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Gait analysis of anterior cruciate ligament reconstructed subjects with a combined tendon obtained from hamstring and peroneus longus

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ABSTRACT

Background: Stability of the knee joint is achieved by a complex process in which the anterior cruciate ligament (ACL) plays an important role. The rupture of this ligament is quite frequent especially in athletic young subjects. Various methods have been used to reconstruct the ACL. One of the new methods is to use a graft combined from peroneus longus and hamstring. As there is no evidence regarding this method, it was aimed to evaluate the efficiency of this method.

Method: Two groups of normal and those with ACL injury, in whom their ACLs were reconstructed with the new method, participated in this study. The kinematic and kinetic parameters during walking on level surface were evaluated by a motion analysis system (Qualysis) and a Kistler force plate. The difference between the parameters of operated and non-operated sides and also between patients and normal subjects was evaluated by use of a two sample t test (p-value was 0.05).

Results: The results of this study showed that the pattern and magnitude of the loads transmitted by lower extrimity joints differed between normal and ACL reconstructed subjects. The sound side pattern and magnitude of motion were also influenced by ACL insufficiency.

Conclusions: The results of the current study showed that the reconstructed ACL by use of this method did not have enough performance to restore the function of the leg. As the knee joint is unstable following the use of this method, it is recommended to find a new method of ACL reconstruction to improve the function of this ligament after reconstruction.

1. Introduction

Knee joint stability is achieved by a complex process, which is controlled and achieved by muscles and ligaments. The anterior cruciate ligament is one of the important ligaments which plays an important role in controlling anterior tibial translation, axial rotation and varus moment [1,2]. This ligament is considered to be a dynamic structure which consists of two major bundles including antromedial and postrolateral [1–3]. Rupture of the ACL is quite frequent, particularly in young adult male athletes and represents the majority of knee joint ligaments injuries [4]. It is estimated to be the sixth most commonly performed orthopedic procedure performed in the United States with approximately 50,000 to 175,000 annual reconstructions [5,6].

Various procedures have been used to restore the performance of ACL following injury. In most of them the ligament has been reconstructed by use of various grafts obtained from hamstring tendons, and patellar tendon [4,7–9]. The main reasons to reconstruct the ACL ligament are to restore the performance of the knee joint during daily activities and to prevent the consequences associated with rupture of the ligament including meniscal degenerative alternation and osteoarthritis of the tibiofemoral joint [1,2].

The performances of the subjects with ACL injury and those with the ligament reconstruction have been evaluated in various research studies. In the research done by Bacchini et al. the walking performance of the subjects whom their ACL was reconstructed with patellar tendon was evaluated [4]. The ACL was reconstructed according to Kenneth Jon's technique. It has been shown that a voluntary decreased quadriceps action occurred in ACL reconstruction to shift the ground reaction force behind the knee and to decrease the need of ACL function. Based on the result of other studies ACL reconstruction was successful in limiting anterior tibia translation but was insufficient to control a combined rotatory load of internal and valgus torque [3].

The other alternations in sagittal plane seen in ACL reconstruction subjects are decrease in knee flection/extension, increase in hip and pelvic motion, increased hip extensor and decreased knee extensor

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moments [10]. Reducing knee extensor moment may protect the reconstructed ACL from extension strain or may result from impaired neuromuscular control [10].

The pattern and magnitude of axial rotation in ACL reconstructed subjects also differ from that of normal subjects [11]. In the research done by Ristanis et al. the rotational moment of 10 normal and 21 subjects with ACL reconstruction was compared [12]. It was found that during initial swing phase the internal rotation of the knee joint increased in the ACL reconstructed subjects. The results of this research also showed that the rotational moment of the knee joint differed significantly between normal and ACL subjects [12]. The stability of knee joint in the transverse plane is also influenced in ACL ruptured subjects. The distance between the articular surfaces on the lateral side increased and on the medial side decreased. The incidence of osteoarthritis is greater in this group of subjects compared to the normal population [12].

