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Research Article

Proprioceptive Deficit After ACL Reconstruction Surgery Through Force Sense Evaluation

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Abstract

Many studies have already been conducted investigating proprioceptive deficits in subjects with rupture of the Anterior Cruciate Ligament (ACL). However, there are few data related using the paradigm of Force Matching Test. Objective of this study was to verify whether there is knee proprioceptive deficit when analyzed ACL-deficient knee with uninjured knee. 22 participants with ACL rupture and 22 participants with healthy knee were. ANOVA showed differences between the dependent variables Absolute Error and Variable Error, no difference was observed for the Peak Torque. This study concludes that the proprioception and neuromuscular control of force are affected by ACL injury. It may have important implications on the rehabilitation process following the ligament injury

Abbreviations

ACL: Anterior Cruciate Ligament
IKDC: International Knee Documentation Committee
MVIC: Maximum Voluntary Isometric Contraction Test
AE: Absolute Error
VE: Variable Error

Introduction

Proprioception is defined as the conscious ability to perceive joint position, movement and forces produced by body segments [1,2] as it plays a crucial role in joint stability, posture and motor control [3,4]. It is also essential to joint structures proper functioning during the performance of daily activities and to the practice of sports [5]. Proprioception can be divided into the following sub-modalities: joint position sense [6,7], kinesthesia [2] and force sense [8,9]. The mechanoreceptors located in ligaments, tendons and muscles are responsible for detection and transduction of mechanical stimuli produced by stretching and tension in these structures [1,10].

The Anterior Cruciate Ligament (ACL) has a high density of mechanoreceptors, Pacini corpuscle and Ruffini's endings [8], which are responsible for afferent signal acquisition [11] at the same time they contribute to knee proprioception [12,13]. ACL works primarily as a mechanical restrictor for the excessive anterior tibial translation [14]. The mechanical changes by which this ligament is subjected stimulate reflex pathways that interfere in quadriceps muscle contraction and hamstrings in order to provide stability and protect the knee joint [15].

ACL rupture is one of the most common and studied knee lesions [16,17]. In ACL-deficient knees, it has been detected proprioceptive deficits for the joint position sense [18,19] in the threshold for passive movement [18] and for weight discrimination [20]. However, no previous study used the Force Matching Test as a paradigm to observe the proprioceptive deficit, through the force sense submodality after ACL reconstruction surgery. That is considered an important and one of the most reliable ways to evaluate neuromuscular force control, as well as it reflects the daily quadriceps requirements [21]. Therefore, there is a lack of data regarding ACL's functionality to muscle strength control affecting the knee after surgery. In this context, this study aimed at comparing the force sense between limb with total ACL rupture and the uninjured limb, through the force reproduction method before and after the reconstruction surgery, and to verify if there is any correlation between the sense of force the IKDC questionnaires and the Lysholm scale. Our hypothesis is that the injured limb will present worse sense of strength results than the uninjured limb and that after surgery the injured limb and uninjured limb will present similar results.

Materials and Methods

Study Design

This is a prospective, observational, longitudinal study with evaluations on the surgery's eve (pre-op) and 6 months after the surgical procedure.

Subjects

There were chosen randomly 70 male and female patients, all with unilateral ACL rupture. The participants had the following characteristics: 29.9 ± 6.81 years old, 173.1 ± 7.28cm tall; weighed 82.8 ± 15.13kg; the injury mean time up to data collection was 28.5 ± 11.35 months, characterizing chronic ACL injury; regarding the injury occurrence: recreational football (55%), falls (20%), basketball (5%), motorcycle accident (10%) and descending stairs (10%).

