SOCIEDADE BRASILEIRA DE ORTOPEDIA E TRAUMATOLOGIA

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Original Article

Index of fatigue quadriceps in soccer athletes after anterior cruciate ligament reconstruction☆

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ARTICLE INFO

Article history:
Received 12 March 2015
Accepted 14 December 2015
Available online 17 August 2016

Keywords:
Fatigue
Anterior cruciate ligament
Football

ABSTRACT

Objective: The present study aimed to evaluate the muscle fatigue of the quadriceps muscle in high-performance soccer players undergoing (anterior cruciate ligament) ACL reconstruction.

Methods: We evaluated 17 high-performance soccer players from three professional soccer teams of a state in Brazil from August 2011 to July 2012. All subjects were evaluated between 5.5 and 7 months after ACL reconstruction with a Biodex®isokinetic dynamometer (System 4 Pro) with test protocol CON/CON at 60°/s and 300°/s with 5 and 15 repetitions, respectively. In the calculation of local muscle fatigue, the fatigue index was used, which is calculated by dividing the labor done in the first one-third of the repetitions by that done at the final one-third of the repetitions, and multiplying by 100 to express a unit in percentage (i.e., as a discrete quantitative variable).

Results: All subjects were male, with a mean age of 21.3 ± 4.4 years and mean BMI 23.4 ± 1.53 cm; left dominance was observed in 47% ($n = 8$) of athletes, and right dominance, in 53% ($n = 9$) of athletes; and the limb involved in the lesion was the dominant in 29% ($n = 5$) and the non-dominant in 71% ($n = 12$). Fatigue rates were 19.6% in the involved limb and 29.0% in the non-involved limb.

Conclusion: The results allow us to conclude that there was no significant difference between the limbs involved and not in ACL injuries regarding local muscle fatigue. No association was observed between the dominant side and the limb involved in the ACL injury.

☆ Study conducted at the Orthopedics and Traumatology Service, Hospital Universitário Walter Cantídio (HUWC), Universidade Federal do Ceará (UFC), Fortaleza, CE, Brazil.

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http://dx.doi.org/10.1016/j.rboe.2016.08.009

Índice de fadiga do músculo quadríceps femoral em atletas de futebol após reconstrução do ligamento cruzado anterior

Palavras-chave:
Fadiga
Ligamento cruzado anterior
Futebol

RESUMO

Objetivos: O presente estudo propõe avaliar a fadiga muscular do músculo quadríceps em atletas de futebol de alto rendimento submetidos à ligamentoplastia do ligamento cruzado anterior (LCA).

Métodos: Foram avaliados 17 atletas de futebol com alto rendimento que pertenciam conjuntamente a três times de futebol profissional de um determinado estado brasileiro, de agosto de 2011 a julho de 2012. Todos foram avaliados entre 5,5 e 7 meses de pós-operatório de ligamentoplastia do LCA no dinamômetro isocinético da marca Biodex®(System 4 Pro) com protocolo de teste CON/CON nas velocidades de 60°/s e 300°/s com 5 e 15 repetições, respectivamente. No cálculo da fadiga muscular local, usamos o índice de fadiga que é calculado com a divisão do trabalho feito no terço inicial das repetições pelo terço final das repetições e a multiplicação por 100 para expressar uma unidade em porcentagem (i.e., variável quantitativa discreta).

Resultados: Todos eram do sexo masculino, com média de 21,3 ± 4,4 anos; IMC médio de 23,4 ± 1,53 cm; com dominância à esquerda em 47% (n = 8) dos atletas; e a direita em 53% (n = 9) dos atletas; o membro envolvido na lesão foi o dominante em 29% (n = 5) dos casos e o não dominante em 71% (n = 12). Os índices de fadiga foram de 19,6% no membro envolvido e de 29,0% nos membros não envolvidos.

Conclusão: Os resultados nos permitem concluir que não há diferença significativa entre os membros envolvidos e não envolvidos na lesão de LCA no que diz respeito à fadiga muscular local. Também não foi observada associação entre ser destro ou canhoto com o membro envolvido na lesão de LCA.