The results of gait analysis confirm that the peak of knee adduction movement increases by 21% in ACL reconstructed subjects [13]. It is controversial whether spatiotemporal gait parameters (walking speed, stride length, and cadence) are influenced in reconstructed ACL compared to normal subjects. The shorter step length of the reconstructed ACL may be a result of not being able to fully extend the knee while walking at the end of the swing phase [14]. This is a mechanism used by the body to protect the injured ligament during walking [14,15].

In the above research studies the ACL was reconstructed by the use of a patellar tendon, hamstring muscles and maybe Achilles tendon. Kerimoglu et al. were the first who reported the use of peroneus longus tendon (PLT) to reconstruct the ACL ligament. They evaluated the subjects based on Lysholm and Knee Documentation Committee scores after 5 years of follow-up. They reported that no patient complained of ankle instability and dysfunction due to the removal of the PLT. They concluded that this method can be used to reconstruct the ACL [16]. However, they did not evaluate the performance of the ankle and knee joints by motion analysis which is a gold standard in this regard [17]. In some subjects the hamstring tendon thickness less than 7 mm which is appropriate to be used for ACL reconstruction due to technical errors of removing tendons or even normal variation in hamstring tendons. In these cases the combination of hamstring and PLT can be used in order to achieve appropriate thickness of the tendon which can be used to reconstruct the ACL. Unfortunately, there were no research studies that evaluated the performance of the ACL subjects with the above mentioned method. Therefore, the aim of this research was to compare the performance of the subjects with reconstructed ACL based on this method with that of normal subjects.

2. Method

2.1. Subjects

Two groups of subjects (each group consisted of 15 subjects) were recruited in this study. The number of participants was decided based on the number of subjects in previous studies using motion analysis of subjects with ACL reconstruction, which varied between 10 and 20 [10,11,22,24]. They were asked to walk with a comfortable speed over a level walkway. The ACL was reconstructed with a graft obtained from hamstring and peroneus longus tendons. They used a functional knee orthosis for three months after surgery. The subjects participated in this research six months after ACL reconstruction surgery. The time of their involvement in this study (which was 6 months) was based on the recommendations of other studies in this regard [18,19]. There was also a control group matched with the first group, based on age, height, weight and sex. The inclusion criteria for selecting the normal subjects were to have no musculoskeletal disorders which prevent their walking and standing performance and have nearly the same age as that of reconstructed ACL subjects.

Table 1 shows the characteristics of the subjects in this study. An ethical approval was obtained from Isfahan University of Medical Science Ethical Committee. Moreover, the subjects were asked to sign a consent form before data collection.

Table 1
The characteristics of the subjects who participated in this study.

Subjects	Age (year)	Height (m)	Number
ACL reconstructed	33 ± 2.6	1.75 ± 0.05	15
Normal	32 ± 3	1.74 ± 0.06	15

2.2. Parameters

Outcome variables included hip, knee and ankle joints and pelvis range of motions in three planes, maximum ground reaction force (GRF), spatiotemporal gait, and the moments applied on the hip and knee joints.

2.3. Procedure

For tracing the movement of the subjects an array of seven high speed cameras by Qualysis Company was used. Moreover, the force applied on the leg was measured by a Kistler force plate. The locations of markers were recorded by Track-Manager software. The subject's lower body anatomy was reconstructed by Visual 3D software produced by C Motion Company. The angles of the pelvis, hip, knee and ankle joints were also measured using this software. Force plate data was also processed in 3D to calculate the resulting moments of the lower limb joints.

Sixteen markers (with 14 mm diameters) were attached to right and left anterior superior, iliac spine (ASIS), right and left posterior superior iliac spine (PSIS), right and left medial and lateral malleolus, right and left medial and lateral sides of the knee joints and first and fifth metatarsal heads. Moreover, four marker clusters comprising of four markers attached on rhomboid plates were attached to the antero-lateral surface of the leg and thigh by use of extensible Velcro straps. The subjects were asked to walk along the level surface to collect five successful trials. The collected data were filtered with a Butterworth low pass filter with a cutoff frequency of 10 Hz and split to gait cycle internal using heel strict data. Fig. 1 shows the procedure undertaken in motion analysis research.

