option for injured patients who desire to return to sports that involve running and sudden directional changes. There are several graft options for ACL reconstruction, however, no single option is best for all patients [10, 13]. Autografts constructed from the patellar tendon (PTA), hamstring tendons (HTA), or quadriceps tendon (QTA) are most commonly used due to lower failure rates compared to allograft alternatives [13, 28, 30, 33, 34, 38]. However, allografts may still be selected for ACL reconstruction for some athletes due to the absence of donor site morbidity, decreased

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post-operative symptoms, less range of motion impairment and the improved cosmesis [11, 21, 39].

Knee proprioception following ACL reconstruction using different graft sources has been studied with varying methods and results [4, 6, 32, 35]. Proprioceptive ability, which is evaluated by joint position sense (JPS) [8], and the time threshold to passive motion detection [5] can at least partially be improved following ACL reconstruction by improving knee joint biomechanics [6, 35]. Relph and Herrington [35] reported that elite athletes who returned to sports after ACL reconstruction using HTA or PTA had impaired joint position sense compared to healthy individuals at 17.9 ± 4.7 months since surgery even after being 6.2 ± 0.6 months back to their respective sports. Similarly, Buyukafsar et al. [6] reported impaired proprioception at 60° knee flexion in subjects who underwent ACL reconstruction using allografts. We were only able to identify one previous study that compared subjects following ACL reconstruction using autograft or allograft tissue sources with a non-impaired control group [32]. In terms of joint position sense or time threshold to passive motion detection, Ozenci et al. [32] failed to identify any significant group differences.

There are also variable findings regarding the influence of graft source on muscle strength impairments following ACL reconstruction. Some studies reported similar knee extensor and flexor strength impairments regardless if autografts or allografts were used [26, 39, 40], although long-term knee flexion strength impairments were reported following HTA use compared to tibialis anterior allograft use [25]. Studies of self-reported knee function outcomes based on differing graft source have also found only minimal influence on patient outcomes [15, 24].

Comparing outcomes between patients with differing ACL graft sources may improve our understanding of the influence of graft selection on functional outcomes post-ACL reconstruction. The purpose of this study was to compare knee active joint position sense, knee extensor and flexor strength symmetry and knee function between subjects who underwent ACL reconstruction using differing graft sources [QTA, HTA, and tibialis anterior allograft (TAA)] and a matched age, gender and activity level healthy control group. It was hypothesized that compared to an age and gender-matched healthy control group, subjects who were post-ACL reconstruction would display impaired active joint position sense, knee extensor and flexor strength symmetry and knee function at 1 year post-surgery. A secondary hypothesis was that differences would exist between the QTA, HTA and TAA groups.

Materials and methods

Ethical approval was received from the Research Ethics Committee of Hacettepe University (GO 18/504-41). Written informed consent was obtained and from all subjects prior to study participation. Inclusion criteria for ACL reconstructed group were age between 18 and 45 years, ACL rupture with a Grade I or II meniscus tear, no articular cartilage defects and no multiple ligament injuries. Patients with associated collateral ligament or posterior cruciate ligament injuries, Grade III meniscus tears, or any history of knee, hip and ankle surgery or injury were excluded from study participation.

Sixty-seven out of 74 subjects, post-ACL reconstruction, who met the inclusion criteria, consented to study participation. A cross-sectional, case–control study design was used. The HTA was selected for patients who had concerns related to possible patellofemoral joint discomfort. The QTA was selected for patients who desired a stiffer autograft for contact sports. The TAA was selected for patients with concerns related to cosmesis and harvest site discomfort concerns. To obtain more homogenous study groups all participants had the same Tegner Knee Score, none were professional or elite level athletes and all had experienced a primary non-contact injury mechanism.

Twenty healthy subjects of comparable age, gender and Tegner Knee Score activity level to the ACL reconstructed group subjects served as the control group. Control group subjects were excluded from study participation if they had a history of knee injury or surgery. All tests were performed bilaterally for control group subjects. The dominant side of the control group was compared with the surgical side of the ACL reconstructed group.

