Asian Journal of Sports Medicine

ORIGINAL ARTICLE

Studying the Balance of the Coper and Non-Coper ACL-Deficient Knee Subjects

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Authors' Contribution

- A Concept / Design
- B Acquisition of Data
- C Data Analysis / Interpretation
- D Manuscript Preparation
- E Critical Revision of the Manuscript
- F Funds Collection
- G Approval of the Article

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Received:
Accepted:
Available Online:

Abstract

Purpose: **It seems that there is an association between the anterior cruciate ligament (ACL) and stability of the knee. This study aimed to evaluate the balance condition of the injured and non-injured sides of the coper and non-coper ACL-D (deficient) subjects during single and bilateral standing conditions.**

Methods: **This case-control study was carried out on 10 coper and 5 non-coper ACL-D knee subjects and 15 sex-age matched healthy subjects. A Zebris platform pedobarograph tool was used in this study. The subjects were tested barefoot during single and bilateral leg stance conditions. The outcome measurements included measurement of the center of pressure (COP) path line length, confidence ellipse area and sway velocity.**

Results: **In double leg stance, data analysis revealed that the COP path line length, confidence ellipse area and sway velocity all showed a significant increase in the injured leg of the non-coper ACL-D subjects when compared to the injured leg of the coper ACL-D and healthy subjects (*P*=0.002). During single leg stance, all of the parameters showed significant increase in the injured leg of both coper and non-copers of the ACL-D subjects relative to the healthy subjects (*P*<0.05).**

Conclusion: **This study confirmed a balance deficiency in the injured and apparently healthy leg of the non-coper and coper ACL-D knee subjects. Increased COP path line length, sway velocity and the coinfidence ellipse area clearly showed an impaired body balance. The reduced postural control of the non-coper ACL-D knee subjects in bilateral standing could be more evidence of their poor knee stability status.**

Key Words: Anterior Cruciate Ligament; knee; Balance; Injury

Asian Journal of Sports Medicine, Volume 5 (Number 2), June 2014, Pages: 91-98

INTRODUCTION

The anterior cruciate ligament (ACL), as the principal knee stabilizer in both static and dynamic movements in the sagittal plane, works mainly to prevent anterior tibial translation relative to the femur in an open kinematic chain (OKC) and vice versa [1,2]. In addition, this ligament plays a key role in the tibio-femoral rotational axis, particularly tibial internal rotation during knee flexion[3]. The incidence of the ACL injury is much higher in athletes than normal people [4]. When this ligament tears, the subjects become either copers or non-copers [5]. The minority coper subjects (14-20%) are those who use some complex neuro-musculo-skeletal strategies to dynamically stabilize their ACL-minus knee and are able to return to their professional sport at their pre-injury level [6,7]. However, the rest of the ACL-deficient (non-coper) subjects exhibit knee instability and use different strategies to be able to have normal daily activities [8-10]. These subjects definitely need ACL-reconstruction surgery to return to sport. Moreover, in addition to the mechanical support, the ACL contains loads of proprioceptive receptors to supply proprioception of the knee joint [11-15]. Therefore, tear of the ACL will result in reduction of the knee's sense of position and hence its stability.

To study the ACL-deficient knee subjects' stability conditions, many researchers have studied the balance parameters including the center of pressure (COP) path line length and the sway velocity of the COP during static and dynamic stability tests [16-19] and reported some controversial findings. Some reported balance problems in injured and apparently healthy knees of these patients [20-22]. However, O'connell et al found no significant differences in static tests in terms of their postural sway [19]. In 1998, Lysholm et al found postural control impairments during only single leg stance [17]. An association between the single leg stance and the functional abilities of the ACL-D knee subjects was reported by Shiraishi et al and was confirmed by Ageberg et al. using a stabilometer tool, Baier and Hopf have already reported a less amplitude of the center of pressure's movement in these patients showing a better function of them [26].

