ORIGINAL ARTICLE

COMPARATIVE ANALYSIS OF POSTURAL CONTROL IN INDIVIDUALS WITH AND WITHOUT INJURIES ON KNEE ANTERIOR CRUCIATE LIGAMENT

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SUMMARY

Standing balance is the process which keeps the pressure center (PC), a projection of gravity center on the ground inside the support area of the body. This study evaluates postural control in patients with unilateral lesion of knee anterior cruciate ligament and in healthy individuals (control group), through parameters of pressure center.

Nineteen healthy individuals (11 men, 8 women, ages ranging from 18 to 30 years) and nineteen patients with unilateral lesion of anterior cruciate ligament of the knee (18 men, 1 woman, ages ranging from 15 to 33 years) were evaluated by FSCAN MAT® version 3848 (Tekscan®, Boston, MA, USA) sensors. Four different static tests with unilateral support were made, alternating the sides (dominant and non dominant) and keeping open or closed eyes.

The following parameters were calculated: total length of path, anteroposterior amplitude, mediolateral amplitude and maximum speed of pressure center.

The results have pointed out that: the dominance of lower limbs does not significantly influence the balance of healthy individuals; vision is an important factor in posture control and the unilateral lesion of anterior cruciate ligament of the knee affects the balance in unilateral support, on both sides, although more evident on the side with the lesion.

Keywords: Balance; Anterior cruciate ligament; Knee.

INTRODUCTION

Balance is the process of maintaining the projection of gravity center (GC) inside the body support base[1], which requires continuous adjustments of the muscular activity and joint positioning. The individual's pressure center (PC), the point in which the vector resulting from the vertical strength of ground reaction is located, representing the weighted average of all pressures of the surface area touching the ground, shall move continuously when compared to GC dislocations, according to the inverted pendulum model presented by Winter[2].

The three systems involved on balance control are: vision, vestibular system and somatosensorial system. The vestibular system in sensitive to linear and angular accelerations, while somatosensorial system is composed by many receptors that perceive the position and speed of all body segments, their contact with external objects, including the ground, and gravity direction[2]. Through vision, an individual can reasonably maintain balance, even after vestibular system is destroyed or after loosing the majority of proprioceptive information[3].

Nearly all disturbances of nervous and musculoskeletal systems lead to balance control degeneration. This fact may not be apparent until the individual is deprived of his/her compensation system, by which intact systems compensate the defective one due to Central Nervous System's (CNS) ability to adapt[2].

Knee joint stability depends on the interaction among its geometry, soft tissues restraint and applied body weight and muscular action loads. While bone structure and meniscal characteristics provide a low level of knee stability, material and ligament, capsules and soft tissues directions properties significantly contribute to its stability. Compressive forces, resulting from body weight and muscle activity, provide additional strength preventing an overload on ligaments when the knee is submitted to excessive loads in more aggressive activities[4].

Additionally to mechanical stability, the knee has nervous receptors in its structure. Neuromuscular control system sensors, called mechanoreceptors[4], found in joints, skin and muscles, inform the CNS about changes in position, motion perception and joint tension[5]. Missed information by the anterior cruciate ligament (ACL) mechanoreceptors can be compensated by information coming from other knee structures, through a specific training[6].

Proprioceptive neurophysiologic function of the ACL has been considered as important as its biomechanical role in maintaining joint stability[7]. Complications that occurred after ACL injury, such as osteoarthrosis, seem to happen not only due to mechanical instability, but also to the reduction or change of the proprioceptive information[5,8]. Many theories suggest that the ACL receptors and other knee structures' receptors play a fundamental role on maintaining the dynamic stability of this joint, based on existent reflex paths between the knee and thigh musculature[4].

In order to quantify balance, many authors have been studying the PC dislocation. By tracking instantaneous PCs travel during

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the support phase, patient's balance and the progression pattern may be determined[9].

Uncountable ways to measure the neuromuscular control of an unstable knee due to ACL injury or after surgical reconstruction have been reported, such as joint position tests, kinesthesia tests, muscle recruitment associated to the reaction time after external or internal stimuli, postural control and gait analysis[10,11]. Tests simulating functional activities and measuring balance and body oscillation for lower limbs are the most appropriate means to evaluate the combination of peripheral, vestibular and visual contributions to neuromuscular control.

