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PRESS

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CONTENTS

LIST OF ORIGINAL PUBLICATIONS

The thesis is based on the following original papers, which will be referred to in the text by the Roman numerals (I–V):

I. Gapeyeva H., Ereline J., Pääsuke M., Eller A., Pintsaar A. Strength characteristics of knee extensors after arthroscopy. In: Ueda S., Nakamura R., Ishigami S. (Eds.) *The 8th World Congress of the International Rehabilitation Medicine Association (IRMA VIII).* T. II. Bologna: Monduzzi Editore, 1997, pp. 1253–1256

II. Eller A., Pintsaar A., Rohtlaan E.-M., Gapejeva J. Changes in functional characteristics and myosin heavy chain composition in m. vastus medialis before and after arthroscopy for knee injury. *Knee Surgery, Sports Traumatology and Arthroscopy,* 1999; 7: 107–110

III. Gapeyeva H., Pääsuke M., Ereline J., Pintsaar A., Eller A. Isokinetic torque deficit of knee extensor muscles after arthroscopic partial meniscectomy. *Knee Surgery, Sports Traumatology and Arthroscopy,* 2000; 8: 301–304

IV. Gapeyeva H., Pääsuke M., Vaher V., Ereline J., Pintsaar A., Eller A. Recovery of knee extensor muscle contractile properties after arthroscopic partial meniscectomy. *Journal of Sport Rehabilitation,* 2001; 10: 298–307

V. Gapeyeva H., Pääsuke M., Ereline J., Eller A., Pintsaar A. Isokinetic strength and tone of knee extensors following partial meniscectomy: one-year study. In: Martos E. (Ed.) *XXVII FIMS World Congress of Sports Medicine.* Bologna: Monduzzi Editore, 2002, pp. 245–251

This thesis contains unpublished data related to report V.

ABBREVIATIONS

ACL	anterior cruciate ligament
CNS	central nervous system
CRS	Cincinnati Rating System
CSA	cross-sectional area
EMG	electromyography
HRT_{ES}	half-relaxation time of electrically evoked tetanic contraction
MHC	myosin heavy chain
$MRFD_{ES}$	maximal rate of isometric force development during electrically evoked tetanic contraction
MRI	nuclear magnetic resonance imaging
MVC	maximal voluntary contraction
NMES	neuromuscular electrical stimulation
PT	peak torque
RF	*rectus femoris* muscle
RFF	frequency of damped oscillation of *rectus femoris* muscle
ROM	range of movement
VI	*vastus intermedius* muscle
VL	*vastus lateralis* muscle
VLF	frequency of damped oscillation of *vastus lateralis* muscle
VM	*vastus medialis* muscle
VMF	frequency of damped oscillation of *vastus medialis* muscle

1. INTRODUCTION

The first known operations on the meniscus were done in the late 1800s. In the 1950s, the advent of arthroscopy provided the orthopaedic surgeon with a sophisticated tool both for closed diagnosis of meniscal disorders and for their treatment. The first examination of a knee joint took place in 1918 by the Japanese surgeon K. Takagi. In 1962, M. Watanabe published data about the first arthroscopic meniscectomy — removal of a flap tear. The technique was quickly developed by R. Jackson. Total meniscectomy was advocated as recently as 1971 for meniscal pathology. With the development of the arthroscope, as well as the recognition of the importance of the menisci to knee function and load transmission, the role of partial meniscectomy has become much more viable. Surgical arthroscopy, including meniscectomy, ACL reconstruction, meniscal repair, and allograft reconstruction has gained wide acceptance throughout the world.

Meniscal injuries have a high incidence (7–30% of the knee injuries according to the data of different authors). Partial meniscectomy accounts for approximately 40% of the total arthroscopic procedures performed. It has been shown that partial medial or lateral meniscectomy leads to a significant increase in the risk of osteoarthritic changes in the operated knee joint. The knee extensor muscle weakness was observed previously after meniscal tears, whereas the maintenance of hamstring strength was noted.

Thigh muscle atrophy and strength deficit is the major problem in rehabilitation following meniscectomy. Traditional rehabilitation programmes give attention to returning to the activities of daily living but do not always prepare the individuals for recreational activities including running, turning, and jumping.

Most studies of changes in the force-generating capacity of the knee extensor muscles before and after arthroscopic meniscectomy have focused on maximum voluntary isometric or isokinetic strength deficits in the operated in relation to the non-operated extremity. Less attention has been paid to the changes in electrically evoked contractile characteristics and in the tone of the knee extensor muscles following arthroscopic meniscectomy. In order to solve these problems, the method of neuromuscular electrical stimulation (electrically evoked tetanic contraction characteristics) can be used to measure the force-generating capacity and time course of contraction and relaxation within the muscles independent of volition, skill, and motivation of the subject. Myotonometry allows to estimate the state of muscle tissue (muscle tone) and to estimate the rehabilitation process.

The present study was designed to evaluate the recovery of voluntary isometric and isokinetic strength, electrically evoked tetanic contraction and tone characteristics of the knee extensor muscle in 17–35 year-old moderately physically active subjects following arthroscopic partial meniscectomy.

2. REVIEW OF LITERATURE

2.1. Meniscal injuries: epidemiology, risks, causes, types, and symptoms

2.1.1. Epidemiology of injuries and risk factors

Knee joint injuries are reported to constitute 23–31% of injuries according to the data of different authors (Neumann *et al.*, 1969; Galasko *et al.*, 1982), and ranging from 18 to 50% of injuries in athletes (McKenzie *et al.*, 1985). Meniscal injuries form from 6.9 to 8.6% of knee injuries (2.7% overall risk per athlete per year); medial collateral ligament injuries — 24.5% of all knee injuries (8% overall risk per athlete per year); and ACL injuries — 8.3% (2.8% overall risk per athlete per year) (Kujala, 1986; Jackson *et al.*, 1991). Ligamental injuries account for 25–40% of all knee injuries (DeHaven and Lintner, 1986). The medial meniscus sustains more injuries than the lateral meniscus at a ratio of 3:1, but other authors place it as high as 8:1 and in miners at 20:1. The difference in ratios is correlated with the particular movements and positions of these varied professions and activities (Cailliet, 1992).

The results of Baker *et al.* (1985) indicated that the incidence of meniscal injury resulting in meniscectomy was 61 per 100, 000 population. The sex ratio was three males to one female. Medial versus lateral meniscus injury was 81 versus 19%. Their data showed that there are differences in the ratio of medial versus lateral meniscal disruption associated with specific sports activities (the predominance of medial meniscectomy was 90% in baseball, 78% in skiing, 75% in basketball and football, and 55% in wrestling).

There are opposite opinions in regard to constitutional and muscular inadequacy, ligamentous laxity, faulty stressful work habits, obesity, excessive knee *valgus* or *varus* that place unequal stress upon knee structures, and violent sports that contribute to meniscus tear and degenerative changes (Lysens *et al.*, 1984; Lorentzon, 1988; Cailliet, 1992).

More often meniscal injuries occur in athletes: football players, track-and-field athletes, alpine skiers, and tennis players (Hale and Mitchel, 1979; Olson, 1979). It is well documented that female athletes participating in jumping sports demonstrate a four- to six-fold higher incidence of knee injury than male athletes participating in the same sports (Whiteside, 1980; Zelisko *et al.*, 1982; Chandy and Grana, 1985; Engstrom *et al.*, 1991; Arendt and Dick, 1995).

Some reports attribute injury rate differences to physiological differences such as increased joint laxity among women (Haycock and Gilette, 1976; Zelisko *et al.*, 1982; Chandy and Grana, 1985; Huston and Wojtys, 1996) while others refute this claim (Weesner *et al.*, 1986). It has also been argued that anatomical differences in pelvic structure and lower extremity alignment (the Q-angle) may account for differences in injury rates for men and women (Haycock and Gilette, 1976; Zelisko *et al.*, 1982). Some reports have suggested that the hormone oestrogen is directly involved in increased injury rates in women (Zelisko *et al.*, 1982; Woitys *et al.*, 1998). However, Sallis *et al.* (2001) reported that no statistically significant gender difference was found for anatomical location of injury in seven similar sports (basketball, cross-country running, soccer, swimming, tennis, track, and water polo) for young athletes.

In other studies excessive height and weight have been found to predispose individuals to acute (Blyth and Mueller, 1974) and overuse (Watson, 1981; Kujala *et al.*, 1986) injuries. However, other authors (Jackson *et al.*, 1978; Lysens *et al.*, 1984) found no statistically significant differences between anthropometric data and acute and overuse sports injuries. A strong relationship has been found between overweight and the development of osteoarthritis, especially in the knees (Leach *et al.*, 1973; McGoey *et al.*, 1990). Taimela *et al.* (1990) suggest that the relationship between body size and injuries may be due to the high position of the centre of gravity or to length of the limbs. Greater limb length could produce greater leverage and thus more stress on the limb joints in situations that require a rapid change of direction.

A number of studies have indicated risks associated with position, experience, playing surface, footwear, and fitness level (Mueller and Blyth, 1974; Cahill and Griffith, 1978; Keene *et al.*, 1980; Nigg and Denote, 1980; Canale *et al.*, 1981; Jackson *et al.*, 1991). Many reports suggest that poor physical fitness and lack of practice may lead to an increased incidence of injuries (Nicholas, 1974, Wright, 1979). Untrained female athletes had a 3.6 times higher incidence of knee injury than trained female athletes and 4.8 times higher than male athletes (Hewett *et al.*, 1999).

These studies did not provide a basis for preventive action with regard to knee injuries. An area that is receiving much consideration is that of prophylactic knee bracing, which has became increasingly popular since 1984. Controversy surrounds this subject, with arguments being put forward both for (Hansen *et al.*, 1985; Baker *et al.*, 1987; Zarins and Adams, 1988) and against the bracing effects (Hewson *et al.*, 1986; Grace *et al.*, 1988).

2.1.2. Mechanisms, types, and symptoms of meniscal tear

The exact mechanism of meniscal injury is not always clearly ascertained by a careful history or an exacting examination. The menisci are frequently injured or torn as they became trapped, pinched or crushed between the femoral condyles and the tibial plateau by twisting activities during weight-bearing but can also be damaged by direct blows to the knee or chronic trauma (Davies *et al.*, 1980b).

The causative mechanism must be considered to be flexion and extension of the knee, combined with forceful internal or external rotation that occurs when the tibia is fixed to the ground in a weight-bearing posture; thus the leg cannot avoid or minimize the torsion stress. From the crouched position with knees fully or even hyperflexed the femur must internally rotate upon the tibia during re-extension to the erect posture. Another theory postulated to explain the mechanism of meniscal tear is that, combined with flexion and external rotation, a forced *valgus* of the knee occurs in which the medial joint space is opened (Cailliet, 1992).

Meniscal tears can be either traumatic or degenerative in nature. Meniscal tears are uncommon in persons under 10 years of age but become increasingly common during and after adolescence (Clark and Odgen, 1983). Degenerative tears can be found in as much as 60% of the population over age 65 (Noble and Hamblen, 1975). Most of these tears, however, are asymptomatic and occur in association with the degenerative joint disease. The changing patterns of meniscal injury with chronological age most likely correlate with normal alterations in collagen fiber orientation with ageing, as well as increasing intrasubstance degeneration (Noble and Hamblen, 1975).

Meniscal tears are classified into peripheral, middle and central tears (Weiss *et al.*, 1989). Meniscal injuries can be further classified on the basis of their tear patterns (Metcalf, 1991; Hinkin, 1995): (a) vertical or longitudinal (bucket-handle), (b) flap or oblique, (c) radial or transverse, (d) horizontal, (e) complex degenerative.

Most meniscal tears affect the medial meniscus and tend to involve the posterior horn. Meniscal tears are either partial or full along the meniscus thickness and stable or unstable. An unstable tear is one where the entire tear or a portion thereof can be displaced into the joint space. There it may become trapped, causing pain by traction at the meniscocapsular junction. It may be responsible for symptoms of catching, locking, and effusion (Dandy, 1981). Tears around the periphery of the meniscus or to the ligamentous attachments may heal because of the blood supply to this area. Tears involving the avascular body of the meniscus (in the outer 20 to 30% towards the periphery, or in the so called red-red zone) will not heal and usually result in persistent symptoms (Booher and Thibodeau, 1985).

2.2. Partial meniscectomy and post-traumatic changes in the knee

2.2.1. Partial meniscectomy procedure

Arthroscopic meniscal surgery is usually carried out if at least one of the following situations exists (Grøntvedt *et al.*, 1994): (a) typical symptoms of joint-line pain and catching, effusions, locking, and giving-way; (b) positive physical examination findings of localized joint-line tenderness, effusion, limitation of motion and meniscal catch signs; (c) articular symptoms that fail to respond to non-surgical treatment for 6–8 weeks; and (d) one should be aware of other sources of knee pain that occasionally mimic meniscal tears: the patellofemoral pain syndrome, popliteal tendinitis, *pes anserinus* tendinitis, the iliotibial band friction syndrome, *osteochondritis dissecans*, etc.

Depending of the severity of the injury, there are three options for the treatment of meniscal tear: simple observation, meniscectomy, and meniscal repair (Grøntvedt *et al.*, 1994). Tears that are stable, < 1 cm in length and do not cause significant mechanical symptoms may be treated by simple observation (Weiss *et al.*, 1989). Those tears that are unstable and contribute to mechanical symptoms are treated by operative intervention.

Partial meniscectomy is the most commonly performed arthroscopic procedure (Grøntvedt *et al.*, 1994; Rath and Richmond, 2000). They account for about 41% of the total arthroscopic procedures performed (Grøntvedt *et al.*, 1994). Metcalf (1988, 1991) has outlined principles for partial meniscectomy.

The torn central margins of the meniscus are removed during a partial meniscectomy, preserving the important circumferential outer fibres and capsule. O'Conner (1984) described the four goals of a partial resection: (1) only the torn portion of the meniscus that is catching or sliding into the central tibial femoral interface during weight-bearing is removed; (2) careful trimming and contouring of the remaining meniscal rim is done to help prevent further tearing; (3) preservation, if at all possible, of the capsular rim of the meniscus helps to maintain joint stability; (4) the normal adjacent articular cartilage is protected during the meniscal resection.

If a meniscal tear is extensive and fragmented, a partial meniscectomy cannot be performed and total meniscectomy may be done using arthroscopic instrumentation. Tears around the periphery of the meniscus or the ligamentous attachments (the peripheral one-third) may heal because of the blood supplies to this area using various techniques. Tears involving the avascular body of the meniscus will not heal and usually results in persistent symptoms (King, 1936; Booher and Thibodeau, 1985; Grøntvedt *et al.*, 1994). After examining the natural history of arthroscopic medial meniscectomy in knees with an isolated meniscal injury it was concluded that preoperative participation in sport was a predictor of a better outcome (Chatain *et al.*, 2001).