The normal distribution of the mentioned parameters has been tested using the Shapiro–Wilk test. Since the parameters had a normal distribution the parametric statistical test was used to evaluate the difference between the performances of the reconstructed ACL subjects on both sides and also to compare the normal and ACL subjects. Two sample t test were used to compare the mean of the parameters.

3. Results

The mean values of stride length, speed and cadence were 1.25 ± 0.114 (m), 1.031 ± 0.16 (m/s) and 8.43 ± 8.8 (steps/min), respectively in the operated subjects compared to 1.26 ± 0.13 (m), 1.06 ± 0.21 (m/s) and 100.76 ± 10.5 (steps/min) in normal subjects. There was no significant difference between the mean values of spatio-temporal gait parameters between normal and ACL reconstructed subjects (p-value > 0.05).

Table 2 summarized the range of motions of the hip, knee; ankle and pelvis of ACL reconstructed subjects (sound side and operated side) and normal subjects. The range of flexion/extension motion of the knee joint was 59.6 ± 6.9 and 55.58 ± 7.87 in normal and ACL reconstructed sides, respectively (p-value > 0.05). The range of dorsi/plantar flexion angle of ankle joint was 25.7 ± 2.79° in sound side compared to 24.8 ± 4.47° in the operated side.

There was a significant difference between the range of motion of the hip joint in the sagittal and coronal planes of normal and ACL reconstructed subjects. However, the mediolateral rotation of the hip joint decreased in ACL reconstructed subjects (p-value = 0.005). The adduction/abduction excursion of the knee joint decreased significantly following the ACL reconstruction. Although the range of the knee joint in the sagittal plane decreased in ACL subjects, the difference is not significant. The motion of ankle joint also differed in normal and ACL reconstructed subjects. The excursion of mediolateral rotation of the ankle joint was 17.29 ± 8.72 in ACL reconstructed subject, compared to 14.56 ± 5 in normal subjects (p-value < 0.5). There was no difference between the pelvis motions in normal and the ACL reconstructed subjects (p-value > 0.05).

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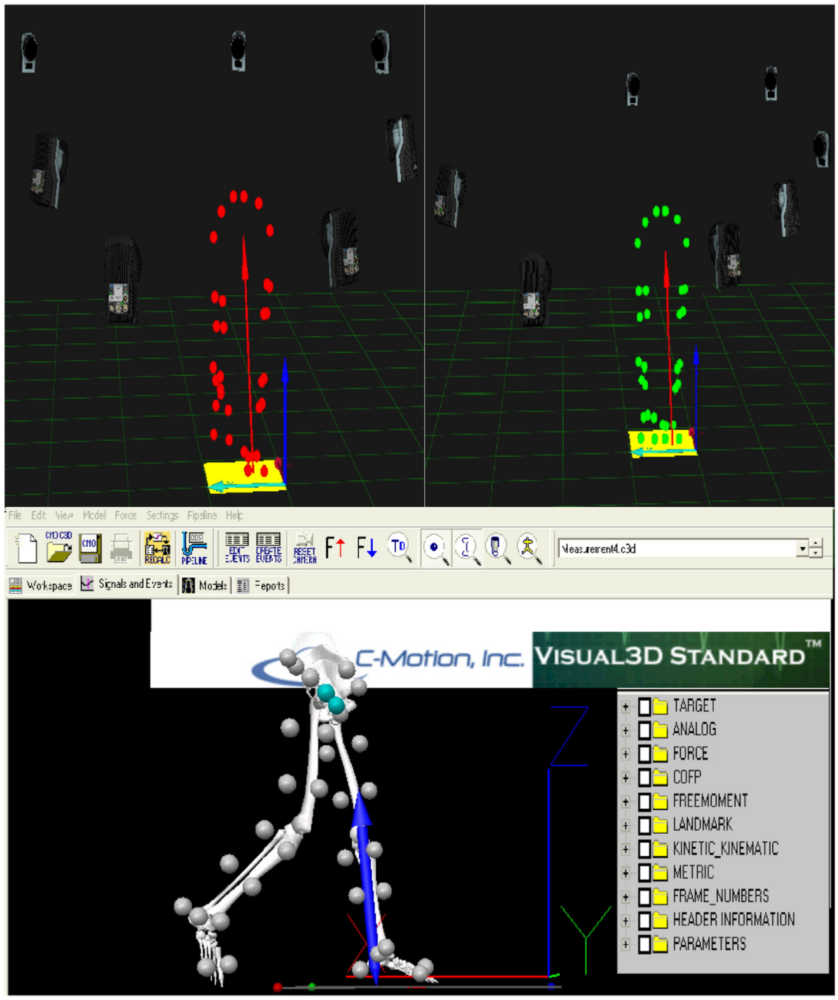

