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ORIGINAL ARTICLE • KNEE - SPORT

A comparative study of the neuromuscular response during a dynamic activity after anterior cruciate ligament reconstruction

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Abstract

Background Injury to the anterior cruciate ligament (ACL) not only causes mechanical instability but also produces proprioceptive deficit with an altered neuromuscular response. After ACL reconstruction, patients in general continue to complain of a feeling of knee instability. The objective of our study was to assess patient proprioception and its evolution over time by measuring the muscle latency time during a dynamic activity.

Methods Twenty-five patients with an ACL tear following sports injuries were included in a prospective, comparative, matched controlled study. The study group consisted of the injured knees in those patients, while the control group consisted of the contralateral non-injured knee in the same patients. The neuromuscular response in five leg muscles (vastus medialis, vastus lateralis, rectus femoris, semitendinosus and biceps femoris) was measured during a dynamic activity through the muscle latency time via the use of electromyography.

Results The comparison of the reaction time in the vastus medialis showed that time in the injured knee was longer at pre-op, but it reduced over time reaching a value at 6 months post-op that was close to the reaction time in the non-injured knee group. In the rectus femoris, biceps femoris and semitendinosus muscles, the reaction times in the injured knee group were similar to those in the non-injured knee group at pre-op and post-op visits.

Conclusion Before ACL surgery, the muscle latency time of the vastus medialis was significantly longer in the injured knee group than in the non-injured knee group. 'Muscle reflex reaction' as a response during a dynamic task improved in the ACL reconstructed patients at 6 months post-op.

Level of evidence Prospective, comparative, matched controlled study.

Keywords Anterior cruciate ligament · Latency · Proprioception · Matched controlled study · Electromyography

Introduction

Active adult patients commonly present with lower extremity injuries related to different sports activities which affect their anterior cruciate ligament (ACL). Anterior cruciate ligament reconstruction is known to restore joint stability. A knee with an ACL graft that is capable of providing mechanical support cannot directly activate the muscular agonist to provide dynamic support or play a role in pre-programming the activation of the muscles to avoid re-injuries [1, 2].

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Proprioception is receptor and neural arc mediated. The stimulation of mechanoreceptors in the ligaments of the knee initiates several types of muscle reflex contractions through the neural arc involving the dorsal root ganglion sensory neurons [3]. Mechanoreceptors may not be present after ACL tear [4] and loss of feedback from mechanoreceptors and abnormalities in gamma loop information may explain muscular alterations.

The re-establishment of neuromuscular control of the lower extremity is one of the keys to restoring dynamic joint stability and functional movement patterns [5–7]. Therefore, improvement of the neuromuscular control of the knee following ACL injury or reconstruction should enable better outcomes in terms of functional activities and reduce the re-injury rate [8].

While the majority of studies assessing knee proprioception have been performed through static tasks, investigations using dynamic activities may provide more information to help treat ACL pathologies.

The objective of our study was to assess the proprioceptive deficit in patients after ACL reconstruction through the measurement of electromyography signals during dynamic knee contraction. The study hypothesis was that the differences in the muscle latency time between the injured knee and the non-injured knee groups would reduce over time.

Methods

Patients demographic

Twenty-five patients with an ACL tear following sports injuries were recruited into this prospective, comparative, matched study between 2010 and 2012. The study group consisted of the injured knee (the injured knee group), while the control group consisted of the contralateral non-injured knee (the non-injured knee group) in the same patients.

The diagnosis of a complete ACL tear was based on clinical symptoms, on positive Lachman's and pivot shift tests, and was confirmed by magnetic resonance imaging.

Mean patient age was 22 ± 4.61 years, mean mass was 71.18 ± 10.57 kg, and mean height was 177.55 ± 9.69 cm. Eighteen patients were male (72%).

All patients participated in sports. Male patients played basketball (11 cases), handball (6 cases) and football (1 case). Female patients played basketball (4 cases), handball (1 case), taekwondo (1 case) and rugby (1 case).

All individuals participated in more than 200 h of sports activity per year, including jumping, pivoting and twisting actions. Patient exclusion criteria were metabolic and neuromuscular disorders, previous injuries and surgeries in the knee, and cartilage lesions grade 3 or higher.

Ethics approval

The study was approved by the University Institutional Review Board. All subjects signed an informed consent agreement prior to their participation.

Surgical and rehabilitation information

Arthroscopic surgery was performed to reconstruct the ACL on all patients by the same surgeon (the senior author OG). A 9-mm-wide autologous bone-tendon-bone graft was harvested. Bioresorbable screws were used for the graft attachment.

