ORIGINAL ARTICLE

Neuromuscular Functional Changes of the Quadriceps after Anterior Cruciate Ligament Reconstruction

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ABSTRACT

Objective: *To determine the factors related to quadriceps weakness, to evaluate electromyographic changes in the quadriceps and to attempt to determine the neuromuscular restoration period after anterior cruciate ligament (ACL) repair.*

Methods: *A total of 30 patients (28 males and 2 females) who underwent surgery conducted by two surgeons were reviewed prospectively. All ACLs were reconstructed arthroscopically with anterior tibial tendon allograft, using an anteromedial portal. The patients' quadriceps muscles' neuromuscular activity was determined with electromyography at early and late periods (1–3 months and 6–12 months, respectively).*

Results: *A significant difference was observed (*$p < 0.01$*) in the quadriceps circumference between the operated extremities (average, 48.4 cm) and the healthy limbs (average, 50.6 cm), according to measurements obtained on the sixth month after surgery. The tourniquet time was greater than 50 minutes in patients with quadriceps atrophy. A significant elongation was observed in the* motor unit potential *duration of the operated ipsilateral side, compared to the contralateral side (*$p < 0.001$*) at the early-term period. Differences were observed between the ipsilateral MUP amplitude and the durations of early- and late-term patients, but were not significant.*

Conclusion: *Our study demonstrated that atrophies are significantly overcome in the first year after surgery. The electromyographic examinations indicated that tourniquet use not only caused functional harm in the quadriceps muscle but it also caused structural damage. However, these structural injuries did not result in negative effects on the clinical success.*

Keywords: Anterior cruciate ligament, electromyography, neuromuscular function, pneumotic tourniquet, quadriceps atrophy.

INTRODUCTION

Anterior cruciate ligament (ACL) rupture is one of the most common knee injuries (1, 2). Although conservative treatment may potentially be successful in the appropriate population, patients whose goals are to return to advanced sport activity may not be successfully treated with conservative approaches (3). The goal of ACL reconstruction (ACLR) is to restore intact knee stability and normal knee kinematics (4), notwithstanding the different types of reconstruction that have been reported previously by several authors (1, 5–11). The use of a tourniquet has been recommended to increase the operative success of bloodless surgery without complications, although its use has effects on quadriceps inhibition (6–11).

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The quadriceps strength is related to the success of ACLR and to early recovery with full function and without any limitations (12, 13). A quadriceps strength deficit has been well recognized as related to the ACL injury and is increased by ACLR (14, 15). Additionally, the mechanism of quadriceps weakness may be explained by preoperative, intraoperative and post-operative deficits. There is no consensus regarding the recovery of quadriceps strength and the factors that affect this period. We aimed to determine the factors related to these mechanisms to evaluate the electromyographic (EMG) changes in the quadriceps and to attempt to determine the neuromuscular restoration period after ACLR.

MATERIALS AND METHODS

We reviewed prospectively 30 patients (28 males and 2 females) with a mean age of 25 years (range, 17–38 years) who underwent surgery conducted by two surgeons. Patients with multiple ligament injuries or multiple traumas were excluded from the study because of the lack of compliance with standard physical therapy. Patients whose hamstring tendon or patellar tendon was used for ACLR were also excluded. Anterior cruciate ligament deficiency was diagnosed by a clinical examination that was supported by radiological views on standard knee X-rays and knee magnetic resonance imaging.

Quadriceps strength and knee range of motion (ROM) were evaluated at the first examination. Range of motion and isometric quadriceps exercises were initiated immediately. Surgery was delayed until full ROM and strong quadriceps strength were obtained.

All ACLs were reconstructed arthroscopically using anterior tibial tendon allograft via an anteromedial portal. Anatomical single-bundle ACLR was performed in all patients using the ZipLoop Extended ToggleLoc system (Biomet Sport Medicine, IN, USA). Any additional surgical procedures for meniscal tears by partial meniscectomy or meniscal repair were all performed using closed (arthroscopic) techniques. The same anaesthetic technique of spinal anaesthesia was used in patients with ACL deficiency. The surgery was initiated after a pneumatic tourniquet was applied to the thigh. The tourniquet time was recorded.

Post-operative physical therapy was instituted on the second day after surgery. A muscle strength programme was initiated. Ambulation with a brace and crutches was permitted within the first 3 weeks. We examined all patients in the outpatient clinic every week. The rehabilitation programme was implemented together with the physiotherapist. All patients ambulated without a brace and were engaged in daily activities within 6 weeks. A return to sports activities was allowed after 6 months.