Conscious proprioception tests, such as those of joint position and kinesthesia, are the most used ones, but they do not reproduce a function employed on usual activities. They are performed in equipments, such as: the isokinetic dynamometer, the electrogoniometer, or the continuous passive movement apparatus. In joint position tests, the individual's ability to reproduce joint angles is focused, while in kinesthetic tests the individual's ability to notice peripheral segments motion is assessed. Tests may be performed both in active and passive modes[11]. The main test is the one determining the threshold of the passive motion detection, in which the knee is passively moved both for flexion and for extension, and the subjects respond as soon as motion is noticed[10].

Reaction time is one of the ways to estimate latency between an external stimulus and a reflex muscle contraction. Muscle activation characteristics (beginning, end and magnitude) are measured by electromyography[10,11].

During static posture, the key measure used to calculate balance is PC oscillation, although there is no consensus regarding its importance on ACL injuries.

The most frequently used equipment for measuring PC in many pathologies, which can be found in literature, are the strength platform[12,13,14,15] or an equipment similar to extensometric platforms[8,16,17,18]. However, there are other equipment able to measure PC, such as pressure sensors.

The objective of this study was to observe postural control with single-foot support in individuals with unilateral ACL injury through variants derived from PC, measured by pressure sensors, as well as to observe the influence of lower limbs and vision dominance on balance.

MATERIALS AND METHODS

The system used to record the PC dislocation was the FSCAN MAT, version 3848 (Tekscan®, Boston, MA, EUA) with high-resolution pressure sensors, 0.8382 centimeters apart from each other, and two transducer units attached to the computer system IBM-PC through coaxial cords. That equipment records the vertical force under an individual's foot (pressure) in each point of a resistive frame composed by overlying lines and columns. It shows the PC dislocation in real time, called by the equipment as "force center" (Figure 2). The acquisition frequency was 30 Hz. The test can be seen both as a chart and numerically regarding the PC, force or pressure. The PC, which was the parameter we analyzed in this study, can be determined by co-ordinates of lines and columns of the sensor. If the distance between each two adjacent lines or columns is known (0.8382 cm), we can then calculate the distances between points, thus determining its dislocation.

Two groups were evaluated: a control group (GCON) and another group composed by patients diagnosed with unilateral injury of the ACL (GLES). The lower limb mostly used for kicking was determined as the dominant.

GCON was formed by 19 individuals, 11 men and 8 women with ages ranging from 18 to 30 years old, 17 with dominant right lower limb[15]. Nobody reported history of lower limb (LLLL) musculoskeletal or spine injuries, and no history of neurological, vestibular or uncorrected visual disorders; they didn't use drugs, alcohol or medicines that might compromise balance.

GLES was formed by 19 individuals with ACL injury, followed up at the outpatient practice of the Orthopaedics and Traumatology Institute (IOT) in Hospital das Clínicas - Medical School, University of São Paulo (HC-FMUSP). ACL injury diagnosis was performed through clinical examination and magnetic resonance (MR). Inclusion criteria for GLES were identical to those for GCON, except for the history of lower limb (LLLL) musculoskeletal injury, since subjects necessarily had unilateral ACL injuries.

From the 19 individuals, 18 were men and one was a woman, with ages ranging from 15 to 33 years old; 12 had a dominant right lower limb and 7 had a dominant left lower limb; 8 presented right lower limb injury and 11 presented it at left lower limb.

Subjects were regularly evaluated, first with eyes opened and then closed. Initially tested lower limb was alternated between right and left, following the order of the evaluations performed in a consecutive fashion. Each subject was evaluated for four conditions: opened eyes and supported by the right lower limb (OR); opened eyes and supported by the left lower limb (OL); closed eyes and supported by right lower limb (CR); closed eyes and supported by the left lower limb (CL). Data acquisition time was 10 seconds for each condition. Before the beginning of the tests, the individual tried the equipment and postures so he/ she could be familiar to them. Between evaluations, intervals between each acquisition were allowed, according to each subject's needs, in order to avoid fatigue effects. Each condition was repeated three times, being considered for analysis the average of the three measures. The individual was asked to remain as steady as possible during test performance. Before test, a brief evaluation was performed in order to assure that the inclusion and exclusion criteria had been met.