To reduce bias, the patients were operated at a window range of 2–3 months after the injury following a rehabilitation protocol that aimed to achieve a normal gait pattern, regain a full range of motion and eliminate inflammation symptoms. After surgery, an accelerated rehabilitation program was performed: the patients were allowed to walk with crutches immediately after surgery and were permitted to bend the knee to 90°.

Data collection

The patients were assessed using the International Knee Documentation Committee (IKDC) score form, the Lysholm scoring system and the 12-Item Short Form Health Survey (SF-12) pre-operatively, at 4 months and at 6 months post-operation.

Muscle reflex contraction was measured using electromyography (EMG) in five muscles: vastus medialis, vastus lateralis, rectus femoris, semitendinosus and biceps femoris.

Measurement set-up

A motion analysis system (ELITE, BTS, Italy) was used to synchronize the EMG signals. Signals were collected by bipolar surface electrodes (Ag-ClAg, Blue Sensor N-00-S. Medicotest) and registered with a telemetric system (TELEMYO 16). Raw signals were amplified and band-pass-filtered in a working frequency of 1000 Hz (Noraxon USA, Inc, USA).

In accordance with the technique described by Cram and Hermens [9, 10], electrodes were placed with a 2-cm spacing. The normalized activity of each muscle was measured after a maximum voluntary contraction (MVC) over a period of 5 s and repeated 3 times in a prone vs supine position of the body, depending on a flexion or extension function of the lower extremity [11]. Normalization was performed by setting the root mean square (RMS) amplitude at a percentage related to the MVC.

Nine body surface markers were attached to the skin of the subject limb with adhesive tape (Fig. 1). Four optical cameras captured images at a frequency of 100 Hz. Marker locations were as follows: greater trochanter, lateral condyle, lateral malleoli, fifth metatarsal patella, anterior tibial tuberosity, medial femoral condyle and medial joint line of the knee.

Assessment was performed in a biomechanical laboratory. Each subject warmed up by jogging for 5 min; then, the reflective markers and electrodes were placed.

Patients performed a single leg jump from a 25-cm tall box, with their hands on their hips and without gaining momentum. The subjects repeated this task five times with each leg (injured/non-injured); the mean values per each patient, leg, and muscle were considered in the analysis.

The knee was analyzed when landing on a single leg, a dynamic activity that produced a peak muscle force [12]. The beginning of the landing phase was defined as the touchdown recorded with the optical cameras. The latency time

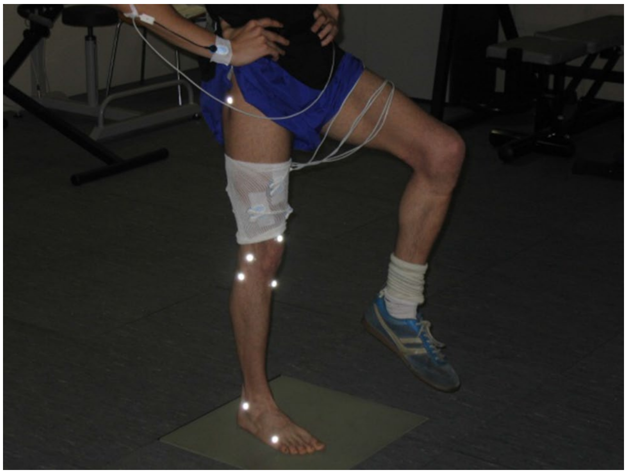

Fig. 1 Subject with reflective markers and surface electrodes starting an experimental session obtaining static references placement

of each muscle was defined as the time from touchdown to peak amplitude of EMG activity (RMS) in each muscle [13]. RMS was normalized at the maximum activity of the muscles as defined above. In addition, the static position of the limb and its dynamic motion at 25° of flexion were recorded in order to calculate kinematic values of tibiofemoral translation and rotation [12, 14].

Statistical analysis

Parametric or nonparametric tests were chosen on the basis of the data distribution. Specifically, the Spearman's rank correlation coefficient was used to assess the correlation between variables. Furthermore, the Wilcoxon signed-rank test and Friedman test were used to evaluate the changes in the other clinical scores and in the muscle latency time over time.

Latency time between the two groups (injured knee vs. non-injured knee) and over time was compared using a repeated measures mixed effect model, which accounts for the correlation of the repeated measures of the patient over time: latency time = study group $*$ time + (1|patient) ("*" indicates that the 2 predictors and their interaction are taken into account in the model; the interaction term takes into account that the simultaneous influence of the two variables on the response might not be additive). The response (i.e., the latency time) followed a gamma distribution.