The inclusion criteria for the study were: (1) age between 18 and 40 years; (2) diagnosis of isolated ACL rupture confirmed by magnetic resonance imaging (patients with other associated lesions were excluded because our objective was only to study the ACL lesion implications); (3) positive Lachman and Drawer tests [22] (all clinically evaluated by the same physician). The exclusion criteria were: (1) previous ACL reconstruction surgery; (2) presence of any type of associated lower limb injury, including meniscal injury, chondral injury or articular cartilage degeneration (characterized by joint crackling in any knee compartment) and/or knee osteoarthritis signs diagnosed by resonance; (3) to be involved in any therapeutic practice to improve muscle strength, motor control or balance at the beginning of the project, since any of such practices might, somehow, interfere or even improve proprioception and knee strength. Besides turning the group into a non-homogeneous one, 6 months without any kind of physical activity would be enough to turn all the participants into viable ones to the study, and (4) have practiced physical activity regularly in the past six months (so that the sample was homogeneous and because practicing any physical activity could positively or negatively influence the studied variables).

Out of these 70 patients, 15 were excluded because they did not meet the study criteria inclusion, thus remaining 55. Out of these 55, 2 others were excluded after the surgical procedure because they were diagnosed with osteomyelitis, 3 were excluded for being diagnosed with infection at the surgical site, 3 gave up participating in the study soon after the surgical procedure, 3 gave up participating in the study in the third month. Therefore, only 44 participants completed the study.

Prior to the beginning of the evaluations, all participants signed a Consent Form, in which the study objectives and experimental conditions were described in detail. The study was approved by the Institutional Ethics Board (CAAE number 04019712.8.0000.5273). The study was done in accordance with the ethical standards of the institutional and national research committee and with the 1964 Helsinki declaration.

Evaluation

All the patients were evaluated the day before the surgery and 6 months after the surgical procedure. Data was collected prospectively as the patients were operated, by a blinded researcher. Patients from both groups had similar surgical incisions, so that it was not possible to the participants and to the researchers distinguish between the surgical techniques by ectoscopy.

Knee Function Measurement

The present study used the International Knee Documentation Committee (IKDC) [23] and Tegner Lysholm Knee Scoring Scale [24] documents, both translated and validated to Portuguese [25,26].

Procedure and Experimental Task

An isokinetic dynamometer (CSMI®, HUMAC NORM®) was used for the evaluations. The participants were positioned sitting comfortably, with the lateral femoral condyle aligned with the dynamometer axis of rotation and the ankle attached to the lever for knee evaluation by a Velcro® strip (Figure 1). All participants underwent two tests, carried out in a single session: (1) Maximum Voluntary Isometric Contraction Test and (2) Force Matching Test. Both tests were performed in isometric and with knees at 60° of extension. The two limbs were separately evaluated and in a random order. All tests were conducted by the same evaluator. The evaluator was blind to the groups.

Figure 1: *Volunteer positioned for evaluation on the isokinetic dynamometer*

Maximum Voluntary Isometric Contraction Test (MVIC)

Before MVIC test was carried out, the participants were submitted to a familiarization moment with the equipment consisting of five repetitions without any resistance and on the knee at the participant's full range of motion. It was then followed by a specific warm up exercise which consisted of three isometric submaximal contractions (subjective effort: 20%, 40% and 60% of the maximum force) with 1 min pause between them. The MVIC was conducted after 3 min of rest, with three 6-second trials, each on them interleaved by 3-min pause. The highest instantaneous torque value found was considered 100% of MVIC. The limbs were evaluated in random order.

Force Matching Test

The force sense was assessed using the Force Matching Test. The knee extensors Force Matching Test was performed after 10-min rest from MVIC test. It was chosen 20% MVIC as reference contraction intensity. The procedure consisted of two steps: (1) a reference contraction, in which visual feedback of torque level produced was provided in order to help subjects to keep the torque level desired, immediately followed by (2) a matching contraction, without visual feedback, when the subjects were instructed to reproduce as accurately as possible the reference contraction previously experienced. Three attempts were made with an interval of 3-min between them. Each isometric contraction lasted 6-seconds. These procedures are the same used by Godinho *et al.* [27] and are based on other force sense protocols [2,9,19,28].