2.2.2. Biomechanics and function of menisci following meniscectomy

The menisci provide several integral elements to knee function, which include load transmission, shock absorption, joint lubrication, and joint nutrition and stability. The menisci act as a structural transition zone between the femoral condyles and tibial plateau. The menisci appear to transmit approximately 50% of the compressive load through a range of motion of 0 to 90 degrees (Shrive *et al.*, 1978; Radin *et al.*, 1984). The contact area is increased, protecting articular cartilage from high concentrations of stress. The circumferential collagen fibre orientation within the meniscus is uniquely suited to this capacity.

As the load is applied, the menisci will tend to extrude from between the articular surfaces of the femur and tibia. In order to resist this tendency, circumferential tension is developed along the collagen fibres of the meniscus as hoop stresses. The circumferential continuity of the peripheral rim of the meniscus is integral to the meniscal function. Partial meniscectomy, or bucket-handle tearing, will still preserve the meniscal function so long as the peripheral rim is intact. Conversely, if a radial tear extends to the periphery and interrupts the continuity of the meniscus, the load-transmitting properties of the meniscus are lost (Shrive *et al.*, 1978).

Fairbank (1948) was the first to significantly appreciate the load-bearing function of the meniscus with his observations in the post-meniscectomy knee. He documented an increase in degenerative changes of the articular surface after total meniscectomy, which he attributed to loss of meniscal function, and recognized the potential for long-term alterations in joint function and biomechanics after total meniscectomy. The tibial-femoral contact area decreased by up to 75% in post-meniscectomy knees (Baratz *et al.*, 1986). This decrease resulted in a 235% increase in contact stresses after total meniscectomy. Ahmed and Burke (1983) found a 40% increase in contact stresses. Other reports have been quite variable, with estimates of the increase in contact stress ranging from 450% to 700% (Shrive *et al.*, 1978). In contrast, partial meniscectomy results in only a 10% decrease in the contact area and a 65% increase in contact stress (Baratz *et al.*, 1986).

Joint stability is also affected by the menisci. The medial meniscus is recognized as a secondary stabilizer to anterior translation (Levi *et al.*, 1982). This becomes particularly important in the ACL-deficient knee, in which an increase in anterior translation after total meniscectomy has been demonstrated (Levi *et al.*, 1982). Consequently, the medial meniscus is prone to injury in the ACL-deficient knee as it attempts to limit anterior translation. The menisci have also been demonstrated to contribute to *varus/valgus* stability, as well as to internal and external rotational stability (Markolf *et al.*, 1981; Seales *et al.*, 1981).

Medial meniscal excursion was approximately 5.1 mm, and lateral meniscal excursion, 11.2 mm according to MRI. The posterior horn excursion has been noted to be less than that of the anterior horn, both medially and laterally (Thompson *et al.*, 1991). Most lateral meniscal motion occurs after 5 to 10 degrees of flexion, whereas most medial meniscal displacement occurs after 17 to 20 degrees of flexion (DePalma, 1954). The posterior oblique ligament is firmly attached to the posterior medial meniscus, thereby limiting its displacement and rotation. This increases the risk of injury to the medial meniscus. Conversely, the relatively increased mobility of the lateral meniscus is also responsible for the more frequent occurrence of injuries on the medial side.

2.2.3. Long-term results of partial meniscectomy

As technology advances, the majority of cases treated (50–80%) have a successful outcome, but controversy exists whether repair yields a normal and functional meniscus, thereby preventing osteoarthritis (Grøntvedt *et al.*, 1994). Later results of studies of Rockborn and Messner (2000) and Hoser *et al.* (2001) demonstrated a high incidence of degenerative changes, a high rate of re-operation — 29% after initial arthroscopic lateral meniscectomy, 20% after medial meniscectomy in the long term, and a relatively low functional outcome score.

With the loss of meniscus tissue the protective surfaces, or articular cartilage, covering the femur and tibia may begin to degenerate through bone on bone contact resulting in osteoarthritis (Fairbank, 1948; Lanzer and Komenda, 1990). Baratz *et al.* (1986) reported that after a partial meniscectomy, there is a 67% average increase in stress on the articular cartilage. More than 60% of patients who underwent a partial meniscectomy have clearly developed degenerative changes in the knee joint within 5 years of a meniscectomy (Bolano and Grana, 1993). Rangger *et al.* (1995) noted osteoarthritic deterioration in 48% of patients after arthroscopic partial meniscectomy. After seven years following meniscectomy joint space reduction was more common after initial meniscectomy than after open meniscal repair. After thirteen years the incidence and severity of arthrosis did not differ significantly between the two groups, even when successful repairs were compared to meniscectomy (Rockborn and Messner, 2000).

Male patients had better radiographic results than female patients (Burks *et al.*, 1997; Krüger-Franke *et al.*, 1999) but not better functional scores. The results of surgery of medial meniscus and lateral meniscus tear were not significantly different. Knees with a femoral-tibial anatomic alignment of >0 degree of *valgus* compared with < or =0 degree and that had undergone medial meniscectomy had significantly better radiographic results. Patients with ACL tears and meniscectomy did significantly more poorly than stable knee joints with meniscectomy in regard to radiographic grade change, Lysholm satisfaction index, Tegner level, and medial joint space narrowing (Burks *et al.*, 1997). Medial meniscectomy and the amount of meniscus removed were risk factors for postoperative radiographic change (Higuchi *et al.*, 2000).

Burks *et al.* (1997), Krüger-Franke *et al.* (1999) and Higuchi *et al.* (2000) showed that age, gender, the degree of cartilage degeneration, and any angular deformity of the knee joint at the time of operation had no significant relation and did not influence the radiological results.

However, other authors reported that meniscectomy, *varus* knee alignment at the follow-up evaluation, the presence of medial compartment cartilage degeneration at the time of the first arthroscopy, resection of the posterior one-third of the meniscus or medial rim resection and the age older than 30 years (Maletius and Messner, 1996; Rockborn and Gillquist, 1996) or 35 years

(Chatain *et al.*, 2001) at the time of the operation were associated with a higher incidence of osteoarthritis and were predisposed to a poor radiological result.

Complications following arthroscopy are rare (in the case of open meniscal repair the complication rate was reported approximately 25% (Plasschaert *et al.*, 1998). There have been reports of osteonecrosis of the knee in young (Santorini *et al.*, 1995; Rozbruch *et al.*, 1996) and older patients (41 to 79 years) (Johnson *et al.*, 2000), quadriceps tendon rupture (Viola *et al.*, 2001), popliteal pseudoaneurysms (Mullen and Jabaji, 2001; Kiss *et al.*, 2001) and popliteal nerve lesion (Rodeo *et al.*, 1993) after arthroscopic meniscectomy.

2.3. Knee extensor muscle function after meniscal injuries

2.3.1. Knee extensor muscle dysfunction following arthroscopic meniscectomy

Lower extremity neuromuscular function after operative or non-operative treatment of meniscal injury may be a very important prognosticator of future knee performance (Zimny and Wink, 1991). Researchers have documented the role of muscle activity in the knee joint protection by two pathways: (1) strain relief of the knee ligaments (Golgfuss *et al.*, 1973; Markolf *et al.*, 1978) and (2) impact absorption of load transmitted through the lower extremity (Winter, 1983; Farley and Gonzalez, 1990). These functions are achieved by generating resistance to knee motion (such as joint stiffness) through quadriceps, hamstring, and gastrocnemius muscle contractions. Golgfuss *et al.* (1973) demonstrated the strain-relieving effect of a quadriceps contraction on the medial structures of the knee. Markolf *et al.* (1978) emphasized the powerful protective effect of well-conditioned lower extremity muscles. They reported a tenfold increase in knee-joint stiffness when knee muscles were contracted.

Dysfunction of the knee extensor muscles is a frequently encountered problem in clinical practice. Apart from nervous lesions and certain inhibitory mechanisms, operative procedures may results in long-standing muscular insufficiency (Haffajee *et al.*, 1972).

Muscle function can be measured by a variety of methods characterized as the isoinertial, isokinetic, semi-isokinetic and isometric testing modalities (Osternig, 1986; Baker *et al.*, 1994; Fleck and Kraemer, 1997; Bohannon, 2001). Further, the contraction mode (concentric, eccentric, or isometric) and velocity may vary considerably in training and testing (Knuttgen and Kraemer, 1987; Hortobagyi and Katch, 1989).

Isometric and dynamic muscle actions are different physiological phenomena (Olson *et al.*, 1972; Osternig *et al.*, 1977; Duchateau and Hainaut, 1984; Hortobagyi *et al.*, 1987; Sale *et al.*, 1992; Young and Bilby, 1993; Baker *et al.*, 1994). One factor that must clearly be responsible for performance differences between isometric test and the dynamic test is the use of elastic strain energy during the dynamic test (Baker *et al.*, 1994). Young (1984) found that in isometric contraction, type II fibres might have about twice the specific strength of type I fibres.

The kinematics of the knee joint was directly and significantly correlated with the strength of the quadriceps in patients after ACL reconstruction. There was a clinically and statistically significant difference in the recovery of the quadriceps and gait parameters according to the type of operation that had been performed (Snyder-Mackler *et al.*, 1995).

Previously it was observed that knee extensor muscles cannot be fully activated during voluntary contractions following knee injuries (Hamberg *et al.*, 1983; Herzog and Suter, 1997). Many of authors noted the maintenance of hamstring strength following knee surgery (Vegso *et al.*, 1985; Durand *et al.*, 1991).

Hurley *et al.* (1994) noted that greater joint damage is associated with greater arthrogenic inhibition of motoneurons, quadriceps weakness, and joint instability. Huber *et al.* (1998) studied inhibition of quadriceps motoneurons of volleyball players by the interpolated twitch technique during isometric contractions at knee angles of 30 and 60 degrees from full extension. This technique involves applying an electrical stimulus to the voluntarily contracted quadriceps muscles to estimate the number of motor units not fully activated during the contraction. Previous knee joint injury did not affect the knee extensor isometric PT but produced a difference in the inhibition of motoneurons — the inhibition of motoneurons of quadriceps in legs with previous injuries was significantly lower than in legs with no previous injury. Moderate pain in the knee during the test did not affect the inhibition of motoneurons but was associated with reduced knee extensor isometric PT. Authors considered that the loss in knee extensors PT associated with pain might be caused by atrophy of the quadriceps as a consequence of the disrupted training routine. Athletes with previous knee injury were able to produce the same knee extensor isometric PT probably because of their ability to recruit the available motor units more completely, and it may compensate for the possible loss in muscle mass during the period of injury and detraining. The results of Cruz-Martinez *et al.* (2000) suggested that the decrement in activated motor units may cause the disproportionate weakness of the quadriceps muscle on the first days after immobilization.

Durand *et al.* (1993) showed that meniscal tears affect the motor control mechanisms involved in the submaximum locomotor activities (motion of hip, knee, and ankle in the sagittal plane and the EMG activities of five muscles at walking and stair climbing). Decrease in torque, EMG amplitude and EMG frequency of knee extensors found after knee ACL and meniscal injury is due to intra-articular and periarticular afferent processes (Engelhardt and Freiwald, 1997; Woitys and Huston, 2000). Locomotor abnormalities in movements and

VL and VM muscle activations were generally found in patients after medial meniscectomy with strength deficits greater than 25% (Moffet *et al.*, 1993).

Isokinetic strength deficits were found preoperatively and 3 and 8 weeks post-operatively in knee extensors after arthroscopic meniscectomy in comparison with a group of matched healthy subjects. These deficits were related to a tendency to lower activation levels of the VM but not the VL or RF muscles. No strength deficits were found in the knee flexors preoperatively or 3 and 8 weeks post-operatively (Durand *et al.*, 1991).

Kannus and Järvinen (1991) showed greater strength deficits at higher speeds of isokinetic movement in patients with medial ligament compartment. Zaccherotti *et al.* (1997) assessed the degree of recovery of quadriceps and hamstring isokinetic strength in athletes following arthroscopic ACL reconstruction by comparison with normal subjects after a 5-year follow-up using Cybex II at 1.05, 2.09 and 3.14 rad/s. The mean isokinetic PT deficit for patients treated by two methods was 3% and 6% versus the contralateral limb and 5% and 9% versus the controls, respectively.

Lorentzon *et al.* (1989) found no significant correlations between isokinetic performance and muscle size or qualitative morphology or morphometric data of the quadriceps muscle in patients with chronic ACL rupture and concluded that strength decrease cannot be explained by muscle atrophy or structural changes *per se*.

Atrophy developing in the quadriceps femoris muscle following knee injury is one of the serious problems not only in the field of orthopaedics but also in rehabilitation. However, the pathogenesis of this atrophy has not yet been elucidated. Atrophy of the quadriceps musculature is frequently associated with chronic knee injury. This atrophy may persist despite the patient's ability to return to athletic competition.

Baugher *et al.* (1984) found that clinical evidence of atrophy in ACL insufficient knee correlated with a relative decrease in the size of type II or fast twitch muscle fibres. Nakamura *et al.* (1986) noted the atrophy of type I fibres only in ACL and ACL plus meniscal injuries. Type II fibres were atrophied in patients with sustained meniscal injuries and with collateral ligament injuries. By contrast, Okada (1989) observed neither changes in the fibre type composition non neurogenic findings though its results confirmed the atrophy in VM muscle 4 weeks and in VL muscle 12 weeks after knee injuries (including meniscal injury) of rats.

Clinical examination of the knee joint and VM muscle biopsies preoperatively and 4 weeks post-operatively showed that after meniscectomy more marked quadriceps atrophy developed in the patients with a good preoperative muscle status, and the surface area of type I and II fibres of the operated patients diminished compared with the samples from the healthy volunteer controls (Karumo *et al.*, 1977). These authors observed that the earlier period of rehabilitation after knee surgery is characterized by particular immobilization of the joint and is associated with atrophy of slow twitch muscle fibres.

Some studies focused on the influence of muscle disuse on contractile properties. The results of Koryak (1995) suggest that muscle disuse is associated with both atrophy and a reduction in contractility in the development of maximal force and decreased central (motor) drive. The change in the muscle contractile properties may indicate changes in the kinetically active status of the muscle. Seki *et al.* (2001) studied the effects of joint immobilization on the contractile properties of first interosseous muscle. The twitch and tetanic contraction parameters evoked by percutaneous stimulation were tested before immobilization, after three and six weeks of immobilization and after a 6-week recovery period. The results suggested that the changes in contractile properties of the first interosseous muscle seen after immobilization are causally linked to the changes in firing rate modulation of muscle motoneurons.

However, the changes in the knee extensor muscle electrically evoked tetanic contraction characteristics after meniscectomy were not the object of systematic research.

2.3.2. Function of different parts of quadriceps muscle after knee injury

The major muscle of the knee extensor group is the quadriceps femoris, comprising four heads: the RF and three *vasti* muscles: the VM, VL and VI. All the four muscles converge into a common tendon that crosses the knee joint and is attached to the tibial tuberosity via the patella (Cailliet, 1992). The RF muscle always acts to generate a hip flexion movement and a knee extension movement (Zajac and Gordon, 1989). The RF muscle alone cannot fully extend the leg; the *vasti*, especially the VM, perform this function. The patella mechanically increases the efficacy of the extensor mechanism by improving leverage (Cailliet, 1992).