Posture adopted for the test was: subject standing up with a single-foot support looking to horizon (or with the head directed to horizon, in case of closed eyes condition), with trunk in an upright and comfortable position, with upper limbs positioned along the body, while the non-supported lower limb remained with the hip in a neutral position and knee flexed at 90º (Figure 1). Supported lower limb's hip and knee remained in neutral angle. All subjects performed the tests on bare feet.

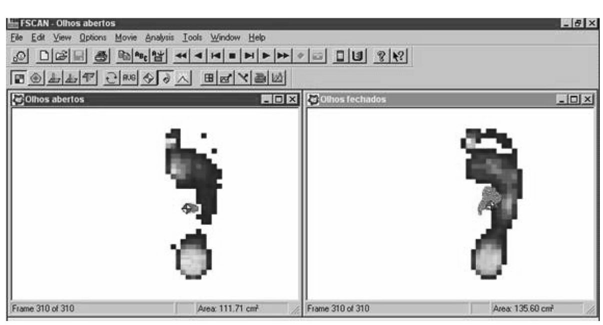

Figure 2 – *Screen showing the PC dislocation in opened eyes condition (left) and closed eyes condition (right) in the F-SCAN.*

Data obtained from the F-MAT were converted to Microsoft Excel, where the following parameters were analyzed: total length of PC dislocation travel (TL); PC dislocations range in anteroposterior (AP) and mediolateral (ML) directions, and the maximum speed achieved by the PC (MS).

Once the PC was given through the co-ordinates X and Y, the length of the PC dislocation travel between two consecutive pictures (TL_{inst}) was calculated by Pythagoras' theorem:

TL_{inst} 2 = ((Y_b '" 0.8382) - (Y_a '" 0.8382)) 2 + ((X_b '" 0.8382) – (X_a '" 0.8382)) 2

Where,

TL_{inst} (cm) = length of the PC dislocation travel from point "a" to point "b"

Y_b = anteroposterior final ordinate

Y_a = anteroposterior initial ordinate

X_b = mediolateral final abscissa

X_a = mediolateral initial abscissa

0.8382 (cm) = distance between sensors

Thus, total length of the PC dislocation travel (TL) was obtained by the sum of the 300 "TL_{inst}" in each test:

TL = TL_{inst} (1st picture) + TL_{inst} (2nd picture) + ... + TLinst (300th picture)

PC anteroposterior dislocation range (AP) and the PC mediolateral dislocation range (ML) were obtained from the difference between the maximum and minimum values of the PC dislocation, in the directions below, respectively:

AP = ($Y_{máx}$ '" 0.8382) – ($Y_{mín}$ '" 0.8382)

and

ML = ($X_{máx}$ '" 0.8382) – ($X_{mín}$ '" 0.8382)

Figure 1 – Subject positioned for test on the F-SCAN MATT.

Where,

AP (cm) = PC anteroposterior dislocation range

$Y_{máx}$ = maximum value for the anteroposterior ordinate

$Y_{mín}$ = minimum value of the anteroposterior ordinate

ML (cm) = PC mediolateral dislocation range

$X_{máx}$ = maximum value for the mediolateral abscissa

$X_{mín}$ = minimum value for the mediolateral abscissa

0.8382 cm = distance between sensors

Maximum speed reached by PC dislocation (MS) between two consecutive pictures was measured by:

MS = $TL_{instmáx}$ / 0.033332

Where,

MS (cm/s) = maximum speed reached by PC between two consecutive pictures

$TL_{instmáx}$ (cm) = length of the maximum PC dislocation travel between two consecutive points.

0.033332 (s) = interval between the acquisitions of two consecutive pictures

The descriptive statistics was performed for measured quantitative parameters, by calculating: average, standard deviation, standard error, minimum and maximum values.

The comparison between control and case groups was done through Student's T-test on parametric samples and through Mann-Whitney U-test on non-parametric samples. For the purposes of comparing control group's dominant and non-dominant sides, case group's injured and non-injured sides, and opened and closed eyes conditions, either the paired t-test was applied to parametric samples or the Wilcoxon test on non-parametric samples. For all the tests, a significance level of 5% ($\alpha = 0.05$) was adopted.