Fig. 1. The different stages of gait analysis procedure used in this study, recording the trajectories of the markers (top left), labeling of the markers (top right) and modeling of the legs and pelvis (down).

Table 3 summarized the moments of the hip, knee and ankle joints of normal subjects and ACL reconstructed in the sound and operated sides. The mean values of hip flexion moment were 0.81 ± 0.51 Nm/BW in operated and sound sides, respectively (p-value < 0.5). The rotation moment of the knee joint decreased significantly in the operated side compared to the sound side (0.23 ± 0.19 and 0.08 ± 0.04). In contrast the rotation moment of the ankle joint increased by more than 30% in operated side than in normal side (p-value = 0.00).

Although there was no difference between the extensor moment of the hip joint in normal and ACL reconstructed subjects, the flexor moment differed between the subjects. The adductor moment of the knee joint was 0.51 ± 0.27 Nm/BW in the operated side compared to 0.35 ± 0.126 in normal subjects (p-value = 0.048). The rotatory moment of the knee joint also differed between normal and ACL reconstructed subjects (p-value = 0.015).

Fig. 2 shows the pattern of the knee joint flexion/extension, abduction/adduction and rotation of normal and ACL reconstructed subjects. The moments of the knee joint are also shown in Fig. 3.

4. Discussion

The anterior crucial ligament plays an important role in controlling anterior tibia translation, varus and knee joint axial rotation [2,4]. Lesions of this ligament are quite frequent, particular in young adult subjects involved in various sporting activities [6].

Table 2
Hip, knee, ankle and pelvis of normal and ACL reconstructed subjects X is defined as flexion/extension, Y is defined as abduction/adduction and Z is defined as internal/external rotation.

Parameters	Normal side	Operated	p-Value	Normal subject	Operated	p-Value
Hip X	37.94 ± 3.32	37.33 ± 4.04	0.358	39 ± 5	37.33 ± 4.04	0.16
Hip Y	12.64 ± 5.08	15.44 ± 8.01	0.159	13.8 ± 3.7	15.44 ± 8.01	0.26
Hip Z	16.23 ± 6.7	14.3 ± 3.16	0.21	11 ± 2.6	14.3 ± 3.16	0.0057
Knee X	59.6 ± 6.91	55.58 ± 7.87	0.1	61.15 ± 12.33	55.58 ± 7.87	0.126
Knee Y	12.6 ± 5.3	16.42 ± 8.62	0.1	9 ± 3.3	16.42 ± 8.62	0.006
Knee Z	19.75 ± 4.77	17 ± 5.005	0.096	15.7 ± 6	17 ± 5.005	0.3
Ankle X	28.1 ± 1.79	24.8 ± 4.47	0.05	30 ± 5.54	24.8 ± 4.47	0.048
Ankle Y	17.4 ± 4.92	18.09 ± 8.31	0.3	14.56 ± 5	18.09 ± 8.31	0.137
Ankle Z	14.65 ± 7.64	17.29 ± 8.72	0.9	11.51 ± 5.01	17.29 ± 8.72	0.046
Pelvis X	7.03 ± 1.76	6.79 ± 2.2	0.39	6.1 ± 5.63	6.79 ± 2.2	0.38
Pelvis Y	4.77 ± 5.22	3.88 ± 2.46	0.32	7.1 ± 7.54	3.88 ± 2.46	0.122
Pelvis Z	10.1 ± 2.24	10.8 ± 3.89	0.315	11.33 ± 2.39	10.8 ± 3.89	0.35

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Table 3
The moments transmitted by the ankle, knee and hip joints in normal and ACL reconstructed subjects, Nm = Newton meter.