Introduction

Rupture of the anterior cruciate ligament (ACL) is a recurring and functionally limiting injury among soccer players. The literature indicates that in European soccer, a high performance athlete will injure the ACL for every 2000 hours of sports practice, that 14% of knee sprains injure this structure, and that every season each club plays 12.8 matches understrength due to ACL rupture.[1] This injury is common in high performance soccer players, who make sudden hyperextension, valgus twist, and excessive knee rotation movements with the foot planted on the ground.[2]

In addition to the large number of individuals exposed to such lesions, injuries resulting from soccer practice and the high risk for their occurrence have been the subject of interest and concern of healthcare professionals. After all, in most cases these injures are incapacitating and prevent the athletes from participating in training and competition for various periods of time, so that the injury can be correctly and consistently treated.[3]

In addition to the known biomechanical functions, anatomical studies have also shown that the ACL has a sensory function, due to the presence of mechanoreceptors.[4] After total or partial ACL rupture, individuals may present joint proprioception deficit,[5] deficiency in perception of change position during passive movement,[6] and contraction reflex of the muscles posterior to the tibia relative to the femur, especially the hamstring group of the affected side.[7] These proprioceptive changes, in turn, inhibit the action of the motor units of the knee extensor muscle group, thus reducing the strength, power, and endurance, leading to a possible loss of performance.[2]

ACL reconstructive surgeries are commonly performed in orthopedic practice. Choosing the best autograft for ACL reconstruction in knees with insufficiency of this ligament has been the subject of debate. Grafts from the central third of the patellar ligament were widely used in the 1980s and 1990s. In the late 1990s, the use of the flexor tendons of the semitendinosus and gracilis increased. So far, there is disagreement in the choice of graft for ACL reconstruction.[8]

The muscle dysfunction observed in patients after ACL reconstruction includes weakness of the quadriceps muscle, promoted by reduction of the overload, as well as joint swelling and pain, which can even persist more than six months after surgery with aggressive rehabilitation. This weakness is due to an incomplete voluntary muscle activation arising from arthrogenic muscular inhibition, which is a reflection of the continuous inhibition of the muscles around the knee when there is damage to this joint; it slows down rehabilitation as it prevents muscle strength gain in the quadriceps femoris and changes proprioception.[9]

Muscle fatigue can be defined as a decrease in muscle performance during physical activity, making the individual unable to maintain the expected strength, power, and/or endurance. This fact is accompanied by changes in muscle

electrical activity, in which there is a decrease in the excitement of motor units and change in the impulse conduction velocity. Although this is an important issue, it is not fully elucidated.[10–12] According to the definition of muscle fatigue and its aspects, it is possible to hypothesize that there is a change of this variable in the quadriceps muscle after ACL rupture.

Two types of muscle fatigue are traditionally described: that resulting from changes in skeletal muscle homeostasis, regardless of the neural impulse conduction velocity and designated by fatigue of peripheral origin; and that resulting from alterations in the neural input that reaches the muscle, translated by a progressive reduction of the conduction velocity and frequency of the voluntary pulse to the motoneurons during the period, usually called fatigue of central origin.[13]

One way to assess the muscle balance between the quadriceps and hamstrings is a test performed in a device called isokinetic dynamometer. The evaluation of muscle strength through an isokinetic dynamometer has been used in the diagnosis of neuromuscular disorders, rehabilitation, training, and research, as an indicator of the function and performance of certain muscle groups.[14]

Studies differ on the muscular fatigue levels in subjects undergoing ligament reconstruction surgery; the idea of testing and assessing the true behavior of the extensor muscles in the muscle fatigue process arose from the fact that the results in the literature are conflicting. Moreover, with the increased incidence of ligament injuries in professional soccer players, the impact of surgery on the performance of these high-performance athletes can be observed directly and clearly; in the future, rehabilitation protocols that enable improved performance and increased resistance to fatigue can be proposed.