The VL muscle has been used for nearly 40 yrs to represent the quadriceps femoris in the physiological and biochemical studies of the human muscle. The findings of Trappe *et al.* (2001) supported the use of VL tissue to represent the quadriceps femoris muscle in research. Recently, non-invasive measures such as computed tomography (Rice *et al.*, 1989; Overend *et al.*, 1992), MRI (Narici *et al.*, 1988, 1992) and ultrasonography (Esformes *et al.*, 2002) have allowed for the accurate determination of muscle size. In particular, MRI resolution allows for the discrimination of a specific muscle group (e.g. the four muscles of the quadriceps femoris) (Narici *et al.*, 1992, 1996). Narici *et al.* (1988) showed that MVC force of knee extensors in a group of 24–31 year-old male subjects was 93% greater than that of knee flexors. The maximum CSA of knee extensors (at 2/3 upper femur height) was found to be 93% larger than CSA of knee flexors (at 1/3 lower femur height). However, when MVC force of knee extensors and flexors were standardized for their respective CSA, no significant difference was found between their stress: 80.1±N/cm^2 for knee extensors and 70.5±N/cm^2 for knee flexors.

The data of Trappe *et al.* (2001) from the study on ten young (3rd decade) and ten elderly (8th decade) subjects suggested that the percentage of total quadriceps femoris taken up by each muscle was similar between the young and the old (RF: 10 vs. 11%; VL: 33 vs. 33%; VI: 31 vs. 31%; VM: 26 vs. 25%) and that atrophy of each of the four muscles of the quadriceps femoris is similar in ageing men and women.

Galtier *et al.* (1995) noted that the innervation mode seems to be determinant to explain the two functions of VM muscle (knee extension and patellar alignment). The authors found two innervation possibilities — either only one nerve pedicle from the femoral nerve associated with cartilage degeneration located on the lateral facet of the patella, or two pedicles from the femoral nerve, associated with either no arthrosis or diffuse cartilage degeneration.

EMG studies have been performed to determine the role of VL and VM muscles in different knee pathologies (Reynolds *et al.*, 1983; Moller *et al.*, 1986; Voight and Wieder, 1991). Narici *et al.* (1989) studied the influence of 60 days training and 40 days-detraining in MVC, integrated EMG activity, and the CSA of the quadriceps muscle. Preferential hypertrophy of the VM and VI compared to those of the RF and VL muscles was observed.

However, there is not enough data in regard to the tone of RF, VL and VM muscles for knee joint injury.

2.3.2. Rehabilitation following arthroscopic meniscectomy

Guidelines for knee rehabilitation after conventional open meniscectomy are generally well known. Less agreement exists on rehabilitation following arthroscopic meniscectomy. Rehabilitation following knee surgery can be divided into four phases: the immediate post-operative period, early healing phase, late healing phase, and conditioning for return to pre-injury activity (Zarins *et al.*, 1985). A smaller incision causes less soft-tissue injury to skin, capsule, synovium, and other periarticular structures, resulting in less quadriceps inhibition and a more rapid recovery (Zarins *et al.*, 1985).

Following arthroscopic meniscectomy, patients are routinely able to walk without support within 1 to 3 days, return to work after 1 to 2 weeks, resume athletic training by 2 to 4 weeks, and return to competition in 3 to 4 weeks (St-Pierre, 1995). The recovery after arthroscopic meniscectomy may depend on the presence or absence of preoperative strength deficits, and thus, on whether the dominant or non-dominant leg is injured. In patients with no preoperative deficits and a normal post-surgery evolution full recovery may be expected within 6 weeks if pain and swelling are brought under control (St-Pierre, 1995).

Hurley *et al.* (1994) showed that intensive rehabilitation had little effect on either quadriceps arthrogenic muscle inhibition or atrophy. No difference was observed in the clinical and histochemical findings between the patients given routine and intensive physiotherapy (Karumo *et al.*, 1977). By contrast, other studies (Jokl *et al.*, 1989; Moffet *et al.*, 1994b; Vervest *et al.*, 1999) noted the significant residual strength deficits of knee extensors in untreated patients, who received no specific physiotherapy treatment but were given instructions in post-surgical management and prescribed exercises by the orthopaedic surgeon (two to three times larger than those in patients who participated in the supervised programme to accelerate knee strength recovery). A model for predicting physical therapy visits needed to achieve minimal functional goals after arthroscopic knee surgery was elaborated by O'Connor and Jackson (2001).

Depending on the intervention, strength deficits of the affected compared to the unaffected knee extensor muscles may persist. The study by Stam *et al.* (1993) did not support the general opinion that a strength imbalance of the knee extensors of both legs will result in further injury of the knee joint and suggested that the strength of knee extensors of the operated leg may increase and symmetry may be reached even if the training programme is ended and normal activities are resumed. According to another opinion, aggressive physiotherapy can eliminate strength deficits following knee injury through an increased ability to recruit the knee extensors in patients (Herzog and Suter, 1997). The review by Goodyear-Smith and Arrol (2001) noted one study which found that physiotherapy was beneficial for regaining muscle strength and on pain assessment but did not translate into functional improvement. Unfortunately, there is really no research on the human model to determine what intensity, frequency, and duration is too much or too little (Hasson, 1995). Subjects are dependent on their own experience and those of their coaches and therapists.

3. OBJECTIVES OF THE STUDY

The general objective of the present study was to evaluate the knee extensor muscle function in young moderately physically active subjects aged 17–35 years after arthroscopic partial meniscectomy.

More specifically, the present study had the following aims:
(1) to investigate the recovery of isometric maximal voluntary contraction force of the knee extensors following arthroscopic partial meniscectomy;
(2) to study the changes in isokinetic peak torque of the knee extensors in patients following arthroscopic partial meniscectomy;
(3) to assess the recovery of electrically evoked tetanic contraction characteristics of the knee extensors in patients following arthroscopic partial meniscectomy;
(4) to evaluate the changes in tone characteristics of *rectus femoris*, *vastus lateralis*, and *vastus medialis* muscles following arthroscopic partial meniscectomy.

The following research hypotheses were proposed:
(1) the post-operative recovery of isometric maximal voluntary contraction force and isokinetic peak torque of the knee extensors is prolonged compared with the recovery of electrically evoked tetanic contraction characteristics and tone characteristics in patients following partial meniscectomy;
(2) a significant difference exists in the time-course in the post-operative recovery of tone characteristics of three parts of the quadriceps muscle — *rectus femoris*, *vastus lateralis* and *vastus medialis* muscles in patients following partial meniscectomy.

4. MATERIALS AND METHODS

4.1. Subjects

4.1.1. Description of subjects

The data of 64 men and 25 women aged 17–35 years at the time of operation for arthroscopic partial medial meniscectomy, living in Tartu and Tallinn and the surrounding counties, were used (Table 1). The arthroscopic operation was performed by the same surgeon at the Hospital of University of Tartu. Thirty healthy subjects (15 males and 15 females) aged 18–23 years without any history of required injuries of the lower extremities were tested (dominant leg) on one occasion to serve as a control group (Study V).

All measurements were performed at the same time of day at the Laboratory of Kinesiology and Biomechanics, University of Tartu, during the period of five years.

Table 1. Anthropometric characteristics of the subjects (mean ± SE)

Papers	Age (yr)	Height (cm)	Body mass (kg)
Study I (Paper I)			
men (n=6)	22.5 ± 2.4	179.4 ± 2.4	74.2 ± 3.9
women (n=5)	21.7 ± 2.3	165.7 ± 0.9	60.7 ± 2.9
Study II (Paper II)			
men (n=8)	24.9 ± 3.1	182.0 ± 3.0	79.4 ± 4.3
women (n=5)	22.5 ± 2.5	168.0 ± 3.0	64.2 ± 2.3
Study III (Paper III)			
men (n=21)	26.4 ± 1.9	179.0 ± 1.7	77.5 ± 3.0
Study IV (Paper IV)			
men (n=14)	26.4 ± 2.3	179.6 ± 2.1	74.4 ± 3.5
Study V (Paper V and unpublished data, included in this thesis)			
men, patients (n=15)	24.9 ± 3.1	182.4 ± 0.3	79.4 ± 4.3
women, patients (n=15)	22.5 ± 2.5	168.7 ± 0.3	64.2 ± 2.3
men, controls (n=15)	21.5 ± 0.7	183.1 ± 0.4	84.6 ± 2.0
women, controls (n=15)	20.5 ± 0.6	169.2 ± 0.4	58.9 ± 1.9

Note: $p>0.05$ compared with the male patients and controls and the female patients and controls (Study V)

The subjects had been moderately physically active throughout their lives, undertaking aerobic exercises or sports games 3–4 times a week, whereas no competitive athletes were included. They had no orthopaedic or neurological limitations or contraindications for exercise testing or rehabilitation training. None of the patients had had any previous surgery on the knee.

In most cases the subjects dominant leg was right (86.7% in men and 80.0% in women) (Table 2, Study V). The patients' non-operated extremities had no orthopaedic or neurologic pathology.

Table 2. Data about the dominant leg injury in patients (Study V)

Dominant/non-dominant leg injury	Medial meniscal tear	
	n	%
Men		
Total	15	100.0
Dominant leg	13	86.7
Non-dominant leg	2	13.3
Women		
Total	15	100.0
Dominant leg	12	80.0
Non-dominant leg	3	20.0

Patients with concomitant injuries, for example, lesions of the lateral meniscus, cruciate ligaments, osteochondral injuries, or chondral damage in other components were excluded (Studies II–V). During the measurements the patients did not use any medication.

The period from knee injury to the operation was 0.5–40 months (Table 3, Studies I–V).

Table 3. Period from knee injury to the operation (Studies I–V)

Study	Period of symptoms before operation (months)	
	men	women
I	0.5–12	4–12
II	3.3 ± 1.4	16.0 ± 6.3 *
III	3.5 ± 1.6	–
IV	3.7 ± 1.2	–
V	3.3 ± 1.4	8.8 ± 2.1 *

Note: * $p<0.05$ as compared to male and female patients

The subjects were informed about the content of experiments and asked to give their consent in written form. The study carried the approval of the University Ethics Committee (minutes No. 74/43, 08/23/1999).

4.1.2. Rehabilitation programme

The patients were instructed to perform standard isometric exercises at home to restore strength of the knee extensor muscles. Immediately after the surgery and through the third post-operative week multiple-angle isometric and co-contraction exercises plus straight leg raising (in supine position, 20 to 70 degrees knee flexion, 10 s up and 10 s down) were used to limit knee muscle atrophy. Thereafter, in weeks 4–8 ergometry on stationary bicycle was recommended. Nine weeks after the surgery the therapeutic exercise procedures progressed gradually from submaximal to maximal to ensure normalcy of tibiofemoral and patellofemoral joint ROM and closed kinetic chain exercises (Timm, 1994). Three weeks later the open chain exercises were added. There was no physiotherapist supervision over the realization of this plan.

4.2. Study design

The subjects were given instructions and the strength testing and NMES procedures were demonstrated 24 to 48 hours before the first study. This was followed by a practical session to familiarize the subjects with the procedures. Prior to testing, each subject underwent a 10 min period of warm-up exercises (submaximal leg ergometry for 6 min at low intensity followed by stretch exercises).

Study I discussed changes in isometric MVC force and isokinetic PT (at 1.57, 3.14, and 4.71 rad/s) of the knee extensors before and one month after arthroscopic knee surgery.

Study II was devoted to measurement results of isometric MVC force of the knee extensors, thigh girth, and MHC composition in VM muscle before and 6 months after arthroscopically treated meniscal lesions.

Study III showed isokinetic PT deficit (at 1.05 and 3.14 rad/s) of the knee extensors 1, 3, and 6 months post-operatively after arthroscopic partial medial meniscectomy.

Study IV analysed the changes in electrically evoked tetanic contraction properties of the knee extensor muscles preoperatively, 2 weeks, 3 months and 6 months after arthroscopic partial meniscectomy.

In study V the complex analysis of changes in isokinetic PT (at 1.57, 3.14, and 4.71 rad/s) of the knee extensors and of the tone of RF, VM and VL muscles (Paper V) and of isometric MVC force and electrically evoked tetanic contraction characteristics of knee extensors was performed preoperatively, and 1, 3, 6 and 12 months post-operatively in patients with arthroscopic partial meniscectomy (unpublished data, included in this thesis). The data of patients were compared with controls.

4.3. Methods

4.3.1. Self-reported assessment of knee joint condition and function

Patient-reported measures for the assessment of knee joint pain and swelling were evaluated on a scale (Table 4, Studies IV and V).

Table 4. Pain and swelling scores (Stam *et al.*, 1992)

Pain score		**Swelling score**	
0	no pain	–	no clinical signs of intra-articular effusion
1	occasional moderate pain	±	clinical signs of intra-articular effusion
2	continuous moderate pain	+	patellar tap sign after compression of the supra-patellar pouch
3	occasional severe pain	++	patellar tap sign after compression of the supra-patellar pouch
4	continuous severe pain		

The modified knee questionnaire (CRS) was used in Study V (Table 5) for the assessment of knee joint symptoms and the level of its function.

Table 5. Scales of the modified knee questionnaire (CRS) (Noyes *et al.*, 1984)

Parameter	**Scale (points)**	
	max (the best)	**min (the worst)**
Symptoms		
Pain in knee joint	20	0
Swelling of knee joint	10	0
Giving-way	20	0
Function		
Overall activity level (fitness level)	20	0
Walking	10	2
Stairs climbing	5	1
Running activity	10	2
Jumping or twisting activities	5	1
Total	100	6

A B

Figure 1. Recording of isometric maximal voluntary contraction force and electrically evoked isometric tetanic contraction characteristics of the knee extensor muscles: position of a subject (A) and placement of elecrostimulation electrodes (B).

4.3.2. Isometric dynamometry

During the measurement of the isometric MVC force of the knee extensor muscles the subjects were seated in a dynamometric chair (Fig.1A) with the knee and hip angles equal to 90 and 110 deg, respectively (Pääsuke *et al.*, 1999). The body position of the subject was secured by Velcro belts placed over the chest and hip. The unilateral knee extension force was recorded by a standard strain-gauge transducer mounted inside a metal frame that was placed around the distal region of the ankle of the tested leg above the malleoli using a Velcro belt. The electrical signals from the strain-gauge transducer were digitized online (sampling frequency 1 kHz) and stored onto a hard disk of computer for further analysis.

Strong verbal encouragement was used to motivate the subjects. The instructions given were designed as follows — peak force is to be obtained as forcefully as possible extend the leg against a cuff fixed to the strain gauge system. The maximum contraction effort was held for approximately 3 s.

A rest period of 1 min was allowed between the attempts. Three maximal attempts were recorded and the best result was taken for further analysis (Studies I, II, IV, and V).