The patients' quadriceps muscles' neuromuscular activity was determined using EMG performed at an early- and late-term period (1–3 months and 6–12 months, respectively). The EMG needle was inserted into the vastus lateralis from the upper edge of the patella and advanced proximaly up to 8–10 cm at the anterolateral femur. The vastus lateralis spontaneous activity and voluntary and maximal muscle contractions were assessed according to needle EMG, after determining muscle localization with the leg in extension (16). Nihon Kohden needle EMG equipment was used to analyse the quadriceps EMG activities. Equipment adjustments were conducted as shown in the Table (16). The amplitude and duration measures of MUP (total action potential from the muscle fibres belonging to a motor unit) were obtained. The ipsilateral and contralateral vastus lateralis EMG tracings of the patients were divided into two groups, specifically post-operative early term (1–3 months) and late term (6–12 months), and their qualitative visual analysis was conducted blindly.

Table: Values used for analysing quadriceps muscle activity as measured using an EMG device

Setting	Resting	Voluntary contraction	Maximal contraction
Sweep speed (ms/div)	10	10	100
Sensitivity (μV)	100	500–1000	1000
Filter			
High Hz (kHz)	10	10	10
Low Hz (kHz)	2–20	2–20	2–20

Quadriceps atrophy was determined as the measurement of thigh circumference, 8–10 cm above the upper edge of the patella. In clinic after surgery, the patients underwent Lysholm orthopaedic knee scoring analysis. SPSS v.20.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. The paired *t*-test and one-way analysis of variance were used for numerical value comparisons for both groups. p values of less than 0.01 were considered significant.

RESULTS

The average tourniquet time during surgery for the patients who participated in the study was 59.75 ± 12.33 minutes (range, 35–100 minutes). Of the seven ACLR patients who underwent meniscal repair, five underwent meniscectomy.

A significant difference was observed ($p < 0.01$) between the operated extremities (mean, 48.4 cm) and the healthy limbs (mean, 50.6 cm) in the quadriceps circumferential measurements conducted on the 6th month post-operatively. Muscle strength was determined as 5/5 in all patients and knee ROM was analysed thoroughly during muscle strength examination.

Quadriceps atrophy of 0.5–2.5 cm was detected in 18 of 30 patients. Tourniquet time was longer than 50 minutes in patients with quadriceps atrophy; however, there was no statistical significance between those patients without atrophy and those with atrophy ($p = 0.250$).

The statistical analysis demonstrated a significant elongation in the MUP duration for the early operated (ipsilateral) period compared to the contralateral side ($p < 0.001$, standard deviation [SD] 10.1 ± 12.3). The amplitude values obtained from the ipsilateral muscles were observed to be smaller than the contralateral values, whereas no significant difference between the amplitude values was observed (Figs 1 and 2).

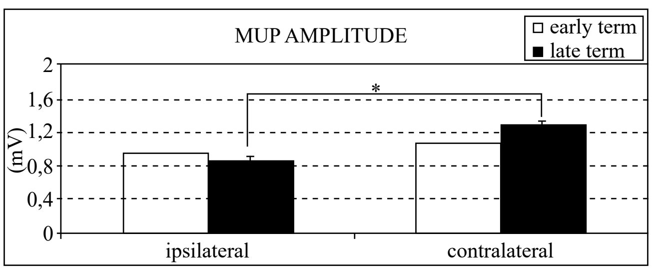

Fig. 1: Schematic of MUP amplitude obtained in the post-operative late-term period (operated side and its contralateral) ($p < 0.01$, SD 0.42 ± 0.18).

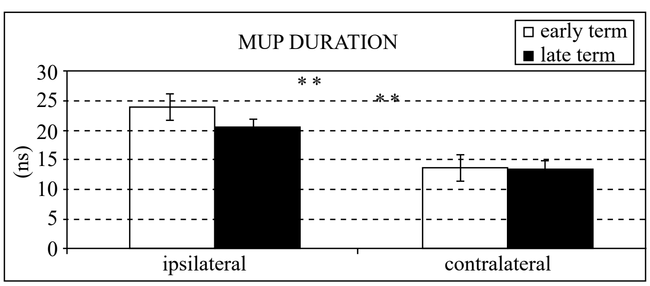

Fig. 2: Schematic of MUP durations obtained post-operatively in the early- and late-term periods (operated side and its contralateral) (duration of early term $p < 0.001$ and SD 10.1± 12.3) (late term $p < 0.001$ and SD 7.2 ± 8.7)

