Arthrogenic quadriceps inhibition and rehabilitation of patients with extensive traumatic knee injuries

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(Received 28 January/17 September 1993; accepted 19 October 1993)

1. The relationship between joint damage, quadriceps weakness and arthrogenic muscle inhibition was investigated in eight patients who had sustained extensive traumatic knee injury. Isometric and isokinetic quadriceps and hamstring voluntary strength, and quadriceps arthrogenic muscle inhibition during isometric contractions, were measured before and after 4 weeks (approximately 100 h) of intensive rehabilitation.

2. Compared with the uninjured leg, before rehabilitation the injured leg had larger amounts of quadriceps arthrogenic muscle inhibition \( P < 0.025 \), quadriceps \( P < 0.0001 \) and hamstring \( P < 0.0001 \) weakness and severe functional joint instability. There was a negative correlation between the amount of arthrogenic muscle inhibition and quadriceps voluntary contraction force \( P < 0.025 \).

3. After rehabilitation in the injured leg there were small hamstring strength increases \( P < 0.05 - 0.025 \), but no overall significant quadriceps strength increase. Arthrogenic muscle inhibition was statistically unchanged. Severe functional joint instability was still reported by all patients.

4. Previous studies have shown that minimal joint damage evokes relatively less arthrogenic muscle inhibition that does not impede rehabilitation. These data indicate that greater joint damage is associated with greater arthrogenic muscle inhibition, quadriceps weakness and joint instability. Furthermore, intensive rehabilitation had little effect on either quadriceps arthrogenic muscle inhibition or atrophy.

INTRODUCTION

Knee joint pathology that causes painless effusions can prevent full voluntary activation of the quadriceps muscles acting across the joint [1–4]. This phenomenon has been called arthrogenic muscle inhibition (AMI) [2, 3]. It has been suggested that AMI contributes to the muscle atrophy that occurs with joint pathology [3], and may impede restoration of muscle strength, thus hindering effective rehabilitation.

We have demonstrated quadriceps AMI in the absence of pain or effusion in osteoarthritic knees [5] and traumatically damaged joints, i.e. sub-acute anterior cruciate ligament (ACL) ruptures [6], where the amount of AMI appeared to be related to the degree of joint damage sustained.

Previously, to investigate the effect of rehabilitation on inhibited muscles, we studied a group of patients with isolated ACL ruptures [7]. The initial amount of quadriceps AMI was small, reflecting the isolated ligament rupture, and was unchanged after rehabilitation, although quadriceps strength increased significantly. Therefore small amounts of quadriceps AMI do not prevent a quadriceps strength increase [7].

However, ruptures of the ACL are more commonly accompanied by damage to other joint structures [8], which appears to be associated with larger amount of AMI [6]. Therefore, rehabilitation of patients with extensive joint damage may be more adversely affected by the larger amounts of AMI.

We have investigated the relationship between isometric and isokinetic quadriceps and hamstring strength and quadriceps AMI, in patients with ACL rupture and associated joint damage, before and after a period of intensive rehabilitation.

METHODS

Patients

Eight male patients were investigated (mean age 26 years, range 22–37 years). Their mean height and body mass were 180 cm (range 173–193 cm) and 81 kg (range 70–96 kg), respectively.

Joint damage reported at arthroscopy, time from injury to entry into the study, quadriceps AMI in the injured and uninjured legs and strength in the injured leg are detailed in Table 1. All the patients complained of severe quadriceps muscle weakness, disabling joint instability and functional limitation.

Key words: arthrogenic muscle inhibition, articular afferents, functional joint stability, muscle strength, rehabilitation.

Abbreviations: ACL, anterior cruciate ligament; AMI, arthrogenic muscle inhibition; EMVC, estimated maximum voluntary contraction; MMVC, measured maximum voluntary contraction; MVC, maximum voluntary contraction.