The median time from the index ACL injury to surgery was 13.0 months (range 12.0–15.0 months). Subjects who had undergone ACL reconstruction were allocated into three surgical groups: the QTA group included 22 subjects (17 men and five women); the HTA group included 24 subjects (18 men and four women); and the TAA group included 21 subjects (17 men and 4 women). Graft fixation was the same for each group (femoral interference screw, tibial staple with trans-tibial tunnel bone graft). Surgical procedures were standardized and all were performed by the same experienced knee surgeon (MND).

Each subject had complied with the same post-operative rehabilitation program that focused on progressive quadriceps femoris strengthening (augmented with neuromuscular electrical stimulation), and neuromuscular control therapeutic exercise training. Early rehabilitation focused on joint effusion and pain control. When specific criteria were met, progressive lower extremity strengthening and functional therapeutic exercises were implemented

[19]. Subjects had to fulfil a return to sport criteria to be released back to sports activities [1].

Knee strength assessment

Peak concentric knee extensor and flexor torques were measured at 60°/s and 180°/s angular velocities (Biodex System 3 Dynamometer, Biodex Corp., Shirley, NY, USA). During testing, subjects were seated with 85° hip flexion and a knee flexion angle of 90°. Dynamometer arm length was adjusted according to subject leg length. The device monitor was positioned to enable direct visual feedback. Prior to data collection, subjects performed three submaximal knee extension and flexion contractions to warm-up and to familiarize themselves with testing procedures. During data collection subjects performed 10 maximum effort concentric knee extension and knee flexion repetitions. During data collection subjects were instructed to "kick out as hard and fast as possible to full extension and to pull back as hard and fast as possible" to 90° knee flexion. A 2-min recovery period was given between each test. The non-surgical side was always tested first and standard verbal encouragement was given to each subject during test performance. Callaghan et al. [7] demonstrated that isokinetic knee extensor testing showed significant test–retest reliability with ICC values of 0.82–0.85. The quadriceps index (QI) and hamstring index (HI) were used to define strength symmetry (involved peak torque/uninvolved peak torque*100) [19]. Symmetry was defined using a cut-off of 90%. Patients who were post-ACL reconstruction had to demonstrate ≥ 90% limb symmetry to return to sport-specific training [19, 27].

Active joint position sense assessment

Joint position sense was measured using the dynamometer and active knee joint angle reproduction testing (ICC = 0.91–0.89) [20]. Subjects were seated with 85° hip flexion and 0° knee flexion. To eliminate visual input subject eyes were covered with a mask. Subjects were instructed regarding 15°, 45° and 75° knee flexion target angles. During testing subjects moved their knee at a self-determined speed to each target angle and attempted to hold that position for a minimum of 10 s [29]. This angle was recorded from the on-screen goniometer and a total of six repetitions were recorded at each target angle. Differences between subject angle replication and the target angle (15°, 45° and 75° knee flexion) were recorded. Mean differences were compared using statistical analysis.

Knee functional outcomes

A validated Turkish version of the International Knee Documentation Committee questionnaire subjective score was used to determine patient perceived knee function [9]. One leg hop for distance test was used to determine knee functional performance. During the one leg hop for distance test subjects stood on one leg with the front of their shoe positioned behind a mark on the floor. Subjects were instructed to jump as far as possible with a controlled landing. Tests were performed with the nonsurgical limb first and then the surgical limb. Three successful jumps were performed with each side. Distances were measured in centimetres and the average of the three trials was recorded. Limb symmetry index (LSI) was calculated as the (surgical limb hop distance/non-surgical limb hop distance)*100 [29].

Statistical analysis

An a priori sample size estimate revealed that 20 subjects/group would be needed based on a mean group knee extensor torque difference of 17 ± 11 Nm between ACL reconstruction group subjects and the control group (alpha level = 0.05, the statistical power of 80%). Data were visually analysed for distribution normality using histograms, Q–Q plots and Shapiro–Wilk tests (SPSS ver. 19.0, SPSS Inc., Chicago, IL., USA). Since peak isokinetic muscle group torque, active joint position sense values and IKDC Subjective survey results were normally distributed, a series of one-way ANOVA tests were used to compare differences between the QTA, HTA and TAA groups and with the control group. When statistically significant differences were observed, Tukey's HSD pairwise post hoc tests were used to better delineate the specific location of group differences. Chi-square tests were used to determine proportionate group differences for knee extensor muscle torque and active joint position sense. An alpha value of $p < 0.05$ was chosen to indicate statistical significance.