Parameters	Normal side	Operated	p-Value	Normal subject	Operated	p-Value
Hip FMT (Nm/body mass)	0.576 ± 0.33	0.43 ± 0.38	0.29	0.465 ± 0.187	0.43 ± 0.38	0.428
Hip EMT (Nm/body mass)	0.75 ± 0.37	0.81 ± 0.51	0.39	0.517 ± 0.181	0.81 ± 0.51	0.044
Hip AMT (Nm/body mass)	1.01 ± 0.33	0.98 ± 0.45	0.419	0.9 ± 0.16	0.98 ± 0.45	0.295
Hip ERMT (Nm/body mass)	0.283 ± 0.175	0.195 ± 0.14	0.163	0.219 ± 0.043	0.195 ± 0.146	0.01695
Hip IRMT (Nm/body mass)	0.148 ± 0.178	0.147 ± 0.09	0.497	0.2 ± 0.14	0.147 ± 0.095	0.1
Knee FMT (Nm/body mass)	0.45 ± 0.35	0.46 ± 0.46	0.494	0.61 ± 0.5	0.46 ± 0.46	0.243
Knee EMT (Nm/body mass)	0.55 ± 0.442	0.88 ± 0.7	0.1	0.5 ± 0.1	0.88 ± 0.7	0.2
Knee AMT (Nm/body mass)	0.42 ± 0.159	0.51 ± 0.27	0.17	0.35 ± 0.126	0.51 ± 0.27	0.048
Knee ERMT (Nm/body mass)	0.23 ± 0.19	0.08 ± 0.04	0.027	0.166 ± 0.09	0.08 ± 0.04	0.015
Knee IRMT (Nm/body mass)	0.127 ± 0.058	0.2 ± 0.19	0.12	0.13 ± 0.06	0.2 ± 0.19	0.13
Ankle PFMT (Nm/body mass)	1.27 ± 0.71	1.52 ± 0.57	0.9	1.38 ± 0.31	1.52 ± 0.57	0.26
Ankle AMT (Nm/body mass)	0.22 ± 0.17	0.32 ± 0.16	0.2	0.24 ± 0.168	0.32 ± 0.16	0.143
Ankle RMT (Nm/body mass)	0.16 ± 0.15	0.21 ± 0.14	0.006	0.136 ± 0.066	0.21 ± 0.14	0.06

FMT = flexion moment, EMT = extension moment, AMT = adduction moment, ERMT = external rotation moment, IRMT = Internal rotation moment, PFMT = plantar flexor moment, RMT = rotation moment.

Various surgical procedures have been used to reconstruct this ligament including: use of the patellar tendon, hamstring tendon and Achilles tendon [4,8]. The results of various research studies have shown that the pattern and the range of motion of the lower limb joints differed between normal subjects and those with ACL reconstruction [1,12,20,21].

It means that the reconstructed ACL may restrict some abnormal motions of the knee joint, most of the subjects decreased the range of motion of the lower limb joints to decrease the performance of this ligament [22,23]. Moreover, it has been reported that walking speed and stride length decreased in this group of subjects in contrast to normal subjects [14].