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Table 1. Joint injuries sustained by each patient, time from injury to entry into the study, amount of AMI before and after rehabilitation and change in the injured and uninjured legs, and measured quadriceps strength (MMVC) before and after rehabilitation and percentage change in the injured leg

<table>
<thead>
<tr>
<th>Patient no.</th>
<th>Mechanical joint damage associated with ACL rupture</th>
<th>Time since injury (months)</th>
<th>Quadriceps strength (MMVC) of injured leg (N)</th>
<th>Inhibition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>1</td>
<td>Partial medial meniscectomy; anterior knee pain</td>
<td>8</td>
<td>314</td>
<td>385</td>
</tr>
<tr>
<td>2</td>
<td>Comminuted fracture of the tibial plateau</td>
<td>8</td>
<td>139</td>
<td>171</td>
</tr>
<tr>
<td>3</td>
<td>Fractured femoral condyle; total medial and partial lateral meniscectomy; ruptured medial and lateral collateral ligaments</td>
<td>6</td>
<td>205</td>
<td>311</td>
</tr>
<tr>
<td>4</td>
<td>Partial lateral meniscectomy; dislocating patellar; synovectomy</td>
<td>60</td>
<td>366</td>
<td>384</td>
</tr>
<tr>
<td>5</td>
<td>Degeneration of femoral condyle; medial meniscectomy; ruptured posterior cruciate ligament</td>
<td>34</td>
<td>396</td>
<td>398</td>
</tr>
<tr>
<td>6</td>
<td>Medial meniscectomy; ruptured medial collateral and posterior cruciate ligaments</td>
<td>3</td>
<td>359</td>
<td>525</td>
</tr>
<tr>
<td>7</td>
<td>Fractured tibial plateau; medial meniscectomy; ruptured medial collateral ligament</td>
<td>4</td>
<td>418</td>
<td>361</td>
</tr>
<tr>
<td>8</td>
<td>Ruptured medial collateral ligament</td>
<td>5</td>
<td>421</td>
<td>462</td>
</tr>
</tbody>
</table>

They had been referred for conservative rehabilitation to improve muscle strength and functional ability, before referral for surgical stabilization if conservative treatment was unsuccessful.

There were no clinical effusions evident.

Pain was not a clinical feature of their condition. However, during the test procedures, pain levels were assessed verbally on a 0–10 scale. The patients were advised that they could stop the test at any stage if they wished.

The patients were otherwise healthy, well-motivated, military personnel, with no history of contralateral knee pathology.

**Rehabilitation regimen**

Each patient underwent 1 month of closely supervised intensive rehabilitation for approximately 5 h/day 5 days/week, giving a total of 100 h of exercise.

The programme consisted of the type of progressive treatment regimen commonly employed in the rehabilitation of ACL-deficient patients [9]. In general terms, the daily routine consisted of 2 × 30 min sessions of hydrotherapy, 2 × 30 min of individual physiotherapy modalities as appropriate (e.g. ice, ultrasound, joint mobilization, etc.), 2 × 30 min of recreational activities as appropriate (e.g. gentle jogging) and 4 × 30 min of exercises in small groups.

During the four exercise sessions each patient performed individually prescribed sets of exercises (e.g. straight leg raises, leg-presses, step-ups, etc.) according to their abilities, which were progressed (i.e. weight-bearing exercises, use of weights, height of step) as the patient’s abilities improved. In these classes the patients performed a total of about 1000 quadriceps contractions each day, these being maximum, or near maximum efforts. The classes were performed under the close supervision of a senior physiotherapist, who gave vigorous verbal encouragement to ensure full compliance and maximal effort.

The regimen was individually adapted for each patient’s deficits, as is routine clinical practice [9], but all the patients received approximately the same intensity and modality of treatment, irrespective of the amount of quadriceps weakness or AMI present.

**Measurement of isometric and isokinetic quadriceps and hamstring muscle force**

Detailed descriptions of equipment, patient positioning and theoretical background of percutaneous electrical twitch interpolation have been reported previously [5, 6]. Briefly, muscle force generation was recorded through a Cybex II+ dynamometer, using a modified level arm adapted to increase accuracy and sensitivity. The patient was securely strapped on the seat of the dynamometer. Three isometric maximum voluntary contractions (MVCs) were recorded with the patient’s knee flexed to 90° for the quadriceps, and to 60° flexion when measuring hamstring strength. Three isokinetic MVCs at angular velocities of 30, 60, 90, 120 and 180°/s, were recorded during a quadriceps MVC between 90° knee flexion and full extension, and hamstring MVC between full extension and 90° flexion.

The peak force of the strongest contraction at each velocity was measured, irrespective of the angle at which it occurred; this is termed the measured maximum voluntary contraction (MMVC).
Measurement of isometric quadriceps inhibition

The presence and magnitude of quadriceps AMI was determined by superimposing percutaneous electrical stimulation at 1 Hz during an isometric MVC [10]. If the voluntary contraction is fully activated, i.e. uninhibited, electrical stimulation cannot generate additional force. However, if it is inhibited, additional force will be generated. The amount of quadriceps AMI was estimated by comparing the amplitude of the twitch superimposed during an MVC with that obtained when the resting muscle is stimulated. Correcting for the amount of AMI gives an estimate of the ‘real’ isometric quadriceps strength if the quadriceps could be fully activated, the estimated maximum voluntary contraction (EMVC). The results of this technique compare favourably with tetanic and supramaximal femoral nerve stimulation [10], but it is much more comfortable and is well tolerated by patients.

