CHRONIC ANTERIOR CRUCIATE LIGAMENT TEAR
Knee function and knee extensor muscle size, morphology and function before and after surgical reconstruction

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av

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Umeå 1988
Knee function and knee extensor muscle size, morphology and function before and after surgical reconstruction

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ABSTRACT

Knee function was evaluated by knee score, activity level, clinical findings and performance tests, muscle size by computerized tomography (CT), morphology by light (LM) and electron microscopy (EM), muscle function by electromyography (EMG) and isokinetic performance in 29 patients with chronic anterior cruciate ligament (ACL) tear. Preoperatively CT disclosed a significant mean atrophy of the quadriceps and nonsignificant changes of the other muscle areas of the injured leg. Morphology of m. vastus lateralis of the injured leg was normal in more than half of the biopsies preoperatively, the rest showed signs of nonoptimal activation. Significant decreases in all isokinetic parameters were noticed together with significantly decreased EMG of the quadriceps muscle of the injured leg.

After surgical reconstruction the knees were immobilized in a cast for 6 weeks at either 30° or 70° of knee flexion. After cast removal CT showed significant decreases of all areas which also remained after training. The 30° group showed larger fibres (intracellular oedema) and more frequent morphological abnormalities than the 70° group. Fourteen weeks postoperatively the patients were allocated to either a combination of isometric and progressive resistance training or isokinetic training for 6 weeks. CT showed slightly larger areas at 20 weeks postoperatively than at 6 weeks. Morphological abnormalities were still prominent at 20 weeks postoperatively. Maximum isokinetic knee extensor mechanical output and endurance were markedly decreased at 14 weeks postoperatively but both improved progressively during the one year rehabilitation, mostly during the intensive 6 week training period but irrespective of training programme used. Fatiguability/endurance level improved over the preoperative level. Muscular work/integrated EMG was stable while EMG/t increased indicating neuromuscular relearning.

The clinical result at 28 months followup was excellent or good in 93% of the patients and clinical stability improved in 66%. Independent upon primary knee immobilization angle or training programmes no differences could be demonstrated with respect to stability, range of motion, function or isokinetic mechanical output. Isokinetic performance was still significantly lower in the injured compared to the noninjured leg and not significantly different from the preoperative values. Morphology, only 6 cases, showed abnormalities similar to preoperative findings.

In conclusion, the reason for the decreased maximum and total knee extensor performance in these patients with ACL tears is suggested to be nonoptimal activation of normal functioning muscle fibres depending on changes in knee joint receptor afferent inflow. No differences concerning the markedly improved postoperative clinical result could be seen between the different treatment modalities used. A nonoptimal muscular activation might explain the still decreased isokinetic performance present at followup.

Key words: knee joint; ligaments, articular; surgery; muscle fibre; isokinetics; exercise therapy; muscular atrophy; electromyography
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by

Lars-Gunnar Elmqvist

Umeå 1988
To my family
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<table>
<thead>
<tr>
<th>CONTENTS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Original papers</td>
<td>7</td>
</tr>
<tr>
<td>Abbreviations</td>
<td>8</td>
</tr>
<tr>
<td>Introduction</td>
<td>9</td>
</tr>
<tr>
<td>Aims of the investigation</td>
<td>15</td>
</tr>
<tr>
<td>Subjects and methods</td>
<td>16</td>
</tr>
<tr>
<td>Results</td>
<td>22</td>
</tr>
<tr>
<td>General discussion</td>
<td>25</td>
</tr>
<tr>
<td>General summary and conclusions</td>
<td>33</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>35</td>
</tr>
<tr>
<td>References</td>
<td>37</td>
</tr>
<tr>
<td>Paper I</td>
<td>43</td>
</tr>
<tr>
<td>Paper II</td>
<td>63</td>
</tr>
<tr>
<td>Paper III</td>
<td>75</td>
</tr>
<tr>
<td>Paper IV</td>
<td>99</td>
</tr>
<tr>
<td>Paper V</td>
<td>119</td>
</tr>
</tbody>
</table>
ORIGINAL PAPERS

This thesis is based upon the following papers, which in the text are referred to by their Roman numerals:


III Sjöström M, Elmqvist L-G, Lorentzon R: Muscle fine structure and chronic anterior cruciate ligament tear. Qualitative evidence for the underlying patho-physiological mechanism of muscle weakness. In manuscript


ABBREVIATIONS

ACL - anterior cruciate ligament
CSA - cross-sectional area
CT - computerized tomography
CW - contraction work
CW/iEMG - electrical efficiency
iEMG - integrated electromyography (arbitrary units)
IP - instantaneous power
J - joule
MP - mean power = CW/manoeuvre time
Nm - newtonmeter
PT - peak torque
ROM - range of motion (degrees)
W - watt
INTRODUCTION

The anterior cruciate ligament is the most commonly injured ligament of the knee joint (Johnson 1982, Odensten 1984, Casteleyin et al 1988). Descriptions of its anatomy, function and injuries have appeared in a vast number of publications, especially during the last four decades. An extensive historical review as well as anatomical and functional descriptions of the ACL have been presented in "The Crucial Ligaments" (Feagin 1988).

The mechanisms of ACL injury are several. The most common one is the classic combination of external rotation and valgus stress of the lower leg in relation to the thigh (Fig 1), occurring while running, stopping suddenly or changing direction (Johnson 1982, Noyes et al 1983). Other mechanisms are hyperextension or backward fall, the latter usually occurring during downhill skiing (Johnson 1988). In Sweden up to 83% of the injuries occur in sports and the rest are caused by traffic accidents or various falls (Odensten 1984, Sandberg 1986).

Figure 1. The tip of the ski is caught in the snow twisting the knee of the skier.

Studies of the natural history of ACL tear are virtually impossible to perform because there are always a number of unreported injuries (Garrick 1988). Many recreational athletes do not perceive themselves as being injured or the examining doctor does not recognize the injury (Johnson 1982, Garrick 1988). However, diagnosis made by arthroscopy makes it possible to estimate the incidence of ACL tear in those subjects seeking medical advice. The highest injury rate occurs in males in their third decade (Noyes et al 1983a, Odensten 1984, Sandberg 1986).
The diagnosis of ACL tears is based upon patient history, clinical examination and operative findings. Attempts to achieve numerical scores of the symptoms have resulted in several types of functional knee scores. These have been extensively discussed and described by Lysholm and Gillquist (1982). Their score was later modified by Tegner and Lysholm (1985). Since the degree of symptoms generally is dependent upon the activity level of the patient, Tegner and Lysholm (1985) also introduced an activity scale making it possible to grade the "handicap" of the patient. The knee score and the activity level complement each other and should always be used in combination (Tegner et al 1985, Tegner et al 1988).

