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Research Article
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Knee Joint Mobility during Straight and Circular Gait after ACL Reconstruction

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Abstract

Purpose: To compare straight and circular gait on knee kinematics and kinetics after anterior cruciate ligament reconstruction.

Methods: Ten male volunteers who had underwent specific anterior cruciate ligament reconstruction walked on a straight and on a circular path in their self-selected speed, one year after the reconstruction. Kinematic and kinetics characteristics were measured by a six cameras Vicon 612, in combination with a three-dimensional force platform.

Results: While walking straight, the only statistically significant difference was detected in the maximum value of knee varus, with the reconstructed group to show lower values compare to the control (17.39 deg vs. 20.59 deg, p=0.000). While walking on a circular path, the reconstructed group had higher internal rotation of the tibia relative to the control group both when the limb was on the lateral (18.33 deg vs. 10.96 deg, p=0.040) and the medial side (16.22 deg vs. 11.51 deg, p=0.022) of the circular path.

Conclusions: Straight line gait combine with circular gait may reflect better knee kinematic and kinetic behavior after anterior cruciate ligament reconstruction, than straight line gait alone.

Keywords: Gait analysis; ACL knee kinematics; Circular gait

Introduction

Gait analysis is widely recognized as a central element in the quantitative evaluation of gait, and in the planning of treatments for subjects with movement disorders [1]. Also, gait analysis is an effective tool for evaluating and quantifying the effects of surgical intervention or other treatment on a patients gait.

Anterior Cruciate Ligament Reconstruction (ACLrec) is a common subject in studies where gait analysis is used to monitor the outcomes of surgical intervention. Many studies, reveal inadequate knee joint stability even after ACLrec [2-8]. Possibly, ACLrec can restore the forward sliding of the tibia but not the rotary motion of the joint. Yet, incomplete restoration of rotary motion of the knee, possibly leads to the development of osteoarthritis [9-12]. These become more important since it is known that 20% of all human daily activities involves turns [13], where the knee joint is rotated more. Therefore, apart from the exploration of walking, stair descent and ascent, running and hopping [5,7,8], it is important to evaluate other tasks such as turning in order to monitor the success of ACLrec. Tasks involving twisting movements are very important for controlling the functional recovery of ACL and the rotary motion of the knee.

When walking in a straight line, forces are applied equal to the body by both legs. Turning, however, or walking on a circular path, requires dynamic gait asymmetry in the lower limbs. One limp should have different kinematic and kinetic characteristics relative to the other to make the turn. The above become more significant when the person has gait difficulties, which may derive from incomplete functional recovery of the affected limb, after ACLrec. It has been found that when walking straight forward, people with ACL rupture, exhibit increased internal rotation of the tibia relative to the normal [14,15], while reconstruction can partially restore tibia rotation to normal levels [15]. Moreover, it has been found that while pivoting after strenuous activities that stress the legs (like stairs descent), internal rotation of the tibia does not return to normal levels in people who have undergone ACLrec of up to two years after surgery [10]. Regardless the ACLrec surgical technique (single or double bundle technique) or the graft type (hamstring, bone patellar tendon), rotary instability of the knee is still a matter of concern among surgeons [3,16]. Moreover, during rotational tasks, there is an increased momentum in lateral axis on the corresponding leg, which may be more stressful for the joint in contrast to walking in a straight line [17].

It is well known that the kinematic behavior of the knee is task dependent. Therefore it is essential to investigate such tasks. Maybe, the study of knee joint motion during various daily activities will help to better understand the adaptation of people in postoperative rehabilitation of ACL. Since it is known that there is an excessive tibia rotation of the knee, even after ACLrec, it is important to specify the tasks and the magnitude of such alterations.

Nearly all research involving human gait is focused on walking in a straight line, even though 20% of all steps in activities of daily living involves turns [13]. Turning is a requirement for most locomotor tasks; however knowledge of the biomechanical requirements of successful turning is limited [18]. Evidence suggests that turning is a greater challenge for individuals with mobility problems than walking in straight line is [17,19]. Compared to other demanding turning activities

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that have been studied [5,7,8], we believe that the task of circular gait is considered more daily, less demanding and frequently used. Circular gait includes more "turn continuation steps", that is steps that occurred during a multiple step turn that does not initiate or terminate the turn [20]. According to Taylor et al. [20], "turn continuation steps" made up a sizeable portion of total turning steps in daily activities. Also, it is supposed that circular gait, is a task that may reflect thoroughly knee rotary impairment, since the majority of kinematic changes probably occur in the coronal and transverse plane [20]. Finally, it is well known that many gait analysis laboratories use only the task of walking in a straight line [18,21], a task which may not be sufficient to draw useful conclusions in persons with knee rotary impairment.