RESULTS

Results are shown on Tables 1 and 2 and on Figures 3 – 8. Significant differences were found regarding vision, both in GCON and in GLES.

Regarding lower limbs' dominance, no significant differences were found in any analyzed parameters; the results of dominant and non-dominant lower limbs for the GCON were gathered for GLES comparison purposes.

By comparing injured lower limb to the non-injured lower limb in the GLES, significant differences were noticed only on TL and AP with opened eyes.

Non-injured lower limb (GLES) showed differences in comparison to normal individuals in all parameters, except for the TL (opened and closed eyes), and for AP and MS (opened eyes).

Differences were statistically significant in all parameters assessed when comparing GCON to injured lower limb of the GLES.

DISCUSSION

Instability is a frequent manifestation in individuals suffering ACL injuries, being a limiting factor for daily activities. Many methods have been used to evaluate postural control aiming to quantify this disorder for enabling a better follow-up on the evolution of surgical or conservative treatment of patients with this kind of injury.

Strength platform and its adjustments are the instruments most frequently used to measure balance of individuals with ACL injury or submitted to any kind of treatment[8,10,17,18,19]. No papers describing the use of pressure sensors for that purpose, such as the F-SCAN MATT, were found.

Young individuals were studied in order to avoid bias from balance problems or greater body oscillation showed by the elderly[20]. Segregation by gender, when studying a group of young individuals, is not required.

The PC is considered as the vector resulting from vertical force reaction on the ground and the PC dislocation refers to GC acceleration[2]. Some authors believe that the PC location corresponds to the GC location[17]; however, although the differences of concepts, everyone takes into account for evaluation purposes the point at the strength platform marked as "force center", regardless PC or GC names used. There are other authors estimating GC through "oscillation magnetometry"[21,22] or through motion analysis system.[22].

The method employed in this study was considered as easy to apply and sensitive to the instability caused by ACL injury. The use of static tests is not recommended[18]. Dynamic tests, such as those using a balance platform are the most appropriate.

We concluded that the lack of visual information results in a poor balance, both for control group and injured group.

It is believed that the significant differences seen in TL and AP between injured lower limb and non-injured lower limb in the GLES are due to the great instability caused by the ACL injury at anteroposterior direction. In the studies by Zätterström et al.[19] and O'Connell et al.[18] no differences were seen between injured limbs and non-injured limbs and the authors believe that this fact is due to a bilateral compromising in individuals with unilateral ACL injury. In individuals submitted to ACL reconstruction, Harrison et al.[8] and Henriksson et al.[17] did not see significant differences as well.

Care must be taken when considering the non-injured lower limb as a normality parameter, while for a rehabilitation program, the non-injured lower limb shall not be neglected.

Differences seen in all comparative parameters between GCON and the injured lower limb in GLES were also found by Fridén et al.[23] and Zätterström et al.[19]; as opposite to O'Connell et al.[18] who didn't find differences in this kind of comparison. Harrison et al.[8] and Henriksson et al.[17] didn't find differences among normal individuals and individuals with ACL reconstruction.

Balance deficit found in this study could be explained by biomechanical factors, such as muscle laxity or atrophy, as well as by proprioceptive deficiency found in individuals with ACL injuries. Zätterström et al.[19] concluded that the isolated improvement of muscular strength is not able to fully restore balance in individuals with ACL injuries. Henriksson et al. noticed that, even in individuals with laxity on the injured side compared to the non-injured side, there is no difference on postural oscillation between limbs. The influence degree of biomechanical and proprioceptive factors was not evaluated in this study.

We suggest that, in future studies, the test employed here is used for following up the surgical or conservative treatment of individuals with ACL injuries. The evaluation of other musculoskeletal disorders on lower limbs or of other conditions leading to a balance change is also of great value. The use of the test might not be limited only to an evaluation of the treatment provided, but might also be used as a preventive or prognostic means, if, for example, it correlates a poorer postural control to a predisposition to injuries and falls. There is, also, a lack of studies correlating balance to the influence degree of muscle strength, proprioception, joint laxity, and response time to stimulus.