The Lachman (Torg et al 1976, Jonsson et al 1982) and pivot shift tests (Galway et al 1972) are the most important clinical examinations used to diagnose the ACL injuries although they are often difficult to perform in the acute phase, because of pain. Examination under anesthesia is considered necessary for an adequate diagnosis at least in the acute phase (Sandberg 1986).

To further sharpen the diagnostic accuracy and to map out the complete intraarticular pathology (meniscal or cartilage lesions, and capsular rifts), a thorough arthroscopical examination is necessary before deciding upon treatment (Noyes et al 1980, Lysholm et al 1981, Simonsen et al 1986).

**Treatment**

The treatment of ACL injuries is a controversial topic. There are three main different approaches.

**No treatment.** This evidently occurs for those patients who do not know the existence of their ACL injury either because they do not seek medical advice or they receive an improper diagnosis. However, a certain number of these patients are diagnosed when they do seek medical advice several years after the initial injury. Common symptoms and clinical findings at that time are giving way, pain, swelling, locking, muscular weakness and radiological signs of degenerative changes (Fetto and Marshall 1980, McDaniel and Dameron 1980, Sherman et al 1988).

**Nonoperative treatment.** After the exact diagnosis is established the patients are counselled on which types of activity that are considered safe (Noyes et al 1983b), muscle training is started (Johnson 1982, Giove et al 1983, Tegner et al 1986) and in some cases braces are given (Johnson 1982, Noyes et al 1983b). With a nonoperative programme Noyes et al (1983b) reported improvement in 36% of the patients, failure in 32% while 32% remained the same. Tegner (1986) showed significant improvement of the knee score in 77% of his patients after a 3 month progressive resistance strength training programme. On the contrary, Kannus and Järvinen (1987) in an 8 year followup of a conservative programme, which consisted of 4-5 weeks of initial plaster immobilization followed by 6 months of muscle training, found a 35% failure rate in their patients.

**Surgical treatment** The reports of surgical treatment far outnumbers the reports of
nonoperative treatment (cf Surin 1985) and more than three score of procedures have been described for reconstruction of a torn ACL (Ferkel et al 1988). The procedures can be extraarticular, intraarticular or a combination of both and include the use of autografts, homografts or fabricated prosthetic devices.

In the present study we have chosen to follow surgically treated patients with the use of the intraarticular technique described by Marshall and coworkers (1979). They reported 90% good results using a knee score after 22 months followup. Roth et al (1985) using a similar technique with both augmented and nonaugmented autografts, had an improved subjective evaluation of function in 66-83% of their patients with 51-64 months followup.

An international survey in the early 1980's showed that the most commonly used measures in the immediate postoperative phase, at that time were plaster fixation for 6 weeks and the avoidance of weightbearing by the use of crutches (Paulos et al 1981). Four years later another survey showed a tendency for shorter immobilization time and use of electrical stimulation (Bilko et al 1986). The plaster fixation is used with various degrees of knee flexion (Paulos et al 1981, Clancy et al 1982, Bilko et al 1986). Partial motion with hinged cast (Häggmark et al 1979, Sandberg et al 1987) or brace (Noyes et al 1987) with or without weightbearing has also been recommended. Early motion (Noyes et al 1987) and continous passive motion have quite recently been applied to ACL repairs (Hamilton et al 1988).

Physical rehabilitation

Nonoperative or operative treatment always includes some kind of physical rehabilitation in order to maintain or increase thigh muscle strength. The training concepts most often used are those given by DeLorme (1945, heavy resistance), or by Hislop and Perrine (1967, isokinetic training). Moreover, electrical stimulation (Eriksson et al 1979) has been used to regain the initial muscle power loss after operative procedures.

Some studies (Pipes and Wilmore 1975, Grimby et al 1980, Smith and Melton 1981) claim that isokinetic training results in greater muscle strength than progressive resistance training while others (Halkjær-Kristensen & Ingemann-Hansen 1985) did not find any differences between several different training regimens including both isokinetic and progressive resistance training.

Thigh muscle training before considering surgical reconstruction of a torn ACL has been emphasized (Baugher et al 1984, Johnson 1982, Tegner et al 1986) to improve the knee function of patients with ACL tears. Giove et al (1983) stressed hamstring training while Murray et al (1984) found no support for this postulate. Gerber et al (1985) questioned the reasons to train at all while Tegner et al (1986) found that strength increase of the hamstrings and, above all, the quadriceps muscle improved knee function in 80% of their conservatively treated patients.

Followup of ACL reconstructed patients has shown that normal or almost normal muscle
function was found in patients with clinically good results (Arvidsson et al 1981, Johnson et al 1984, Odensten 1984).

At the start of this study in 1982, isokinetic training was considered contraindicated during the first 30 weeks of the recommended one-year postoperative training period (Paulos 1981). Postoperatively most commonly used muscle training programmes start with hamstrings and initially assisted, but later unassisted quadriceps extension exercises (Paulos et al 1981, Johnson personal communication 1982).

Measurements of muscle size
To study hypo- and hypertrophy of skeletal muscles in response to altered activity due to injury, surgery, immobilization and training, anthropometry i.e. limb circumference and skinfold measurements (Ingemann-Hansen and Halkjær-Kristensen 1977), ultrasonography (Young et al 1982) and computerized tomography (Häggmark et al 1978, ) have been used. The latter gives more detailed information of the various components of the extremity than simple measurements. Thus more reliable information of the influence of different conditions on the limb can be attained (Ingemann-Hansen and Halkjær-Kristensen 1980, Gerber et al 1985, Johansson et al 1987, art). In the present study we have used computerized tomography to estimate the muscular components of the thigh.

Muscle morphology
In patients with untreated chronic ACL tears selective atrophy of Type 1 muscle fibres of the vastus medialis has been demonstrated (Edström 1970). However, Baugher et al (1984), who also used biopsies from the vastus medialis showed Type 2 atrophy. Gerber et al (1985) found decrease in both fibre types of the vastus lateralis, while Nakamura et al (1986) showed Type 1 fibre atrophy in patients with chronic ACL tears before surgery.

There are contradictory opinions of the result of immobilization on muscle morphology. Muscle fibre composition was unaltered while fibre size of both Types I and II were decreased 0-42 days after effective immobilization for leg fractures (Sargeant et al 1977). Other authors found mainly a decrease in Type I fibre size of the vastus lateralis (Häggmark et al 1981) after immobilization at 10-15° of knee flexion, while fibre Type 2 atrophy was shown in normal m triceps brachi after immobilization (MacDougall et al 1980). Type 2 fibre atrophy was reported in patients with different knee injuries after an unspecified duration of immobilization (Young et al 1982). Arvidsson et al (1986) found an equal decrease in fibre area for both Type 1 and 2 fibres when immobilizing patients in 45-50° of knee flexion after ACL surgery but no change in fibre distribution. Insignificant changes in both fibre type areas but a decrease in the relative number of Type 1 fibres were noted by Halkjær-Kristensen and Ingemann-Hansen (1985) in patients immobilized at 5-15° of flexion after medial collateral ligament injuries.
Experimental studies in animals have shown that increased tension of muscles can retard degradation of proteins and stimulate amino acid transport and protein synthesis thus resulting in hypertrophy of the muscle (Goldberg et al 1975, Goldspink 1977). Immobilization of rabbit calf muscle fibres in a relaxed position results in a high degree of light morphological degenerative changes such as poor muscle fibre organization, cell necrosis and decrease in fibre size while almost no abnormalities were noted when the muscle fibre was immobilized in a stretched position (Sjöström et al 1979). To my knowledge no human studies using different angles of fixation and thus different muscle tensions of the muscle fibre have been reported.