Measurements of AMI, isometric strength and isokinetic strength were taken at the beginning and end of the training period.

Subjective assessment

Before and after rehabilitation each patient was questioned about their knee pain, the incidence and frequency of joint instability, confidence in their injured and uninjured legs, and functional ability and limitations.

Ethical approval

Approval was obtained for this study from the local ethical committee. All subjects verbally consented to participate after being informed of the nature of the study and the techniques involved.

Statistics

Two-tailed Wilcoxon's signed rank test was performed on the amount of quadriceps AMI before and after rehabilitation. A one-tailed Wilcoxon's signed rank test was performed on the quadriceps and hamstring strength changes after rehabilitation, as it was postulated that these would increase after rehabilitation. To establish a correlation between quadriceps AMI and weakness the Spearman rank correlation test was performed. The level for statistical significance was set at \( P < 0.05 \). The data are presented as means ± SEM.

RESULTS

Quadriceps inhibition

Before rehabilitation there was bilateral quadriceps AMI (Fig. 1). AMI in the injured leg (45.6 ± 10%) was greater than that in the uninjured leg (18.6 ± 8%).

Fig. 1. Percentage inhibition in the quadriceps of the injured and uninjured legs before (■) and after (●) rehabilitation. There was no significant change in AMI after rehabilitation. Values are means ± SEM. Statistical significance: *\( P < 0.025 \) between inhibition in injured and uninjured legs.

After rehabilitation, AMI of the injured leg and uninjured leg decreased to 28.5 ± 5% and 10.4 ± 4%, respectively (Fig. 1); however, these decreases did not attain statistical significance. A difference (\( P < 0.025 \)) in the amount of AMI in the injured and uninjured legs was still apparent.

Pain

Four patients reported pain during testing (mean 2, range 0–6). However, no patient considered that pain impeded their performance, or chose to stop the test procedures.

There was no correlation between the pain intensity and the amount of inhibition measured.

Quadriceps strength

Isometric strength. Before rehabilitation the MMVC of the injured leg was 40.5 ± 5% of the uninjured leg (\( P < 0.0001 \); Fig. 2). When corrected for inhibition the EMVC of the injured leg was 62.0 ± 8% (\( P < 0.0001 \); Fig. 2) of the uninjured leg.
After rehabilitation the MMVC of the injured leg was 45.5 ± 4% (P < 0.0001; Fig. 2) of the uninjured leg, and the EMVC was 64.0 ± 7% (P < 0.0001; Fig. 2) of the uninjured leg.

Before rehabilitation there was a negative correlation (r = -0.78, P < 0.025) between the amount of quadriceps inhibition and the quadriceps isometric MMVC of the injured leg when related to the predicted normal values for body weight [11].

Isokinetic strength. The quadriceps strength of the uninjured leg was unchanged except for a decrease at 90°/s (P < 0.05; Fig. 3a). Increases were only found in the injured leg during isometric contractions (P < 0.05) and isokinetic contractions at 60°/s (P < 0.01; Fig. 3a).

Hamstring strength

Isometric strength. Before rehabilitation the isometric hamstring strength of the injured leg was 73.4 ± 6% (P < 0.0001; Fig. 2) of the uninjured limb. After rehabilitation the hamstring strength of the uninjured leg was unchanged (Fig. 3b), and the isometric strength of the injured leg was still weak, being 76.0 ± 7% of the uninjured leg (P < 0.0001; Fig. 2).

Isokinetic strength. The hamstring strength of the injured leg increased at three isokinetic test velocities (P < 0.05–0.025; Fig. 3b).

Subjective outcome

Although the patients reported subjective benefit from rehabilitation, none attained their functional level before injury and all remained severely disabled, experiencing joint instability, muscle weakness and decreased confidence in their injured legs. Six patients were very dissatisfied with the outcome of rehabilitation and were awaiting surgical stabilization of their joints.