Different findings in the literature could be related to some factors including the different assessment tools used by the researchers, the time past injury of the patients and also the different acitivity levels of the subjects. In other words, they have focused on ACL-D knee subjects without considering the patients' abilities in functional activities. Since they did not differentiate the subjects into coper and non-coper groups, there are some inconclusive results among nonhomogenous subjects who use different strategies to achieve stability. The current comparative study aimed to investigate the balance conditions in the injured and non-injured legs of the coper and non-coper ACL-D knee and matched healthy subjects during the single and double leg stance.

METHODS AND SUBJECTS

Subjects:

This case-control study was carried out on ten non-coper and five coper unilateral ACL-minus knees and 15 normal subjects (Table 1). The sample size used for this study, based on the following formula was 11.

$$N = \frac{(u+v)^2(\sigma 1^2 + \sigma 2^2)}{(\mu 1 - \mu 2)^2}$$

$\mu1-\mu2=3$mm, $\sigma1=0.67$ for normal subjects, $\sigma2=1.67$ for ACLD subjects, $u=1.64$ if $\beta=5\%$, $v=1.96$ if $\alpha=5\%$.

The ACL-D subjects were selected based upon the inclusion and exclusion criteria among the patients refered to the sport injury clinic of the Tehran's Sports Federation of Medical Sciences in 2012. All subjects had to be able to stand on their injured limb and have balance with open eyes. In case of existing meniscal or other knee ligament injuries, knee limitation of motion, inflammation, pain higher than 3 in VAS or having other injuries in the opposite limb, the subjects were excluded. The control group also included 10 normal subjects sex-age matched to the non-coper ACL-D and five normal subjects sex-age matched to the coper ACL-D subjects. All subjects signed a consent form to voluntarily participated in this study and the Ethical Committee of the University of Shahid Beheshti approved the project.

Study design:

The ACL-D subjects were referred by an orthopedic surgeon and the first researcher, who is a physiotherapist expert in orthopaedic physical therapy, examined the subjects and recorded their range of movements, swelling, and their ability to stand on their injured and healthy limbs individually and checked all inclusion/exclusion criteria. The subjects were allocated into coper group if they had returned to all of their pre-injury level activities and had no knee instability during the last six months in level one (jumping, pivoting and hard cutting) and level two activities (lateral movements). The coper subjects must also have a KOOS score higher than 80 (out of 100). The non-coper ACL-D subjects were those who had not been able to return to their pre-injury level activities, had at least once giving way during the last six months and their KOOS score was less than 80 (out of 100)[25]. A Pedobarograph system (Zebris, (FDM-SX) Company, Germany) with the size of 55*40*2.5 Cm, 1920 capacitive sensors with sensory areas of 54.2*33.9 Cm and a frequency rate of 100 Hz was used to assess the balance status of the subjects. Nakhaee et al (2008) reported a good ICC of >0.90 for this

Published by: Tehran University of Medical Sciences (http://asjsm.tums.ac.ir)

Table 1: The demographic characteristics of the subjects in this study

Groups	No	Age (years)	Height (Cm)	Weight (Kg.)	Time past Injury (months)	KOOS Score (out of 100)
Coper	5	26.0 (3.0)	176.0 (4.0)	69.0 (4.0)	18.2 (5)	85 (3)
Non-coper	10	24.0 (2.0)	180.0 (6.0)	71.0 (10.0)	13.0 (7.4)	66 (7)
Control	15	23.7 (2.4)	179 (5.5)	70.9 (11.0)	-	-

system[25]. Measurement of the COP path line length and the sway velocity [26] are frequently used in studying balance conditions in different subjects [24,27-30]. The confidence ellipse area or sway index, which is the standard deviation of the vector of COP [26,33], is also another parameter studied in this area. A sample of the results graph of a Zebris pedobarograph is shown in Fig. 1.

In this study, all subjects were tested the single and double leg stance tests with barefoot as following. To exclude any bias of ordering, the tests were randomly carried out on the subjects.