Training after immobilization in healthy subjects results in increase in Type 2 fibre size in the triceps brachi (MacDougall et al 1980). In patients with knee ligament injuries no change of fibre size was found either after training for 6 weeks starting 14 months postoperatively (Grimby et al 1980) or after 4 weeks of several different training programmes starting directly after the immobilization period (Ingemann-Hansen and Halkjær-Kristensen 1983, Halkjær-Kristensen and Ingemann-Hansen 1985).

**Isokinetic exercises**

Isokinetic exercises and recordings of mechanical output of different muscles have been used in many investigations since Hislop and Perrine in 1967 introduced the concept of isokinetic exercise. The knee extensor performance during single maximum contractions of healthy subjects have been extensively investigated mostly in athletes (Thorstensson et al 1976, Perrine and Edgerton 1978, Johansson 1987). There are also several reports of the isokinetic performance of knee injured patients (Arvidsson et al 1981, Halkjær-Kristensen and Ingemann-Hansen 1985, Roth et al 1985, Tegner et al 1986).

Muscular fatigue can be defined as failure to maintain required or expected force or power output (Edwards 1983). Muscular endurance, according to Hislop and Perrine (1967), refers to the capacity to extend the power output over specific intervals of time.

Isokinetic knee extensor performance during repeated contractions has been studied in order to evaluate quadriceps fatiguability and endurance. Thorstensson and Karlsson (1976) found in well trained subjects that knee extensor peak torque decreased throughout 50-100 repeated contractions. Similar findings have been reported by other authors (Nilsson et al 1977, Komi 1984, Lorentzon et al 1987). In patients with ACL tears endurance and fatiguability have been investigated, however with questionable technique (Roth et al 1985).

**EMG**

Integrated EMG is a well established measure of the number of muscle fibres activated and of their firing frequency (Goodgold and Eberstein 1977). Surface recording of iEMG is representative of the EMG activity of the muscle (cf Milner-Brown and Stein 1975). IEMG represents the input to the muscles during the isokinetic contraction, while the
output is represented by the contraction work. By combining output and input (CW/iEMG) an analysis of the electrical efficiency of the muscle can be obtained (Fugl-Meyer et al 1982).
GENERAL AIM

The general aim of this prospective investigation of patients with chronic anterior cruciate ligament tear was to characterize knee function and knee extensor performance before and after surgical reconstruction according to Marshall and to relate parameters of performance to knee extensor macro- and micro-scopical anatomy and to neuro-motor drive.

Specific aims

The more specific aims were
- to investigate the preoperative condition of the thigh muscles with respect to: cross-sectional area, morphology, and isokinetic performance of the knee extensors (I);
- to determine the preoperative electromyographic activity of the quadriceps and its relations to the isokinetic performance (II);
- to evaluate microscopical changes of the m. vastus lateralis preoperatively, after postoperative immobilization of the knee at two different angles of fixation, after training using two different programmes and at followup (III);
- to investigate the mechanical output (peak torque, contraction work and fatiguability/endurance) of the knee extensors during the first year of postoperative physical rehabilitation and the influence of two different training programmes (isokinetic and progressive resistance training) in the early period of rehabilitation (IV);
- to determine the long-term effects on knee function of the operative procedure, of the two angles of postoperative immobilization and of the two different training programmes (V).
SUBJECTS AND METHODS

The subjects in this thesis were all patients with chronic anterior cruciate ligament ruptures treated with reconstruction of the ligament according to the technique described by Marshall et al (1979).

Twenty-nine patients (6 women and 23 men), with a mean age of 25 years (range 16-37) at the time of surgery were investigated. Mean duration of symptoms was 39 months (range 7-185). Mean followup time was 28 months (21-42). The numbers of patients participating in each study were distributed as follows:

- Paper I - 18 (all men);
- Paper II - 11 (subsample of I);
- Paper III - 29 (6 women and 23 men);
- Paper IV - 17 (4 women and 13 men);
- Paper V - 29 (6 women and 23 men).

Before giving their consent all subjects were carefully informed about the design and purpose of each particular investigation and its possible negative effects. Eleven patients participated in all five studies, seven in only two (III,V) and the remaining eleven in 3 - 4 studies.

Surgical technique

All patients underwent an ACL reconstruction using an over-the-top technique with a quadriceps-tendon patellar periosteum patellar tendon graft according to Marshall and co-workers (1979).

Postoperative treatment and training

The patients were immobilized for 6 weeks postoperatively in either 30° (n=17) or 70° (n=12) of knee flexion (Fig. 2) with a plaster and using crutches without weightbearing. No isometric exercises were allowed during this period. During the following 8 weeks, a carefully monitored program was started to increase range of movement and strength of the operated limb. The program started with flexion and isometric quadriceps exercises for 3 weeks, followed by 3 weeks of dynamic quadriceps exercises against the weight of the limb and ending with 2 weeks of progressive resistance exercises. A removable splint was used during the first 2 weeks of exercises followed by a derotation brace initially with 30° of extension deficit. Increased weight-bearing commenced 8 weeks postoperatively and full weight-bearing was allowed 14-16 weeks postoperatively.

After the 14th week 17 patients (Group I; Fig 2) underwent isokinetic training using biofeedback while 12 patients (Group C) followed a combination of isometric and progressive resistance training for 6 weeks. Of the patients in Group I 10 had been
immobilized at 30° and 7 at 70° knee flexion while the corresponding numbers for Group C were 7 and 5.

![Diagram showing the different postoperative treatments](image)

Figure 2. Diagram showing the different postoperative treatments (see text).

After the 20th week the training was the same for all groups continuing with progressive resistance and coordination exercises. When 65-75% of the mechanical output of the noninjured leg was reached, usually during the 32-36 weeks postoperatively, subjects were encouraged to start jogging. Approximately 40 weeks postoperatively sports-related exercises were started. Return to light work started after 20 weeks and to heavy work or full time sports activities about one year postoperatively.

**Knee symptoms, and activities of daily life and sports**

Knee symptoms of the patients were assessed by the original Lysholm knee scoring scale (Lysholm and Gillquist, 1982). The maximum score is 100 points, a score below 65 is considered poor and above 83 points good or excellent (Tegner and Lysholm 1985).