A p value of <0.05 was considered to indicate statistical significance.

Statistical analysis was performed using SPSS (IBM SPSS Statistics, v. 15, Illinois, Chicago, USA), with the exception of the gamma mixed effect model that was performed using R version 3.3.1.

Table 1 Model estimates for response time in terms of study group, visit and interaction-visit effect for each muscle

	Estimate	95% CI	*p* Value
MODEL A: vastus medialis			
Group (ref injured)	0.24	0.02; 0.46	0.0322
4 month (ref pre-intervention)	−0.14	−0.36; 0.08	0.2162
6 month (ref pre-intervention)	−0.05	−0.28; 0.17	0.6497
Group × 4 month	−0.09	−0.4; 0.23	0.5878
Group × 6 month	−0.37	−0.69; 0.06	0.0209
MODEL B: vastus lateralis			
Group (ref injured)	0.13	0; 0.25	0.0452
4 month (ref pre-intervention)	−0.12	−0.28; 0.03	0.107
6 month (ref pre-intervention)	−0.13	−0.28; 0.03	0.1014
MODEL C: rectus femoris			
Group (ref injured)	−0.07	−0.19; 0.05	0.2417
4 month (ref pre-intervention)	−0.29	−0.44; −0.15	< 0.0001
6 month (ref pre-intervention)	−0.34	−0.49; -0.19	< 0.0001
MODEL D: biceps femoris			
Group (ref injured)	−0.06	−0.22; 0.1	0.451
4 month (ref pre-intervention)	−0.49	−0.69; −0.3	< 0.0001
6 month (ref pre-intervention)	−0.69	−0.88; −0.5	< 0.0001
MODEL E: semitendinosus			
Group (ref injured)	0.13	−0.04; 0.29	0.1250
4 month (ref pre-intervention)	−0.58	−0.78; −0.37	< 0.0001
6 month (ref pre-intervention)	−0.6	−0.81; −0.4	< 0.0001

Model A shows a significant difference between groups (injured–non-injured) in muscle response time (delay in injured). *p* value 0.0322. The trend shows a symmetry in latency over time. *p* value 0.0209. Model B shows a significant difference between groups in muscle response time (delay in injured). *p* value 0.0452. Model C, D and E present an improvement in muscle reaction time over the follow-up in both groups

Ref: stands for reference; 95% CI: 95% confidence interval

Results

Two patients were lost to follow-up due to personal issues and could not complete the study. All remaining 23 patients concluded the study.

This study compares the changes in latency time for the 6 months after ACL repair in both groups for the 5 muscles (Table 1). For the vastus medialis, model A shows that the reaction time in the injured knee group initially was longer than in the non-injured knee group. The reaction time in the non-injured knee group tended to remain the same over time. However, the significant interaction term indicates that the reaction time reduced more over time in the injured knee group than in the non-injured knee group. The reaction times were similar at the 6 month visit (Fig. 2a).

For the vastus lateralis, model B shows that the initial reaction time in the injured knee group was, on average,