The other method which has been used to reconstruct the ACL, is using a graft obtained from the peroneus longus tendon (PLT). This method was reported by Kerimoglu et al. in 2008. The subjects were followed 5 years after surgery. They reported that the subjects had no complications of the knee and ankle joints [16]. However there is no research which evaluated the performance of the subjects with ACL reconstruction based on this method. In some subjects the thickness of hamstring tendon is not enough to be used for ACL reconstruction. Therefore, a new procedure is suggested based on a graft obtained from hamstring tendon and PLTs. There has been no previous research regarding the gait performance of these subjects compared to normal subjects. Therefore, the aim of this study was to compare the kinematics and kinetics of the lower limb joints in the subjects who received this type of ACL reconstruction.

Based on the results of this study, the pattern and magnitude of the lower extremity joints in operated and none operated sides was nearly the same. It can be concluded that the rupture of the ACL not only has an influence on the performance of the joint and musculoskeletal system in the operated side but also has a negative influence on the normal side. The main reason is that the subjects try to increase the symmetry of gait by decreasing the excursions of the joints and stride length in the normal side [15,23].

In contrast to normal subjects, there is a significant difference between the ranges of motion of the joints in ACL reconstructed subjects. The hip joint range of rotation decreased in ACL reconstructed subjects compared to normal subjects. This may be a mechanism which was used by the subjects to decrease the rotatory moments of the knee joint (as can be seen the rotatory moment applied on the ACL reconstructed knee joint decreased significantly compared to normal subjects, Table 3). In most of the research studies it was mentioned that knee joint flexion/extension decreased significantly [10,23,24]. It has been shown that the subjects put the knee joint in some degree of flexion to decrease quadriceps action, to shift GRF behind the knee joint and to decrease the need of ACL function [14]. The results of this study showed that the subjects may not use this procedure and they tried to obtain full range of motion at the knee joint.

The medial–lateral stability of the knee joint decreased in the subjects with ACL reconstruction, Table 2. It means that the range of abduction/adduction is more in these subjects compared to normal. One of the performances of ACL is to control the medial–lateral moment of the knee joint (varus moment) [1,2]. The result of this study showed that the reconstructed ligament did not restrict the instability of the knee joint in coronal plane. Although in the patients with ACL reconstructed with a tendon of patellar or hamstring, the rotatory moment of the knee joint decreased significantly in contrast to normal [11,23], in the current research, the difference was not significant. However, it cannot be concluded that the new method is better than the previous one.

The moments applied on the joints were also measured in this research study. As can be seen in Table 3, there was no difference between flexion, extension, adduction and rotation moments of the hip joint of normal and ACL reconstructed sides. However, the extensor moment applied on the hip joint increased significantly in ACL reconstructed subjects compared to normal subjects. The results of this research are the same as the results of the research done by Michelle et al., which showed that those with ACL reconstruction exhibit lower knee extensor moment and greater hip extensor moment compared to control group [10]. It was also mentioned that the other reason to increase hip extensor moment is to reduce anterior tibial translation [10]. Therefore, it can be concluded that the ACL reconstructed subjects compensate the knee extensor moment by an increase in extensor moment transmitted through the hip joint [22].

Although there was a slight increase in adductor moment applied on the hip joint, the adductor moment of the knee joint increased significantly in ACL reconstructed subjects. The results of this research is the same as the one done by Butler et al., which showed that the adductor moment of knee joint increased by 21% in ACL reconstructed subjects compared to normal subjects [13].

Based on the results of various research studies an increase in magnitude of adductor moment increased the loads applied on the knee joint and therefore increase the symptom of knee osteoarthritis.

Generally the pattern of the loads transmitted by the leg is influenced by ACL reconstruction (Table 3). It may be due to an involuntary mechanism employed by the body to decrease the loads on ACL and to decrease the need to use this ligament to control rotational and transitional movements of the knee joint [23,24]. As far as the results of reconstruction are successful the need to use compensatory mechanism decreases.