Activities of daily life and sports were graded according to Tegner and Lysholm (1985) on a scale with 11 levels, where 10 represents an elite soccer player and 0 a patient unable to work because of knee problems.

**Clinical examination**

Knee examination was made by routine methods. The stability of both knees was evaluated by standard stability tests, i.e. varus-valgus, anterior-posterior and rotational. The stability was defined as tibial translation in mm: +1 = 0-5 mm; + 2 = 5-10 mm; + 3 = > 10 mm. Pivot shift was assessed as either negative or positive; negative meaning absence of the pivot-shift sign.

The thigh circumference was measured by tape at a point 2/5 of the distance between the lateral knee joint line and the major trochanter of the femur. This made possible measurement at the same relative level in all patients.
Performance tests
These consisted of four different tests according to Tegner et al (1986a):
- running in a figure-of-eight;
- a one-leg hop;
- running up and down a spiral staircase;
- running up and down a 55 m slope with two turns.
As the reference values of Tegner et al (1986a) were necessarily not valid for our testing facilities we calculated our own values: mean ± 2 standard deviations for the values four in 30 healthy persons performing the four different tests.

Measurements of thigh cross-sectional areas (CSA)
Computerized tomography (CT) was performed using a Siemens Somatom 2 Scanner measuring the cross sectional area 20 cm proximal to the knee joint line. Area calculations were made with the statistical evaluation program of the computer. M. vastus lateralis was not separated from m. vastus intermedius (Fig. 3). The CT scans were performed preoperatively, at six weeks and at twenty weeks postoperatively.

Figure 3. CT cross-section of the thigh at 20 cm above the knee joint line. M vastus lateralis and intermedius are marked in white.

Morphology
Open muscle biopsies were taken from the superficial layer of m. vastus lateralis at the reconstructive procedure, at six weeks, at twenty weeks and 2 years postoperatively. The biopsy site was defined at the same level as the CT scans were performed. Each biopsy was initially divided into halves, one of which was prepared for enzyme histochemistry. From each specimen 300 to 400 fibres were classified according to their staining characteristics for alkaline mATPase (pH 9.4) into fibres with either low (Type I) or high
(Type II) activity (Fig. 4). For determination of fibre cross-sectional area a digitizing tablet was used connected to a microcomputer; 100 fibres were measured per fibre type and specimen. All the measurements were performed by one and the same observer to reduce the error of the method.

Figure 4. Light micrograph showing cross-sections of muscle fibres treated for visualization of mATPase at pH 9.4. Fibres are tightly packed, of equal size and polygonal in shape. Magnification approximately x250.

Isokinetic performance
In all studies, except for paper III, isokinetic performance of the m. quadriceps was evaluated using two regularly calibrated Cybex ® II dynamometers (Lumex Inc, New York). Throughout usage both dynamometers were calibrated by applying known weights to the lever arms at different velocities of angular motion. Using this method of calibration, changes between calibrations never exceeded ± 2 Nm. Subjects were supine, with the hips flexed approximately 20°, the pelvis firmly strapped and the knees hanging over the edge of a plinth. Both legs were tested in randomized order.

Maximum isokinetic knee extensor performance during single contractions were measured at preset velocities of angular motion of 30, 90 and 180 °/s, while repetitive manoeuvres were performed at 90 °/s (IV). Peak torque (Nm) and manoeuvre time (s) were recorded for each contraction. Contraction work (J) was calculated using the formula 

\[ J = \beta \cdot \int_0^{\Delta t} M \, dt, \]

where \( \beta \) is the angular velocity in radians/s, \( \Delta t \) manoeuvre time and \( M \) the torque. Instantaneous power (IP) and mean power (W) were also calculated (Fugl-Meyer et al 1982).

During single contractions, the manoeuvre with the highest peak torque from three attempts at each angular velocity was used.
During the repetitive test, 100 contractions were scheduled and CW-values for the initial level of performance (mean of contractions 1-5), slope of decline (linear regression of contractions 6-25), end of slope (mean of contraction 25-27), endurance level (mean of contractions 50-75) and level of performance at the end of the test (mean of contraction 96-100) were used.

Muscular fatigue is defined as failure to maintain initial (or expected) force or power output. Muscular endurance is defined as time to fatigue (Edwards 1983).

Attempts to assess knee extensor isokinetic work (see above) during repetitive contractions using planimetric methods have been made in both healthy subjects (Nilsson et al 1977, Aniansson et al 1978) or subjects with ACL tears (Roth et al 1985). Failure to recognize that work is the product of force and distance resulted in underestimation of the actual work when using an angular velocity above one radian/s (Fig. 5).

Figure 5. Diagram illustrating the relative difference in actual work performed (J) and the planimetrically calculated values (Nms) at different angular velocities. Only at one point, 57.3 °/s = 1 rad/s are the values identical.

Mean planimetric values (Nms) and correctly defined values of CW (J) for different velocities of angular motion (°/s) are given for the patients in paper I.

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<th>°/s</th>
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<tr>
<td></td>
<td>J</td>
<td>Nms</td>
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<tr>
<td>30</td>
<td>293</td>
<td>563</td>
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<tr>
<td>90</td>
<td>244</td>
<td>156</td>
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<td>180</td>
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Lever arm length was identical for all subjects at all tests. For all subjects this meant that the position of the resistance-pad was between 60 and 80% of the length between the medial knee joint line and the medial malleolus of the lower leg. Throughout this study we have generally used relative values (per cent of the noninjured leg). Hence, the fixed position is generally without influence on the results given. For a particularly tall subject the fixed length of the lever arm may lead to underestimation (2-3%) of mechanical output in relation to a short person (Janson et al 1988).

**Electromyography**

Electromyographic activity was registered during both single and repetitive isokinetic manoeuvres with pairs of surface electrodes (Medicotests, Ølstykke, Denmark) over the maximum protusions of m. vastus lateralis, m. vastus medialis and m. rectus femoris. The electromyographic signals were full wave rectified, low pass filtered (100ms) and integrated (iEMG) (Fig. 6). The ratio of contraction work/ integrated electromyographic activity (CW/iEMG) was calculated as an expression of output/input balance: “electrical efficiency”.

![Figure 6. Schematic description of the quantification (iEMG) of the electromyographic signal.](image)

**Statistical methods**

Results in tables and in text in papers I, II and III, are given as mean ± standard deviation and in papers IV and V as mean ± standard error of the mean. To evaluate associations between pairs of variables, linear regression analyses were used. For comparison of data, the Wilcoxon non parametric test and Student’s t-test were used. For one-way variance analysis, the Kruskal Wallis test was used in paper V (Snedecor & Cochran 1967). In all papers the chosen level of significance was \( p < 0.05 \).
RESULTS

Only those results considered to be of general importance will be mentioned; for details see the separate papers.