The main objectives of rehabilitation after ACL reconstruction are to regain normal joint stability, restore full range of motion, achieve good muscle strength in the injured limb, increase neuromuscular control, resume normal functional activity, and minimize the risk of secondary structural damage to the knee, with the primary objective of achieving post-surgical knee symmetry.[15] Therefore, the rehabilitation protocol should be carefully planned in order to first restore range of motion and then gradually increase endurance and muscle strength.[14]

This study aimed to assess the fatigue index of the quadriceps in high-performance soccer players undergoing ACL reconstruction, using the contralateral limb as a reference.

Methods

This was a cross-sectional study, developed at the Human Motion Analysis Laboratory from August 2011 to July 2012, which was approved by the Research Ethics Committee under protocol No. 230/2011. A free and informed consent form was signed by the participants, who confirmed their voluntary participation in the research.

The study included 17 high-performance soccer players from three professional football teams in a state in Brazil; all those who suffered ACL injury and underwent ligament reconstruction surgery were included. Athletes were referred by the medical departments of the teams for which they played. To participate in the study, athletes were required to present no decompensations of the cardiorespiratory system, such as uncontrolled hypertension, angina, or arrhythmia; in addition, athletes who had acute pain before or during the tests (analog pain scale equal to or above 70/100 mm), untreated injury, or any other factor that would affect their performance on the test were excluded.

A Biodex® isokinetic dynamometer (System 4 Pro) was used to assess quadriceps muscle fatigue. The athletes underwent a light aerobic warm-up session, without stretching exercises, for five minutes before the isokinetic test. The dynamometer chair was positioned so that the hip would be at 85° flexion, and that the motion axis of the equipment was aligned with the lateral intercondylar space. Then, subjects were seated in the dynamometer chair and the position was stabilized with braces placed at the trunk, abdomen, and non-assessed thigh levels, in order to prevent compensatory movements. The lever arm of the equipment was fixed at 2 cm above the medial malleolus. The test always started in the dominant limb. The established isokinetic protocol was that of concentric contractions (CON/CON) with two speeds: 60° and 300°/s, with 5:15 repetitions, respectively, with an interval of 30 seconds of rest. The equipment was calibrated to the range of motion from the maximum flexion to the maximum extension for each participant, in which the reference point was 90° flexion. The limb was weighed by the equipment itself to avoid bias caused by gravity. After the positioning and alignment procedures, individuals were asked to make five movements of flexion and extension at submaximal intensity in order to complete the warm-up process, and to familiarize themselves with the equipment and testing procedures. The upper limbs were fixed laterally to the chair in an appropriate place. Subsequently, the test was initiated, whereupon a verbal command was given by the same examiner during all tests.

To test the hypothesis that fatigue in the quadriceps femoris muscle is more likely to occur in the limb involved in ACL injury muscle than in the non-involved limb, the inferential Student's *t*-test for paired samples was used, as the healthy limb was adopted as control to the injured limb. For analysis and processing of the data, SPSS (version 15.0) was used; a 5% significance level was adopted for all calculations.

In the calculation of local muscle fatigue, the fatigue index was used, which is derived by dividing the work done in the first third of the repetitions by that done in the final third of repetitions, and multiplying that by 100 to express the value as a percentage (i.e., a discrete quantitative variable).[16]

The characteristics of the sample were expressed through descriptive measures such as measures of central tendency (mean) and dispersion (standard deviation). To determine the distribution of the data, the Kolmogorov–Smirnov test was used, which indicated that the data followed a standard normal distribution.

Results

Sample characterization

Data regarding the characteristics of participants in the sample are presented in Table 1.

Table 1 – Sample characterization.

Age (years)	21.3 ± 4.4[a]	
BMI (kg/cm^2)	23.4 ± 1.5[a]	
Sex	100% male	
Dominant side	47% (n = 8) Left	53% (n = 9) Right
Injured limb	29% (n = 5) Dominant	71% (n = 12) Non-dominant

BMI, body mass index.
[a] Values expressed as mean ± standard deviation.