Results

Subjects who underwent ACL reconstruction and control group subject demographics are presented in Table 1. The mean follow-up time for the ACL reconstructed group was 15.6 months (range between 12 and 18 months).

Active joint position sense assessment

Active knee joint position sense reproduction was poorer in the ACL reconstruction groups compared to the healthy control group at the 15° target angle ($F_{3.86} = 24.56$, $p < 0.001$). There were no joint position sense differences between the control and ACL reconstructed groups at the 45° and 75° target angles (Table 2). Post hoc tests at 15° target angle revealed that the active joint position sense value was lower for the QTA group compared to the TAA ($p < 0.001$) and

Knee Surgery, Sports Traumatology, Arthroscopy (2020) 28:645–652

Table 1 Demographic characteristics of ACL reconstruction and control subject groups

Variables	HTA ($n=24$)	TAA ($n=21$)	QTA ($n=22$)	Control ($n=20$)	*p*
Age (year)	26.7 ± 4.6	26.4 ± 5.5	27.8 ± 2.8	28.7 ± 3.1	n.s.
Weight (kg)	76.1 ± 7.5	74.1 ± 5.7	78.1 ± 7.1	67.9 ± 6.8	n.s.
Height (cm)	176.9 ± 7.9	174.9 ± 4.9	178.5 ± 7.5	172.2 ± 5.1	n.s.
BMI (kg/m^2)	24.2 ± 1.2	24.1 ± 1.5	24.4 ± 1.3	22.9 ± 2.1	n.s.
Time after surgery (months)	13.3 ± 1.8	13.1 ± 1.9	13.5 ± 2.1	–	n.s.
Concomitant meniscus tears (*n*)					n.s.
Grade I	3/24	2/21	1/22		
Grade II	1/24	2/21	2/22	–	
Grade III	–	–	–		

HTG hamstring tendon group, *ATT* tibialis anterior tendon group, *QTG* quadriceps tendon group, *BMI* body mass index

Table 2 Active joint position sense results between ACL reconstruction and control groups

Variables	HTA ($n=24$)		TAA ($n=21$)		QTA ($n=22$)		Control ($n=20$)		*p*
	Mean ± SD	Δ deficit	Mean ± SD	Δ deficit	Mean ± SD	Δ deficit	Mean ± SD	Δ deficit	
15° target angle	17.7 ± 2.3	2.7°	18.2 ± 3.1	3.2°	12.7 ± 1.9	2.3°	15.4 ± 1.6	0.4°	< 0.001*
45° target angle	46.9 ± 5.5	1.9°	46.7 ± 5.4	1.7°	45.6 ± 2.9	0.6°	45.9 ± 4.7	0.9°	n.s.
75° target angle	75.1 ± 3.4	0.1°	75.6 ± 8.5	0.6°	74.3 ± 2.1	0.7°	74.9 ± 5.1	0.1°	n.s.

Δ deficit was calculated as (target angle-detected angle)

HTA hamstring tendon autograft, *TAA* tibialis anterior allograft, *QTA* quadriceps tendon autograft

*One way ANOVA test, $p < 0.05$

HTA ($p < 0.001$) groups. Significant joint position sense differences were not observed between the HTA and TAA groups. A greater proportion of QTA group subjects failed to identify the 15° active joint position sense target angle compared to the other groups ($p < 0.0001$).

Strength symmetry assessment

The QI differed between the ACL reconstruction groups and the control group at both 60°/s ($F_{3,86} = 12.19$, $p < 0.001$) and at 180°/s ($F_{3,86} = 6.91$, $p < 0.001$) angular velocities. At 60°/s, post hoc tests revealed that the QI was higher in the control group compared to the HTA ($p = 0.009$), QTA ($p < 0.001$) and TAA ($p = 0.002$) groups. Among the ACL reconstruction groups, the QI level was higher in the HTA group compared with the QTA group ($p = 0.020$) (Table 3).

At 180°/s angular speed, QI was higher in control group compared to QTA ($p = 0.044$) and TAA ($p = 0.001$) groups. There was no difference in QI between the HTA and control groups ($p =$ n.s). Comparisons between the ACL reconstruction groups revealed that the QI was higher in the HTA group than the QTA group ($p = 0.005$) and the TAA group ($p = 0.036$). The QI results were similar between QTA and TAA groups ($p =$ n.s.). There were no differences in HI results between subjects who were post-ACL reconstruction and healthy control subjects both 60°/s and at 180°/s angular speeds (all *p* values were n.s.) (Table 3).