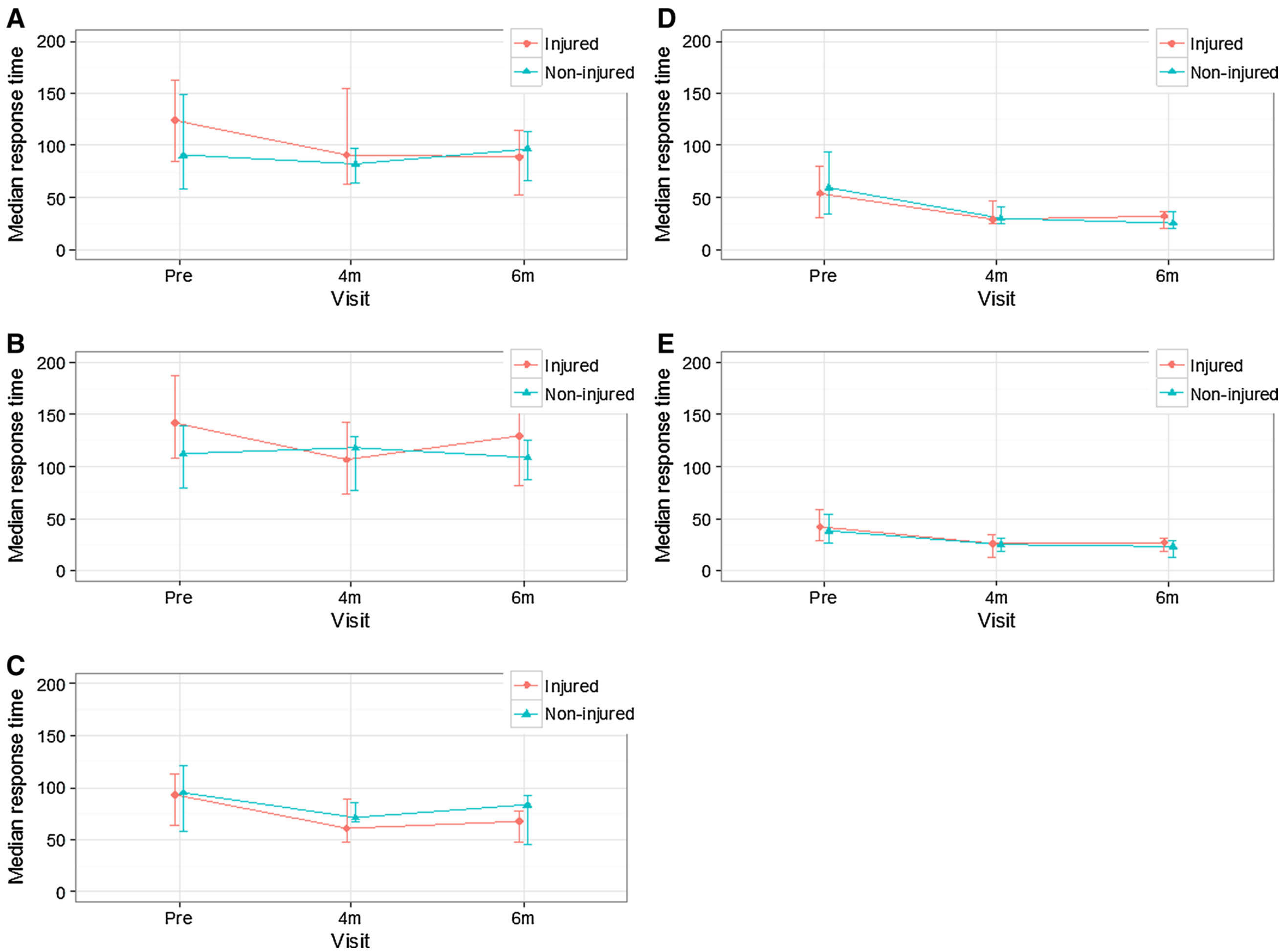

Fig. 2 Interaction between study groups (injured knee group vs non-injured knee group) and visit on the reaction time (response time) in vastus medialis (**a**), vastus lateralis (**b**), rectus femoris (**c**), biceps femoris (**d**) and semitendinosus (**e**)

slightly longer (130 ms) ($p=0.0452$). Over time, both groups tended to stay in baseline times (Fig. 2b).

For the rectus femoris, model C shows that injured and non-injured knee groups had the same reaction time on average. Over time, both muscles tended to reduce reaction time, decreasing by 25 ms at 4 months from pre-intervention visit, and decreasing by 29 ms at 6 months from pre-intervention visit. Interaction term was not statistically significant (Fig. 2c).

For the biceps femoris, model D, and semitendinosus, model E, results show that injured and non-injured knee groups had the same reaction time on average. Over time, both muscles tended to reduce reaction time. Interaction term was not statistically significant (Fig. 2d, e).

SF-12 scores and Lysholm scale scores show a significant improvement (Table 2). There was a significant correlation between SF-12 physical score and Lysholm scale score at 6 months (Table 3).

Discussion

In the study, we measured a decrease in the muscle latency time over time in the injured knee in the vastus medialis, rectus femoris, biceps femoris and semitendinosus, while no significant changes over time were observed in the vastus lateralis. Specifically, the vastus medialis was the most affected muscle before ACL reconstruction in terms of latency time increase; after ACL reconstruction, the latency time decreased and reached the levels of the latency time in the contralateral muscle. In contrast, rectus femoris, biceps femoris and semitendinosus muscles, although responding to the injury with a delayed response pre-operatively, changed to better neuromuscular function after surgery. However, at 6 months post-surgery, there was no significant difference when comparing both injured and non-injured knee groups.