Paper I

The CSA of the m quadriceps of the injured leg was significantly smaller (5.1%) than that of the noninjured leg. The other muscle CSAs of the injured leg did not evidence such differences, although the hamstrings had slightly greater CSA on the injured than on the noninjured side. Biopsies from the m vastus lateralis of the injured leg had normal light microscopical findings in eleven of the eighteen subjects while six showed minor (centrally located nuclei, reduced fibre size and irregular shape of both Type I and II fibres) and one, more obvious abnormalities. All isokinetic knee extensor parameters (PT, CW, MP) were significantly reduced (12.9 - 28.6%) in the injured compared to the noninjured leg even after correction for quadriceps CSA. Active ROM was also significantly reduced. No significant relationships were found between isokinetic performance and CSA and quantitative or qualitative morphology. Moreover meniscal and articular cartilage lesions did not significantly influence any of the measured parameters of size, morphology and isokinetic performance.

Paper II

In comparison with the noninjured leg, the iEMGs of the injured legs were significantly lower for rectus femoris but not for the vasti at all angular velocities, also after correction for differences in active ROM. The summed iEMGs were significantly smaller at 90°/s and 180°/s in the injured than the noninjured leg, both before and after correction for ROM, but not so at 30°/s. Electrical efficiency (CW/iEMG) was similar in both legs.

Paper III

Preoperatively the morphology was normal in just over half of the biopsies; the rest showed centrally located nuclei, and apparent fibre size variation. Patients with very low knee function score had a higher degree of muscle fibre abnormality. After 6 weeks of immobilization the 30 group fibres were slightly larger than the 70 group fibres, due to intracellular oedema. 30 group fibres also had a larger number of internal structural disturbances. After 20 weeks abnormalities were still present but not as pronounced as earlier and resembled those seen preoperatively. The 30 group contained patients both with the "best" and the "worst" morphology. At the 2 year biopsy there were still abnormalities with irregular fibre profile and size variations similar to the preoperative findings.

Changes in the gross muscle areas also occurred during the different phases of treatment which are only to a very small part presented in this paper. Hence, the following table is given showing the reduction (per cent of preoperative value) in muscle CSA (mean
values ± SEM) for the patients at 6 and 20 weeks postoperatively.

<table>
<thead>
<tr>
<th>Angles of immobilization</th>
<th>6 weeks</th>
<th>postoperatively</th>
<th>20 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>30°</td>
<td>n=17</td>
<td>n=12</td>
<td>n=29</td>
</tr>
<tr>
<td>70°</td>
<td>n=11</td>
<td>n=29</td>
<td>n=59</td>
</tr>
<tr>
<td>Thigh circumference</td>
<td>7.2±0.8*</td>
<td>11.0±1.0</td>
<td>8.7±0.7</td>
</tr>
<tr>
<td>Total thigh area</td>
<td>9.7±1.8*</td>
<td>18.3±1.8</td>
<td>13.2±1.9</td>
</tr>
<tr>
<td>Total thigh muscle area</td>
<td>25.7±1.9*</td>
<td>36.5±3.7</td>
<td>30.1±2.1</td>
</tr>
<tr>
<td>M. quadriceps</td>
<td>35.3±1.4*</td>
<td>42.6±3.2</td>
<td>38.3±1.7</td>
</tr>
<tr>
<td>M. vastus lateralis</td>
<td>29.6±2.1*</td>
<td>37.7±3.6</td>
<td>32.9±2.1</td>
</tr>
<tr>
<td>Hamstrings</td>
<td>14.3±3.6*</td>
<td>29.8±5.2</td>
<td>20.6±3.4</td>
</tr>
</tbody>
</table>

* = p<0.05, 30-group values significantly smaller than those of the 70-group; †= p<0.05, 20 week values significantly greater than 6 week values

The differences in reduction of CSA between the 30 and the 70 group remained after 20 weeks, however no differences were seen between the two training groups.

**Paper IV**

Fourteen weeks after the ACL reconstruction mechanical output of single maximum and repetitive knee extensions were around half of the preoperative values. The mechanical output improved successively, especially during the intensive training period between weeks 14 to 20 postoperatively. The improvement was independent of training methods: isokinetic or the combination of isometric and progressive resistance. Quadriceps CSA of the injured leg was reduced from 95% of the noninjured leg preoperatively to 69% at 20 weeks postoperatively. After one year of physical rehabilitation maximum performance of the injured leg was back to preoperative values for PT and even higher for CW. The noninjured leg also increased in output and thus the injured leg remained significantly lower than the noninjured leg (83% and 81% for PT and CW respectively). Endurance level and mean cumulated work were significantly improved compared to preoperative values. CW/iEMG remained stable throughout the one year period while EMG/t was increased by 34%.

**Paper V**

The knee function score and activity level were significantly improved from 60.5 to 93.6 and from 3.9 to 6.3 respectively and 27 out of the 29 patients were classified excellent or good. Clinical stability improved in two-thirds of the patients. In fact, knee function tests were normal in 79% of the patients. Isokinetic performance of the knee extensors was
significantly lower in the injured (78-90%) compared to the noninjured leg and did not differ from the preoperative values.

Independent upon the primary knee immobilization angle (30° or 70°) or training regimens no differences with respect to stability, ROM, function or isokinetic knee extensor performance could be seen an average of 28 months after ACL reconstruction.
GENERAL DISCUSSION

In our modern society with a high standard of living, leisure and sport activities of various types are becoming more and more popular. When people, not only elite sportsmen, are injured the majority wants to continue their activities and therefore demands optimal treatment. Many of the increasing number of sport injuries affect the knee joint where the ACL is the most often damaged ligament (Johnson 1982, Odensten 1984, Casteleyn et al 1988). Conservative treatment fails in at least one third of the patients with ACL tears (Noyes et al 1983b) and surgical reconstruction is therefore necessary. Most intraarticular techniques with or without extraarticular augmentation give in the hands of an experienced orthopaedic surgeon usually reasonably good results at least for seven to eight years (Johnson et al 1984, Zarins and Rowe 1986). However, the surgical reconstruction of the ACL is technically a complicated procedure (Marshall et al 1979, Odensten 1984, Eriksson 1986, Zarins and Rowe 1986) with a rehabilitation time of about one year (Eriksson 1981, Bilko et al 1986, Sandberg and Balkfors 1988). Various ways of shortening the postoperative rehabilitation without jeopardizing the long-term results have been tried (Häggmark et al 1979, Eriksson et al 1979, Morrissey et al 1985, Noyes et al 1987, Hamilton et al 1988, Glousman et al 1988)

In the present study a consecutive series of 29 patients with chronic ACL tears have been observed from a preoperative stage, through the surgical reconstruction and the early postoperative rehabilitation period, to a 2 year followup. Two different angles of immobilization postoperatively and two different training programmes have been used. The main objectives of this study were to assess the effects of these different treatment modalities on knee function and on size, morphology and function of the quadriceps muscle.