Analysis of Signals by the Isokinectic Dinamometer

The obtained torque signals provided by the isokinectic dynamometer were sent to a computer and analyzed according to a procedure developed to MatLab 7.02c (MathWorks Inc, USA). First and foremost, all signals were submitted to a 2nd class low pass butterworth filter in both directions. It allowed the phase zero and the 10Hz cutoff frequency. For this study it was considered only the 2 to 4 seconds curve zone. With such signals we were able to obtain the MVIC peak torque values as well as the observed and reproduced force values during force reproduction test. They were used to calculate the individual error value. In order to normalize toque values, the study used each participant body mass as a variable [27]. The proprioceptive performance was obtained from Absolute Error (AE) and Variable Error (VE) values. The AE was equal to the arithmetical mean from individual errors in relation to the reference force. It portrays the individual accuracy in reproducing the experienced force; by the same token, the VE is obtained using standard deviation for each individual error. It shows the consistency on the conducted reproductions [29].

Statistical Analysis

The individual error value for each attempt was set by the difference between the matching contraction and the experienced reference contraction. The Force Matching Test performance was set by the absolute error (AE) values and variable error (VE). Schmidt & Lee [29] described in detail the calculations of each index. In short, the AE is obtained by the arithmetic mean of individual errors in module and determines the individual accuracy to reproduce the force, and the VE is the standard deviation of individual errors and determines the consistency of reproductions made. Only the period between 2 to 4 seconds on torque curves were used to establish AE and VE. Pilot tests have shown this period was necessary for stabilizing the contraction strength, in addition to being less affected by fatigue.

The study relied on descriptive statistics (mean ± SD). The dependent variables were the MVIC, AE and EV. The AE and EV were expressed as percentage of MVIC. The MVIC values were standardized by the respective participant´s body weight in order to allow the comparison between the subjects.

All variables were tested for normality by the Henze-Zirkler's Multivariate Normality Test. Lysholm and IKDC scores (p <0.001).

Comparisons between the measures taken at the two moments (pre-op and after), taking into account the effect of the intervention and time were performed using two-way ANOVA for repeated measures: moments (pre-op x after) and limb (injury limb x healthy limb). Sphericity was checked and, if not verified, the Greenhouse-Geisser correction was then applied. The Scheffé post hoc test was used for pairs' comparison, when applicable. Likewise, Friedman's ANOVA test was applied to the Lysholm and IKDC scores.

Moreover, the present study seeked to identify the correlation between the dependent variables observed here through Pearson's correlation test.

The statistical significance level was established as $p \leq 0.05$ for all tests. All analyses were performed using the SPSS® (IBM®. Chicago, IL, USA).

Results

The MVIC, EA and EV variables presented similar results. The ANOVA found the main limb effect for MVIC, EA and EV variables (F = 1.331, p = 0.034; F = 48,940, p < 0,001; F = 5.297, p = 0.005) and for the moment (F=4.175, p=0.016; F=3.304, p=0.038; F=4.802, p=0.009). The post hoc test found significant difference between limbs. (p < 0.001). The healthy limb presented the highest values for MVIC and the lowest for AE and VE in both moments (table 1). It was found significant difference between the moments (p < 0.001), with the injured limb presenting higher MVIC values for the post-op moment when compared to the pre-op moment, as well as for the other variables (table 1).

Table 1: *The results of the comparison between injured and uninjured limbs in force matching test and MVIC (mean ± SD).*

	Pre surgery			Post-surgery		
Limb	AE (% MVIC)	VE (% MVIC)	MVIC ($N.kg^{-1}$)	AE (% MVIC)	VE (% MVIC)	MVIC ($N.kg^{-1}$)
injury	1,6 ± 0,24	1,5 ± 0,32	1,5 ± 0,74	1,0 ± 0,33#	1,1 ± 0,22#	2,2 ± 0,44#
healthy	0,5 ± 0,53*	0,5 ± 0,69*	3,2 ± 0,81*	0,4 ± 0,61*	0,5 ± 0,88*	3,4 ± 0,88*

AE: absolute error; VE: variable error; MVIC: maximum voluntary isometric contraction; *: significantly different from the injury side; #: significantly different from the pre surgery moment

The Lysholm score and IKDC improved when compared before and 6 months after surgical procedures (p<0.001).