The purpose of this research was to compare kinetic and kinematic outcomes on two tasks: a. straight line gait and b. circular gait, on people after ACLrec. The hypothesis of our study was that the classical gait analysis, in which a person walks in a straight line, it is not sufficient to evaluate his gait ability and the outcomes would be different if this person walked on a circular path. We believe that the tibia rotation after ACLrec is normal during straight line gait and excessive during circular gait. Therefore, the circular gait task is necessary when evaluating people with knee mobility problems in general.

Methodology

Sample

Ten male volunteers (men) who had undergone ACL reconstructions were selected. The participants showed no other injury to the knee joint except ACL tear preoperatively. Anthropometric characteristics (Table 1) were recorded. Two groups were formed a) ACLrec group, which included the reconstructed knee of the participants and b) Control group, which included the healthy knee of the participants.

Surgical reconstruction

Quadrupled hamstring auto graft (semitendinous and gracilis ST/G) was used. The graft was placed in an oblique position, at: 10.00-10.30 o clock for the right joint and at: 1.30-2.00 o clock for the left joint. Positions refer to clockwise from the anterior aspect of the joint. For fixation of the graft Bio-TransFix cross pin was used. All operations were performed by the same surgeons. Participants followed a specific postoperative rehabilitation program for 12 weeks.

Measurement protocol

Participants walked on a circular path (marked on the floor) with 1m radius. The radius was chosen because it is representative of many corners in the community such as hallways, doorways and sidewalks [17]. Five attempts were performed with their right foot in contact to the force plate and five attempts with their left one, which were recorded and selected for further analysis. The same procedure was followed in the opposite direction (Figures 1 and 2).

Gait speed adapted to their individual pace and ranged from 0.6 to 1.4 m/sec. Measurements were performed by the same researcher in the laboratory of Physical Education and Sports Department of Aristotle University of Thessaloniki.

Data analysis

Kinematic and kinetics characteristics was measured by a six cameras Vicon 612 (Oxford Metrics, Oxford, England), in combination with a three-dimensional force platform Bertec 4060 (Columbus OH). Sixteen skin reflectors placed at specific anatomical points of the legs and pelvis according to Vicon's Plug in Gait model. Dependent variables considered in this investigation were a) ground reaction forces in three axes of motion and b) range of motion in the knee joint in three axes of motion.

Statistical analysis

The two groups were tested for normal distribution (kolmogorof-Smirnof test p> 0,05) and equality of variance (Levense test, p>0,05). Students paired T-test, was used to determine the differences between the two groups. The level of significance was set at p<0,05. All tests were performed using IBM SPSS 21. Also, the effect size was used, when the differences among groups were significant (Gpower 3.0.10, Franz Faul, Universitat Kiel, Germany), to determine if these differences were large or small compared to the number of participants.

Mass (kg)	87.6 (15.50)
Height (cm)	182.80 (4.54)
Age	28.20 (6.09)

Table 1: Antropometric characteristics of the participants (mean and sd).

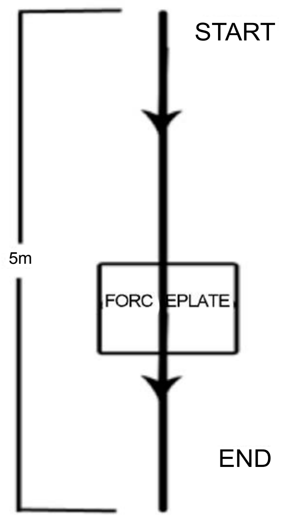

Figure 1: Experimetnal design of the first task, gait in straight line.

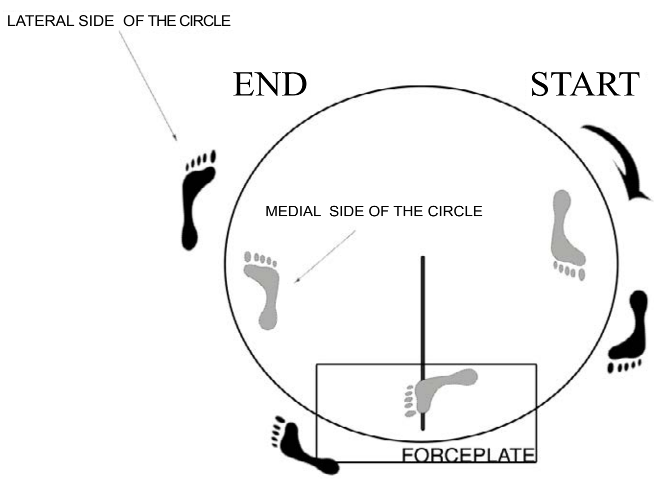

Figure 2: Experimental design of the second task, circular gait.