Preoperative findings

A thorough knowledge of the preoperative status of the patients is mandatory as a base reference.

The patients in this study reported symptoms of knee instability for a mean of 39 months and had clinical findings of anterior sagittal instability and a positive pivot shift sign. Pes anserinus transfers and suture of the ACL had been tried, unsuccessfully in ten patients. One third of the patients had previously been operated for meniscus lesions and thirteen had meniscus lesions requiring surgery at the reconstructive procedure. Minor degenerative articular cartilage lesions were found in 58 per cent of our patients at operation (V). Similar findings have repeatedly been reported by other authors (Marshall et al 1979, Johnson et al 1984, Roth et al 1985, Zarins and Rowe 1986). The patients had not undergone any organized or supervised training programme aiming at strengthening the thigh musculature but had only been given instructions to perform simple resistance exercises of the quadriceps muscle. Hence no specific preoperative training programmes
had distorted knee function and thigh muscle parameters. Therefore, our subjects represent, in relevant aspects, the usual population of subjects with chronic anterior cruciate ligament tear requiring surgical reconstruction.

Morphologically (III) every second muscle biopsy, or slightly more, was normal preoperatively and the remaining biopsies showed variations in muscle fibre size and shape and disturbances in the internal organization. These changes were neither primarily myogenic, i.e. not due to disuse or reactive processes, in origin, nor did they reflect any peripheral nerve damage. However, the findings suggested an inconsequent or nonoptimal activation of the muscle fibres. Fibre sizes and proportions were similar to those of clinically healthy subjects (Sjöström et al 1982, Lexell et al 1983). No selective fibre type atrophy was found in the biopsies, which agrees with Gerber et al (1985) and Wigerstad-Lossing et al (1988) but disagrees with other authors who found either Type I atrophy (Edström 1970, Nakamura et al 1986) or Type II atrophy (Baugher et al 1984).

CT measurements of the thigh muscle areas (I) disclosed significantly smaller quadriceps CSA of the injured compared to the noninjured leg and also, although not significantly, greater CSA of the hamstrings. The hamstrings are agonists to the ACL. Therefore, increased hamstring strength has been considered beneficial for these patients by Giove et al (1983) while Murray et al (1984) did not find any effects of this. The present finding (I), of a slight spontaneous hamstring hypertrophy has also been found to correlate inversely with the knee function score (unpublished data) i.e. low knee score and increase in hamstring size follow each other.

The present findings on thigh CSAs are in accordance with those of Gerber et al (1985), although their measurements were performed at slightly different levels of the thigh. However, in another investigation of old ACL tears there were no significant differences in the muscle CSA between the quadriceps or the vastus lateralis of both legs preoperatively (Wigerstad-Lossing et al 1988).

The preoperative iEMG registrations of the quadriceps of the injured leg were significantly lower than those of noninjured leg (II). The similar activation patterns of all three investigated parts of the quadriceps muscle suggest that the vastus lateralis, used for the muscle biopsy, is representative of the entire quadriceps muscle also in patients with ACL tear (II). The dependence of iEMG on the manoeuvre time is agreement with that found in knee extensors and plantar flexors in healthy subjects (Fugl-Meyer et al 1982, Johansson et al 1987). The electrical efficiency (mechanical work/iEMG) was similar in both legs indicating normal muscle function.

Despite these reasonably normal knee extensor muscle characteristics, the isokinetic performance (PT, CW, MP, and active ROM) of the injured leg was significantly lowered compared to the noninjured leg (I). Other investigations have reported similarly decreased values of mechanical output in patients with torn ACL (Murray et al 1984, Roth et al
The main explanation of this lowered mechanical output, and the morphological disturbances discussed above, appears to be changes in joint receptor afferent inflow due to rupture of the ACL leading to deficits in motor unit activation and synchronous function (I,II,III). In recent years several investigators have found evidence for the proprioceptive function and importance of the ACL. Mechanoreceptors have been identified in the ACL (Schutte et al 1987). Solomonow et al. (1987) presented evidence for a direct reflex arc from the ACL to the hamstring muscles and also for a secondary reflex arc from the mechanoreceptors in the muscles or joint capsule providing activation of the hamstrings and inhibition of the quadriceps muscle upon knee instability. Stretching of the ACL during arthrotomies in humans (Grüber et al 1988) has been reported to give muscular responses in the synergistic muscles emphasizing the proprioceptive function of this ligament. Experimental studies in the cat has shown that the posterior cruciate ligament plays an important "sensory" role in the regulation of muscular stiffness of the knee joint (Sojka et al 1988).

### Immobilization

When this investigation started in 1982, it was most common to immobilize patients with ACL reconstruction in a cast with various (10-60) degrees of knee flexion during the immediate postoperative phase (Eriksson et al 1979, Marshall et al 1979, Clancy et al 1982). Increased strain of the ACL has been found when using an angle of less than 30° of knee flexion during immobilization (Paulos et al 1981, Arms et al 1984). Restricted motion was also used by some orthopaedic surgeons usually after 1 to 3 weeks of casting (Häggmark et al 1979, Paulos et al 1981).

Both *in vitro* and *in vivo* studies in animals have shown that immobilization of a muscle under tension retards the protein degradation process and stimulates both the transport of amino acids into the muscle fibre and their incorporation into muscle protein (Goldberg et al 1975). Studies on rat soleus and extensor digitorum longus muscles have shown a decrease in muscle weight already one week after immobilization in a shortened position and a gain of weight using a lengthened position (Goldspink 1977). Light microscopical studies in rabbits have shown serious pathological changes in the soleus muscle fine structure already after one week of immobilization in a slackened state but few, if any, abnormalities were noted after three weeks of immobilization in a stretched state (Sjöström et al 1979).

Our patients were immobilized at 30° and 70° of knee flexion (30-group and 70-group), during the immediate postoperative phase (III). The exact increase in passive tension of the different heads of the quadriceps resulting from the increase in flexion from 30° to 70° is not known. However, in a pilot study the lengthening of the vastus lateralis measured during knee flexion from 30° to 70° was found to be 4 mm/50 mm of muscle length, i.e. 8% lengthening. Increase of knee joint flexion from 30° to 75° during
isometric contraction results in increased tension of the patellar ligament by 23% (Smidt 1973).