Fatigue index of the non-involved limb

The fatigue index of the quadriceps femoris muscle in the limb not involved with ACL injury is shown in Fig. 1.

Fatigue index of the involved limb

The fatigue index of the quadriceps femoris muscle in the limb involved with ACL injury is shown in Fig. 2.

Fig. 3 presents the mean fatigue index for extension of the limbs involved and not involved in reconstructive surgery.

Discussion

Studies that characterize isokinetic performance are frequent in the sports literature, mainly due to the high prevalence of ligament injuries in high-performance soccer players, which are due in part to the changes in the sport observed in recent years, in which the physical requirements have become higher, pushing these athletes to work close to their performance limit and favoring the occurrence of injuries.

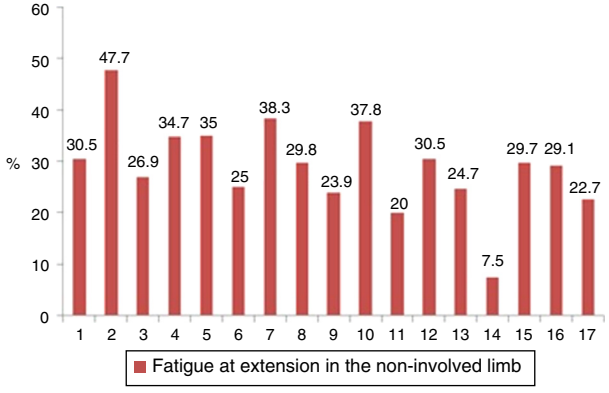

Fig. 1 – Fatigue at extension in the limb not involved in reconstructive surgery.

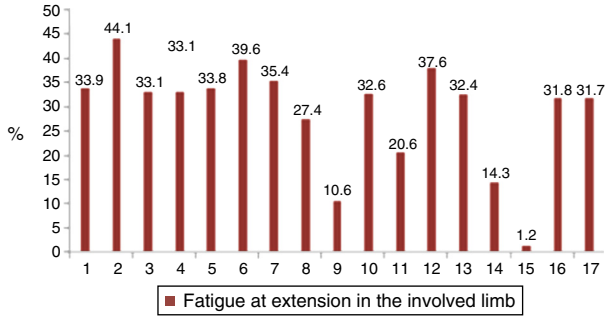

Fig. 2 – Fatigue at extension in the limb involved in reconstructive surgery.

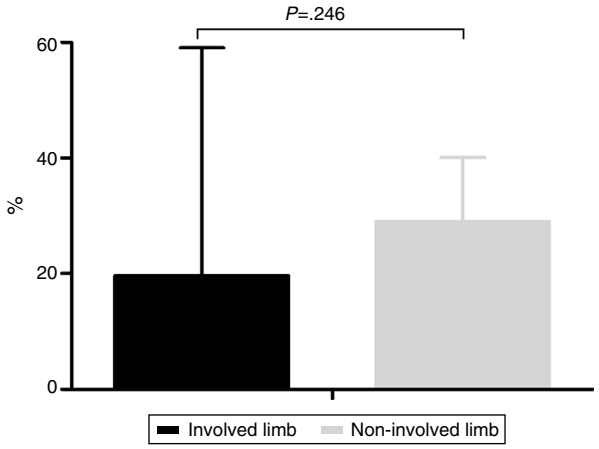

Fig. 3 – Mean fatigue index for extension of the limbs involved and not involved in reconstructive surgery.