DISCUSSION

This study investigated quadriceps AM1 and quadriceps and hamstring weakness and strength increase after rehabilitation in a small group of patients who had sustained ACL rupture and associated joint damage. Before rehabilitation, large amounts of quadriceps AM1 were associated with severe quadriceps weakness. After rehabilitation, quadriceps AM1, and both the measured and estimated quadriceps force of the injured leg were essentially unchanged. Therefore force loss due to quadriceps weakness, i.e. 36%, and AM1, i.e. 18%, were unchanged by rehabilitation. Small hamstring strength increases occurred across the spectrum of test velocities. All the patients continued to experience severe functional disabilities. These results indicate a very poor response to conservative rehabilitation and six patients were awaiting surgical stabilization.

The results of other studies of conservative rehabilitation of ACL-deficient patients have been very inconsistent [12-17]. A good response to conservative treatment has been found in patients with isolated ACL ruptures and small strength deficits [12-14]. These indicators are associated with relatively small amounts of quadriceps AM1 (10–20%) that does not prevent quadriceps strength increases, as shown in our previous study [7]. Conversely, a poor response to conservative rehabilitation [14-16] is reported in patients with ACL ruptures and associated joint damage, who also have increased joint laxity and instability [17], quadriceps weakness and an inability to reverse the muscle weakness [17]. These features are associated with larger amounts of quadriceps AM1 (30–45%), as demonstrated by the present study.

Therefore one possible explanation for the poor response to conservative rehabilitation may be the degree of quadriceps AM1 present after injury. Since the development of high force is considered necessary for strength increase [18], an inability to fully activate a muscle will decrease force generation and as a consequence reduce the mechanical stimulus for hypertrophy. Accordingly, if large amounts of quadriceps AM1 limit force generation to below the threshold for the mechanical stimulus for hyper-
tropho, strength increase may be impeded. However, smaller amounts of AMI that permit generation of forces above the threshold for mechanical stimulus for hypertrophy would not prevent strength increase, as demonstrated in our previous study [7].

It might be argued that the injury may somehow alter the muscle structure, which cannot then respond to the stimuli for hypertrophy in the normal way. However, there is little evidence to support this hypothesis, since the peri-articular muscles were undamaged by the trauma and the muscle structure is unaltered [19]. Furthermore, the quadriceps strength increase of patients with isolated ACL ruptures [7] demonstrates that it is not the specific injury that prevents hypertrophy.

Another possible cause of the reduced efficacy of conservative rehabilitation may be that the duration of rehabilitation is too short to produce strength increases. However, significant strength increases were evident in patients with isolated ACL ruptures who underwent the same type of rehabilitation regimen [7]; therefore it does not appear to be the duration of this rehabilitation regimen that prevents strength increase.

Our evaluation of function was a relatively crude, subjective evaluation of overall ability and joint instability, permitting only limited inference of an association between reduced quadriceps activation and functional ability. Since the relationship between quadriceps AMI and function is very important, it would be beneficial to refine the assessment of functional ability, and relate this to initial amounts of AMI and changes after rehabilitation.

The results raise two points that require clarification. First, the presence of AMI in quadriceps of the contralateral uninjured limb suggests that AMI may not result from joint pathology. However, most normal healthy subjects can fully activate their quadriceps AMI may be evoked by damage to articular mechanoreceptors eliciting abnormal joint afference that decreases excitability of the spinal neurons controlling quadriceps activity [20, 21]. As these spinal neurons receive bilateral convergent input [22], a unilateral joint injury may produce abnormal afference, which may be perceived as having arisen bilaterally, and result in bilateral reduction of quadriceps activation.

Secondly, one patient (Table 1, patient no. 2) appeared to be fully inhibited, yet paradoxically generated force. The most likely explanation of this anomaly is that the superimposition of electrical stimulation on to very weak contractions was potentiated, exaggerating the degree of AMI. This suggests that, although the technique of twitch interpolation is a useful tool to estimate the extent of muscle activation up to 70–80% [10], there may be a threshold above which the extent of muscle inhibition may be exaggerated. Therefore caution should be exercised when interpreting data from traces with very large amounts of AMI or very weak contractions.

In summary, severe joint damage is associated with relatively large amounts of quadriceps AMI, severe quadriceps weakness and disabling joint instability. Since muscle weakness and joint instability predispose joint degeneration [23], large numbers of patients with extensive traumatic and arthritic joint damage are referred for rehabilitation to increase muscle strength and joint stability. These results suggest that even very intensive rehabilitation regimens may achieve these aims.

ACKNOWLEDGMENTS

We thank Mr Danny Wilson, MCSP, for supervising the rehabilitation of these patients. We are grateful to the Arthritis and Rheumatism Council for financial support.

REFERENCES