Depending on the variables measured, isometric tests of muscular function have been reported to have high test-retest reliability (Viitasalo *et al.*, 1980; Abernethy *et al.*, 1995). Some results suggest that isometric tests have limited value when assessing dynamic performance (Murphy and Wilson, 1996).

4.3.3. Isokinetic dynamometry

Isokinetic concentric PT of the knee extensors was recorded by a Cybex II dynamometer (Lumex Inc., USA). After calibrating the dynamometer, the subjects were seated in the adjustable chair and the thigh, hip, and chest were stabilized using straps. The rotation axis of the knee joint was aligned with the axis of the dynamometer lever arm. The force pad was placed 3–4 cm superior to the medial malleolus with the foot in the plantigrade position. The knee of the measured leg was positioned at a flexion of 90°. The ROM during the test was set using the goniometer through an arc at a knee angle of 90° to full extension. The subjects were instructed to hold their arms across the chest to further isolate knee joint extension movements. Verbal encouragement was given during every trial. The subjects were asked to produce knee extension as forcefully and quickly as possible through a complete ROM during the test.

Three attempts of unilateral concentric knee extension were carried out at low (1.05 or 1.57 rad/s), moderate (3.14 rad/s), and high (4.19 or 4.71 rad/s) angular velocities, and the one with the highest PT value was used for further analysis (Papers I, III and V). The trials proceeded from the lower angular velocity to the higher velocity. The non-operated leg was examined first. A rest period of 1 min was allowed between the attempts. All torque measurements were gravity corrected. The isokinetic knee extension PT deficit in the operated leg was calculated in relation to the non-operated leg as a percentage.

The perceived advantage of isokinetic assessment is easier to achieve measurement reliability and objectivity (i.e. there is greater control over velocity of motion, technique and extraneous movement). Furthermore, assessments of strength and power can be made within one contraction and avoiding the artificial strength-power dichotomy (Viitasalo *et al.*, 1980; Abernethy *et al.*, 1995; Dvir, 1996).

4.3.4. Neuromuscular electrical stimulation

The subjects' position in a specially designed dynamometric chair was the same as mentioned above (chapter 4.3.2, Fig. 1A).

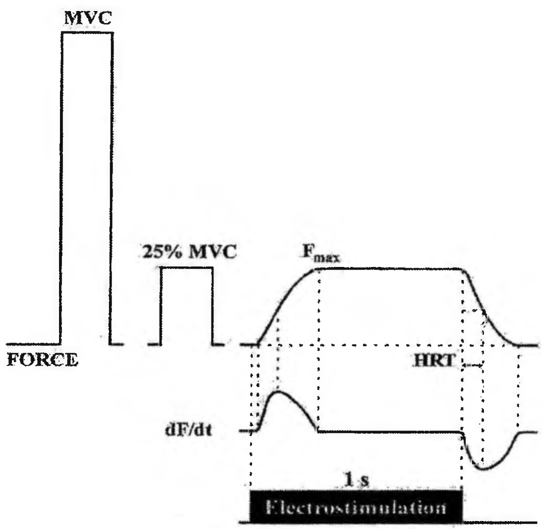
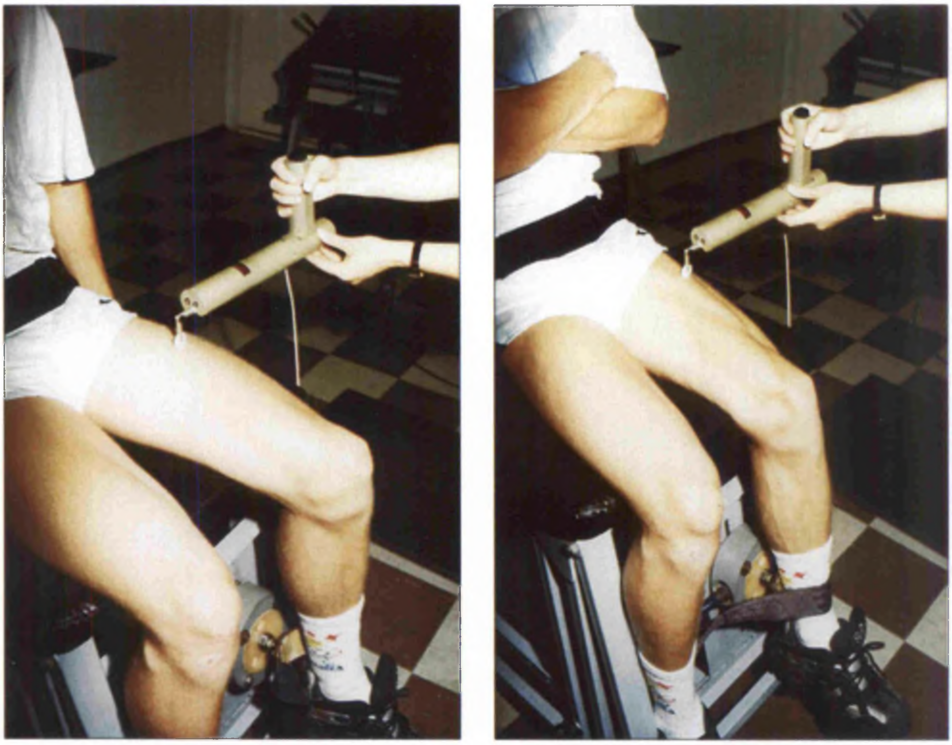


Figure 2. Schematic representation of the force-time curve for the analysis of isometric maximum voluntary contraction (MVC) and electrically evoked tetanic contraction of knee extensor muscles: F_{max} – maximum tetanic contraction force; dF/dt — the first derivate of force development, HRT – half-relaxation time.

During the recording of force-time and relaxation-time characteristics of the electrically evoked tetanic contraction of the knee extensor muscles, two large (23 × 7 cm) carbon rubber electrodes (Nemectron, Germany) were used (Fig. 1B). The anode was placed about 10 cm proximally from patella and cathode 10 cm proximally from the anode.



A **B**

Figure 3. Recording the tone characteristics of the *rectus femoris* muscle at rest (A) and during maximum voluntary isometric contraction (B).

Transcutaneous NMES from a standard electrostimulator (Medicor, Hungary) at a frequency of 50 Hz, impulse duration 1 ms and train duration 1 s was performed. Electrical stimulation impulses were monophasic rectangular waves. The stimulation voltage was adjusted to provide the tetanic force of about 25% from the isometric MVC force of the knee extensor muscles.

The interval between the final MVC force trial and the start of the electrical stimulation trials was 5 min in order to minimize the effects of muscle fatigue. Prior to stimulation subjects had been instructed to relax their musculature. The force-time curves of the electrically elicited tetanic contraction were analysed online. The next values were recorded (Fig. 2): $MRFD_{ES}$ — the first derivate (dF/dt) of the force development, and HRT_{ES} — the time of half of the decline in the tetanic force.

4.3.5. Myotonometry

The dynamometric chair and the subjects' position used for recording tone parameters of the knee extensor muscles were described previously (Fig. 1A). The tone parameters of three muscles — RF, VL and VM muscles at rest (Fig. 3A) and during MVC (Fig. 3B) — were studied by using a Myometer UT-90 elaborated at the University of Tartu (Vain, 1980, 2000).

The method is based on recording the damped oscillation of tissue after a short calibrated mechanical impulse (kick) on the muscle belly. This method has been used for the last 35 years in research of the condition of the peripheral part of the neuromuscular system (skeletal muscles) (Vasjukov, 1967; Pahomova, 1973; Vysochin, 1974).

The working principle of the Myometer is as follows. The testing end of the device is placed perpendicularly to the skin surface. The electromagnet of the testing end driver produces a short impulse, which is forwarded by means of the testing end to the contact area. For our study the duration of the impact on the contact area was 12 ms. The studied tissue responds to such a mechanical impact with damped oscillations during 0.3–0.5 s. The oscillations are recorded by the acceleration transducer, which is located on the testing end. The acceleration value of the first period of oscillations, calculated from the oscillogram, characterized the deformation of the tissue that was caused by the testing end. The local deformation of tissues caused by the testing end is 2–3 mm. The mechanical energy impulse created by the electromagnet of the Myometer is small and the same goes for the force deforming the tissue (up to 0.4 N). The oscillation graph is registered and analysed online (Fig. 4). The tone of the knee extensor muscle was estimated (Study V) by the frequency of muscle oscillation (ν, Hz) using the formula: $\nu = 1/T$, where T is the period of damped oscillation. This parameter characterizes the functional state of muscle fibres and connective tissue (Vain, 1993, 1995).

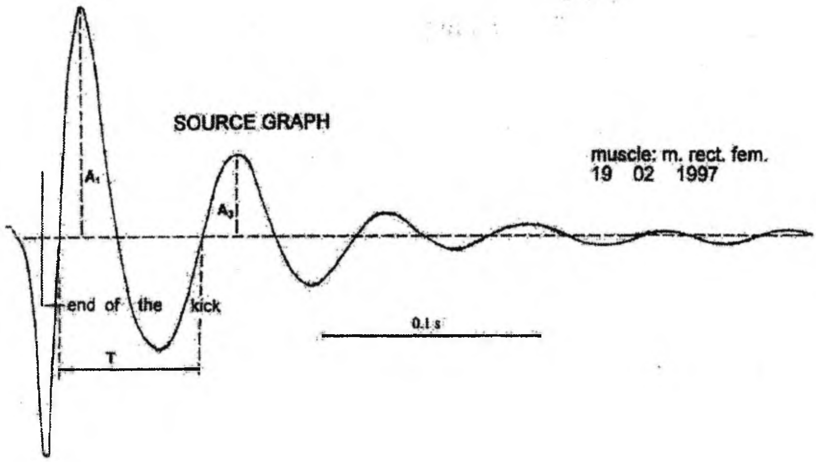


Figure 4. Scheme of experimental curve of damped oscillation for *rectus femoris* muscle at rest recorded by Myometer: T – period of damped oscillation and A_1, A_3 – 1st and 3rd amplitudes of damped oscillations.

The Myometer (Vain, 1980, 2000) has some advantages over other devices for tone recording, which are based on pressure measurement distributed in the research object by different hand-held mechanical and digital devices — tonometer Szirmai, hardness meter (Horikawa *et al.*, 1993; Ashina *et al.*, 1998), mechanical tissue compliance meters (Fisher, 1987), digital tissue compliance meter (Ylinen *et al.*, 1993), compliance-independent pressure transducer (Kovac *et al.*, 1994; Paris-Seeley *et al.*, 2000). The Myometer allows to estimate muscle tone (stiffness) during the short time of the measuring procedure and without significant influence on blood circulation in skeletal muscles. Kawchuk and Herzog (1995) showed that the reliability and accuracy of the hand-held tissue compliance meter was poor (0.22). Bizzini and Mannion (2002) investigated the reliability and validity of a hand-held Myometer and noted that the intraclass correlation coefficients ranged from 0.62 to 0.87 for natural oscillation frequency.

This device has previously been used for studies in different areas by researchers of the University of Tartu (Pääsuke, 1986; 1987; Gapeyeva, 1987; Gapeyeva *et al.*, 1997, 2000; Hein and Vain, 1998; Vain and Viir, 2000; Veldi, 2001).

4.3.6. Thigh girth measurement

There are many ways how the circumference around the hip region has been measured (Norton and Olds, 1996). Usually are measured the proximal, mid-thigh, and distal circumferences. Injuries of the knee joint often are associated with muscle atrophy in distal part of thigh. One common technique of thigh girth measurement in distal part is the following: the measuring tape is placed around the thigh just proximal to the femoral epicondyles (Callaway *et al.*, 1988).

In our study (Paper II) the circumferences of the thigh muscles were measured at 10 cm and 20 cm superior to the adductor tubercle on a line connecting the tubercle with the anterior superior iliac spine (Godfrey *et al.*, 1979). Each measurement was made with the subject standing, with the heels about 10 cm apart and the weight evenly distributed between both feet. An inelastic measuring tape (Lufkin, USA) was positioned horizontally around the hip. The zero end of the tape was placed below the measurement value. Each person was measured with the tape in complete contact with the skin but without compression of the soft tissues. The median values of triplicate measures on each thigh level that are most likely to produce accurate values were recorded (Ross and Marfell-Jones, 1991).

4.3.7. Statistical evaluation of the data

Standard statistical methods were used to calculate the mean and standard error of mean (±SE).

One-way analysis of variance (ANOVA) for repeated measures followed by Tukey *post hoc* comparisons was used to evaluate the differences between the injured and non-injured leg, between the groups and between the different testing periods (Studies III–V). The differences between the mean values of patients and controls were tested for significance by using the Student's *t*-test (Studies I–II and V).

The level of $p<0.05$ was selected to indicate statistical significance.

5. RESULTS

5.1. Self-reported measures of pain, swelling, and physical activity level

There was no significant difference (p>0.05) in the mean age, height, and body mass between male and female patients and controls of the corresponding group (Table 1, Study V).

Complaints of occasional moderate pain (pain score 1) were distributed as described in Paper IV and shown in Table 6 (Study V).

Table 6. Post-operative contribution of pain score (occasional moderate pain = 1 pt) and swelling of the operated knee following arthroscopic partial meniscectomy in men (n=15) and women (n=15)

Pain and swelling	Post-operatively							
	1 month		3 month		6 months		12 months	
	men	women	men	women	men	women	men	women
Pain								
Pain in general	1	2	–	2	–	1	–	–
Pain during testing	6	7	1	1	–	–	–	–
Intra-articular effusion								
–	2	1	12	11	15	15	15	15
±	7	8	3	4	0	0	0	0
+	6	6	0	0	0	0	0	0
++	0	0	0	0	0	0	0	0

The results of study IV suggested that post-operatively no patients scored 2, 3, or 4 when asked to record the pain. Two weeks after the surgery one patient experienced occasional moderate pain in general and six patients during the strength test. Three months after the surgery only one patient complained moderate pain during the strength test. Six months postoperatively no pain was experienced.

Two weeks after the surgery all patients had moderate to severe symptoms of intra-articular effusion. During the period of rehabilitation there was a tendency to a graduate reduction of swelling of the operated knee. Clinically detectable signs of intra-articular fluid were observed only in one patient three months after the surgery. Six months later postoperatively no swelling was found.

The results of modified knee questionnaire (CRS) are presented in Table 7 for patients following partial meniscectomy (Study V).