Knee function outcome assessment

IKDC subjective survey scores ($p =$ n.s.) and limb symmetry index for one leg hop testing ($p =$ n.s.) were similar between the ACL reconstruction and healthy control groups (Table 3).

Discussion

The most important findings of the present study are that the active joint position sense and quadriceps strength symmetry index differed in individuals who had undergone ACL reconstruction compared to healthy control group subjects. A significantly higher proportion of QTA group subjects failed to identify the 15° active joint position sense assessment position, consistently overshooting the target angle ($p < 0.0001$) compared to the other ACL reconstructed groups. A second important finding in the present study is that even though QI scores were decreased in all ACL reconstruction groups compared to the healthy control group, the HI was similar. Graft source comparisons revealed that the active joint position sense deficit at the 15° target differed between groups

Table 3 Group quadriceps index, hamstring index and limb symmetry index comparisons

Variables	HTA ($n=24$)	TAA ($n=21$)	QTA ($n=22$)	Control ($n=20$)	p
60°/s (PT/BW)					
QF-A	1.7 ± 0.4	1.7 ± 0.5	1.6 ± 0.4	1.9 ± 0.2	< 0.001*
QF-B	1.9 ± 0.4	1.9 ± 0.8	1.9 ± 0.4	2.2 ± 0.6	n.s.
QI (%)	89.5 ± 14.2	87.7 ± 9.4	79.7 ± 10.5	100.6 ± 9.3	< 0.001*
HS-A	1.7 ± 0.2	1.7 ± 0.3	1.3 ± 0.2	1.4 ± 0.2	n.s.
HS-B	1.7 ± 0.3	1.7 ± 0.4	1.7 ± 0.3	1.7 ± 0.3	n.s.
HI (%)	88.3 ± 9.1	91.1 ± 11.1	93.5 ± 11.6	94.4 ± 12.4	n.s.
180°/s (PT/BW)					
QF-A	1.4 ± 3.3	1.3 ± 0.3	1.2 ± 0.3	1.8 ± 0.3	0.005*
QF-B	1.7 ± 2.2	1.7 ± 0.4	1.7 ± 0.3	1.1 ± 0.2	n.s.
QI (%)	97.6 ± 16.1	89.9 ± 13.3	84.7 ± 8.4	100.5 ± 11.5	< 0.001*
HS-A	1.4 ± 0.2	1.4 ± 0.2	1.4 ± 0.2	1.5 ± 0.2	n.s.
HS-B	1.4 ± 0.2	1.4 ± 0.3	1.4 ± 0.2	1.4 ± 0.31	n.s.
HI (%)	87.9 ± 11.5	92.9 ± 11.9	95.1 ± 15.5	98.4 ± 11.2	n.s.
OLHT (cm)					
A	145.5 ± 21.1	133.6 ± 31.3	140.2 ± 32.6	144.0 ± 21	n.s.
B	152.5 ± 19.1	151.7 ± 28.6	155.4 ± 22.1	153.1 ± 23.1	n.s.
LSI (%)	95.3 ± 7.1	91.2 ± 9.1	91.9 ± 9.4	94.6 ± 6.3	n.s.
IKDC	82.8 ± 10.5	84.3 ± 10.1	82.7 ± 9.1	89.9 ± 8.7	n.s.

A anterior cruciate ligament reconstructed side for patients and dominant side for controls, *B* uninvolved side for patients and non-dominant side for controls, *QF* quadriceps femoris, *HS* hamstring, *PT/BW* peak torque/body weight, *QI* quadriceps index, *HI* hamstring index, *LSI* limb symmetry index, *HTA* hamstring tendon autograft, *TAA* tibialis anterior allograft, *QTA* quadriceps tendon autograft, *IKDC* International Knee Document Committee 2000 Subjective Knee Form

*One-way ANOVA test, $p < 0.05$

with the QTA group displaying a greater proportion of subjects who overshot the target angle.