Single leg stance test:

In this test, the subjects stood on the platform on one foot while their hands were next to their bodies and

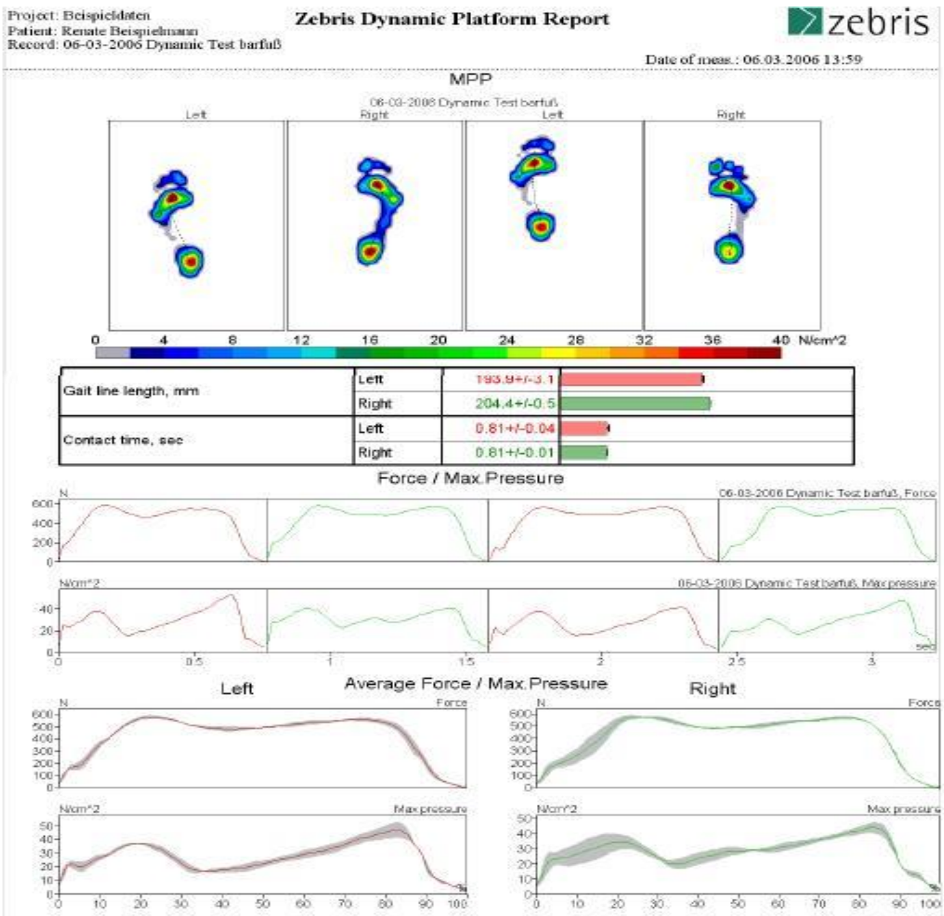

Fig. 1: A sample of data derived in this study by Zebris Pedobarograph

stared at the front wall. The data was captured for ten seconds. Five successful trials were recorded with thirty seconds rest interval. In healthy subjects, this test was carried out on the leg of the knee matched with the ACL-D subjects.

Double leg stance test:

In this test, all subjects stood on the platform on both feet while their hands were next to their bodies and stared at the front wall. The data captured for ten seconds and five successful trials were recorded with thirty seconds rest interval.

Statistical analysis:

The outcome measurements in this study were COP path line length, sway velocity and confidence ellipse area. They were measured in the injured legs of the coper and non-coper ACL-D and the matched knee of the healthy subjects. All data was derived and the SPSS version 20 was used for data analysis. The independent t-test was used for comparison between two groups. One-way ANOVA was used for between group data analysis and the Bonferroni post Hoc Test was used for within group tests. All non-parametric data were analyzed using a Kruskal-Wallis test and the p-value was set to $\alpha=0.05$.

Pilot Study:

Before carrying out the main study, to ensure if the pedobarograph system used in this study was reliable, a pilot study was conducted on five healthy subjects. The subjects stood on the platform with single leg for ten seconds three times with a 30 seconds rest interval. The whole test was repeated one week later. The Intraclass Correlation Coefficient (ICC) obtained in this study was 0.90%, which shows a good repeatability result and convinced the researchers to continue the study with more subjects.