After 6 weeks of immobilization the microscopical investigation (III), using both light and electron microscopy, gave somewhat contradictory results at first sight. The muscle fibres of the 30-group were larger than those of the 70-group but qualitatively they showed a greater number of internal structural disturbances. The water content of the 30-group fibres was also increased, i.e. the protein proportion had decreased and the fibres showed clear signs of oedema compared to those of the 70-group i.e. the larger size of the muscle fibres of the 30-group was caused by pathological changes. Consequently, fibre size determinations alone without a qualitative evaluation do not give sufficient information about the true morphological status of the muscle. No change in mean fibre type proportions were found. Thus, no relative decrease of Type I fibre occurrence was noted. Häggmark et al (1981) found a selective fibre Type I atrophy after knee surgery and immobilization for 5 weeks in 10° to 15° of flexion. In a later investigation, the same authors (Häggmark et al. 1986), found a significant decrease in percentage of fibre Type I from 54 to 43%, in patients with knee ligament surgery and 5 weeks immobilization in 10-15° of flexion. Halkjær-Kristensen and Ingemann-Hansen (1985) also found a significant decrease in fibre Type I proportion from 42.3 to 37.2% in patients with medial collateral ligament injuries treated with a cast in 5-15° flexion for 5 weeks. Mean fibre area of both Type I and II were unchanged. On the contrary, Arvidsson et al (1986) in patients operated with an ACL reconstruction, did not find any significant changes in fibre Type I percentage after 5 weeks of immobilization in 45° of knee flexion. Mean fibre area showed a significant decrease in all groups except in female patients with electrical stimulation during the immobilization period. Wigerstad et al (1988) found no changes in fibre proportions or mean fibre areas after 6 weeks of immobilization in 20-30° flexion with concomitant electrical stimulation in patients with ACL reconstructions. No qualitative evaluations of the different muscle fibres were performed in any of these investigations.

Thigh circumference and computerized tomographic measurements of the various parts of the injured thigh showed significant differences between the two groups after immobilization; the 70-group having greater relative decrease in all respects, as shown in the results (III). Anthropometric measurements used by Halkjær-Kristensen and Ingemann-Hansen (1985) showed a 25% reduction in CSA of the quadriceps after 5 weeks cast in 5-15° of flexion. Using CT, Arvidsson et al (1986) in their patients with 45° immobilization during 6 weeks found significant decrease for quadriceps CSA varying between 13 to 31%. The greatest reduction was noted in females without electrical stimulation during the immobilization period. The greater decrease in quadriceps CSA in the present investigation compared to other cited studies might be explained by the fact that no training at all, or weightbearing, were
allowed during the 6 week immobilization period. Halkjær-Kristensen and Ingemann-Hansen (1985) allowed full weightbearing without crutches and used several different training programmes during immobilization, although without any different result in quadriceps CSA. Arvidsson et al (1986) and Wigerstad-Lossing et al (1988) used electrical stimulation without or with isometric contractions. The less decrease in total thigh CSA (13.2%) than in the total thigh muscle CSA (30.1%) is due to an increase in the subcutaneous tissue which is in accordance with other authors (Arvidsson et al 1986, Lopresti et al 1988).

The muscle performance was measured at 14 weeks postoperatively, and no significant differences were found between the 30- or 70-groups at this time as well as throughout the entire period including the followup (V).

Few studies have measured the mechanical output immediately after removal of the cast. Patients having electrical stimulation during casting after ACL reconstruction were shown to have a 60% decrease in isometric torque production measured immediately after 6 weeks of immobilization in comparison with preoperative values (Morrissey et al 1985). The control group had an 80% decrease and twelve weeks postoperatively all patients had a 50% decrease in mean isometric quadriceps torque. After 6 weeks of cast immobilization Wigerstad-Lossing et al (1988) found a 58% reduction of quadriceps isometric strength in the control group and 39% in the electrical stimulation group. In the present study (IV), the decrease in peak torque at fourteen weeks was 56% using isokinetic technique.

The knee function, activity level and clinical status of these subjects at the followup were not in any respect influenced by the different immobilization angles (V).

Physical rehabilitation
According to Paulos et al (1981) the physical rehabilitation of patients after ACL reconstruction is equally as important as the surgical procedure itself. Their programme with 5 phases of rehabilitation after ACL reconstruction started during the 1st postoperative week with isometric exercises and continued with progressive resistance training from the 12th week. Isokinetic exercises were contraindicated up until the 30th postoperative week. At the time when the present study was designed isokinetic training had recently been claimed to give greater muscle strength in healthy subjects (Pipes and Wilmore 1975, Smith and Melton 1981) and in patients with knee ligament injuries (Grimby et al 1980). Thus, it seemed important to evaluate the effects, if any, of early postoperative isokinetic training. Therefore, in this study a 6 week intensive training period was started at the 14th postoperative week with the patients allocated either to isokinetic training or to a combination of isometric and progressive resistance training (see subjects and material).
Morphologically after completion of the 6 week training period all biopsies still showed abnormalities resembling those seen preoperatively. Those patients who had been immobilized at 30° and had had nonisokinetic training showed both the "best" and the "worst" morphology (III). This suggests that the mode of immobilization and the training principle (isokinetic or combination training) are of less importance than the intensity of training. Surprisingly, after training there were still remaining morphological abnormalities that implied a non-optimal stimulation of the fibres, either by deficient afferent nervous inflow (see earlier in the discussion) or insufficient training. However, in a study by Ingemann-Hansen and Halkjær-Kristensen (1985) no fibre abnormalities could be detected after training although only a minority of their patients had ACL tears. No changes in fibre distribution or mean fibre area were shown in our patients (III). This is in agreement with other authors who started training either at a short (Ingemann-Hansen and Halkjær-Kristensen 1985) or at a long time (Grimby et al 1980, Thomee et al 1987) after knee ligament surgery. Several different progressive resistance and isokinetic training programmes were used in these investigations.

The patients had a significant decrease in CT measured quadriceps CSA of the injured compared to the noninjured leg after training i.e. 20 weeks postoperatively (IV). Compared to the measurement 6 weeks postoperatively a significant increase, independent upon mode of training, had occurred for all muscle areas (unpublished data). Ingemann-Hansen and Halkjær-Kristensen (1983) showed a significant increase in thigh volume after 4 weeks of training but still a significant difference between the two legs. Another study by the same authors (1985) using 5 different training programmes, also during 4 weeks, did not show any differences in CSA between the 5 programmes. Both these studies were made around 3 months postoperatively. Thomee et al (1987) also described a remaining decrease of 18% in quadriceps CSA after 8 weeks of training approximately 8 months postoperatively and a nonsignificant increase during the training period. Unfortunately the present study was not designed to make any measurements of the cross-sectional areas of the thigh later than 20 weeks postoperatively. Taken all parts together, it appears that at least quadriceps CSA increase is independent upon the content of the different training programme used. Furhtermore, the regaining of quadriceps muscle mass requires a very long time.

Isokinetic performance during single maximum and repetitive contraction was considerably decreased at the start of training (I,IV). Fatiguability, endurance level and cumulated work were in general regained after the intense training period (at 20 weeks postoperatively) while peak torque of single contractions still was significantly reduced. Since there was only a slight reduction of iEMG/t a deficient central nervous drive can hardly be blamed for the decrease in mechanical output. The very stable output/input balance (CW/iEMG) during all fatiguability/endurance tests suggests that the muscle fibre per se functions normally. Thus, the reduced mechanical output at the end of training
must be due to the above mentioned reduction in quadriceps muscle mass. The increase in iEMG/t, although nonsignificant, at the end of the one year of physical rehabilitation indicates that neuromuscular relearning is an important factor for late recovery after ACL reconstruction.