Regarding the anthropometric data described in Table 1, the mean age of the patients was 21.33 ± 4.4 years, which corroborates the literature, since ACL lesions occur more often in young individuals who practice some kind of sport, particularly in male patients.[17]

In the present study, it was observed that 71% (n = 12) of the patients had the non-dominant limb involved in the ACL injury, which is justifiable, as rotational trauma is the most frequent mechanism of this injury. In such cases, the body rotates externally on the limb resting on the ground.[18]

The classic mechanism of ACL injury is twisting with the foot fixed standing on the ground; in this mechanism, the tibia moves anteriorly in relation to the femur. Other types of trauma can also cause ACL cruciate injuries, especially during sports practice, but the anterior projection of the tibia relative to the femur is undoubtedly the main cause of ligament injury.[18,19]

It was observed that 47% of the present athletes had the left side as dominant and hence 53% were dominant in the right limb (OR: 0.476, 95% CI: 0.057–3.990), showing that there was no association between right or left dominance with the limb involved in ACL injuries.

In the present study, of the 17 athletes studied, the mean fatigue index in extension of the limb involved in the lesion was 19.6% ± 39.4 and the mean index fatigue in extension observed in the limb not involved with the lesion was 29.0% ± 11.1 ($p = 0.246$). Although the fatigue index was higher in the non-injured limb, there was no significant difference between the limbs involved and not involved in ACL injuries regarding the variable of local muscle fatigue.

According to Oliveira,[20] there are statistically significant differences between the limbs that donate and receive patellar grafts only in extension, peak values of torque, mean power, and resistance to fatigue regarding the quadriceps and the hamstrings. Bonato et al.[21] observed that individuals

with ACL injuries have less resistance to fatigue than healthy subjects, due to the weakness of the quadriceps femoris. However, McNair et al.[22] believe that patients with chronic ACL lesions develop type II muscle fiber hypertrophy as these subjects showed greater resistance to fatigue than healthy individuals.

The onset of fatigue may be related to the increased lactic acid concentration in the extracellular medium of muscle tissue. Theoretically, the increase of lactic acid concentration leads to a decrease in extracellular pH, which is related to the decrease in potential of the conduction velocity of the action potential through muscle fiber.[23]

Anatomical studies of the human knee have demonstrated that nerve fibers penetrate the cruciate ligaments. In an ACL injury, there is loss of proprioceptive information, thereby aggravating the instability of this joint by decreasing the sense of position and the absence of the stimulus for reflex contraction. The remaining knee structures have other sources of proprioceptive information; through specific training of neuromuscular coordination required to stabilize the joint, this response should occur through dynamic control, in order to decrease the response time of muscle reaction.[24]

Muscle fatigue is a frequent phenomenon in training and competition routines of some athletes; it can degrade performance and predispose them to a number of musculoskeletal injuries. This damage can be temporary, lasting for minutes or hours after exercise, or persist for long periods of time, such as several days.[25] The short-term losses result from metabolic disturbances after high intensity exercise.[26] In turn, the long-term damage may be related to tissue injury caused by exercise and the phenomenon known as delayed onset muscle soreness.[27]

Several therapeutic strategies that are widely used in sports to accelerate the process of post-exercise muscle recovery have been studied, such as active recovery, cryotherapy, massage, heat contrast therapy, hydrotherapy, stretching, hyperbaric oxygen therapy, non-steroidal anti-inflammatory drugs, and electrical stimulation.[28]

The main causes for the reduction of proprioceptive reactions are joint injuries, namely the rupture or permanent distension of articular components constituting the ligaments, tendons, and the capsule, which not only results in a mechanical change, but also in loss of positional sense, due to a dysfunction in the peripheral mechanoreceptors. The development or restoration of proprioception, kinesthesia, and neuromuscular control of the injured individual minimizes the risk of injury recurrence and restores the kinesthetic awareness.[24,29,30]

Conclusion

The results allow for the conclusion that there is no significant difference between the involved or uninvolved limbs in ACL injuries regarding local muscle fatigue. No association was observed between the dominant side and the limb involved in the ACL injury.

Longitudinal studies evaluating various isokinetic parameters are still scarce in the literature; therefore, new studies are recommended for the analysis of these parameters. These studies should include a larger number of individuals, include other sports, and involve both genders.

Conflicts of interest

The authors declare no conflicts of interest.

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