RESEARCH ARTICLE

Coordination of the Lower Limbs of Soccer Players after Anterior Cruciate Ligament Reconstruction with Allograft and Autograft during Landing

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Received: 14 August 2023 *Accepted: 30 October 2023*

Abstract

Objectives: Quantitative biomechanical tests, along with physical assessment, may be useful to understand kinematics associated with graft types in anterior cruciate ligament surgery, particularly in individuals aiming for a safe return to sport.

Methods: Sixty male soccer players in three groups participated in this study. Three equal groups of healthy, auto transplanted and allotransplanted participants, matched for age, gender, activity level and functional status, landed with one foot on a force plate. Their kinematic information was recorded by the motion analyzer and used to describe coordination the variability by measuring coupling angles using vector coding.

Results: The coordination variability of the allograft group in the surgical limb was significantly greater than that of the healthy group at least 9 months after the reconstructive surgery of the ACL and at the stage of return to sports, ($F(6, 35) = 2.79$, $p = 0.025$; Wilk's $\Lambda = 0.676$, partial $\eta^2 = 0.32$). The coordination pattern in the surgical and healthy limbs of the surgical groups also differed from that of the healthy people, which was more pronounced in the allograft group, ($F(6, 35) = 2.61$, $p = 0.034$; Wilk's $\Lambda = 0.690$, partial $\eta^2 = 0.31$).

Conclusion: These results show that the allograft group has a different coordination variability at return to sport than the healthy group, so they may need more time for excessive training and competition.

Level of evidence: II

Keywords: Allograft, Anterior cruciate ligament (ACL), Autograft, Coordination variability

Introduction

Anterior cruciate ligament (ACL) injury is considered one of the most common knee injuries.[1] ACL injury results in relative disruption of the excitatory pathways and changes in spinal and supraspinal motor control, followed by changes in the accuracy of deep joint sensation and changes in motor control strategy, postural control, muscle strength, and co-contraction and movement patterns.[2] Thus, ACL injury is considered a neurophysiologic dysfunction and is not just a peripheral musculoskeletal injury.[3,4] Most athletes who wish to continue their athletic activities after an ACL injury are advised to undergo reconstructive surgery.[5] Different types of grafts are used for ACL reconstructive surgery, each with advantages and disadvantages.[6,7] Autograft reconstruction results in damage to the graft donor site,[8,9] but proper cellular repair, lower treatment costs, and no disease transmission are among the advantages of using autografts.[10-13] The advantages of using allografts are less

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THE ONLINE VERSION OF THIS ARTICLE ABJS.MUMS.AC.IR

pain after the operation, shorter operation time and no damage to the donor site,[14] but one of the problems with using this type of graft is the transmission of the disease to the recipient[15]. Therefore, there are opinions on the use of autografts and allografts.[16-18] After ACL reconstruction , athletes returned to intense sports activities with a high risk of injury to both knees, with 23% of young athletes reportedly suffering a re-injury to the both knees,[19] accompanied by a risk of osteoarthritis (OA) in the operated knee[20] In a complex system, multiple degrees of freedom are expected to produce a specific output pattern, and the system can produce the same specific pattern under different conditions.[21]

Failure to return to sport activities and re-injury after ACL reconstruction may be due to lack of coordination of degrees of freedom or a lack of coordination in multi-joint tasks in jumping activities between injured and uninjured limb.[22-26] Coordination variability is a functional issue that adapts to optimal coordination situations.[27] There are also side effects and a lack of neuromuscular control coordination on return to sport, even up to 24 months after ACL reconstruction.[28,29] For the athlete to perform an effective activity in different domains, the coordinative structures must have a combination of stability and flexibility.[30] One way to measure relevant sensory information is to measure the coordination characteristic during multi-articular postural coordination,[31,32] and it appears that measuring outcome measure alone leads to a flawed analysis of human movement coordination[33] performing quantitative biomechanical tests, along with physical assessments may be useful to understand the functional and physical relationship associated with graft types.[34]

The aim of this study is to quantify and compare joint coordination patterns and variability in the joints of soccer players with ACL autograft and allograft reconstruction with the healthy group during landing which is one of the injury mechanisms to determine the potential risks of injury and re-injury, involving many segments of the lower limb. The study of coordination patterns provides comprehensive information on how the neuromuscular system organizes the degrees of freedom of movement. The angular displacements of two adjacent joints were recorded based on the relative movement of the joints using vector coding method for kinematic analysis of the lower limbs. The advantages of vector coding are that the interpretation is made from the most important position signals and is used for sinusoidal and non-sinusoidal information. It does not require normalization and has more clinical applications. It is hypothesized that the coordination variability of the surgical group is greater than the healthy group and their coordination pattern is different from the healthy group.