Results

First task: straight line gait

There were no statistically significant differences in most angles of the knee joint during walking in straight line between the two groups (Table 2). The only statistically significant difference was detected in knee varus, with the control group to show higher values compare to the ACLrec group (20.59 deg vs. 17.39 deg, p = 0.000).

Regarding the rotational movement of the joint, both groups seemed to have the same average for internal rotation and external rotation of the joint. The ground reaction forces did not appear to differ significantly between the two groups (Table 3).

Second task: circular gait

There were statistically significant differences between the two groups on the knee angles (Table 2). Specifically, the ACLrec group had greater internal rotation of the tibia (Figure 3) compare to the control group (18.33 deg vs. 10.96 deg, p = 0.040) when the limb was on the medial of the circle. Similarly, the limp placed on the lateral of the circular path, presented greater internal rotation of the tibia in the ACLrec group compared to the control group (16.22 deg vs. 11.51 deg, p = 0.022, Figure 4). Other angles of the knee were not found to differ significantly. The two groups showed the similar angles both in flexion and extension of the knee and at the varus valgus motion of the joint.

Ground reaction forces appear to differ significantly between the two groups (Table 3).When the limb was on the medial side of the circle, the Fz was higher for the ACLrec group compare to Control (1.12 BW vs. 1.08, p=0.03). Also, for the same limb, the mediolateral force was significant lower for the ACLrec group compare to the Control (0.09 BW vs. 0.11 BW, p=0.02). When the limb was on the lateral side of the circle, the only significant difference between the two groups, occurred in the Fz, where the ACLrec group showed higher values compare to control (1.04 BW vs. 1.02 BW, p=0.00).

Summarizing, there were statistically significant kinematic and kinetic differences between the two groups. Ranges of motion of the joint vary in longitudinal axis (Table 4) while the two groups revealed different kinetic model. Knee internal rotation was greater for the ACLrec group compared to the Control, both when the limp was on the medial and the lateral side of the circle. Also, differences were found

Group	ACLrec (mean. sd. ES)	Control (mean. sd)	p
Flexion (deg)	69.88 (2.08)	67.63 (7.02)	0.22
Extension	5.47 (4.48)	4.22 (1.24)	0.33
Varus (max) (deg)	17.39 (1.86)* (ES=1.97)	20.59 (0.75)	0.00
Valgus (min) (deg)	4.08 (0.73)	3.98 (1.50)	0.85
Internal rotation (deg)	9.33 (3.04)	11.91 (6.10)	0.33
External rotation (deg)	-14.19 (4.08)	-9.70 (5.23)	0.12

*significant deferent among groups, p<0.05

Table 2: Maximum angles of the knee during straight line gait.

	Initial support			Terminal support		
Group	ACLrec (mean, sd)	Control (mean, sd)	p	ACLrec (mean, sd)	Control (mean, sd)	p
Fz (BW)	1.14 (0.13)	1.16 (0.14)	0.31	1.15 (0.12)	1.15 (0.12)	0.97
Fx (BW)	0.06 (0.02)	0.05 (0.00)	0.54	0.06 (0.01)	0.06 (0.00)	0.51
Fy (BW)	0.17 (0.07)	0.18 (0.03)	0.63	-0.17 (0.03)	-0.19 (0.04)	0.07

Table 3: Maximum GRF during straight line gait.

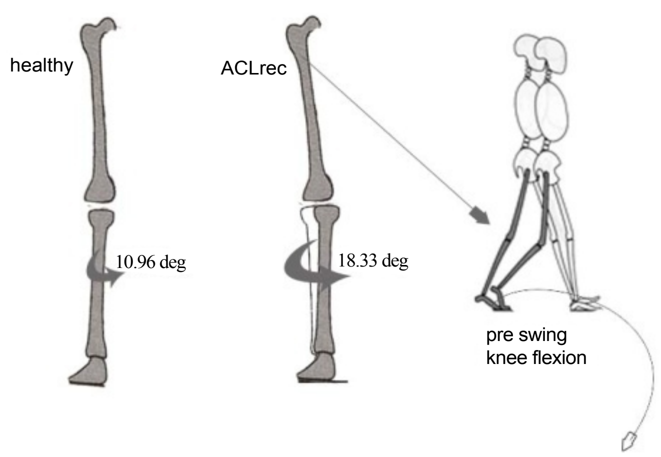

Figure 3: Maximum rotation of the tibia between the ACLrec and control (healthy) leg during circular gait. Limb placed on the medial side of the circle.