Group	Control						Injured			
Side	dominant		Non-dominant		both		Non-injured		injured	
Eyes	opened	closed	opened	closed	opened	closed	opened	closed	opened	closed
TL	30.92(±7.01)	70.11(±14.77)	30.86(±5.20)	74.85(±21.23)	30.89(±6.09)	72.48(±18.20)	33.31(±5.84)	82.96(±24.28)	35.60(±7.28)	83.06(±23.58)
AP	2.39(±0.47)	4.84(±0.86)	2.51(±0.39)	5.22(±1.38)	2.45(±0.43)	5.03(±1.15)	2.41(±0.52)	6.12(±1.99)	2.92(±0.63)	5.97(±1.84)
ML	1.81(±0.31)	3.81(±0.57)	1.87(±0.29)	3.92(±0.80)	1.84(±0.30)	3.87(±0.69)	2.21(±0.35)	4.37(±0.66)	2.26(±0.38)	4.33(±0.77)
MS	13.25(±2.97)	33.07(±7.30)	13.62(±2.93)	36.71(±12.06)	13.43(±2.92)	34.89(±10.00)	15.00(±3.22)	44.92(±21.34)	15.18(±3.11)	43.83(±19.90)

Labels:TL – Total travel length (cm). AP – Anteroposterior range (cm). ML – Mediolateral range (cm). MS – Maximum speed (cm/s).

Table 1 - *Average values for measured variants, in the different conditions studied*

Comparisons	Variants and conditions							
DM x ND	TL OE	TL CE	AP OE	AP CE	ML OE	ML CE	MS OE	MS CE
P=	0,4798	0,0998	0,1221	0,1230	0,1517	0,2604	0,3159	0,0895
OA x OF	TL DM	TL ND	AP DM	AP ND	ML DM	ML ND	MS DM	MS ND
P=	< 0,0001 *	< 0,0001 *	< 0,0001 *	< 0,0001 *	< 0,0001 *	< 0,0001 *	< 0,0001 *	< 0,0001 *
OA x OF	TL NI	TL IS	AP N I	AP IS	ML NI	ML IS	MS NI	MS IS
P=	< 0,0001 *	< 0,0001 *	< 0,0001 *	< 0,0001 *	< 0,0001 *	< 0,0001 *	< 0,0001 **	< 0,0001 *
NL x IS	TL OE	TL CE	AP OE	AP CE	ML OE	ML CE	MS OE	MS CE
P=	0,0014 *	0,4858	0,0038 *	0,3574	0,2510	0,4045	0,7869	0,2314
CN x NI	TL OE	TL CE	AP OE	AP CE	ML OE	ML CE	MS OE	MS CE
P=	0,0768	0,0537	0,4012	0,0181 *	0,0002 *	0,0051*	0,0827	0,0338 *
CN x IS	TL OE	TL CE	AP OE	AP CE	ML OE	ML CE	MS OE	MS CE
P=	0,0106 *	0,0483 *	0,0034 *	0,0263 *	<0,0001 *	0,0164 *	0,0419*	0,0319 *

Labels: TL – Total travel length. DM – Dominant side in control group. AP – Anteroposterior range. ND – Non-dominant side in control group. ML – Mediolateral range. IS – Injured side in case group. MS – Maximum speed. NI – Non-injured side in case group. OE – Opened eyes. CN – Total control group (both sides). CE – Closed eyes. * - Significant difference

Table 2 - *Results of statistic comparisons.*

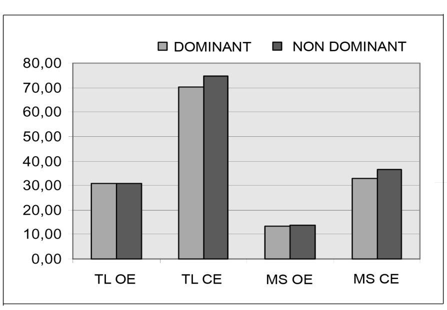

Figure 3 - *Comparison of dominant and non-dominant sides of the control group, considering the variants: total travel length (TL), in cm, and maximum speed (MS), in cm/s, in opened eyes condition (OE) and closed eyes condition (CE).*