Table 7. The results of the modified knee questionnaire (CRS) following arthroscopic partial meniscectomy in men (n=15) and women (n=15)

Parameter	Points (mean ± SEM)	
	men	women
Before the surgery		
Pain in knee joint	13.50 ± 1.05	13.33 ± 0.84
Swelling of knee joint	9.00 ± 0.38	7.33 ± 0.42 xxx
Giving-way	20.00 ± 0.00	20.00 ± 0.00
Overall activity level	13.50 ± 0.73	13.33 ± 0.84
Walking	9.80 ± 0.08	9.82 ± 0.08
Stairs climbing	3.13 ± 0.13	3.50 ± 0.22
Running	6.25 ± 0.25	6.33 ± 0.33
Jumping or twisting	3.00 ± 0.19	3.17 ± 0.17
Total	78.37 ± 1.15	77.33 ± 1.69
1 month later		
Pain in knee joint	15.00 ± 0.65	15.33 ± 0.67
Swelling of knee joint	9.00 ± 0.38	9.00 ± 0.45 *
Giving-way	20.00 ± 0.78	20.00 ± 0.84
Overall activity level	13.00 ± 0.65	14.00 ± 0.89
Walking	10.00 ± 0.00	10.00 ± 0.00
Stairs climbing	3.25 ± 0.16	3.50 ± 0.22
Running	6.25 ± 0.25	6.33 ± 0.33
Jumping or twisting	3.13 ± 0.13	3.50 ± 0.22
Total	79.75 ± 0.82	82.33 ± 1.99 *
3 months later		
Pain in knee joint	15.75 ± 0.96	16.67 ± 1.23 *
Swelling of knee joint	9.25 ± 0.35	9.67 ± 0.33 ***
Giving-way	20.00 ± 0.00	20.00 ± 0.00
Overall activity level	16.50 ± 0.50 ** xxx	16.00 ± 1.79 **
Walking	10.00 ± 0.00	10.00 ± 0.00
Stairs climbing	3.88 ± 0.13 *** xx	4.17 ± 0.17 * x
Running	7.00 ± 0.38	8.33 ± 0.61 * x
Jumping or twisting	3.88 ± 0.13 * xxx	4.33 ± 0.21 *** x
Total	77.25 ± 8.84	86.17 ± 4.26 *
6 months later		
Pain in knee joint	17.50 ± 0.73 **	16.67 ± 1.25 *
Swelling of knee joint	10.00 ± 0.00 *	9.33 ± 0.67 *
Giving-way	19.50 ± 0.50 x	19.33 ± 0.67
Overall activity level	18.00 ± 0.76 ***	18.00 ± 0.89 **
Walking	10.00 ± 0.00	10.00 ± 0.00
Stairs climbing	4.38 ± 0.18 *** x	4.67 ± 0.21 **
Running	8.75 ± 0.37 *** xx	9.00 ± 0.68 **
Jumping or twisting	4.13 ± 0.13 ***	4.33 ± 0.21 ***
Total	92.25 ± 1.50 ***	91.17 ± 3.63 ***

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Table 7. (continued) The results of the modified knee questionnaire (CRS) following arthroscopic partial meniscectomy in men (n=15) and women (n=15)

Parameter	Points (mean ± SEM)	
	men	women
12 months later		
Pain in knee joint	18.00 ± 0.85 **	16.98 ± 0.87 **
Swelling of knee joint	10.00 ± 0.00 *	10.00 ± 0.00 ***
Giving-way	20.00 ± 0.00 *	20.00 ± 0.00
Overall activity level	19.50 ± 0.55 ***	17.83 ± 0.83 ***
Walking	10.00 ± 0.00	10.00 ± 0.00
Stairs climbing	4.87 ± 0.15 ***	4.95 ± 0.12 ***
Running	9.20 ± 0.28 ***	8.91 ± 0.34 ***
Jumping or twisting	4.59 ± 0.12 *** x	4. 37 ± 0.18 ***
Total	98.00 ± 1.47 *** x	92.00 ± 2.31 *** ¤

Note:

* p<0.05, ** p<0.01 and *** p<0.001 compared with values before the surgery;

x p<0.05; xx p<0.01 and xxx p<0.001 compared with values of the previous research stage;

¤ p<0.05, ¤¤ p<0.01 males and females compared.

Patient-reported measures of function (overall point score, CRS, Table 7) differed significantly between the groups of men and women only after 12 months following the surgery.

5.2. Isometric MVC force of knee extensors

Papers I, II, and IV include results in regard to changes in the isometric MVC force of the knee extensors following partial meniscectomy.

Study I showed a significant reduction (p<0.05) in the isometric MVC force of knee extensors of the injured leg before the surgery (20–26% lower than in the non-injured extremity). The voluntary strength characteristics of the injured leg were not recovered to level of the non-injured leg (522.3±55.1 and 715.2±49.7 N respectively in men; 354.0±38.4 and 478.0±32.7 N respectively in women, p<0.05) one month after the operation. The MVC force of the knee extensor muscles was considerably lower (p<0.05) in the injured limb than in the non-injured limb one month after arthroscopic surgery in patients with meniscal lesion (Study II).

The results of Study IV showed a significant decrease (p<0.05) in the isometric MVC force of the knee extensor muscles in the injured leg compared with the non-injured leg preoperatively, 2 weeks and 3 months post-operatively, which corresponded to the isometric strength deficits in the operated leg of 14.2%, 27.1%, and 17.5%, respectively.

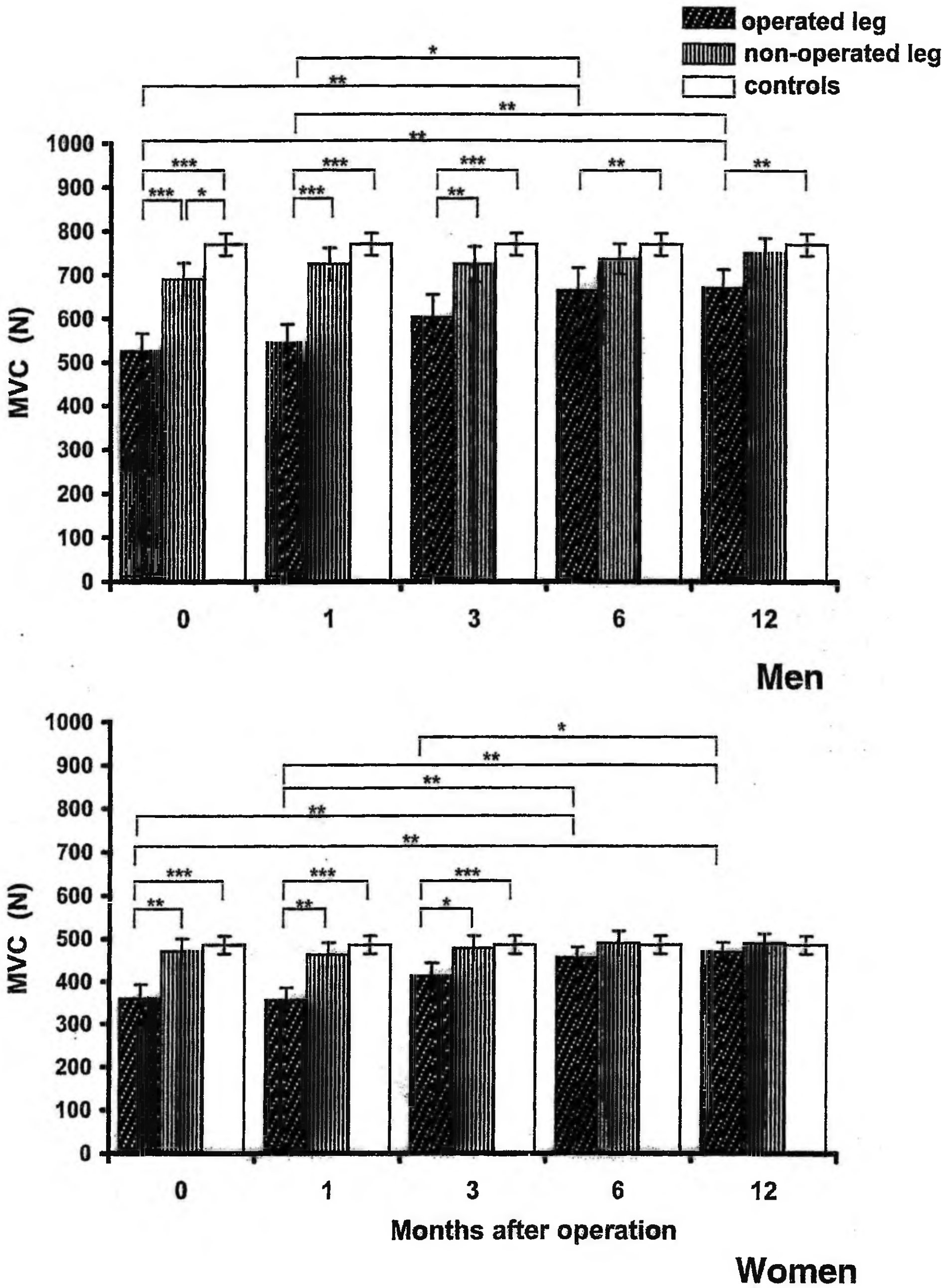

Figure 5. Isometric maximum voluntary contraction (MVC) force of knee extensors in patients following partial meniscectomy and controls (mean±SE).
Note: 0 – preoperative data; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

No significant differences ($p > 0.05$) in the MVC force between the operated and the non-operated leg were observed 6 months post-operatively.

The results of Study V suggested the presence of a significant ($p<0.05$) difference in the MVC force between the operated and the non-operated extremity during three months after the surgery in men and women (Fig. 5).

5.3. Isokinetic PT of knee extensors

Papers I, III and IV include results in regard to changes in isokinetic PT of knee extensors following partial meniscectomy.

Study I noted a significant decrease ($p<0.05$) in isokinetic PT values at angular velocity of 1.43 rad/s in the injured leg before the operation. One month after the operation an 8–10% increase of PT was found in the operated leg at this angular velocity as compared to before the surgery. At angular velocities of 3.06 and 4.59 rad/s no significant differences ($p>0.05$) of isokinetic PT between the pre- and post-operative levels were established.

A significant ($p<0.001$) isokinetic PT deficit of knee extensors in the operated leg at angular velocities of 1.05 rad/s and 3.14 rad/s was observed 1 month (28.6 and 31.0%, respectively) and 3 months (19.8 and 15.8%, respectively) post-operatively (Study III). Six months after a surgery a significant ($p<0.001$) isokinetic PT deficit (18.2%) of the knee extensor muscles in the operated leg was observed only at an angular velocity of 1.05 rad/s.

No significant differences ($p>0.05$) in isokinetic PT of knee extensors between the operated and non-operated leg at an angular velocity of 3.14 rad/s was found 6 months postoperatively.

Study V describes the changes in isokinetic PT during one year after arthroscopic partial meniscectomy. A significant ($p<0.05$) isokinetic PT deficit was found preoperatively in the injured leg as compared to non-injured leg in males and females at angular velocities of 1.57 and 3.14 rad/s and one month post-operatively in males and females at 1.57 rad/s and in males at 3.14 rad/s (Paper V, Fig. 2). No significant ($p>0.05$) pre- and post-operative isokinetic PT deficit of knee extensor muscle in the injured leg was found in males and females at an angular velocity of 4.71 rad/s.

The values of isokinetic PT deficit of knee extensor muscles in the injured leg before the surgery (41 and 43%, 31 and 42%, 31 and 30% at 1.57, 3.14 and 4.71 rad/s for men and women, respectively) decreased 12 months after the surgery (11%, 6 and 5%, 3% at 1.57, 3.14 and 4.71 rad/s, respectively).

Isokinetic PT of the knee extensor muscles of the operated leg recovered to the pre-operation level three months after arthroscopy. Isokinetic PT of the knee extensors of the injured leg differed significantly ($p<0.05$) 12 months post-operatively in men at angular velocity of 1.57 rad/s as compared with dominated leg of controls.

5.4. Electrically evoked tetanic contraction characteristics of knee extensors

The results of Study IV (Paper IV, Fig. 2) demonstrated a decrease ($p<0.05$) in $MRFD_{ES}$ of the tetanic contraction of knee extensor muscles in the injured leg compared with the non-injured leg preoperatively and two weeks post-operatively, which represented deficits in the operated leg of 17.1% and 17.8%, respectively. No significant differences ($p>0.05$) in $MRFD_{ES}$ of the knee extensor muscles were established between the operated and non-operated leg three and six months post-operatively.

The HRT_{ES} of knee extensor muscles in the injured leg was significantly prolonged ($p<0.05$) compared with the non-injured leg preoperatively and 2 weeks post-operatively. The prolongation of HRT_{ES} in the operated leg corresponded to 14.1% and 34.0%, respectively. No significant differences ($p>0.05$) in HRT_{ES} were found between the operated and non-operated leg three and six months post-operatively.

The results of study V showed that the characteristics of electrically evoked tetanic contraction — $MRFD_{ES}$ and HRT_{ES} — of knee extensor muscles of the injured lower extremity significantly differed ($p<0.05$) as compared to the non-injured extremity before the arthroscopic surgery and one month after the surgery in men and women (Fig. 6 and 7).

A significant prolongation ($p<0.05$) in HRT_{ES} of knee extensors was noted three months after the surgery in men. No significant differences ($p>0.05$) were observed in this characteristic between the operated and the non-operated extremity in women three months and in both men and women six and twelve months after the surgery (Fig.7).

5.5. The tone of *rectus femoris*, *vastus medialis* and *vastus lateralis* muscles

In Study V a significant decrease ($p<0.05$) was noted in the muscle tone of the injured leg at rest before arthroscopy, one month (in RF, VM and VL), and three months later (in VM and VL) in men and women as compared to the tone parameters of non-injured leg (Paper V, Fig. 3).

Prolongation of the recovery period for the VMF was observed for both groups of patients during MVC (Paper V, Fig. 4) and in women at rest as compared to RFF and VLF.

The tone characteristics during MVC of the VL muscle in the injured leg did not differ significantly ($p>0.05$) from the data of the non-injured leg. There was no significant difference ($p>0.05$) in the values of tone characteristics (of RFF, VMF and VLF) in the non-injured extremity of patients before and after the surgery as compared to the controls.