Materials and Methods

This is a comparative cross-sectional study and the G*Power software, version 2.9.1.7 was used to determine the sample size. In this programme, in the pilot study (8 subjects per group), the statistical method of MANOVA between factors from the group of F-tests with a 95% confidence coefficient, 90% test power, a first error coefficient of 5%, and an effect size of 0.25 was selected to determine the sample size.[35,36] This study was approved by the Medical Ethics Committee of the University of Medical Sciences of Iran (IR.IUMS.REC.1398.1406). The entire study process was conducted in the School of Rehabilitation Sciences, Iran University of Medical Science, Tehran, Iran. The form for demographic information such as age, height, weight and body mass index (BMI) as well as consent form were completed by all participants. They were then given the Marx Activity Rating Scale (MARS), Tegner Activity Scale (TAS) and International Knee Document Committee (IKDC) questionnaires. The control group consisted of athletes who had not suffered any injuries or operations to the lower limbs and spine in the last six months and were matched to the other two groups regarding age, gender, BMI, and activity level. 60 male soccer players took part in this study, with the first group consisting of 20 healthy individuals (age 21.52±2.46, BMI 22.70±1.37kg/m^2, MARS 15.14±0.85, TAS 8.90±0.30, IKDC 97.83±4.09), the second group consisting of 20 individuals who underwent unilateral ACL reconstruction with semitendinosus gracilis tendon autograft (SGA)(age 23.83±3.01, BMI 24.06±1.14 kg/m^2, MARS 14.94±1.21, TAS 8.88±0.32, IKDC 96.03±3.93) and the third group consisting of 20 individuals who underwent ACL unilateral reconstruction with allograft (Allo) (age 022.63±2.08, BMI 22.89±0.51kg/m^2, MARS 15.13±1.08, TAS 8.90±0.29, IKDC 92.80±18.89) [Table 1].

All of these two surgical groups resumed their pre-injury sporting activities. The groups were matched on the basis of indicators, such as age, gender, BMI, level of sporting activity, and functional status, the minimum and maximum time to return to sport was 9 and 24 months after surgery, respectively. All participants that had a history of bilateral knee surgery, a history of meniscus repair and surgery on the collateral ligaments of the knee, as well as pain and swelling in the knee joint, and also had limited mobility of the joints of the lower limbs, a history of surgery on other lower limbs and the spine, a history of old surgery and injuries to other lower limbs and the spine in the last six months were excluded from the study. All participants warmed up by running on the treadmill at a speed of 7 km/h for 5 min before landing. The athletes stood on one leg while the hip and knee were bent 90 degrees and the ankle was in a neutral position on a 30-centimeter height step that was 11 centimeters away from the edge of the force plate,[37] they were told that the hands were placed on the pelvic of the sides. The participant landed on the force plate (Kistler Group-Swiss, 40*60 cm, type 5691) with a frequency of 100 Hz and filtered at 10 HZ (Butterworth low-pass filter), and was repeated five times at random for each limb. a 3D motion capture system (Qualysis AB, Guthenburg, Sweden) with a frequency of 120 Hz and six cameras recorded kinematic information. Markers were placed on the sacrum, the upper posterior iliac spine, the upper anterior iliac spine, the greater trochanter of the femur, the lateral and medial femoral condyles, the lateral and medial malleolus of the ankle, the dorsum of the foot, and the first and the fifth metatarsus on both sides, and cluster tracker markers were also placed on the outer parts of the thigh and leg segments.[38,39] Based on the studies[38,40,41] hip abduction-adduction/ knee abduction-adduction (HA/KA), hip abduction-adduction/ knee rotation (HA/KR), hip flexion-extension/ knee flexion-extension (HF/KF), hip rotation/ knee abduction -adduction (HR/KA), hip rotation/ knee rotation (HR/KR) and knee flexion-extension/ ankle dorsiflexion- plantar flexion (KF/ADF) were measured. The detailed angular information was entered into MATLAB 2018 B software and the biomechanical analysis was performed using vector coding method. In the vector coding method, the angle-angle diagram representing the angular displacement of two neighboring joints along the X and Y axes was drawn first and the coupling angle was obtained by calculating the angle between the information of neighboring points on the angle-angle diagram with respect to the right horizontal axis, as shown in *eq.* (1).