The gain in isokinetic output during the 6 week training period was independent upon the mode of training (IV). Ingemann-Hansen and Halkjaer-Kristensen (1983, 1985) who, in their investigations of knee injured patients used several different training programmes, could not show any significant differences between the results of the various programmes. These findings of isokinetic performance support the earlier statement (page 19) that the intensity and duration of training is more important than the training principle for the final results. One advantage in using the sophisticated training equipment now available at physical therapy departments and work out institutes could be that it makes it more fun to exercise.

The mechanical output at single contractions at one year postoperatively agrees reasonably well with the values recorded by several other investigators (Sandberg et al 1987, Lopresti et al 1988). However, by one year postoperatively the maximum isokinetic output of the injured leg had not only regained the preoperative value but even equalled the performance of the noninjured leg preoperatively. The noninjured leg also increased its performance, hence the significant difference between the two legs remained throughout the rehabilitation period. The increase of the noninjured leg can be explained by both cross-transfer (Moritani and deVries 1979) and/or increased physical activity (Halkjær-Kristensen and Ingemann-Hansen 1985). Only postoperative comparisons of mechanical output of the injured and noninjured legs does not show when the injured leg achieves a "normal" performance level.

Fatiguability/endurance levels at the end of the one year rehabilitation period were similar to those obtained in male elite orienteers and marathon runners (Johansson et al 1987, Lorentzon et al 1987). No study has been published showing these aspects of isokinetic performance in subjects with ACL tears. Start of isokinetic training before 30 weeks postoperatively (Paulos et al 1981) or use of isokinetic testing of muscle function before 10 months postoperatively (Arvidsson and Eriksson 1988 ) have been considered contraindicated because of the high tensions created in the ACL. However, others have started isokinetic training already one week after removal of the cast (Halkjær-Kristensen and Ingemann-Hansen 1985). In the present study no negative effects of isokinetic training or testing were noticed on stability or knee function later at followup (V).

**Followup**
The patients in this study had excellent or good result in 93% at a followup an average of 28 months postoperatively (V). This followup time is still short and it has been stated that extraarticular as well as intraarticular reconstructions of the ACL do deteriorate with time (Odensten et al 1983). However, no such deterioration was found in a study of patellar...
tendon reconstruction of the ACL evaluated both 2 and 5 years postoperatively (Sandberg and Balkfors 1988). Roth et al (1985) using both augmented and nonaugmented autografts with the Marshall technique, reported improved subjective function in 66-83% with 51-64 months followup.

Microscopically, there were still morphological abnormalities found in all biopsies but no changes in mean fibre size or fibre type proportions (III). Due to the low number of biopsies at followup (6) no conclusions can be drawn as to the influence of the two training programmes or the two immobilization angles on the morphological parameters. The morphological abnormalities seen were similar to those seen preoperatively. One can tentatively suggest that the proposed primary cause of these changes is the torn ACL resulting in disturbed nervous receptor function (cf above) not restituted by an ACL graft.

The isokinetic performance of the knee extensors at the followup was not significantly different from the preoperative values (V), i.e. a significant difference between the injured and noninjured leg still exists. Other followup studies show similar values (Arvidsson et al 1981, Roth et al 1985, Zarins and Rowe 1986).

No correlation was found between the isokinetic performance and knee function score. Such a correlation has previously been shown in patients with ACL tears treated conservatively (Tegner et al 1984) and surgically (Odensten et al 1983b). Our patients obviously improved their knee function because of an increased joint stability and not because of better muscular performance.

One of the main reasons for the followup study was to investigate whether the different treatments used during the postoperative period could affect the long term results. As has already been discussed no negative or specific positive effects were found on knee function, activity level, clinical stability and muscular performance that could be attributed to either the immobilization angles or the training programmes.

Some clinical applications of these findings are that, in case of an acute ACL repair the torn ends should always be adapted together with the augmentation tissue used, to restitute the proprioceptive function, as well as the stabilizing function of the ACL; isokinetic training and testing can be used safely after 3-4 months of physical rehabilitation; the intensity of the training is more important than the method of training. Further investigations of the influence of the proprioceptive inflow from the ACL on the extensor and flexor muscles around the knee joint are highly desirable and experimental studies are already in progress.
GENERAL SUMMARY AND CONCLUSIONS

Findings preoperatively
- A significant decrease in cross-sectional area of the quadriceps of the injured leg.
- Normal microscopical findings in more than half of the muscle biopsies from the vastus lateralis of the injured leg while the others showed abnormalities indicating nonoptimal activation.
- A significant reduction in isokinetic performance of the knee extensors of the injured leg.
- A significant reduction of electromyographic activity of the knee extensors, particularly m rectus femoris, of the injured leg. Change in knee joint receptor afferent inflow was suggested to be the reason for the reduced knee extensor performance.

Findings after 6 weeks of immobilization
- 70° of knee flexion resulted in larger relative reduction of thigh muscle cross-sectional area than in the 30° group
- Microscopically pronounced fibre reactions; 30° of knee flexion resulting in worse than 70°; intracellular oedema caused larger fibre size in the 30° group.

Findings after physical rehabilitation
- Still significantly decreased cross-sectional area of the quadriceps. The atrophy was most likely the cause of early postoperative loss of isokinetic performance.
- Compared to 6 weeks postoperatively there were less but still pronounced microscopical disturbances after intensive training.
- Almost complete recovery of performance loss (> 50% reduction initially) after 6 weeks of intensive training irrespective of training programme. Isokinetic training did not offer any specific advantage in the early muscular rehabilitation after ACL reconstruction.
- After one year maximum knee extensor performance was still unequal between the legs but the injured leg had achieved the normal preoperative noninjured value.
- Fatiguability/endurance level had improved over preoperative value.
- Contraction work/integrated EMG was stable throughout the one year rehabilitation while iEMG/t increased. Neuromuscular relearning appeared to be a sizable factor in late recovery.

Findings at followup
- 93% of the patients showed excellent/good clinical results.
- Clinical stability improved in 66% of the patients.
- Performance tests were normal in 79% of the patients
- Microscopical abnormalities indicating nonoptimal activation still existed
- Isokinetic knee extensor performance was still significantly reduced in the injured leg.
Independent upon primary knee immobilization angle or training programme no differences could be demonstrated with respect to stability, range of motion, function or isokinetic performance in these patients. Isokinetic training did not result in increased remaining instability. Thus the early instituted treatments aiming at rapid improvement of muscle structure and function are of no decisive importance in the long-term course of these patients.
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