



Original Article

Proprioceptive deficit in patients with complete tearing of the anterior cruciate ligament^{☆,☆☆}



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ARTICLE INFO

Article history:

Received 2 July 2013

Accepted 5 August 2013

Available online 22 October 2014

Keywords:

Anterior cruciate ligament

Proprioception

Knee

ABSTRACT

Objective: To investigate the existence of proprioceptive deficits between the injured limb and the uninjured (i.e. contralateral normal) limb, in individuals who suffered complete tearing of the anterior cruciate ligament (ACL), using a strength reproduction test.

Methods: Sixteen patients with complete tearing of the ACL participated in the study. A voluntary maximum isometric strength test was performed, with reproduction of the muscle strength in the limb with complete tearing of the ACL and the healthy contralateral limb, with the knee flexed at 60°. The meta-intensity was used for the procedure of 20% of the voluntary maximum isometric strength. The proprioceptive performance was determined by means of absolute error, variable error and constant error values.

Results: Significant differences were found between the control group and ACL group for the variables of absolute error ($p = 0.05$) and constant error ($p = 0.01$). No difference was found in relation to variable error ($p = 0.83$).

Conclusion: Our data corroborate the hypothesis that there is a proprioceptive deficit in subjects with complete tearing of the ACL in an injured limb, in comparison with the uninjured limb, during evaluation of the sense of strength. This deficit can be explained in terms of partial or total loss of the mechanoreceptors of the ACL.

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[☆] Please cite this article as: Godinho P, Nicoliche E, Cossich V, de Sousa EB, Velasques B, Salles JI. Déficit proprioceptivo em pacientes com ruptura total do ligamento cruzado anterior. Rev Bras Ortop. 2014;49:613-618.

^{☆☆} Work developed in the Research Division of the Neuromuscular Research Laboratory, National Institute of Traumatology and Orthopedics (INTO), Rio de Janeiro, RJ, Brazil.

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<http://dx.doi.org/10.1016/j.rboe.2014.10.007>

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Déficit proprioceptivo em pacientes com ruptura total do ligamento cruzado anterior

R E S U M O

Palavras-chave:

Ligamento cruzado anterior

Propriocepção

Joelho

Objetivo: Investigar, por meio do teste de reprodução da força, a existência de déficits proprioceptivos entre o membro lesionado e o não lesionado (i.e., contralateral normal) em indivíduos que tenham sofrido ruptura total de LCA.

Métodos: Participaram do estudo 16 pacientes com ruptura total do LCA. Foi feito o teste de força voluntária máxima isométrica (FVIM) e reprodução da força muscular no membro com ruptura total do LCA e contralateral saudável, com joelho a 60° de flexão. Foi usada a intensidade-meta para o procedimento de 20% da FVMI. O desempenho proprioceptivo foi determinado por meio dos valores de erro absoluto (EA), erro variável (EV) e erro constante (EC).

Resultados: Diferenças significativas foram encontradas entre os grupos controle e LCA para as variáveis erro absoluto ($p=0,05$) e erro constante ($p=0,01$). Não foi encontrada diferença para o erro variável ($p=0,83$).

Conclusão: Nossos dados corroboram a hipótese de existência de déficit proprioceptivo em sujeitos com ruptura total de LCA em um membro lesionado quando comparado com o não lesionado durante a avaliação do senso da força. Esse déficit pode ser explicado por uma perda total ou parcial dos mecanorreceptores do LCA.

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Introduction

Proprioception is defined as the conscious capacity to perceive position, movement and the forces imposed on and produced by body segments.¹ It has a crucial role in joint stability and postural and motor control.^{2,3} Therefore, it is essential for adequate functioning of the joint structures during day-to-day activities and sports practice.⁴ The main ways of evaluating proprioception are through testing joint position sense (JPS),⁵ the perception threshold for passive movement⁵⁻⁷ and the sense of strength.^{8,9}

With regard to the knee joint, tearing of the anterior cruciate ligament (ACL) is the commonest injury, and its incidence has been increasing over the years.¹⁰ It has been estimated that in the United States, 95,000 people suffer injuries to this ligament every year.¹¹

The ACL functions together with other anatomical structures surrounding the knee so as to maintain static and dynamic balance. It has an important role in proprioceptive monitoring of mechanical receptors such as Pacini corpuscles and Ruffini endings.¹²⁻¹⁵

Many studies have indicated that subjects with partial tearing of the ACL present proprioceptive deficits.¹⁶⁻¹⁸ These deficits can be considered to be factors predisposing toward knee instability¹⁷: they adversely affect the activity, balance and strength of the quadriceps and increase the risk of new injuries to the knee.¹⁹

The functional and proprioceptive levels of the knee in subjects with partial tearing of the ACL have been measured previously and most studies have used tests on JPS or on the threshold of detection of passive movement.^{13,20} All of these studies have found deficits in the injured limb in comparison with the uninjured limb.^{14,21,22} The sense of strength has

received more attention in the literature recently, but few data are available in relation to this paradigm for evaluating proprioception in the knee joint, given that there are no studies that have evaluated patients with total tearing of the ACL.