The results also showed that the mean detection angle was lower in QTA group (12.7°) compared to HTA group (17.7°) and TAA group (18.2°). Interestingly, 20 out of 22 patients (90.9%) of subjects in the QTA group overshot the 15° target angle compared to only 3 of 24 (12.5%) in the HTA group and 2 of 21 (9.5%) in the TAA groups. This difference may suggest greater proprioceptive impairment associated with extensor mechanism autograft harvest in the QTA group. Quadriceps tendon harvest primarily changes the stiffness of the muscle tendon junction (bone one side-muscle on the other side). This might contribute to active JPS changes that become manifest closer to the terminal knee extension. It would be important for the physiotherapist to confirm full re-establishment of rectus femoris extensibility since this is also a hip muscle. Stretching exercises should combine knee flexion with hip extension during the healing process to better ensure normal muscle–tendon length. Additional soft tissue mobilization may also be useful to better ensure that the healing donor site scar does not become a stress riser.

QTA use is growing in popularity for ACL reconstruction [12, 37]. Our findings of decreased QI and 15° active position sense compared to the other conditions suggest that use of this autograft also has the potential for its own unique tissue morbidity associated with harvest and harvest site healing. Grob et al. [18] have described the quadriceps tendon as possessing a complex architecture of superficial, intermediate and deep layers with six contributing elements formed from the lateral aponeurosis of the vastus intermedius, deep and superficial medial aponeurosis of the vastus intermedius, vastus lateralis, tensor vastus intermedius and rectus femoris. Because of these interlinked tissues, QTA harvest with or without patellar bone has the capacity to alter the delicate interplay between extensor apparatus layers thereby impacting knee joint extensor apparatus function [18]. Tendon harvest likely directly removes some Golgi tendon organs, altering muscle spindle kinesthesia, thereby potentially affecting tendon and GTO motor control feedback [23]. Harvest site healing also has the potential to modify tendon compliance, thereby complicating joint motor control [36]. In addition to precise, preferably quadriceps tendon graft harvest lateral to the fusing points [18], physiotherapists should place particular attention on quadriceps femoris stretching in the prone position, combining normal terminal knee flexion with hip extension to better restore more natural rectus femoris length during rehabilitation [31] in conjunction with primary tendon harvest site soft tissue mobilization to better restore pre-morbid collagen tissue alignment, histology, and strength [2]. Lastly, stronger consideration should be given to inclusion of therapeutic exercise into the rehabilitation program to enhance knee joint position sense near terminal knee extension in both weight bearing and non-weight bearing modes.

Proprioception impairments post-ACL reconstruction has been reported previously for a variety of different graft sources [4, 6, 29, 32, 35]. This study observed 15° target angle joint position sense deficits of 2.3° for QTA; 3.2° for TAA and 2.7° for HTA group. Angoules et al. [4] compared passive knee joint position sense at 15°, 45° and 75° target angles for patients who had undergone ACL reconstruction using HTA or PTA at 12 months post-surgery. They observed joint position sense deficits ranging from 2.5° to 2.7° with no group differences. A different proprioception test (active joint position sense detection) and different graft sources were evaluated in the present study. However, in both studies the joint position sense deficits that were observed at 1-year post-surgery were comparable. Ozenci et al. [32] compared active joint position deficits in ACL reconstructed patients with quadriceps tendon allograft (Δ deficit 4.5°) and QTA (Δ deficit 4.7°). The joint position sense deficits observed in the present study (Δ deficit 2.3°) were lower. But a direct comparison between the two studies is difficult because Ozenci et al. [32] did not specify exact target angles. Therefore, it is not clear if there was a joint position sense deficit at the 15° target angle or not. In a recently published study, Buyukafsar et al. [6] reported a mean 1.8° active joint position sense deficit at a 15° target angle, 3.3° mean deficit at a 30° target angle and a 5.2° mean deficit at a 60° target angle in patients who had undergone ACL reconstruction with TAA at 4 years post surgery compared to a healthy control group. They concluded that as knee flexion angle increased, knee joint position sense deficits increased. Given that joint position sense in this study was determined in a weight bearing position, it is difficult to directly compare these results with the current study. Different from the previous studies, in the current study active and a self-selected movement for joint position sense testing was used at specific target angles. Active testing is important because repositioning of the limb actively relies on central motor programs and musculotendinous function rather than a memory of proprioceptive capsuloligamentous coordinates [17]. In other words, information primarily from the muscles and tendons is projected to the central nervous system to regulate motion through agonist–antagonist muscle activity. Therefore, the present study helps improve our understand of the effects of different graft sources on knee proprioception.