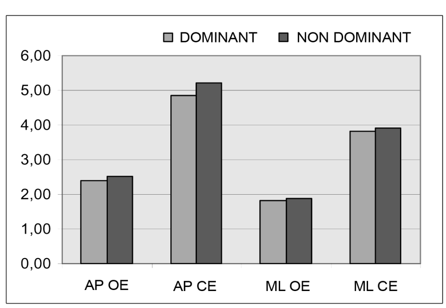

Figure 4 - *Comparison of dominant and non-dominant side in control group, considering the variants: anteroposterior range (AP) and the mediolateral range (ML), in cm, in opened eyes condition (OE) and closed eyes condition (CE).*

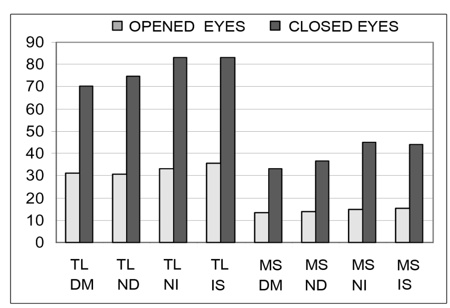

Figure 5 - *Comparison of opened eyes and closed eyes conditions, considering the variants: total travel length (TL), in cm, and maximum speed (MS), in cm/s, on dominant side (DM) and non-dominant side (ND) in control group, an d n injured side (IS) and non-injured side (NI) in case group.*

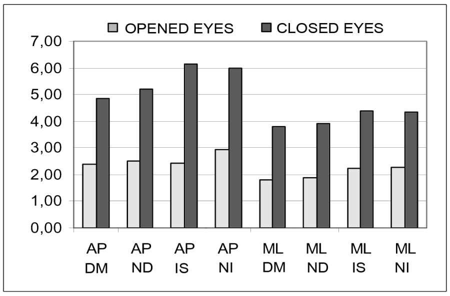

***Figure 6** - Comparison of opened eyes and closed eyes conditions, considering the variants: anteroposterior range (AP), in cm, and mediolateral range (ML), in cm, on dominant sides (DM) and non-dominant sides (ND) in control group and on injured side (IS) and non-injured side (NI) in case group*.

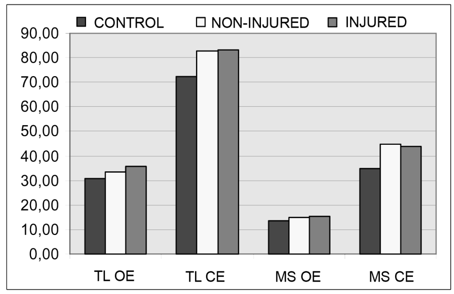

***Figure 7** - Comparison of total control group (including both sides, dominant and non-dominant) and injured and non-injured sides in case group, considering the variants: total travel length (TL), in cm, and maximum speed (MS), in cm/s, in opened eyes (OE) and closed eyes (CE) conditions.*

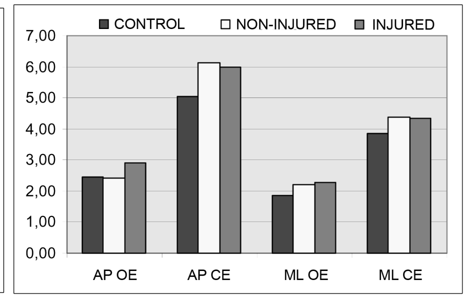

***Figure 8** -* Comparison of the total control group (including both sides, dominant and non-dominant) and injured and non-injured sides in case group, considering the variants: anteroposterior range (AP), in cm, and mediolateral range (ML), in cm, in opened eyes (OE) and closed eyes (CE) conditions.

CONCLUSIONS

1) The method tested with the F-SCAN MATT has shown to be effective on measuring postural control in individuals with ACL injuries.
2) The dominance of the lower limbs does not influence postural control of young healthy individuals.
3) Vision is an important factor on postural control stabilization.
4) ACL injury compromises balance bilaterally; however, this is stronger when support is given by injured lower limb.
5) The use of the non-injured lower limb of individuals with unilateral ACL injuries as a control side should be considered with much care.

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