At the 6-month evaluation, we observed that femoral atrophy persisted in 15 patients (0.3–1.2 cm). At the 1-year evaluation, femoral atrophy was present in eight patients, although it decreased (0.2–0.5 cm). No significant difference was observed between the early period (6–12 weeks) and the mid-term point (6th month) in the analysis of femoral atrophy, whereas a significant difference was observed between the early- and late-term (1-year) periods ($p < 0.001$). According to the EMG measurements, the values for the ipsilateral amplitude and the duration were low, which were significant compared to the contralateral side in the late-term group of patients ($p < 0.01$, $p < 0.001$; SDs 0.42 ± 0.18, 7.2 ± 8.7, respectively). However, a notable difference was observed between the ipsilateral MUP amplitudes and durations of early- and late-term patients, although these differences were not significant.

The average Lysholm orthopaedic knee score was 83.5 ± 6091 at the early-term and 91.6 ± 4.172 at the late-term evaluations. Regarding improvement, the difference in knee scoring was significant between the early- and late-term periods ($p < 0.001$).

DISCUSSION

The goals of ACL surgical treatment are to regain normal joint movement, to restore full knee function and to prevent joint arthrosis as a result of secondary injury (5). Surgical technics and rehabilitation programmes conducted post-operatively are among the predictive factors regarding the restoration of normal knee function (5, 17, 18).

After ACLR, atrophy may occur in the femoral muscles (12, 15). After atrophy develops, permanent weakness may occur in the extensor mechanisms, hindering the return to sport and rehabilitation (12, 19). It is believed that one of the main reasons for persistent weakness may be peripheral muscle changes (12, 15, 19). It was reported that the use of pneumatic tourniquets may cause muscle necrosis based on perfusion injury, and that this process is time dependent (20–22). The average tourniquet time of 59.75 minutes in our study was not long enough for necrosis to occur. No significant difference was detected between muscle atrophy and tourniquet time. However, in patients with longer tourniquet times, muscle atrophy was on average 12 mm greater. Remission of post-operative muscle atrophy, with the aid of muscle activity in the late-term period, signifies that immobilization in the early post-operative term effectively leads to muscle atrophy. The data obtained in our study signify that atrophies are overcome significantly in the first year after surgery.

Muscle cell volume shrinks after atrophy. As a result of the effort used in contraction, the cells within muscle tissues are stimulated not only by their own nerve fibres, but also by collaterals supplied through the nerve fibres of neighbouring cells for increasing the power of the contraction (23). This is designated in EMG studies as the polyphasic shape of the MUP, which should be biphasic or triphasic and elongated with regard to duration. Decreases in muscle volume are distinguished by a decrease in MUP amplitude (16). As deduced from the data analysed obtained from the EMG examination, the polyphasic patterns that were observed in the early post-operative term, with values approaching normal in the late term of extended MUP duration, may be explained by the effect of tourniquet usage in the early term and by the inability to sufficiently exercise due to pain (14, 19). Our data are in parallel with those collected by Krishnan and Williams (12) and Roewer *et al* (13). We identified that EMG fluctuations observed in the early term, in parallel with the increase in muscle volume through the increase in exercise, continued to stabilize towards recovery and approached normal values. The Lysholm knee scores increased significantly in the late term together with the increase in quadriceps volume and power.

Although the data approaching normal values that were obtained from the final post-operative late-term EMG examination may be explained together with the regaining of muscle volume, the occurrence of significant differences indicates that structured fluctuations within the muscle may not be adequately healed within a year. Although change occurring in the muscle is explained by considering tourniquet use during surgery, it was not significantly correlated with the duration of use ($p = 0.250$). Roewer *et al* alternatively surmised that healing occurs within 2 years and that it is correlated more with the duration and adjustment of physical therapy than with structural fluctuations (13).

During ACLR, a tourniquet is used to prevent bleeding and typically to increase the likelihood of operative success. However, EMG examinations indicate that the tourniquet causes not only functional harm to the quadriceps muscle but also causes structural damage. However, such structural damage does not result in negative effects on the clinical success.

Level of evidence: IV

AUTHORS' NOTE

The authors declare that they have no conflict of interest.

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