The results of motion analysis of the knee joint in ACL reconstructed subjects with the aforementioned method showed that there seems to be no significant difference between this method and other methods (reconstruction of ACL with use of hamstring tendon). However, the motions of the ankle joint were influenced due to removal of PLT. The range of dorsi/plantar flexion of the ankle joint decreased in the operated side compared to the intact side and normal subjects, which may be

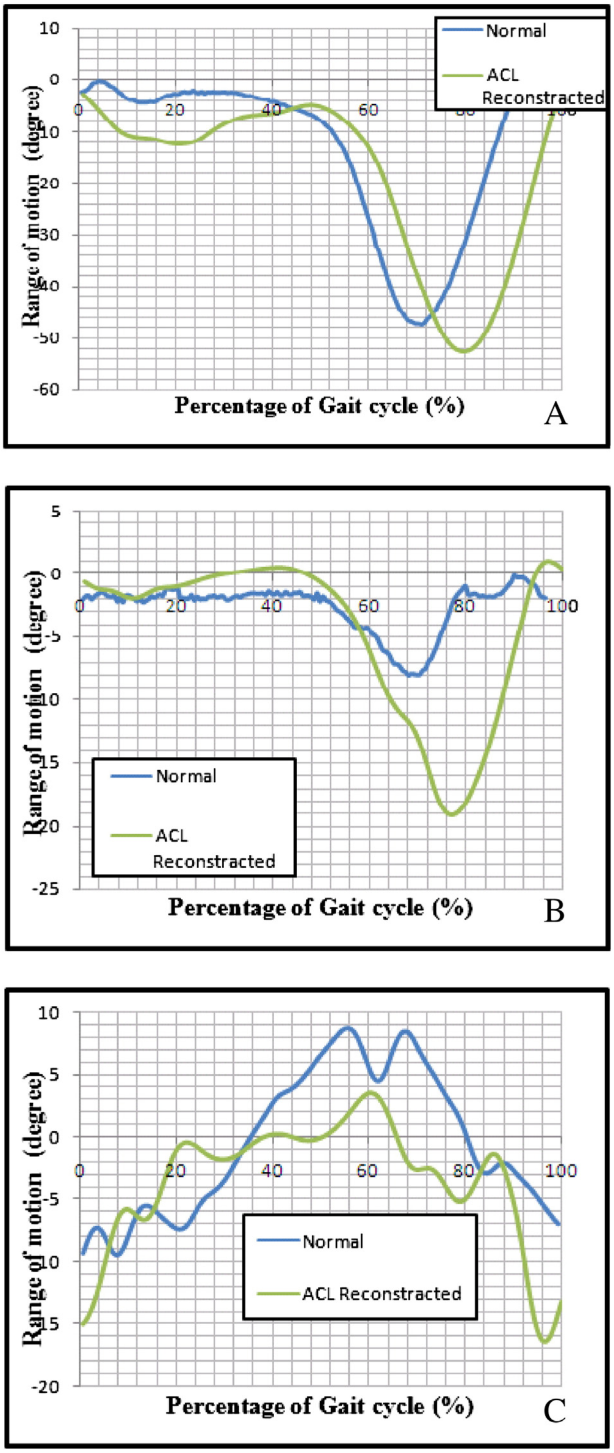

Fig. 2. The patterns of knee flexion/extension (A), abduction/adduction (B) and rotation (C) in normal and ACL reconstructed subjects.

due to the mechanism employed by the subjects to protect the ACL from excessive stress. In contrast, the range of inversion/eversion and rotation of the ankle joint increased, which may be due to instability of the ankle joint in frontal and transverse planes due to removal of PLT.

The moments applied on the ankle joint were also influenced due to the removal of PLT. The rotatory moment of the ankle joint increased significantly in the reconstructed subjects compared to normal subjects (although the mean values of other moments increased in operated subjects the difference was not significant). The main reason to increase the moments of a joint is that instability occurs due to surgery or a