The Kolmogorov-Smirinov (KS) test revealed the parameters to be studied in this study showed a normal distribution and the parametric statistics were used for data analysis.

RESULTS

Table 1 shows the demographic characteristics of the subjects participated in this study. The subjects were matched in terms of the sex, age, height, weight and the time past injury ($P>0.05$).

During the double support test, since both the injured and healthy sides were placed on the platform, only the injured side was used in data analysis. However, during the single leg stance, both feet were placed on the platform individually; the injured and healthy sides were analyzed separately.

In double leg stance, the results showed a significant increase in all three studied COP parameters in the non-coper ACL-D knee subjects when compared to the Copers or the Control groups ($P<0.05$). No significant differences were found among any of the three studied COP parameters between the Copers and the Control groups ($P>0.05$).

During the single leg stance, some differences were

Table 2: The descriptive results for COP during *double stance test*:

Variables	Copers	Non-Copers	Controls	Within groups	P-value (t-test)
Path line length (mm)	83.3	175.1	86.5	Copers vs. Control	0.9
				Non-copers vs. Controls	0.001
				Copers vs. Non-copers	0.002
Confidence Ellipse Area (mm^2)	39.9	158.8	34.5	Copers vs. Control	0.6
				Non-copers vs. Controls	0.002
				Copers vs. Non-copers	0.02
Sway Velocity (m/s)	8.3	17.5	8.6	Copers vs. Control	0.7
				Non-copers vs. Controls	0.001
				Copers vs. Non-copers	0.002

Table 3: The descriptive results for COP during single stance test

Variables	Copers H	Copers Inj.	Non-Copers H	Non-Copers Inj.	Controls	Within groups	P-value (t-test)
Path line length (mm)	143.3	207.1	168.4	259.6	150.5	Copers-H. vs. Control	>0.05
						Copers-Inj. vs. Control	0.009
						Non-copers-H. vs. Controls	>0.05
						Non-copers-Inj. vs. Controls	0.03
						Copers-H. vs. Copers Inj.	0.03
						Non-Copers-H. vs. Non-Copers Inj.	0.07
						Copers-Inj. vs. Non-Copers Inj.	0.2
Confidence Ellipse Area (mm^2)	71.9	114.6	107.2	184.4	51.1	Copers- H. vs. Control	>0.05
						Copers-Inj. vs. Control	0.009
						Non-copers- H. vs. Controls	<0.05
						Non-copers-Inj. vs. Controls	0.001
						Copers- H. vs. Copers Inj.	0.009
						Non-Copers-H. vs. Non-Copers Inj.	0.01
						Copers-Inj. vs. Non-Copers Inj.	0.07
Sway Velocity (m/s)	14.3	20.7	107.2	184.4	15.1	Copers- H. vs. Control	>0.05
						Copers-Inj. vs. Control	0.009
						Non-copers-H. vs. Controls	<0.05
						Non-copers-Inj. vs. Controls	0.03
						Copers-H. vs. Copers Inj.	0.03
						Non-Copers-H. vs. Non-Copers Inj.	0.07
						Copers-Inj. vs. Non-Copers Inj.	0.2

Copers-H.: ACLD Copers healthy side; Cop-Inj: ACLD Copers injured side; Non-Cop.H.: ACLD Non-Copers healthy side; Non-Cop.Inj: ACLD Non-Copers injured side

found between the injured and the apparently healthy knees in all COP parameters. In terms of the Path Line Length, the injured side of both coper and Non-coper groups showed more line length than the healthy sides and the control group. This was significant only when compared to the Control group (P<0.05). However, no significant difference was found between the injured sides of these groups when compared with each other (P>0.05). In addition, the injured sides of both Coper and Non-coper groups showed increased line length relative to their healthy sides, of which there was significance only in the Coper group (P=0.03).

Table 3 revealed that the injured sides of both Coper and Non-coper ACL-D knee subjects showed significantly more confidence ellipse area than the healthy sides of ACL-D subjects and the Control group subjects. It should be added that only the injured side of the Non-coper ACL-D subjects showed significantly more confidence ellipse area than their apparently healthy sides (P=0.01).