$$CA = tan^{-1}\left(\frac{Yi+1-Yi}{Xi+1-Xi}\right) \qquad (1)$$

The variability of the coordination was determined by the standard deviation of the coupling angles in the landing activity and the coordination pattern was determined by measuring the magnitude of the couple angles.

SPSS software (version 21.0, IBM Corp. Armonk, NY, USA) was used to analyze the data, using a meaningful level of 0.05. The statistical indicators mean and standard deviation were used to examine the descriptive data statistics. The Kolmogorov-Smirnov statistical test was used for the normality of the variables. The one-way MANOVA test was used to analyze the changes between the reconstructed and contralateral limbs of each surgical group and the corresponding limbs of the healthy group, and the one-way repeated measures MANOVA test was used to analyze the changes between the two limbs within each group in the variables coordination variability and size. The Cohen´s d effect size index for each of the dependent variables was determined.

Table 1. Demographic (Age, Weight, BMI) and Questionnaires (Marx, Tegner, IKDC) Data (Mean ± SD)

Group	Age	Weight	BMI	Marx	Tegner	IKDC
Auto-graft	23.83±3.01	78.33±7.07	24.06±1.4	14.94±1.21	8.88±0.32	96.03±3.39
Allo-graft	22.63±2.08	76.86±3.13	22.89±0.51	15.13±1.08	8.90±0.29	92.08±18.89
Health	21.52±2.46	69.61±4.46	22.70±1.37	15.14±0.85	8.90±0.30	97.38±4.09

Results

The result of one-way MANOVA shows that there was a statistically significant difference in joint coordination variability between the groups, F (6, 35) = 2.79, p = 0.025; Wilk's Λ = 0.676, partial η^2 = 0.32 in the ACL-reconstructed limbs of the allograft compared to the contralateral limbs of the control group. Specifically, greater variability was found in the coupled motions HF/KF (p=0.010, d=0.15), HR/KR (p=0.022, d=0.12) and KF/AF (p=0.001, d=0.24) during landing [Table 2].

Table 2. Joint coordination variability in the reconstructed for allo-graft versus the contralateral for Control

Coupling	Variability (SD) (Mean ± Standard Deviation)		p-Value	Cohen's d
	allo-graft	Control-Healthy		
HA/KA	47.4±7.9	43.1±9.8	0.130	0.056
HA/KR	48.7±7.7	46.2±8.1	0.317	0.025
HF/KF	36.8±10.2	29.1±8.2	0.010	0.153
HR/KA	52.5±5.1	48.9±6.9	0.061	0.085
HR/KR	53.3±4.6	49.1±6.5	0.022	0.125
KF/AF	37.4±10.6	26.7±8.6	0.001	0.241

There was a statistically significant difference in the magnitude of joint coordination between the groups, *F* (6, 35) = 2.55, *p* = 0.037; Wilk's Λ = 0.695, partial η^2 = 0.31 in the allograft reconstructed limbs compared to the match limbs of the control group. In particular, a greater magnitude was found in allograft group for HF/KF coupled motion (p=0.011, d=0.15) [Table 3].