The symmetry index results of the present study showed that QI was lower in the QTA group compared to HTA and TAA groups. At 180°/s angular speed, the QI was the highest in HTA group (97.6%), with similar results for the QTA (84.7%) and TAA groups (89.9%). As previously mentioned, quadriceps tendon harvest and healing may have contributed to the lowest QI results in QTA group. Interestingly, the TAA group also presented lower QI results compared to HTA group, even there is no donor site deficiency. Yoo et al. [40] reported relatively lower but comparable knee extensor strength results between TAA (78.8%) and HTA (80.9%) ACL reconstruction (180°/s) groups at approximately 2.5 years post surgery. These strength differences between HTA and TAA groups would be related to the prolonged quadriceps femoris atrophy and central inhibition despite the mechanical correction [16].

Individuals with a lower IKDC score and higher one leg hop test deficit are more likely to fail to return to safe sport participation [27, 31]. In the present study, the mean IKDC score of the participants were 82.7 being close to the cut-off values reported by Anderson et al. [3] for healthy individuals ages between 25 and 34 years. Additionally, the one-leg hop test LSI findings were 91.9% in QTA group; 91.2% in TAA group; and 95.3% in HTA group. It was interesting to observe that the QI was lowest in QTA group but these patients had similar OLHT LSI results with the other two groups. In a recently published study, Nagai et al. [29] indicated that OLHT resulted with higher LSI values than isokinetic extensor strength and they indicated that OLHT LSI might show a false-positive result. A possible explanation for this result is neuromuscular alteration to utilize the hip extensor muscles to generate the lost propulsion forces from quadriceps femoris and also from lower extremity.

The primary study limitation is that joint position sense was measured only using the active reproduction test, an open kinetic chain movement without weight bearing. However, this test mode is more sensitive to musculotendinous kinesthesia. Had a more capsuloligamentous dependent passive test mode been used the differences we observed for the QTA group may not have been observed. There are several clinical proprioception test methods, however, there is no consensus about which test provides the most reliable or valid results. Another study limitation is that knee muscle strength was performed in a sitting position. While sitting position effectively evaluates the quadriceps femoris muscle group, it limits the functional test range of the hamstring muscle group as a knee flexor from 0° to 90° and totally negates its vital role as a hip joint extensor. Therefore, strength testing in a sitting position may possess limited validity for making important clinical decisions, particularly regarding hamstring muscle group function [14, 25]. The third limitation is that pre-operative data was not included in this analysis. Subject groups did, however, display similar demographic characteristics, were operated on using the same fixation method by the same experienced surgeon and underwent the same rehabilitation protocol. Only the graft used for ACL reconstruction differed between groups.

The current study found that the QTA subjects overshot target knee extension angle during active joint position sense testing. In addition quadriceps femoris muscle strength deficiency is more evident when compared to the HTA and TAA groups. The direct implication of these findings is that postoperative rehabilitation after ACL reconstruction with QTA should emphasize on to re-establishing on full functional range and strength of the quadriceps femoris. It should be kept in mind that the histological differences regarding the graft taken from small piece of patella to tendon muscle tissue would increase the extensor mechanism stiffness [12, 22]. Specifically, soft tissue mobilization techniques, scar tissue mobility [2] or proprioceptive neuromuscular facilitation techniques would be implemented into the postoperative rehabilitation programs.

Conclusion

Knee proprioception deficits and impaired knee extensor strength were evident among patients at 1-year post-ACL reconstruction compared with healthy control group subjects. At a mean 13.5 months post-surgery, patients who underwent ACL reconstruction using a QTA may be more likely to actively overshoot knee position near terminal extension. Physiotherapists may need to focus greater attention on terminal knee extension proprioceptive awareness and soft tissue mobilization at the quadriceps tendon harvest site among this patient group when designing rehabilitation programs.

Compliance with ethical standards

Conflict of interest All authors have no conflicts of interest with respect to the data collected and procedures used within this study.

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Ethical approval The authors confirm this study meets the guidelines of the Declaration of Helsinki. Ethical approval for the study was received, and written informed consent was provided from all subjects (GO 18/504-41).

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