Thus, the objective of the present study was to use a strength reproduction test to investigate the existence of proprioceptive deficits between the injured limb and the uninjured limb (i.e. the normal contralateral limb), in individuals who have suffered total tearing of the ACL. In this regard, our study hypothesis was that individuals with total tearing of the ACL would present proprioceptive deficits in the injured limb, in comparison with the uninjured limb.

Materials and methods

Subjects

Sixteen volunteers from both sexes aged between 18 and 40 years (mean age, 27.6 ± 2.9 ; mean height, 172.2 ± 6.7 ; and mean weight, 74.4 ± 12.9) participated in this study. All of them presented total tearing of the ACL in one of their legs. Volunteers presenting any of the following were excluded from the sample: previous surgery in the leg with ACL tearing; any other type of injury to that limb; joint degeneration (characterized by joint crepitation in any of the knee compartments); chondral lesions diagnosed through magnetic resonance imaging; and/or signs of osteoarthritis seen on radiographs of the knee. All the subjects were evaluated clinically by the same orthopedist and they signed a consent statement in which the objectives and conditions of the experiment were described in detail. This statement had been approved by our institution's ethics committee in accordance with Resolution 196/96 of the National Health Council.



Fig. 1 – Photo of an individual positioned in the dynamometer.

Experimental procedure and task

An isokinetic dynamometer (CSMI, Humac Norm) was used, and before each test, the equipment was properly calibrated. The subjects were positioned to sit comfortably, with the lateral condyle of the femur aligned with the rotation axis of the apparatus and the ankle fixed to the rod of the knee assessment accessory by means of a Velcro strip (Fig. 1).

The following tests were performed:

- (1) Muscle strength and force reproduction tests were performed with the knee extended at 60°. In order to perform a maximum voluntary isometric strength (MVIS) test, the subjects warmed up and became familiarized with the equipment by means of five repetitions, without resistance imposed by the apparatus, performed over their entire range of joint motion. After this familiarization, the subjects performed specific warm-ups with three submaximal isometric contractions (with subjective effort of 20%, 40% and 60% of the maximum force), with a one-minute interval between them. The MVIS was conducted after a three-minute interval, and three attempts were made with three-minute intervals between them. The greatest instantaneous torque found was taken to be 100% of the MVIS. Each isometric contraction lasted for six seconds. The uninjured limb was evaluated first.
- (2) A reproduction test on the ipsilateral strength of the knee extensors was performed after leaving a 10-min interval following the MVIS test. The target intensity for the procedure was 20% of the MVIS. The procedure consisted

of performing a reference contraction, in which visual feedback of the torque level was used. The subjects were instructed to maintain the desired force level. Immediately after the reference contraction, the subjects attempted to reproduce the force produced previously, as precisely as possible, without visual feedback. Three attempts were made, with three-minute intervals between them. Each isometric contraction lasted for six seconds.

Dependent variables

The individual error value for each attempt was determined as the difference between the reproduced force and the force experienced. The proprioceptive performance was determined by means of the values for the absolute error (AE), variable error (VE) and constant error (CE). Schmidt and Lee²³ described the calculations for each variable, in detail. Briefly, the AE is obtained from the arithmetic mean of the individual errors in the modulus and determines the individual's accuracy in reproducing force; the VE is the standard deviation of the individual errors and determines the consistency of the reproductions performed; and the CE is the arithmetic mean of the individual errors with the signs and determines the tendency to reproduce the force above or below the target (bias). Only the period of the torque curves from two to six seconds was used for determining the AE, CE and VE. Pilot tests demonstrated that this would be the period needed for the subjects to stabilize the intensity of contraction, and within which there would be the least effect from fatigue while sustaining the force.

Statistical analysis

Descriptive statistics (mean \pm standard deviation (SD)) were used to describe the data. The dependent variables were the AE, VE and CE. The data were subjected to the Shapiro-Wilk test of normality. Comparisons were made between the injured and uninjured limbs. The values determined for 20% of MVIS were compared using the t test for paired measurements. The calculations were made using the Statistical Package for the Social Sciences (SPSS Inc. Chicago, IL, USA). The significance level established was $p \leq 0.05$.