The observed IKDC score was 45,46 ± 21,40 points. This value was then related to the MVIC for the injured limb (r =0,549; p<0,001) (figure 2).

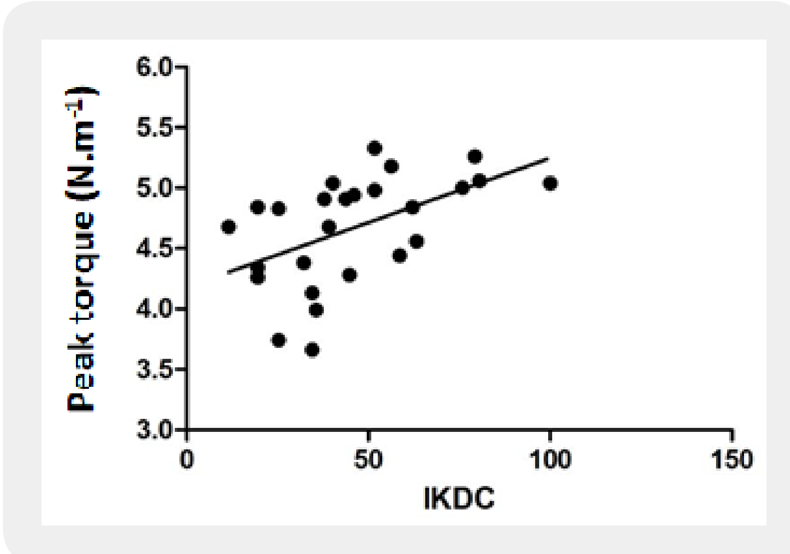

Figure 2: *Difference between values found on the IKDC form x MVIC for the injured limb*

The value observed on the Lysholm scale was 57,59 ± 17,66 points. It was possible to relate it to the MVIC value for the injured limb. (r = 0,481; p<0,001) (figure 3).

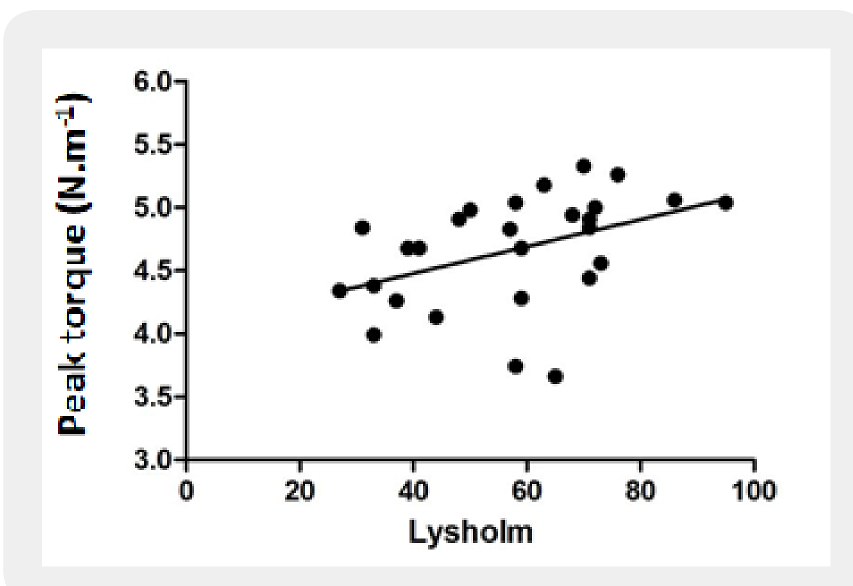

Figure 3: *Pak torque values for injured limb on Lysholm scale.* $(N.m^{-1})$

It was identified a correlation between values found on IKDC form and values found on Lysholm scale (r = 0,542; p<0,001) (figure 4).