Table 2 SF12 questionnaire and Lysholm scale scores

Score	At pre-op	At 4 months	At 6 months	p Value[W] (4 months vs. pre-op)	p Value[W] (6 months vs. 4 months)	p Value[W] (6 months vs. pre-op)	p Value[F]
SF-12 mental	60.11 ± 6.78	–	60.49 ± 3.10	–		0.557	0.221
SF-12 physical	44.84 ± 8.23	–	54.45 ± 4.02	–		0.000	0.003
Lysholm	66.8 ± 11.68	88.4 ± 10.05	92.2 ± 11.16	0.000	0.026		0.000

Tests: W indicates the use of Wilcoxon signed-rank test, while F, the Friedman test

Muscles: VM (vastus medialis), VL (vastus lateralis), RF (rectus femoris), BF (biceps femoris), ST (semitendinosus)

Table 3 Correlation between SF12 questionnaire and Lysholm scale (Test Rho de Spearman)

	Lysholm at pre-op	Lysholm at 6 months
PCS-12 at pre-op	0.293 (p = 0.165)	0.652 (0.001)
MCS-12 at pre-op	−0.231 (p = 0.277)	−0.277 (0.200)

PCS-12 showed significant correlation with Lysholm score at 6 months

These results are in alignment with other authors who investigated bilateral proprioceptive alterations in ACL pathology. Thus, one could state that the agonist muscles to the ACL develop synergies in a cross-connection fashion controlled by supraspinal neurological central function [15–17].

Recent studies looking at changes in quadriceps function following ACL injury have reached some conclusions. Grindem et al. [18] found that more symmetric quadriceps strength prior to return to activity substantially reduce the re-injury rate. Kuenze et al. [19] thought that measuring the magnitude of asymmetry after ACL repair represents an important step in understanding long-term reductions in self-reported function and increased rate of subsequent joint injury in active individuals with ACL repair. In our study, the vastus medialis reactivity shows an asymmetry on individuals with ACL deficit; however, the muscle latency improved by 6 months post-operatively to match that of the contralateral knee.

The findings in our study appear to be in agreement with those documented by Beard et al. [13], who considered the reflex hamstring contraction latency to be a measure of proprioception, and with those of other authors who confirmed that reflex latency can be used as a measurement of active muscle reaction to evaluate neuromuscular response patterns [20, 21].

In our study, we also assessed knee function through the Lysholm scale. The results were comparable to those of other studies on reconstructed ACL patients. We documented a significant correlation between the Lysholm scale and the SF-12 physical component score at 6 months post-surgery.

One limitation of the study is the small number of patients. However, it should be considered that in studies with dynamic activities, there is a risk of re-injury of the ACL; therefore, such studies typically include small numbers of patients. Another limitation is the use of a technique with surface electrodes, as surface electrodes can increase the impedance, and attachment to the skin can cause difficulties in signal collection. A further observation would be the harvesting of an autograft that is widely accepted in the reconstruction of the ACL could influence the muscle function. However, the study is divided into three phases where the preoperatory (before harvesting) showed a delayed latency on vastus medialis and lateralis which would support the neuromuscular alteration in ACL injury. Once ACLR is performed, the trend shows a symmetric muscle response between the groups (injured–non-injured) over time.

Our study was performed by using electromyography, while the two most common techniques to measure proprioception are the threshold to detect passive motion and joint position system [11]. These techniques have been used in many studies, although predominantly in passive tasks in which muscles could not be evaluated as a part of proprioceptive response [15, 22]. We deem that electromyography is a good, non-invasive technique to assess muscle activation also during a dynamic activity.

Our study is significant because, in the last decade, only a few investigations have assessed the neuromuscular response during a dynamic activity prior to and after ACL reconstruction, and very few investigations were randomized controlled trials. For example, Risberg et al. [7] studied the influence of rehabilitation programs on knee function: the significant differences in results between the rehabilitation programs seemed to appear between 3 and 6 months after surgery rather than immediately after surgery [7].

On the basis of assessing the state of muscle function on widely accepted terms of time to return to sport or high daily activity for 6 months after surgery, studies like ours that focus on the objective measurement of the change of the muscle latency time over time may allow patients to return to full activity and to sports earlier than the standard time of 6–12 months.

Conclusion

Neuromuscular activity during a dynamic activity provided a better method of analyzing the muscles' response when ACL injury occurs. We observed a significant delayed latency of the vastus medialis. ACL repair was accompanied by an improvement in muscle reaction time and clinical scores. Biceps femoris and semitendinosus showed better neuromuscular function after surgery, with no significant difference when comparing both knees.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no competing interests.

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