Table 3.Joint coordination phase magnitude in the reconstructed for allo-graft versus matched limb for Control

Coupling	Magnitude Phase (°)(Mean ± Standard Deviation)		p-Value	Cohen's d
	allo-graft	Control-Healthy		
HA/KA	197.1±106.6	152.7±84.8	0.143	0.053
HA/KR	234.0±97.8	182.9±109.4	0.119	0.060
HF/KF	248.5±98.4	157.2±123.1	0.011	0.150
HR/KA	155.1±88.6	129.2±64.8	0.287	0.028
HR/KR	216.6±81.6	192.3±82.6	0.344	0.022
KF/AF	213.5±42.9	196.2±25.2	0.119	0.060

The result shows a statistically significant difference in the magnitude of joint coordination by group, F (6, 35) = 2.61, p = 0.034; Wilk's Λ = 0.690, partial η^2 = 0.31. Notably, a greater magnitude of HF/KF (p=0.011, d=0.14), HR/KR (p=0.014, d=0.14) and KF/AF coupled motions (p=0.042, d=0.09) was observed in the allograft reconstructed limbs compared to the contralateral limbs of control group. When comparing the two surgery groups, there was a statistically significant difference in joint coordination magnitude by group, F (6, 32) = 2.51, p = 0.042; Wilk's Λ = 0.680, partial η^2 = 0.31. Notably, the greater value in the reconstructed limbs was found in the allograft compared to the SGA for HA/KR (p=0.019, d=0.14) and KF/AF coupled motions (p=0.008, d=0.17) [Table 4].

Table 4. Joint coordination phase magnitude (°) in the reconstructed for auto-graft versus allo-graft

Coupling	Magnitude Phase (°)(Mean ± Standard Deviation)		p-Value	Cohen's d
	auto-graft	allo-graft		
HA/KA	148.2±104.1	197.1±106.6	0.158	0.053
HA/KR	152.9±108.3	234.1±97.8	0.019	0.140
HF/KF	162.6±177.1	248.5±98.4	0.064	0.090
HR/KA	157.1±100.8	155.1±88.6	0.949	0.001
HR/KR	178.3±100.1	216.6±81.6	0.197	0.045
KF/AF	184.8±8.9	213.5±42.9	0.008	0.174

There was no statistically significant difference in the variability of joint coordination between the groups, F (6, 29) = .21, p = .971; Wilk's Λ = 0.958, partial η^2 = .04 in the ACL-reconstructed limbs of SGA compared to the match limbs of the control group [Table 5], and there was no statistically significant difference in the magnitude of joint coordination by group, F (6, 29) = .95, p = .476; Wilk's Λ = 0.836, partial η^2 = .16 in the ACL- reconstructed limbs of the SGA compared to the match limbs of the control group [Table 5].

Table 5. Joint coordination variability in the reconstructed for Auto-graft versus matched limb for Control

Coupling	Variability (SD)(Mean ± Standard Deviation)		p-Value	Cohen's d
	auto-graft	Control		
HA/KA	45.4±7.1	43.6±9.0	0.515	0.013
HA/KR	47.0±4.8	46.0±8.2	0.657	0.006
HF/KF	32.2±8.7	31.6±8.1	0.826	0.001
HR/KA	50.1±6.5	49.5±5.6	0.811	0.002
HR/KR	50.2±4.4	49.9±5.2	0.867	0.001
KF/AF	30.9±7.6	29.3±8.9	0.565	0.010

In this way, the results show that there was no significant difference in the coordination variability based on the limbs, F (6, 12)= 2.65, p = 0.173; Wilk's Λ = 0.429, partial η^2 = 0.57 and coordination magnitude, F (6, 12) = 1.75, p = 0.527; Wilk's Λ = 0.690, partial η^2 = 0.31 within the reconstructed and contralateral limbs of the SGA group in the overall coupled motions. There was also no coordination variability based on the limbs, F (6, 15) = 0.569, p = 0.749; Wilk's Λ = 0.814, partial η^2 = 0.18, and coordination magnitude based on the limbs, F (6, 15) = 1.18, p = 0.365; Wilk's Λ = 0.678, partial η^2 = 0.32 within the reconstructed and contralateral limbs of the allograft group in the overall coupled motions.