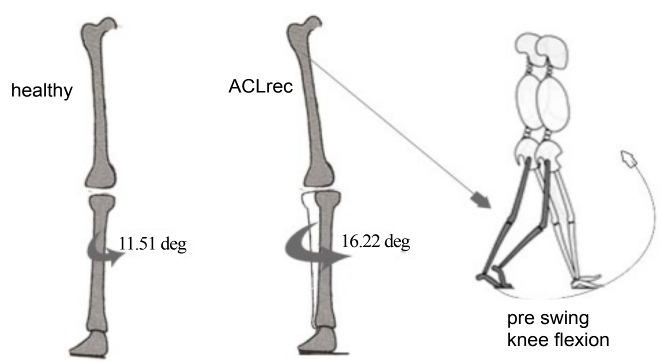

Figure 4: Maximum rotation of the tibia between the ACLrec and control (healthy) leg during circular gait. Limb placed on the lateral side of the circle.

	Foot placed in the medial side of the circle (mean, sd, ES)			Foot placed in the lateral side of the circle (mean, sd, ES)		
Group	ACLrec	Control	p	ACLrec	Control	p
Flexion	65.42 (2.11)	65.55 (2.46)	0.90	69.62 (2.47)	70.73 (3.16)	0.58
Extension	2.41 (1.76)	2.53 (1.63)	0.85	2.02 (0.97)	1.58 (1.38)	0.25
Varus	19.64 (1.51)	19.34 (5.59)	0.86	18.54 (0.39)	20.72 (3.54)	0.16
Valgus	3.90 (3.09)	3.17 (4.78)	0.33	6.10 (0.74)	5.72 (2.50)	0.62
Internal rotation	18.33* (8.07) ES=1.03	10.96 (2.62)	0.04	16.22* (6.33) ES=0.85	11.51 (3.03)	0.02
External rotation	-8.13 (0.72)	-12.28 (4.75)	0.06	-9.26 (2.32)	-10.00 (2.39)	0.10

*significant deferent among groups, p<0.05

Table 4: Maximum angles of the knee while walking on a circular path.

regarding ground reaction forces. ACLrec group showed higher values on Fz both when the limb was on the medial and the lateral side of the circle. Finally, ACLrec group showed lower values on mediolateral force (Fx) when the limb was on the medial side of the circle.

Discussion

During straight line gait, no significant differences where observed in most angles of the knee joint between the two groups. The only significant difference was detected in the knee varus value, where the ACLrec group had lower values compare to the Control group (17.39 deg vs. 20.59 deg, p <0.05). This small difference may be due to more stiff movement on sagittal axis of the ACLrec group. It seems that the ACLrec participants, ended the phase of single support using less force in lateral axis, likely due to fear of a sharp move which simulates the rupture mechanism of the ligament.

During circular gait, there were significant differences between the two groups regarding the rotational movement of the joint. Generally, the joint range of motion on the longitudinal axis, differ between the two groups, indicating different kinetic pattern. Specifically, the rotational movement of the joint was greater for the ACLrec group compared to the Control group (18.33 deg vs. 10.96 deg, p <0.05), both when the foot was on the medial and the lateral side of the circle (16.22 deg vs. 11.51 deg, p <0.05). Regarding GRF (Table 5), Fz was higher during the initial support for the study group (1.12BW vs. 1.08 BW, p<0.05). This fact may be due to the lower absorption capacity of the force during impact and applying greater force to the "braking" of the movement. Also, the medio-lateral force (Fx) was lower in the initial support for the ACLrec group (0.09 BW vs. 0.11 BW, p <0.05), probably because of fear of a great force in this axis, that resembles the injury mechanism. Finally, a higher vertical force (Fz) for the terminal support was observed for the ACLrec group (1.04 BW vs. 1.02, p <0.05). At this phase, there is the maximum internal (Table 6) rotation of the tibia. Possibly, part of the force was "missed" by the increased rotation of the tibia and thus a greater vertical force was needed in order to promote the body.