Results

Time and cause of the injury and associated lesions

The mean length of time from the injury until the data gathering was 3.2 ± 1.6 years. In the majority of the cases, the injuries occurred during recreational soccer practice, all without contact (68.75%). Other cases occurred in relation to surfing (6.25%), falling (6.25%), playing handball (6.25%), playing basketball (6.25%) and suffering motorcycle accidents (6.25%).

Clinical examinations

These are presented in Table 1.

Table 1 – Clinical examinations.

Lachman and anterior drawer				
	–	+ / +++	++ / +++	+++ / +++
Lachman	3	13	0	0
Anterior drawer	0	16	0	0
McMurray and Pivot				
	–	+		
Bocejo	8	8		
Pivot	3	13		

Table 2 – AE, VE and CE determined for 20% MVIS (mean ± SD).

	AE	VE	CE
ACL	4.3 ± 2.2% ^a	1.6 ± 1.2%	4.1 ± 2.3% ^a
Control	3.0 ± 1.3%	1.7 ± 1.1%	1.9 ± 2.1%

^a Significantly different from the control limb.

Values for absolute error (AE), variable error (VE) and constant error (CE)

After the data-gathering, the strength values were standardized in relation to body weight. This was done to make it possible to make comparisons between our subjects. The MVIS calculated for the uninjured limb was 3.2 ± 1.0 N/kg and for the injured limb, 3.0 ± 1.1 N/kg. No statistically significant difference was found for the MVIS ($p = 0.059$). The t test demonstrated a significant difference between the limbs regarding the variables AE ($p = 0.05$) and CE ($p = 0.01$) (Fig. 2). There was no difference regarding VE ($p = 0.83$). The means and standard deviations for the individual errors relating to strength are given in Table 2.

Discussion

The present study had the objective of determining whether patients with total tearing of the ACL presented proprioceptive deficits in the injured limb during assessment of their sense

of strength. For this, muscle strength and force reproduction tests were performed on the injured and uninjured limbs. In this regard, we worked with the hypothesis that individuals with total tearing of the ACL would present proprioceptive deficits in the injured limb, in comparison with the uninjured limb. Our hypothesis was in line with the study by Héroux and Tremblay,¹⁸ who identified proprioception deficits in this same population using a weight discrimination test.

In particular, the sense of strength was evaluated in 16 patients with unilateral total tearing of the ACL, using 20% of their MVIS. Significant differences were found in the force reproduction test between the injured and uninjured limbs. The AE results demonstrated that the injured limb was less capable of accurately reproducing the force, given that the CE results demonstrated that although both limbs tended to overestimate the target, the injured limb overestimated this much more. With regard to the VE, we did not find any statistical difference, which shows that the individuals were consistent regarding the errors.

Using the JPS test, Lee et al.¹⁶ and Carter et al.¹⁷ found significantly different AE values between the injured and uninjured limbs. Héroux and Tremblay¹⁸ conducted a study on the sense of strength using the weight discrimination test and also obtained results that indicated lower acuity in the injured side. The results from our investigation corroborate the results from these three experiments. Few studies on the sense of strength have used the force reproduction test, which makes it difficult to compare the results.

Thus, one likely explanation for the low accuracy of force reproduction on the injured side may be partial failure of the process of calibrating the descending motor commands due to impaired assessment of the force signals resulting from muscle contraction. This possibility raises the question of which afferent information sources are susceptible to being affected by ACL injuries.

Among the receptors, the Golgi tendon organ (GTO) is considered to be the main source of afferent inputs coming from peripheral regions relating to muscle strength and tension.²⁴⁻²⁶ However, because the GTO is located in the muscle-tendon area, it should not be affected by ACL injuries.