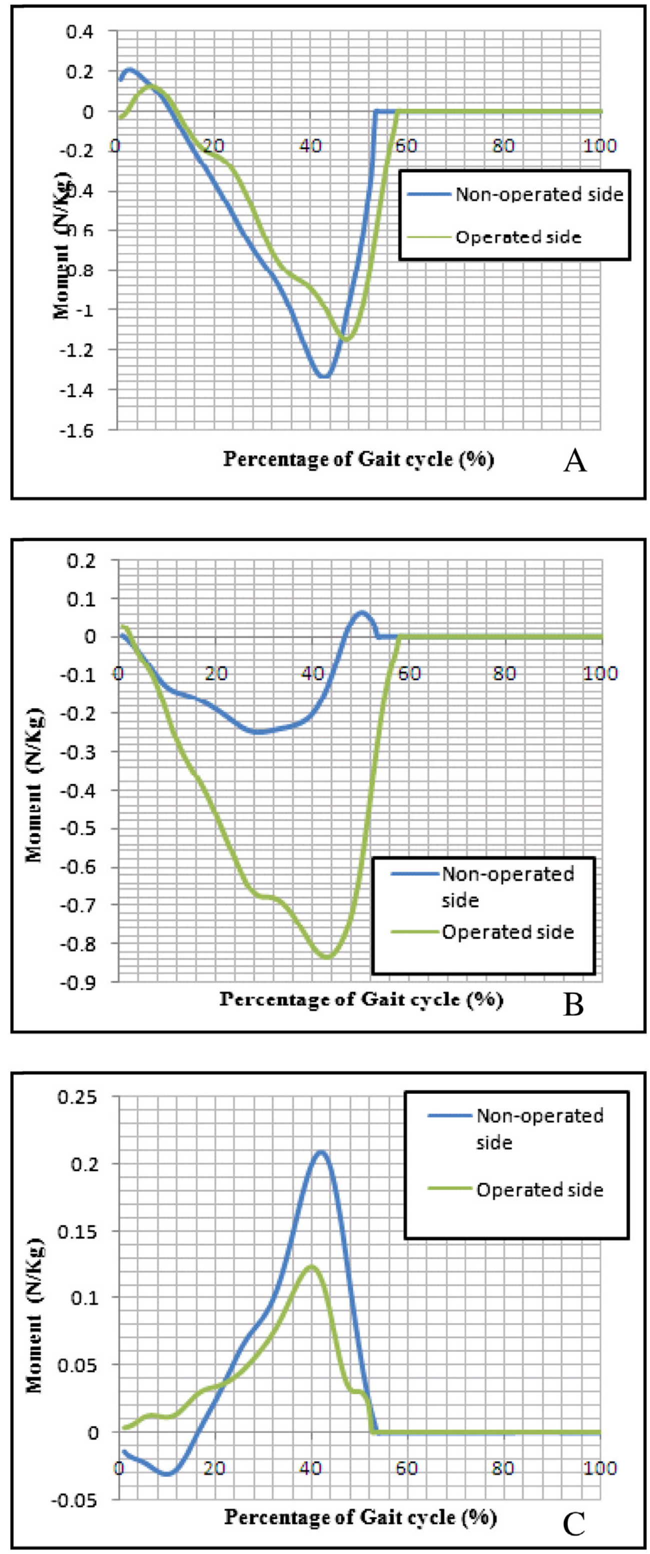

Fig. 3. The moments applied on the knee joint in sagittal (A), frontal (B), and transverse plane (C).

disease. Increasing the moments applied on the ankle joint means more loads applied on the joint. When the loads applied on a structure increase the incidence of degenerative injury will be increased. Therefore, it can be concluded that removal of PLT increases the instability of the ankle joint and increases the loads applied on it.

The main limitation which should be acknowledged in this study was the length of follow-up. Although the subjects were tested

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6 months after reconstruction surgery, this time varied as some of the patients could not have recovered to full activity level at 6 months after the surgery. Therefore it is recommended that in future studies the performance of ACL reconstructed subjects be monitored at various follow-up periods.

5. Conclusion

Using a graft obtained from hamstring and peroneus longus tendons is the other method which has been used to reconstruct ACL ligament. Based on the results of this research the functional performance of the subjects with reconstructed ACL by this method during walking is the same as that of previous reported methods. There is a significant alternation in kinetics and kinematics of human joints which define the insufficient performance of the reconstructed ligament.

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