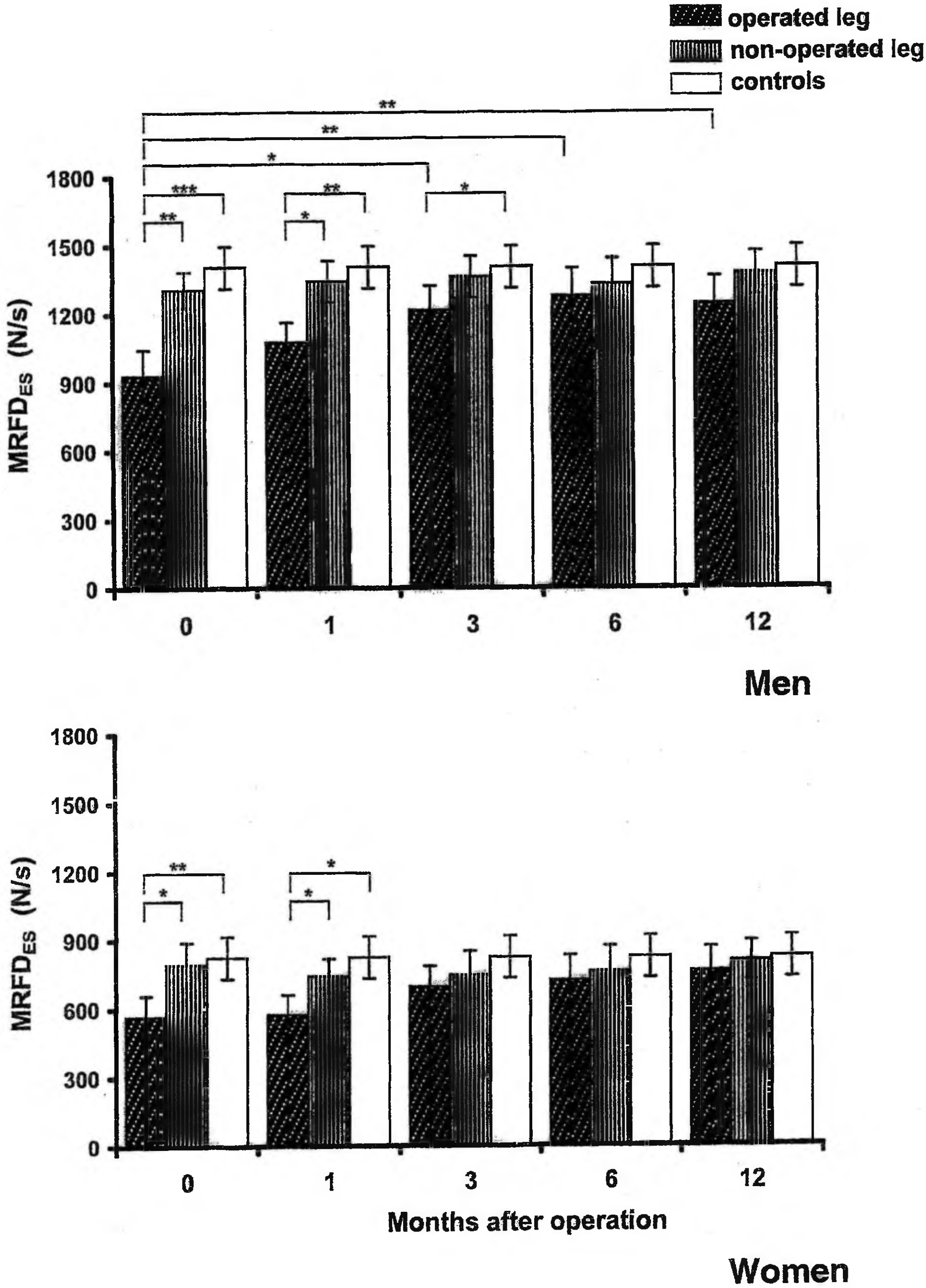

Figure 6. Maximum rate of force development of electrically evoked isometric tetanic contraction ($MRFD_{ES}$) of the knee extensor muscles in patients following partial meniscectomy and controls (mean ±SE).

Note: 0 – preoperative data; * $p<0.05$; ** $p<0.01$; *** $p<0.001$.

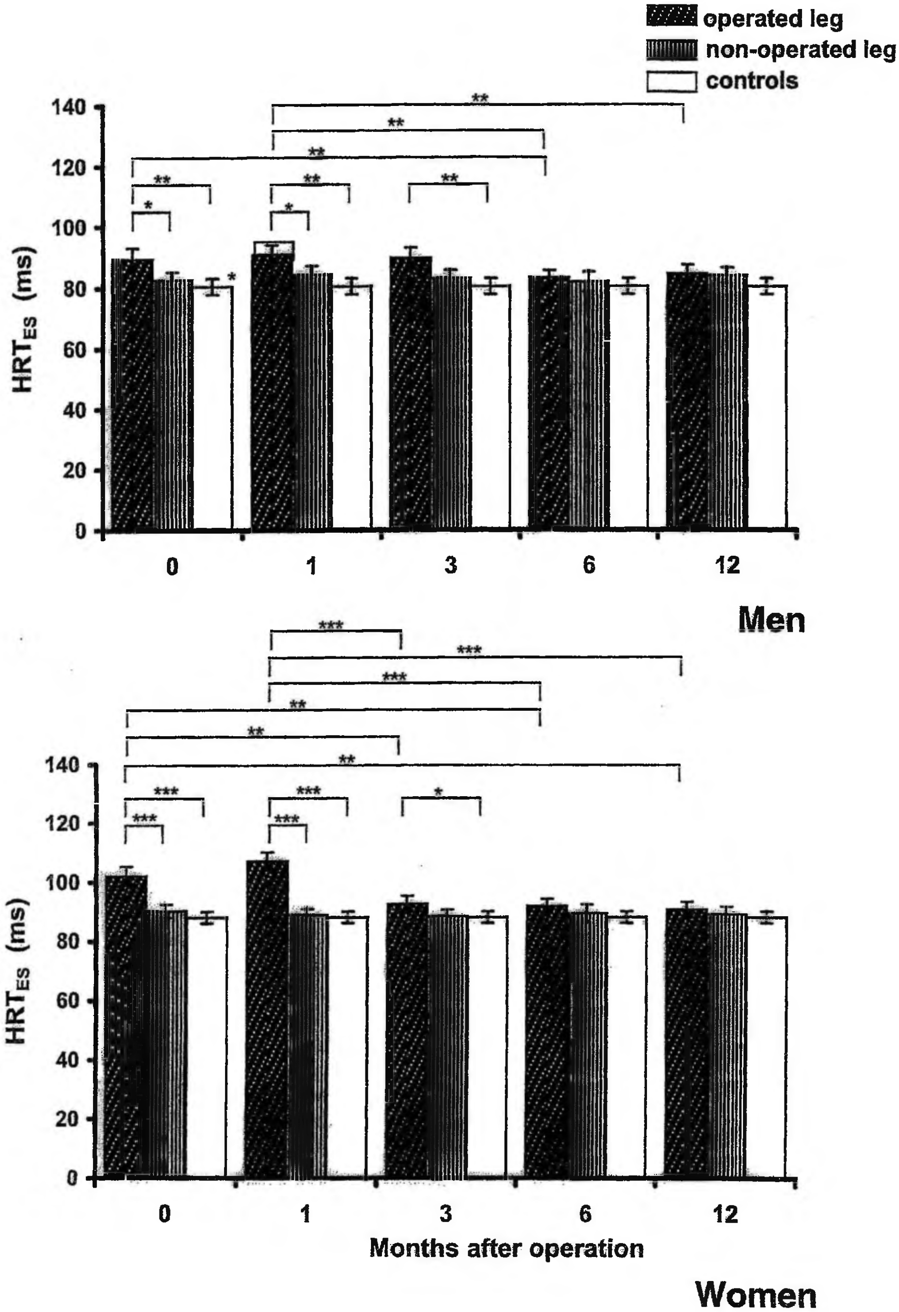

Figure 7. Half-relaxation time of electrically evoked isometric tetanic contraction (HRT_{ES}) of the knee extensor muscles in patients following partial meniscectomy and controls (mean ±SE).
Note: 0 – preoperative data; * p<0.05; ** p<0.01; *** p<0.001.

5.6. Thigh girth parameters

In Study II the thigh circumferences were compared in 13 arthroscopically treated patients with meniscal lesion, both men (n=8) and women (n=5) (mean age 28 years). A minimum tendency to a decrease in thigh girth was observed at 10 cm superior to the adductor tubercle in the injured extremity in men six months after the operation while no statistically significant differences (($p>0.05$) were noted between the thigh girths measured in the operated and non-operated extremities before and six months after the surgery.

6. DISCUSSION

6.1. Subjects

The present study showed that the period from the injury to the operation was significantly longer in women as compared to men (Studies II and V). The percentage of patients who experienced occasional moderate pain during the test decreased until 6.7% six months after the surgery. Our data (Studies IV and V, Table 4) support the observation of Stam *et al.* (1992), suggesting that the experience of pain is not a common finding in the patient groups.

Swelling of the knee, following an arthrotomy, is usually caused by the intra-articular fluid and is considered as a sign of traumatic arthritis (Stam *et al.*, 1992). In Study V 86% of men and 93% of women one month after the surgery; and 20% of men and 26% of women three months after the surgery had moderate to severe symptoms of intra-articular effusion. De Andrade *et al.* (1965) and Shakespeare *et al.* (1985) showed that isolated joint swelling, irrespective of pain, inhibits voluntary muscle action. Thus, the swelling of the knee joint of the patients in this study seems to be an important cause of decrease in the MVC force of the knee extensors. The results of the measurements of the active ROM of the knee in meniscectomy patients suggested a greater limitation of flexion and a smaller limitation of extension in the capsular pattern of the knee (Stam *et al.*, 1992).

According to Bargar *et al.*, (1980) and Levy *et al.*, (1982, 1989), we found that meniscal lesion had no effect on knee stability. Marcacci *et al.* (1999) noted the same effect for associated meniscal lesion.

A statistically significant increase (more than 20%) of the total value of points was noted in both groups of patients six months after the surgery in comparison with the data before the surgery (Study V). Jensen *et al.* (1999) used modified CRS scores as the main outcome measure in patients aged 18–45 years with the patellofemoral pain syndrome reported persistent pain on activity (mean 6.6 years) and at rest (mean 4.3 years). CRS scores at baselines were 56–68 points and 12 months after the treatment it increased up to 75.2 points. In our study (V) the mean overall point score for all the patients was higher than 90 points six and twelve months following the surgery.

These data are comparable with the results of Matava and Siegel (1997) and Siegel and Barber-Westin (1998), who reported 100% excellent results of modified CRS in patients with average post-operative scores of 98 points. There was a complication in study V, where only one woman (3.3% out of 30 patients) needed additional treatment. It can be concluded that all the patients showed significant improvement from their preoperative status and were able to return to an active lifestyle.

6.2. Post-operative recovery of voluntary isometric and isokinetic strength characteristics of knee extensors

The results of these studies indicated that isometric MVC force of the knee extensor muscles of the injured extremity decreased by comparison with the non-injured extremity in patients after partial meniscectomy. This finding is in full accordance with the results of the previous investigations which demonstrated that restricting the movement of the lower limbs after knee surgery or in the conservative treatment of sports injuries leads to atrophy of the knee joint muscle with concomitant loss of its strength (Miller, 1970; McDougall *et al.*, 1980). A prolonged period of time spent with diminished or no weight bearing has a deleterious effect on skeletal muscle function, with decreased protein synthesis, loss of muscle mass, and loss of voluntary strength (Berg *et al.*, 1991; Edgerton *et al.*, 1995).

Several authors reported the recovery of the isometric MVC force of the knee extensor muscles in the operated leg in patients with partial meniscectomy within a period of two months (Stam, 1990; Stam *et al.*, 1992; St-Pierre, 1995). Studies IV and V indicated a significant reduction of the isometric MVC force of the knee extensor muscles in the injured leg in relation to the non-injured leg after three months following arthroscopic knee surgery. The used rehabilitation programme after partial meniscectomy seems to be insufficient for effective recovery of voluntary strength of the knee extensor muscles.

The reduction of maximum voluntary force-generating capacity of the knee extensor muscles in the injured leg may be caused by several factors. Knee extensor muscles are closely related to the anatomy of the knee joint (the patella and the patellar tendon form a part of the knee joint) and instability within the knee can directly affect the quadriceps femoris muscle (Arvidsson *et al.*, 1981).

Muscular force production is determined not only by muscle cross-sectional area, muscle mass, and contractile characteristics of the muscle but also by central excitory drive. Full development of potential muscle tension requires maximal recruitment of the motoneurons of agonists and synergists and an effective inhibition of the motoneurons of antagonists (Sale, 1986).

The results of the study by Urbach *et al.* (1999) showed moderate but significant mean reduction in maximum voluntary activation of the knee extensor muscles in both the injured and uninjured side in comparison with the controls. The deficit of isometric muscle strength on the injured side compared to that of the controls was explained by the voluntary activation deficit and a true muscle weakness. The diminished muscle strength of the uninjured side was explained sufficiently by the voluntary activation deficit alone.

Several authors have showed significant isokinetic PT deficit of the knee extensor muscles in the injured leg in patients with arthroscopic meniscectomy (Hamberg *et al.*, 1983; Stam *et al.*, 1990; 1992, 1993; Moffet *et al.*, 1994a; St-Pierre, 1995). Studies I and III indicated a significant isokinetic PT deficit of the knee extensor muscles in the operated leg one month after the arthroscopic surgery of the knee, which varied in testing at low (1.05 rad/s) and intermediate (3.14 rad/s) angular velocities from 28.6% to 31.0%. This finding is in general agreement with the previously published results by Stam *et al.* (1992). These authors observed in patients with meniscectomy a PT deficit in the knee extensor muscles of the injured leg compared with the non-injured leg in testing at an angular velocity of 1.57 rad/s one month and three months post-operatively (a 30% and 21%, respectively). However, Patel *et al.* (1982) found markedly lower isokinetic PT deficit of the knee extensor muscles in the operated leg (12%) in patients with arthroscopic meniscectomy one month post-operatively. It has been reported that the acceptable muscle strength deficit in the operated leg as the threshold for clinical significance is 10–15% (Grace, 1985; Wrigley and Grant, 1998).

The results of study V showed that the isokinetic PT deficit in the injured leg, which was the highest at 1.57 rad/s (41 and 43% for males and females, before the surgery, respectively), decreased 12 months after the surgery (11% in both groups). In the study of Stam (1990) the isokinetic PT deficit in the injured leg as compared with that in the non-injured leg was significant one month but not three months post-operatively. Isokinetic PT of the operated leg following meniscectomy improved rapidly during the 8 weeks of training, and an imbalance of the knee extensors of more than 10% remained after this period. Attaining symmetrical knee extensor torque takes more time. Campbell and Glenn (1979) found a 10% deficit for isometric and 16% deficit for isokinetic (1.05 rad/s) knee extension in patients 5 to 15 months after meniscectomy.

The information in regard to spontaneous recovery (no supervised training) of muscle torques during the first three months after arthroscopic partial meniscectomy was used to plan a clinical trial investigating the effects of rehabilitation following arthroscopic meniscectomy. Matthews and St-Pierre (1996) concluded that although the quadriceps may recover to the preoperative level by 4–6 weeks following partial meniscectomy, further the recovery does not appear to be possible without training as the quadriceps remains weaker than the contralateral side up to 12 weeks after the surgery.

The major finding of this study (Papers III and V) was the markedly higher difference in isokinetic PT of the knee extensor muscles between the injured and non-injured leg three and six months post-operatively at low rather than intermediate testing velocities. The results of the present study are compatible with the previous data, in which a higher isometric than isokinetic torque and a decreasing torque with an increasing isokinetic velocity was shown for the knee extensor muscles (Osternig, 1975; Perrin, 1993). Thorstensson *et al.* (1977) found a correlation between the maximum torque produced at the highest angular velocity and the percentage of the relative area of type II fibres. Type II fibre atrophy influenced the decrease in torque with increased angular velocity.