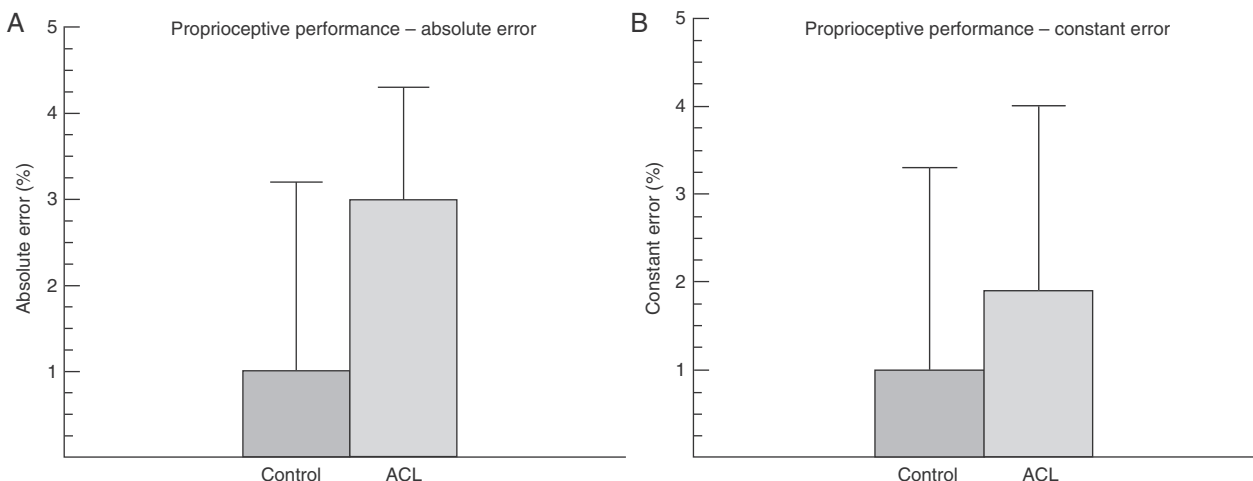


Fig. 2 – Graphical representation of the absolute error (AE) results (A) and the constant error (CE) results (B).

Thus, involvement of the GTO in the low acuity of our subjects seems very unlikely.

There is evidence that afferent stimulation of the ACL may influence knee flexor and extensor activity during voluntary contractions²⁷ and that the sensory innervation of the joints is rarely recovered after injury.²⁸ Our subjects' difficulty in force reproduction can be attributed to loss of innervation of the mechanical receptors of the ACL, which thus reduces the quantity of sensory information relating to tension and force during the test.

It is also possible that some mechanical receptors located in the joint capsule that were spared from injury may nonetheless have been altered. Khalsa and Grigg²⁹ investigated this possibility in an animal model and concluded that the afferent response capacity of the joint capsule was not significantly affected after complete transection of the ACL. Thus, we believe that there was some residual innervation in the injured knee, together with the inputs from the GTO, which remained intact in the quadriceps. This would explain the variability between individuals that was observed. It might also explain why the capacity to reproduce force, albeit reduced in comparison with the uninjured leg, was still relatively well conserved in our subjects.

In relation to the MVIS, our results did not find significantly different values: 3.2 ± 1.0 N/kg for the uninjured leg and 3.0 ± 1.1 N/kg for the injured leg. This differed from what was found by Héroux and Tremblay.¹⁸ We attribute this difference in results to the fact that our subjects were mostly practitioners of physical activity. However, our MVIS values were much higher than those found in the study by Héroux and Tremblay.¹⁸ This was probably because although they also used an isokinetic dynamometer, it was done at with the knee extended at 45°. We used a knee extension of 60°, which produced greater mechanical efficiency of the quadriceps, with the capacity to reach higher peak torque, according to the database of our laboratory (unpublished data). This makes it impossible to directly compare the results, because we used force values that were standardized according to weight.

Thus, our data corroborate the hypothesis that there is a proprioceptive deficit among subjects with total tearing of the ACL in one injured limb, in comparison with the uninjured limb during assessment of the sense of strength. This proprioceptive deficit seems to be better explained in the study by Hogesvorst and Brand,²⁸ along with that of Khalsa and Grigg,²⁹ who attributed the capacity for force reproduction to losses, or to the continuing existence of some residual innervation of the mechanical receptors of the ACL, along with inputs from the GTO, which remained intact in the quadriceps and reduced the quantity of sensory information.

In this regard, because of the absence of studies relating to this problem, we suggest that new studies should be conducted with the aims of expanding the knowledge on this subject and enabling comparison of results.

Conflicts of interest

The authors declare no conflicts of interest.