The rotational movement of the joint after ACLrec was investigated by other authors. Probably, reconstruction repairs only the flexion-extension of the joint but not the rotary movement [2,3,11,16]. It is well known that patients with ACL injury may have poorer proprioception than an uninjured knee [22,23], even more, Fremerey et al. [24] reported that there may be no restoration of ACL proprioception et all. Therefore grafts used for ACLrec may not be sufficient to restore the proprioception receptors of the ligament. Turning is a task that is based more on the central nervous system [18], so it is affected by proprioception, which is lacking in knee joint after ACLrec. It has been shown that when tasks involve athletic-demanding twisting movements, internal rotation of the tibia, doesn't appear normal postoperatively [2,10,25,26]. It is well known that knee kinematics is task dependent. So it is important to verify the tasks that lead to abnormal motion of the joint. In the present study, increased rotational motion of the joint was verified during the task of circular gait. These are very important, as the increased rotational movement of the joint, even at low demanding activities which occurred frequently during the day, may lead to degeneration of cartilage and progressive knee osteoarthritis [10,12].

	Initial stance (mean, sd, ES)			Terminal stance (mean, sd)		
	ACLrec	Control	p	ACLrec	Control	p
Fz (BW)	1.12* (0.22) ES=0.15	1.08 (0.23)	0.03	1.13 (0.24)	1.14 (0.24)	0.50
Fx (BW)	0.09* (0.03) ES=0.72	0.11 (0.03)	0.02	0.14 (0.07)	0.16 (0.04)	0.29
Fy (BW)	0.15 (0.07)	0.12 (0.06)	0.13	0.11 (0.09)	0.109 (0.08)	0.45

*significant deferent among groups, p<0.05

Table 5: Maximum GRF while walking on a circular path. Foot on the medial side of the circle.

	Initial stance (mean, sd)			Terminal stance (mean, sd, ES)		
	ACLrec	Control	p	ACLrec	Control	p
Fz (BW)	1.03 (0.02)	1.03 (0.01)	0.58	1.04 * (0.02) ES=0.96	1.02 (0.01)	0.00
Fx (BW)	0.08 (0.02)	0.07 (0.14)	0.30	0.14 (0.02)	0.06 (0.12)	0.22
Fy (BW)	0.11 (0.04)	0.12 (0.02)	0.77	0.08 (0.02)	0.01 (0.03)	0.269

*significant deferent among groups, p<0.05

Table 6: Maximum GRF while walking on a circular path. Foot on the lateral side of the circle.

Kinematic analysis with external reflectors, poses some limitations that may come either from their movement on the skin or by improper placement. However, it is a widely accepted and reliable method [27,1]. The reliability of the methodology to study rotational movements of the knee increases when compared to the healthy leg, when the markers are placed by the same investigator, when the task does not involve movements at high speed and when there are no overlap reflectors during tasks [28,29]. In this research, the above requirements where applied. Furthermore the goal was to find the differences between the healthy and the reconstructed knee during the tasks, so any deviations from systematic errors of kinematic analysis may affect both legs the same. Also, it must be noted that the circular gait, as applied in the current study, may not be representative of all human turns. Taylor et al. [20] reported different strategies for turning and different kinematic and kinetic characteristics to achieve a human turn. He divided the turn as "step turn", where more steps are needed to achieve the turn, and "spin turn" where a pivot movement executed by the foot in contact to the floor. He found that the "step" turn is less demanding and more closely to straight line gait. Controversy, he reported that the "spin" turn is more demanding and generates greater knee rotation motion. Even though, in the current study the circular gait, resembles Taylors "step" turn, yet excessive tibia rotation was found at the ACLrec group. This assumption makes understandable, that knee joint mobility is still a matter of concern, even at low demanding "non-athletic" activities in people after ACLrec.

In this research effort was made to investigate the effectiveness of ACLrec in the mobility of the knee during walking straight and on a circular path. The results showed that there were significant differences between the two tasks concerning the rotational motion of the knee. It appeared that rotary movement of the knee joint does not appear normal after reconstruction even at low demanding activities. Also it was found that these persons need more force in the vertical axis (Fz), in order to promote the body and complete the task of circular gait.

Future studies should take into account that, during the surgical procedure and subsequent postoperative stage, several factors and different protocols, can play a key role in the clinical outcomes and must be explored and tested in various tasks incurred at gait analysis laboratories. Also, it is essential to examine persons after ACL reconstruction for osteoarthritis, and to correlate the results with the frequency and the type of repetitive daily activities.

Conclusions

During circular gait, the rotational movement of the joint after ACLrec does not appear normal. Knee kinematics is task dependent so it is important to specify the daily tasks that can lead to abnormal kinematics. Classical gait analysis, where a person walks on a straight line, is not sufficient to evaluate knee joint mobility. The above considerations are very important, for the rehabilitation process since it is known that abnormal knee rotation may lead to chondral damage and osteoarthritis.

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