Although the injured sides of both the Coper and Non-coper ACL-D groups showed more sway velocity when compared to their healthy sides of the ACL-D subjects and the control group, it was significant only when the injured sides were compared to the control groups. No significant differences were found between the injured side of the Non-coper ACL-D knee subjects the healthy side of the Non-copers and the injured side of the Coper ACL-D knee subjects (P>0.05)

DISCUSSION

The results of the current study revealed a significantly higher COP line length, confidence ellipse area and sway velocity in the injured leg of both the coper and non-coper ACL-D knee subjects compared to the controls while standing on both feet. The coper subjects showed COP parameters very close to the healthy control subjects. However, during the single leg stance, some different results were shown between the injured and the apparently healthy sides between the coper and non-coper ACL-D knee subjects.

Opposed to the double stance in which the coper and control groups showed very similar results, during one leg stance, except on the sway velocity, the healthy sides of the copers, non-copers and the control groups showed data very close to each other and the injured sides of both the coper and non-coper subjects showed significantly more results than the apparently healthy sides. The very high increased sway velocity on both injured and healthy sides of the non-coper ACL-D knee subjects is expectable as the ACL-minus knees lack propriocpetive sense and hence show increased sway speed.

The results of this study mainly confirmed the findings of some previous authors and objectively proved a less stable knee in the injured side of non-coper ACL-D knee subjects, particularly during a single leg stance such as walking. The results found in this study were in agreement with what the authors hypothesized. In fact, it showed that the postural control of the non-coper ACL-D subjects was lower in their injured leg relative to the healthy one. These are in agreement with some other studies [16,17,19-22].

Since the ACL plays a dual role in mechanical and sensory function of the knee, the postural deficit following ACL rupture may have different reasons. As mentioned earlier, the ACL is a main knee stabilizer preventing tibial anterior translation relative to the femur and its tearing will result in knee instability in ACL-minus knee subjects. The amount of anterior tibial translation is 8-18 mm in the ACL-D subjects, which is higher than normal subjects [34-35]. This clearly shows increased laxity in the ACL-D knees and results in knee instability [36].

Some researchers emphasize on the sensory role of the ACL more than its mechanical role. This originates from many receptors located in the ACL and is responsible for knee proprioception. Any damages to these receptors may result in increased postural sway due to decreased frequency and quality of the afferent signals to the supra-segmental areas [37-38]. Following reduced afferent signals, the postural sway increases while the coordination of the muscles around the knee joint decreases [37]. It is strongly believed that joint receptors continuously provide knee stability via adjustment of muscle stiffening [13,15,39]. In brief, following ACL-deficiency, the postural control impairs, particularly during single leg stance. The significantly higher COP parameters shown in this study confirms the findings of some other studies who all stated that coper ACL-D subjects have higher functional level, balance and postural control [23,40] relative to the non-coper ACL-D knee subjects.

It should be emphasized that the current study has some limitations including the lower sample size, which was due to difficulties in finding coper ACL-deficient knee subjects who are about one-fifth to one-eighth of all ACL-deficient knee subjects. Studying more balance parameters on more coper and non-coper ACL-deficient knee subjects is highly recommended.

CONCLUSION

Following ACL injury, many kinematic and kinetic changes including balance deficiency occurs in ACL-deficient knee subjects. The current study provided objective data that ACL-deficient knee subjects showed lower balance when compared to the normal subjects, particularly in single leg stance. The non-coper ACL-deficient knee subjects showed more static postural imbalances relative to the coper ACL-deficient knee subjects. The foot pressure system (Pedobarograph) proved to be a feasible system to evaluate the balance of the ACL- deficient knee subjects.

ACKNOWLEDGMENTS

The authors wish to thank to the Physiotherapy Research Center of the Shahid Beheshti University of Medical Sciences, Faculty of Rehabilitation for funds and providing the measurement tools and also to all the ACL-D and control subjects for their volountary participation in this study.

Conflict of interests: None

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