REFERENCES

- Lephart SM, Pincivero DM, Rozzi SL. Proprioception of the ankle and knee. *Sports Med.* 1998;25(3):149-55.
- Riemann BL, Lephart SM. The sensorimotor system, part I: the physiologic basis of functional joint stability. *J Athl Train.* 2002;37(1):71-9.
- Riemann BL, Lephart SM. The sensorimotor system, part II: the role of proprioception in motor control and functional joint stability. *J Athl Train.* 2002;37(1):80-4.
- Safran MR, Borsa PA, Lephart SC, Fu FH, Warner JJ. Shoulder proprioception in baseball pitchers. *J Shoulder Elbow Surg.* 2001;10(5):438-43.
- Riemann BL, Myers JB, Lephart SM. Sensorimotor system measurement techniques. *J Athl Train.* 2002;37(1):85-98.
- Allegrucci M, Whitney SL, Lephart SM, Irrgang JJ, Fu FH. Shoulder kinesthesia in healthy unilateral athlete participating in upper extremity sport. *J Orthop Sports Phys Ther.* 1995;21(4):220-6.
- Salles JI, Alves H, Amaral MV, Cagy M, Cunha-Cruz V, Piedade R, et al. Study of proprioceptive function in professional volleyball athletes with atrophy of the infraspinatus. *Br J Sports Med.* 2011;45:535.
- Costello JT, Algar LA, Donnelly AE. Effects of whole-body cryotherapy (-110 °C) on proprioception and indices of muscle damage. *Scand J Med Sci Sports.* 2011;22(2):1-9.
- Simon AM, Ferris DP. Lower limb force production and bilateral force asymmetries are based on sense of effort. *Exp Brain Res.* 2008;187(1):129-38.
- Pap G, Machner A, Nebelung W, Awiszus F. Detailed analysis of proprioception in normal and ACL-deficient knees. *J Bone Joint Surg Br.* 1999;81(5):764-8.
- Miyasaka KC, Daniel DM, Stone ML, Hirshman P. The incidence of knee ligament injuries in the general population. *Am J Knee Surg.* 1991;4(1):3-8.
- Barrack RL, Skinner HB, Buckley SL. Proprioception in the anterior cruciate deficient knee. *Am J Sports Med.* 1989;17(1):1-6.
- Barrett DS. Proprioception and function after anterior cruciate reconstruction. *J Bone Joint Surg Br.* 1991;73(5):833-7.
- Corrigan JP, Cashman WF, Brady MP. Proprioception in the cruciate deficient knee. *J Bone Joint Surg Br.* 1992;74(2):247-50.
- Adachi N, Ochi M, Uchio Y, Iwasa J, Ryoike K, Kuriwaka M. Mechanoreceptors in the anterior cruciate ligament contribute to the joint position sense. *Acta Orthop Scand.* 2002;73(3):330-4.
- Lee HM, Cheng CK, Liau JJ. Correlation between proprioception, muscle strength, knee laxity, and dynamic standing balance in patients with chronic anterior cruciate ligament deficiency. *Knee.* 2009;16(5):387-91.
- Carter ND, Jenkinson TR, Wilson D, Jones DW, Torode AS. Joint position sense and rehabilitation in the anterior cruciate ligament deficient knee. *Br J Sports Med.* 1997;31(3):209-12.
- Héroux ME, Tremblay F. Weight discrimination after anterior cruciate ligament injury: a pilot study. *Arch Phys Med Rehabil.* 2005;86(7):1362-8.
- Gokeler A, Benjaminse A, Hewett TE, Lephart SM, Engebretsen L, Ageberg E, et al. Proprioceptive deficits after ACL injury: are they clinically relevant? *Br J Sports Med.* 2012;46(3):180-92.
- Fridén T, Roberts D, Zätterström R, Lindstrand A, Moritz U. Proprioception after an acute knee ligament injury: a longitudinal study on 16 consecutive patients. *J Orthop Res.* 1997;15(5):637-44.
- Reider B, Arcand MA, Diehl LH, Mroczek K, Abulencia A, Stroud CC, et al. Proprioception of the knee before and after anterior cruciate ligament reconstruction. *Arthroscopy.* 2003;19(1):2-12.

22. Fischer-Rasmussen T, Jensen PE. Proprioceptive sensitivity and performance in anterior cruciate ligament-deficient knee joints. *Scand J Med Sci Sports*. 2000;10(1):85-9.
23. Schmidt R, Lee T. *Motor control and learning: a behavioral emphasis*. 5th ed. Champaign: Human Kinetics; 2011.
24. Jami L. Golgi tendon organs in mammalian skeletal muscle: functional properties and central actions. *Physiol Rev*. 1992;72(3):623-66.
25. Gregory JE, Brockett CL, Morgan DL, Whitehead NP, Proske U. Effect of eccentric muscle contractions on Golgi tendon organ response to passive and active tension in the cat. *J Physiol*. 2002;538 Pt 1:209-18.
26. Gandevia SC, McCloskey DI. Interpretation of perceived motor commands by reference to afferent signals. *J Physiol*. 1978;283:193-9.
27. Hultborn H. State-dependent modulation of sensory feedback. *J Physiol*. 2001;533(1):5-13.
28. Hogervorst T, Brand RA. Mechanoreceptors in joint function. *J Bone Joint Surg Am*. 1998;80(8):1365-78.
29. Khalsa PS, Grigg P. Responses of mechanoreceptor neurons in the cat knee joint capsule before and after anterior cruciate ligament transection. *J Orthop Res*. 1996;14(1):114-22.