It is known that slow- and intermediate-velocity concentric isokinetic contractions differ by recruitment of the motor units. During slow-velocity concentric contractions the high resistance induced by the isokinetic dynamometer implies maximum muscle activation for the given velocity throughout the ROM (Wrigley and Grant, 1998), and a great number of both slow and fast motor units are recruited (Thorstensson *et al.*, 1977; Faulkner *et al.*, 1986). In contrast, during intermediate-velocity concentric isokinetic contraction, the lower resistance induced by the isokinetic dynamometer limits significant muscle activation that is involved primarily only at the beginning (agonists) and at the end (antagonists) of the ROM (Wrigley and Grant, 1998). At faster speeds of contraction, force production is closely related to the proportion of fast motor units within the mixed muscle (Yates, 1981; Faulkner *et al.*, 1986; Veldhuizen *et al.*, 1993). An impaired central drive would therefore be associated with reduced isokinetic muscle performance in the operated leg more at slower than higher testing velocities.

Reduced muscle strength may occur if the patient avoids normal use of the extremity as a consequence of pain. The results of study IV indicated that approximately 40% of patients experienced occasional moderate pain during strength testing two weeks after surgery. Thus, the post-operative deficit in maximum voluntary force-generating capacity of the knee extensor muscles in the operated leg is partly due to the impaired central excitory drive.

The results of studies IV and V indicated that all patients had symptoms of moderate to severe swelling of the knee during the early phase of rehabilitation after the surgery. This is in good agreement with the previous reports of Stam *et al.* (1992). These symptoms may inhibit the voluntary expression of muscle strength (Nicholas *et al.*, 1976; Seto *et al.*, 1988).

The results (Study V) showed a lower level of physical activity of patients before and three months after the surgery as compared to the data 12 months later (CRS scores). The difference in post-operative isometric and isokinetic PT deficits of the knee extensor muscles of the injured leg in testing at different angular velocities may be caused by several factors. Surgery and immobilization are associated with an immediate atrophy of slow-twitch muscle fibres while after a long-term disuse of the knee joint; the atrophy of fast-twitch muscle fibres may become more dominating (Häggmark *et al.*, 1981; Eriksson, 1981; Nakamura *et al.*, 1986: Veldhuizen *et al.*, 1993). Only part of the voluntary muscle strength deficit of the injured leg can be attributed to structural atrophy. Muscular force production is determined significantly by the central excitory drive. Full development of potential muscle tension requires maximum recruitment of the motoneurons of agonists and synergists and an effective inhibition of the motoneurons of antagonists (Sale, 1986).

6.3. Post-operative recovery of electrically evoked tetanic contraction characteristics of knee extensors

This study showed a significant reduction in the electrically evoked force-generating capacity of the knee extensor muscles in the operated leg, as estimated by the $MRFD_{ES}$, preoperatively and following the first two weeks (Study IV), and one month (Study V) after arthroscopic knee surgery. The maximal rate of force development has important functional consequences as it determines the force that can be generated in the early phase of muscle contraction (0–200 ms). It is well documented that the rate of muscle force development is closely related to the speed of Ca^{2+} release by the sarcoplasmic reticulum and the Ca^{2+} sensitivity of contractile proteins as well as myosin ATP-ase activity and the rate of formation of cross-bridges between actin and myosin (Barany, 1967; Blinks *et al.*, 1978; Belcastro *et al.*, 1980; Lewis *et al.*, 1986).

The properties of muscle contraction that depend on the MHC isoform composition decrease in an atrophied muscle (Jokl and Konstadt, 1983). Fauteck and Kandarian (1995) noted the important role of MHC composition in myosin ATP-ase activity and muscle fibre shortening velocity. Eller *et al.* (1999) showed that six months after an arthroscopic knee surgery the proportion of MHC I (slow) isoform composition decreased from 59.4 to 48% in the VM muscle, which consists mainly of oxidative muscle fibres and the slow MHC I isoform (Jokl and Konstadt, 1983; Diffee *et al.*, 1993). Gerber *et al.* (1985) noted a decrease in fibre size for all fibre types and hence no shift in the fibre type in patients suffering from a 10% of quadriceps atrophy of the injured extremity.

It is well known that the immobilization is linked with a decreased force-generating capacity of muscles. Davies *et al.*, (1987) indicated that the electrically evoked tetanic contraction at 50 Hz and MVC force of the *triceps surae* muscle were significantly reduced following voluntary (plaster) immobilization in young subjects (mean age 19.4 yr) and it was associated with a 10% decrease in the CSA of estimated muscle. Thus, the electrically evoked force-generating capacity of the knee extensor muscles of the injured leg may be reduced largely due to leg immobilization and muscle atrophy.

In the present study, a marked prolongation in half-relaxation time of the electrically evoked tetanic contraction, as an indication of the time course of muscle relaxation, was observed in the knee extensor muscles of the operated leg compared with the non-operated extremity preoperatively and after the first two weeks (Study IV) and after one month (Study V) of recovery following arthroscopic knee surgery. Two main factors have been described as responsible for the duration and rate of muscle relaxation: sarcoplasmic reticulum Ca^{2+} uptake and the rate of cross-bridge kinetics (Dux, 1993). The prolonged half-relaxation time could suggest a decreased efficiency in the function of the sarcoplasmic reticulum.

6.4. Post-operative changes in tone characteristics of knee extensors

The results of study V demonstrated a significant decrease in tone at rest and during MVC of the quadriceps muscle in the injured extremity before arthroscopy, one month, and three months later (for VM and VL) in men and women as compared to non-injured leg muscles. The study by Durand *et al.* (1991) showed a tendency to lower activation levels of the VM muscle but not the VL or RF muscles after arthroscopic meniscectomy.

A convenient method to document atrophy is to measure thigh circumference at the same level in both legs. Another method used to reveal atrophy is to note the character of the muscle tone during MVC of the quadriceps, especially of the VM muscle (which is the most sensitive to disuse). The involved leg may have a noticeably decreased muscle size and tone (Davies *et al.*, 1980a; Derscheid and Malone, 1980).

It has been proposed that muscle tone comprises at least two mechanisms: a) a reflex, neurogenic (extrinsic) tone that is graded by reflex pathways and mediated by action potentials, and b) a resting, myogenic (intrinsic) tone that is not mediated by conducted action potentials but it depends upon local conditions in the muscle and is given by the number of sarcomeres and their mean length (Hnik, 1986). The molecular rearrangement in the muscle may involve the development of stable bonds between actin and myosin filaments. In the case of inactivity the number of bonds increases and hence the stiffness of the muscle increases. However, during the brief stretch period of physical activity many of the bonds are broken and muscle tone (stiffness) decreases (Hagbarth *et al.*, 1985; Wiegner, 1987; Lakie and Robson, 1988a,b; Proske *et al.*, 1993).

Previous studies demonstrated a decrease in the tone of muscles participating in knee joint movement both at rest and during MVC caused by trauma (Gapeyeva, 1987; Gapeyeva *et al.*, 1997).

The tone of RF, VM and VL muscles of injured extremity at rest and during MVC had a tendency to increase one and three months after the operation in comparison with the preoperative period. In the case of the physiological increase in muscular stiffness the endo-, peri-, and epimyseum are under a higher mechanical strain, which increases the elasticity of their collagenous fibres (Purslow, 1989; Purslow and Duance, 1991).

Most authors confirm the high susceptibility of the VM muscle, which belongs to antigravity muscle crossing one single joint, to the effects of inactivity due to disuse (Gerber *et al.*, 1985). The amount of connective tissue is increased in the atrophic muscle and the surrounding periarticular tissue, which may lead into the vicious cycle of musculoskeletal degeneration (Appel, 1990). Electron microscopy showed an increase in intracellular fat but no change in mitochondrial volume density or capillarization (Gerber *et al.*, 1985).

One might pose the question about the influence of skinfold thickness on the recorded characteristics of skeletal muscle tone. In our previous study (Gapeyeva *et al.*, 2000) the characteristics of the tone of four skeletal muscles (*tibialis anterior*, *rectus femoris*, *gastrocnemius*, and *biceps femoris*) and skinfold thickness of the above mentioned muscles were recorded in two groups of girls aged 15–17 years, who were physically moderately active and had no health problems. The first group comprised girls with the skinfold thickness above the RF muscle of more than or equal to 12 mm; the second group was composed of girls with the skinfold thickness of less than 12 mm. The regression analysis where the skinfold thickness above the muscles and the Quetellet' index were used as dependent factors, and the tone characteristics in the defined state as an argument, showed in some cases the percentage of the prognosis for model description between 0 and 25. It can be concluded that subcutaneous fat thickness did not influence significantly the characteristics of the muscle tone recorded by this type of myotonometer (Vain, 2000).

6.5. Thigh girth

There was a minimal tendency for thigh girth decrease at 10 cm superior to the adductor tubercle in the injured extremity (Study II) as compared to the non-injured extremity.

The duration of the period from injury to surgery influences the level of thigh muscle atrophy. Atrophy of the thigh will usually be present if the knee injury is a chronic problem. The study by Moffet *et al.* (1994a) suggested the presence of thigh atrophy 0.5–3 cm (20 cm above the lateral joint line) preoperatively in men aged 22–56 years with medial meniscus tear (mean duration of symptoms 25.7 months, range 0.5–195 months). Associated degenerative changes of the articular cartilage were observed at arthroscopy in 10 patients (29.4%) from this group.

As increased muscular activity leads to the enhancement of the structures involved in contraction, inactivity, or disuse is followed by reduction of the muscle mass (Jokl and Konstadt, 1983; Appel, 1990; Andersen *et al.*, 1996). Computed tomography of the limb revealed an 8% decrease in the muscle CSA of affected thigh as compared to the non-affected lower extremity in patients with ACL chronic symptomatic instability. Quadriceps muscle atrophy amounted to 10% and hamstring muscle atrophy only 4%. The atrophy of the VM muscle was significantly greater than of the entire quadriceps in computed tomographic measurements of the lower limb at levels 15 and 25 cm proximal to the medial joint line in study of Gerber *et al.* (1985).

The data showed that thigh circumference underestimates atrophy and is not correlated with the CSA of thigh muscles by MRI or strength in the injured extremities (Arangio *et al.*, 1997; Nicolakis *et al.*, 2000). It can be concluded that thigh girth measurement did not evaluate objectively the level of atrophy in knee extensors following arthroscopic partial meniscectomy. In future, we excluded this method from our research.

7. CONCLUSIONS

1. A significant reduction in voluntary isometric strength of the knee extensor muscles has been observed in the injured extremity preoperatively and three months after arthroscopic partial meniscectomy.

2. A significant isokinetic peak torque deficit of the knee extensor muscles in the injured extremity was noted one month after arthroscopic partial meniscectomy, which varied in testing at low (1.05 rad/s) and intermediate (3.14 rad/s) angular velocities from 28.6% to 31.0%. A postoperative recovery of force-generating capacity of the knee extensor muscles in the injured extremity is more delayed in case of lower than higher speed of contraction.

3. A significant reduction in electrically evoked force-generating capacity of the knee extensor muscles in the injured extremity, as estimated by the maximum rate of isometric force development of submaximal tetanic contraction, preoperatively and one month after arthroscopic partial meniscectomy. A marked prolongation in half-relaxation time of the electrically evoked tetanic contraction, as an indication of the time course of muscle relaxation, was observed in the knee extensor muscles of the injured extremity compared to the non-injured extremity pre-operatively and one month after arthroscopic partial meniscectomy.

4. The study indicated that the recovery of the maximum voluntary isometric force-generating capacity of the knee extensor muscles of the injured extremity to the level of non-injured extremity is more delayed than the recovery of the electrically evoked force-generating capacity and the time course of muscle relaxation in patients following arthroscopic partial medial meniscectomy. The first work hypothesis was partly confirmed.

The results of this study support the use of the submaximum tetanic electrical stimulation technique to evaluate the recovery of the knee extensor muscle contractility during rehabilitation after arthroscopic knee surgery.

5. A significant decrease in tone characteristics of the *vastus medialis* and *vastus lateralis* muscles at rest was retained in the injured extremity as compared to the non-injured extremity three months after arthroscopic partial meniscectomy in men and women.

The recovery of the tone characteristics during maximal voluntary contraction in the *vastus medialis* muscle of injured extremity was more delayed than for the *rectus femoris* and *vastus lateralis* muscles during one year following partial meniscectomy in female patients, who revealed a longer period from injury to surgery. The second work hypothesis was partly confirmed.

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SUMMARY IN ESTONIAN

Reienelipealihase funktsionaalse seisundi taastumine pärast artroskoopilist meniskioperatsiooni

Meniskivigastused moodustavad põlveliigese vigastustest erinevate autorite andmetel 7–30%. Tänapäeval tehakse meniskioperatsioone põhiliselt artroskoopilisel meetodil. Seejuures ligikaudu 40% kõikidest artroskoopilistest meniskioperatsioonidest moodustab vigastatud meniski osaline eemaldamine. On näidatud, et vigastatud meniski osaline eemaldamine on hilisema osteoartriidi üheks riskifaktoriks. Põlveliigese stabiilsuse ja liikuvuse tagamisel on oluline reienelipealihase funktsionaalne seisund, mis pärast meniskivigastusi halveneb oluliselt eelkõige lihasatroofia ja lihaste jõugenereerimisvõime languse tõttu. Enamik uuringuid, mis käsitlevad reienelipealihase funktsionaalse seisundi taastumist pärast meniski osalist eemaldamist, on pühendatud tahtelise isomeetrilise või isokineetilise jõu näitajate määramisele. Eelkõige keskenduvad need uuringud opereeritud ja mitteopereeritud jäseme jõudefitsiidi dünaamikale rehabilitatsiooniprotsessis. Vähem tähelepanu on pööratud reienelipealihase elektrostimulatsiooniga esile kutsutud üksik- või tetaanilise kontraktsiooni parameetrite, samuti lihastoonuse näitajate muutuste uurimisele meniskivigastusega patsientidel. Selle probleemi lahendamiseks on võimalik kasutada elektromüostimulatsiooni meetodit (elektrostimulatsiooniga esile kutsutud kontraktsiooni parameetreid), mille alusel saab hinnata lihaste seisundit sõltumatult patsiendi valukartlikkusest, motivatsioonist jt. subjektiivsetest faktoritest. Lihaste toonuse dünaamika alusel on samuti võimalik hinnata objektiivselt patsientide lihaste seisundit rehabilitatsiooniprotsessis.