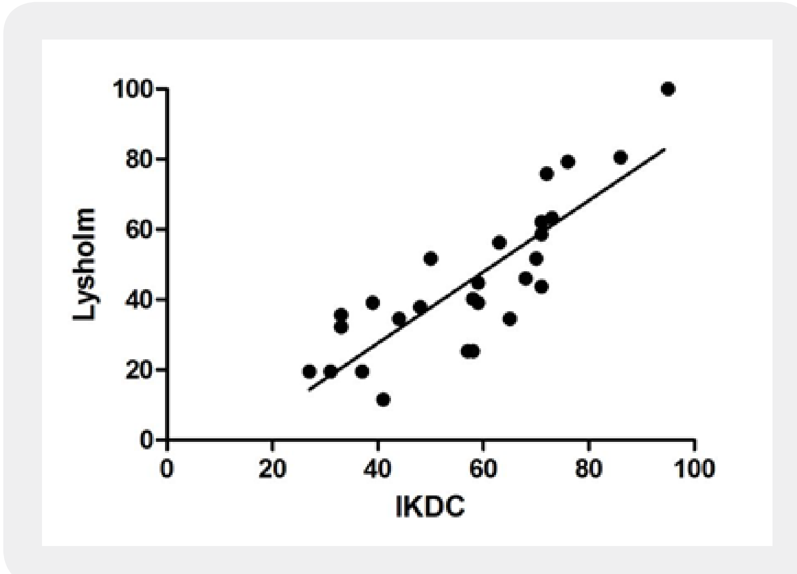

Figure 4: *Correlation between values found on IKDC form x values found on Lysholm scale.*

Discussions

The aim of this study was to compare the sense of force between limbs with total ACL rupture and uninjured limbs through the force reproduction test before and after the reconstruction surgery. Likewise, it aimed at checking if there is any correlation between the sense of force for the IKDC questionnaires and the Lysholm scale. According to the established protocol, participants were subject to MVIC and Force Matching Tests. First, we conducted a comparison between injured and uninjured limbs.

Literature presents diverging opinions regarding force recovering and proprioception after ligament reconstruction surgery. Notwithstanding, so far only one study has brought specific light to the discussion regarding force sense through force match test. However, the referred study did not advance until the post-op phase [27]. The study results have shown the surgery has an effect both on the force and on proprioception, with significative improvement after the surgical procedure. However, the injured limb kept presenting worse results than the healthy one. Héroux and Tremblay [20] and Godinho *et al.* [27] found similar results, reporting a lower accuracy in injured limb during a weight discrimination protocol, however, neither of them have lasted to the post-surgical phase. Regarding the MVIC, the results obtained confirm those presented by [30]. They were able to prove a reduction for the quadriceps MVIC in 50 patients with ACL lesion when compared to the healthy limb.

A similar result was found by Gibson *et al.* [31], with a significant reduction in the quadriceps' peak torque for an ACL injured limb.

Kapreli *et al.* [32], through a brain activation study, have studied functional magnetic resonance imaging (1.5-T scanner) in chronic ACL-ruptured patients (> 6 months). Compared to a healthy control group, it was possible to observe a reorganization in the Central Nervous System, with a decrease in activation for several areas of the cortical sensorimotor system, thus suggesting this lesion might have been considered not only as a simple peripheral musculoskeletal lesion but as a neurophysiological dysfunction. In addition to that, a reduced proprioceptive sensibility has been shown to cause giving way or episodes of instability for the ACL-deficient knee. This is clinically presented as the pivot-shift mechanism [33]. Instability occurs because of the combined effects of excessive tibial translation and lack of reflex stabilization. The lack of knee reflex stabilization is associated with a diminished sensory feedback mechanism, which causes a deficient motor response of the knee muscles. Researchers have established a deficiency in the muscle firing patterns in ACL deficient subjects [34]. Our findings of diminished sensory feedback corroborate with these previous findings of deficient motor response. The degree to which the two are related is still unclear.

There is evidence ACL's afferent stimulation influences the quadriceps and hamstrings activity during voluntary contractions [35] and that complete joint sensory innervations are not recovered after an injury [16,21,36]. Among the mechanoreceptors, the Golgi Tendon Organ (GTO) is considered the main source of afferent inputs related to muscle contraction [1,10]. The GTO is highly sensitive to muscle tension, allowing it to monitor small and rapid changes in contractile forces [37]. However, GTO is located in the tendon tissue and it is not affected by ACL disruption. Thus, a direct involvement of GTO in low accuracy of limb injured seems very unlikely.