Discussion

In contrast to the main hypothesis in the hypothesis section, the coordination variability of the SGA had optimal conditions when returning to sport. However, in the allograft patients, the coordination variability of the reconstructed limbs was significantly higher than in the healthy group, and, they didn't have the optimal variability in the return to sport as the healthy group. An increase or decrease in this variable was found compared to healthy individuals with various injuries and or diseases.[42-44] Alteration of neuromuscular control is considered a variable factor in increasing coordination variability as a potential risk factor for re-injury and progression of OA.[40,45] In the study of two types of Ruffini receptors (type I) and free nerve endings (type IV), they found that the number of Ruffini receptors (type I) was higher per cm^2 in the individuals in the control group from whom a freshly torn ligament was harvested than in the different grafts and the number of free nerve endings (type IV) was lower than the semitendinosus autograft. In the comparison between the grafts, the semitendinosus grafts had the highest number of receptors compared to the allografts. However, the number of these receptors changed significantly in different individuals at different time points after ACL reconstruction (ACLR). In the semitendinosus autograft group , the number of both types of receptors decreased 25 to 120 months after ACLR in individuals of different ages, while the number of these receptors has increased in individuals with allografts and autographt of the patellar tendon.[46]

There was no significant difference in coordination variability in the SGA group, and the results of other studies reporting changes in this variable were not consistent. This difference is likely related to the lack of graft type categories, a different time frame between the time of surgery and return to sport, and possibly activity level. But according to the findings, the presence of high mechanical receptors in the semitendinosus graft at the time of return to sport may create a better proprioception, for the athlete to achieve the same coordination variability as the healthy group in the period after the operation, rehabilitation and sport-specific exercises must be carried out. However, as the researcher noted, the number of mechanical receptors begins to decrease from 25 months after surgery in the autografts, and in order to study the effects of this decrease, the risks and possible changes, further studies are needed in different periods after surgery in this group. The difference in coordination variability in the allograft group compared to the healthy group is greater, especially in the couple angles of HF/KA, HR/KA, and KA/AF, in the allograft group was consistent with many previous studies on the increase in this variable after ACLR. The low number of mechanical receptors in this type of graft and the decrease in proprioception may result in a lack of proper coordination of the lower limb chain and an increase in variability despite passing rehabilitation and sport-specific exercises similar to the SGA. As mentioned above, increased coordination variability compared to the healthy group is considered a potential risk factor for re-injury and progression of OA.[40,45]

ACL tears alone increase inflammatory markers in the knee, which can have influence over the appearance of OA. The biomechanical changes that occur in knees with ACL tears can predispose individuals to secondary chondral and meniscal lesions.[47] Therefore, to reduce the risk of potential injury, especially in adolescents and young people who have a high activity level and have undergone ACL surgery, it seems to be better to delay their return to professional and competitive sport levels than SGA to increase the number of mechanical graft receptors and promote proprioception and adjust coordination variability. Due to proprioception problems in the allograft, specific exercises to modify the coordination pattern with emphasis on technique may be useful for these individuals during the rehabilitation phase.

There are some limitations in this study, the participants were athletes with a high level of sport activity in soccer, who had returned to sports at least 9 months to two years after surgery, and the study in longer time intervals, different sports and different activity levels may be accompanied by other results. Due to the scope and time constraints of the study, only two types of grafts were evaluated in ACL reconstruction surgery, and it was not possible to investigate other types of grafts and surgical techniques in this study. The vector coding method only shows coordination in the spatial domain and does not provide information about the coordination in the temporal domain.

It is suggested to investigate the effects of different exercises, especially pattern modification and proprioception exercises in prospective studies in different graft types.

Conclusion

The results of this study showed that the coordination variability and coordination pattern after ACL reconstruction differed between the two graft types. In the SGA group, the coordination variability and coordination pattern were more similar to the control group. In the allograft group, the variability of coordination in some coupling angles and the coordination pattern varied compared to the control group. According to previous studies also mentioned in this study, two important factors for these differences are changes after ACL injuries, mechanical receptors and muscle problems caused by donor sites. Given these findings, in order to optimize the variables, to more normal conditions, specific exercises should probably be developed for each group in rehabilitation and sports, which of course requires a more detailed study of their training interventions. For athletes who have undergone anterior cruciate ligament reconstruction surgery, the time to return to sport and competition after rehabilitation and specific sports exercises to reduce the risk of re-injury may depend on the type of graft reconstructed.

Acknowledgement

Not applicable

Conflict of interest: None
Funding: None

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