Hultborn [37] suggested that ACL and quadriceps muscle are functionally coupled, with sensory signals arising from the ACL likely modulating quadriceps reflex excitability and influencing activity elicited in knee extensors during voluntary contractions. Similarly, low accuracy of injured limb can occur due to a partial failure of the calibration process of commands to the motors descendants [20]. Therefore, the lack of appropriate ACL mechanoreceptors function can directly be involved with loss of the muscular strength and proprioceptive control. This aspect is probably due to afferent signaling deficient by the partial loss of mechanoreceptors in the ruptured ACL, thus depriving the medulla and cortical motor centers of important afferent sensory information on the modulation of muscle contractility. These results corroborate with the evidence that sensory innervation in joints rarely heals after injury to one of its structures [36].

A relationship between functional tests, measures of proprioception and muscle strength can provide physicians to relevant information on the functional level of the knee of the patient [30]. Despite the present study has observed a positive relation between MVIC and the positive results from IKDC and Lysholm questionnaires, it was not possible to relate MVIC to the results from force sense tests. Such fact suggests that parameters for evolution indexes do not reflect on more control over a participant's own strength. Based on MVIC correlation to IKDC and Lysholm scales, results showed patients who had the highest MVIC values were able to best compensate the absence of mechanoreceptors from the original ACL, either to everyday or sport activities. It increased the values for the analysed data in both scenarios. Carter *et al.* [38] have also observed a relation between the quadríceps MVIC and the performance on dinamic functional tests ("8" shaped run with monopodal jump).

The present study was not able to find any correlation between the subjective questionnaires (IKDC and Lysholm) and the presence of sense of force deficits for the injured limb. A similar result was observed by Fremerey *et al.* [39]. Their study has presented low correlation between the observed results on the proprioception test by the joint position sense with the ACL injured limb and the obtained results on the Lysholm questionnaire. However, the study found a significant relation between proprioceptive results and patient satisfaction [39]. Several other studies could not find significant correlation between their proprioception testing results for the ACL injured limb either before or after surgical reconstruction, having the Lysholm scale as a basis [40]. This study was able to observe that the patients' scores on Lysholm and IKDC questionnaires have presented a significant correlation. Such result somehow matches others tested by some authors [16].

A relationship between functional tests, measures of proprioception and muscle strength can provide physicians to relevant information on the functional level of the knee of the patient [32]. This relationship has been demonstrated by Barrett [41], and Borsa *et al*. [40] who used the joint position sense test and threshold for the detection of passive movement test, finding correlations with the test hop single-legged, which is a test of knee function based on performance. The results from this study are consistent with Barrett [41] findings in that proprioception values demonstrate moderately high correlations with the single-legged hop test, which is a performance-based test of knee function. The single-legged hop test is an integrated measure of neuromuscular control and dynamic stabilization. A high degree of proprioceptive sensibility and functional ability is required to successfully propel the body forward and land safely on that limb. Therefore, subjects with ACL deficiency would be less likely to hop successfully because of the cumulative effects of proprioceptive and functional deficits.

Conclusions

In this way, the present result corroborates and extends previous findings of proprioceptive deficits in injured and healthy limbs in subjects with ACL rupture during pre and post-surgical phases when compared to individuals without any history of injury during the Force Matching Test. The results of this study show neuromuscular control of force is affected by ACL injury. This may have important implications on the rehabilitation process following ligament injury, especially considering neuromuscular exercises to improve and preserve the knee sense of force after surgery. The measures of proprioception are not significantly correlated with function. It is important to highlight the force sense evaluation through matching test might become an important and effective clinical tool as a quantitative follow-up indicator for patient's status during post-op rehabilitation process. It might help professionals deciding the best discharging time and further return to the patient's sports activity.

Conflicts of Interests

All authors declare that they have not any financial or other relationships that may lead to a conflict of interest.

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