Uurimistöö eesmärk

Käesoleva töö eesmärgiks oli uurida reienelipealihase funktsionaalse seisundi taastumist pärast vigastatud meniski osalist eemaldamist artroskoopia meetodil kehaliselt mõõdukalt aktiivsetel patsientidel vanuses 17–35 aastat. Töös püstitati järgmised ülesanded:

1) uurida reienelipealihase tahtelise isomeetrilise maksimaaljõu taastumist pärast artroskoopilist meniskioperatsiooni;
2) uurida reienelipealihase tahtelise isokineetilise jõu näitajate taastumist pärast artroskoopilist meniskioperatsiooni;
3) uurida reienelipealihase elektrostimulatsiooniga esile kutsutud tetaanilise kontraktsiooni näitajate taastumist pärast artroskoopilist meniskioperatsiooni;
4) uurida reiesirglihase, külgmise ja keskmise pakslihase toonuse näitajate muutusi pärast artroskoopilist meniskioperatsiooni.

Uuringus püstitati järgmised tööhüpoteesid:

1) reienelipealihasel taastuvad elektrostimulatsiooniga esile kutsutud tetaanilise kontraktsiooni näitajad pärast artroskoopilist meniskioperatsiooni kiiremini kui tahteline isomeetriline maksimaaljõud ja isokineetilise jõu näitajad;
2) reienelipealihase kolme osa — reiesirglihase, külgmise ja keskmise pakslihase toonuse näitajate taastumine pärast artroskoopilist meniskioperatsiooni kulgeb erineva kiirusega.

Uuritavad ja uurimismeetoodid

Uuringus osales kokku 64 meniskivigastusega mees- ja 25 naispatsienti vanuses 17–35 a. Kontrollrühma kuulus 15 tervet meest ja 15 naist vanuses 18–23 a. Vaatlusalused olid kehaliselt keskmiselt aktiivsed, võistlussportlasi nende hulgas ei olnud. Kõiki meniskivigastusega patsiente opereeris artroskoopiliselt (vigastatud meniski osaline eemaldamine) Tartu Ülikooli traumatoloogia ja ortopeedia kliinikus üks ja sama kirurg. Uuringud viidi läbi Tartu Ülikooli kinesioloogia ja biomehaanika laboris viie aasta vältel. Kasutati isomeetrilise ja isokineetilise dünamomeetria, elektromüostimulatsiooni ja müotonomeetria meetodeid. Patsientide põlveliigese seisundit ja kehalist aktiivsust hinnati subjektiivselt ankeetküsimustikuga.

Reienelipealihase tahtelise isomeetrilise maksimaaljõu määramiseks kasutati spetsiaalselt konstrueeritud dünamomeetrilist seadet (Pääsuke *et al.* 1999). Sama seadet kasutati ka reienelipealihase elektrostimulatsiooniga esile kutsutud isomeetrilise submaksimaalse (25% tahtelisest maksimaaljõust) tetaanilise kontraktsiooni parameetrite (maksimaalse jõugradiendi ja poole lõõgastuse aja) määramisel. Tetaaniline lihaskontraktsioon (1 s kestusega) kutsuti esile ristkülikimpulssidega, mille kestus oli 1 ms ja sagedus 50 Hz, elektrostimulaatori Midicor (Ungari) abil. Reienelipealihase isokineetiline jõumoment nurkkiirustel 1,05; 1,57; 3,14; 4,19 ja 4,71 rad/s määrati isokineetilise dünamomeetriga Cybex II (Lumex Ltd., USA). Reiesirglihase, külgmise ja keskmise pakslihase toonuse määramisel kasutati seadet Myometer UT-90 (Vain, 1980, 2000). Patsiente uuriti enne operatsiooni (I, II, IV, V uuring), kaks nädalat (IV uuring), üks kuu (I, III, V uuring), kolm kuud (III–V uuring), kuus kuud (II, III–V uuring) ja kaksteist kuud (V uuring) pärast operatsiooni. Kontrollrühmade liikmed sooritasid kõik testid üks kord domineeriva jalaga (V uuring).

Uuringu põhitulemused

Patsientide ankeetküsitluse alusel selgus, et vigastatud jäseme põlveliigeses kaob valu ja paistetus täielikult kuus kuud pärast operatsiooni. Vigastatud jäseme reienelipealihase isomeetrilise maksimaaljõu olulist vähenemist võrreldes terve jäsemega täheldati enne ja kolm kuud pärast operatsiooni. Opereeritud jäseme reienelipealihase isokineetilise jõumomendi olulist langust võrreldes terve jäsemega täheldati patsientidel nurkkiirusel 1,05 rad/s ja 1,57 rad/s ühe kuu vältel pärast operatsiooni. Seega reienelipealihase isokineetilise jõu postoperatiivne taastumine meniskivigastusega patsientidel ilmnes väikese vastupanuga kiiretel liigutustel oluliselt varem kui aeglastel ja suure vastupanuga liigutustel.

Uurimistöö tulemusena selgus, et vigastatud jäseme reienelipealihase elektrostimulatsiooniga esile kutsutud tetaanilise kontraktsiooni jõugradient taastus oluliselt varem kui tahteline isomeetriline maksimaaljõud, mis kinnitas osaliselt esimest tööhüpoteesi.

Leiti, et vigastatud jäseme reienelipealihase tetaanilise kontraktsiooni poole lõõgastuse aeg oli oluliselt pikenenud, võrreldes terve jalaga enne operatsiooni ja kahe kuu vältel pärast operatsiooni nii mees- kui ka naispatsientidel.

Uurimistöö tulemused näitasid lihastoonuse olulist langust vigastatud reienelipealihases, võrreldes terve jäsemega, registreerituna nii puhkeolekus kui ka maksimaalsel isomeetrilisel pingutusel enne operatsiooni, ja reiesirglihases ühe kuu, külgmises ja keskmise pakslihases kolme kuu vältel pärast operatsiooni nii mees- kui ka naispatsientidel. Maksimaalsel tahtelisel pingutusel registreeritud toonuse näitajate taastumine vigastatud jäseme külgmisel pakslihasel kulges aeglasemalt võrreldes reiesirglihase ja keskmise pakslihasega, millega leidis osaliselt kinnitust käesoleva töö teine tööhüpotees.

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PUBLICATIONS

I

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Strength characteristics of knee extensors after arthroscopy

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SUMMARY

In this investigation were studied the isometric and isokinetic strength characteristics of knee extensor muscles in a group of eleven patients (six men and five women) aged 17-35 years with acute knee ligament injuries before and one month after the knee arthroscopic surgery. The subjects performed isometric and isokinetic contraction of knee extensors at angular velocities of 1.57, 3.14 and 4.71 rad/s. One month after surgery the subjects showed marked reduction of operated leg knee extensor muscle's maximal voluntary isometric contraction in comparison with non-operated limb (522.3±55.1 and 715.2±49.7 N resp. in men; 354.0±38.4 and 478.0±32.7 N resp. in women, $p<0.05$), also was found the increase of peak torque (PT) values at angular velocity of 1.53 rad/s in operated leg about 8-10 % ($p<0.05$). At other velocities no significant differences of PT between pre- and post-operative level were established.

INTRODUCTION

The function of the knee joint is closely linked to the integrity of the joint structures, ligaments and the coordinated action of surrounding muscles. Even isolated lesions of ligaments, joint surfaces or menisci can lead to loss of strength that may be associated with muscle atrophy and the presence of abnormalities in the muscle activation profiles of the knee extensor muscles (Moffet et al, 1994). Knee ligament injuries are reported to occur in 1-40% of acute knee injuries (Daniel et al. 1990).
Arthroscopic methods in the knee are used for diagnostic procedures and offer the surgeon a minimally invasive method for repairing a wide variety of injuries on both the acutely and chronically injured knee. These procedures are most often associated with minimal morbidity and early initiation of rehabilitation, and patients may return to work and their daily living activities at a faster rate than with conventional surgical methods (Grøntvedt et al, 1994). Objective muscle performance measuring provides baseline data and information concerning rate of change and treatment efficacy.
Commonly used clinical techniques for assessing muscle performance include manual muscle testing, isometric and isokinetic dynamometry (Knapik et al, 1983; Bohannon, 1986; Naughton, 1988; Fisher et al, 1990; Perrin, 1993). For this study, strength is operationally defined as the ability to exert force on instruments specially designed to measure isometric and isokinetic torque of the knee extensors. Isometric strength assessment measures a muscle's maximum potential to produce static force. The primary advantage of isometric resistance is that it can be used to assess strength in or to exercise a muscle group around a joint limited in motion by either pathology or bracing.
The purpose of the present investigation was to study the recovery in the neuromuscular performance characteristics of knee extensor muscles after arthroscopic knee surgery.

MATERIAL AND METHODS

Eleven patients (six men aged 22.5±2.4 yrs, height 179.4±2.4 cm, weight 74.2±3.9 kg and five women aged 21.7±2.3 yrs, height 165.7±0.9 cm, weight 60.7±2.9 kg) with knee ligaments acute injury were investigated before and one month following arthroscopic knee surgery. All surgeries were performed using a standardized arthroscopic procedure. After the operation the patients were taught to perform daily isometric exercises for thigh muscles to avoid their atrophy.
Isometric dynamometry. An electromechanical dynamometric chair was used to measure unilateral isometric voluntary contraction (MVC) of the knee extensor muscles. The subjects were seated with the knee and hip angles equal to 110°. The force produced by isometric voluntary contractions of the knee extensor muscles was measured with a strain gauge which was connected to computer.
Isokinetic dynamometry. Modernized Cybex dynamometer was used to measure maximal voluntary concentric strength of the knee extensor muscles of both the operated and non-operated extremities. Subjects were seated for knee joint testing with stabilization strap at the level of waist and a horizontal pad across the distal part of thigh. The tibiofemoral joint line was palpated and the axis of the dynamometer arm was aligned with the joint line. The sliding cuff of the lower extremity dynamometer arm was positioned proximal to the malleoli. Arms were folded across chest to isolate muscle acting on the knee. Starting position for testing was 90° of knee flexion. The angular velocities used were

1.57, 3.14 and 4.71 rad/s.

Data were compiled and stored in the computer coupled to the dynamometer. Peak torque (PT) at different velocities (gravity-corrected values) was studied. The use of isokinetic dynamometers in rehabilitation and training relates to their ability to quantify muscular performance. Good reliability of isokinetic moments measurements was reported by several investigators (Kramer, 1990; Patterson et al, 1992; Kramer et al, 1994).

Statistics. In the study were compared strength characteristics' values of operated and non-operated extremity, which was undamaged (without history of knee joint injuries). Standard statistical methods were used for calculation of mean, standard error of mean and standard deviation of mean. The differences between the mean values were tested for significance using t-test.

RESULTS AND CONCLUSIONS

Isometric dynamometry. Before the knee operation the subjects showed marked reduction of knee extensors isometric MVC of operated leg (about 20-26% lower than in non-operated extremity). One month after the operation the voluntary strength characteristics of the operated leg were not recovered to the non-operated leg's level (522.3±55.1 N in operated and 715.2±49.7 N in non-operated limb in men; 354.0±38.4 N and 478.0±32.7 N respectively in women, $p<0.05$).

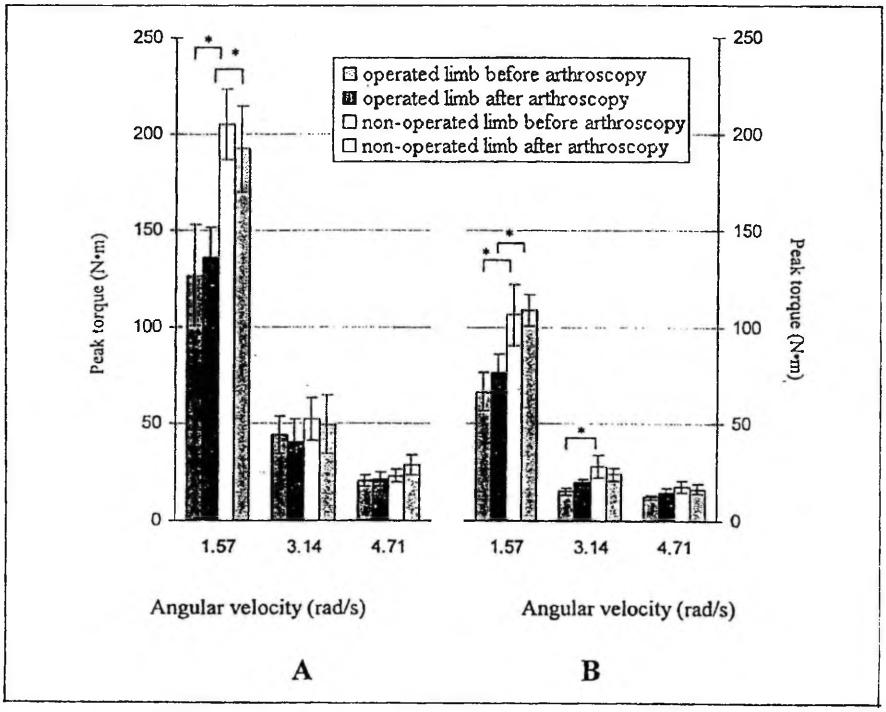

Fig. 1. Peak torque values of knee extensor muscles at different angular velocities before and one month after knee arthroscopy (mean±SE), A – in men (n = 6) and B – in women (n = 5). * $p<0.05$

Isokinetic dynamometry. The mean values of the isokinetic peak torque at three angular velocities are shown on Fig. 1.
There was significant decrease ($p<0.05$) of mean peak torque values at angular velocity of 1.57 rad/s in operated leg before the operation. One month after the operation was found the increase of peak torque in operated leg about 8-10% at this angular velocity in men and women. At angular velocities of 3.14 and 4.71 rad/s no significant differences of PT between pre- and post-operative level were established in group of men, and at velocity of 4.71 rad/s in women.
Results of present study are compatible with other authors' data, in which was established higher isometric than isokinetic torque and decreasing torque with increasing isokinetic velocity for the knee extensor muscles (Osterning, 1975; Perrin, 1993). Thorstensson et al found a correlation between maximum torque produced at the highest angular velocity and the percentage of relative area of type II fibres. Type II fibre atrophy has influenced the decrease in torque with increased angular velocity.
It can be concluded that one month following arthroscopic surgery of acute knee knee ligaments isometric and isokinetic strength characteristics in operated limb still remained lower than in healthy extremity.

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II

Eller A., Pintsaar A., Rohtlaan E.-M., Gapejeva J.
Changes in functional characteristics and myosin heavy chain composition in m. vastus medialis before and after arthroscopy for knee injury.
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Changes in functional characteristics and myosin heavy chain composition in m. vastus medialis before and after arthroscopy for knee injury

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Abstract The aim of this study was to investigate the influence of restriction of movement on the functional characteristics and myosin heavy chain composition of m. vastus medialis. The subjects of this study were 13 arthroscopically treated patients with meniscus lesions (both men and women, mean age 28 years). All measurements were performed and biopsies were taken bilaterally before and 6 months after knee arthroscopy. Thigh girth was measured to determine the degree of atrophy. A tendency towards decreased thigh girth in the injured leg was noted. As an estimate of functional characteristics, maximum voluntary contraction (MVC) was measured. The MVC of the injured limb was lower than that of the non-injured limb (mean values 548.2 ± 54.1 and 705.4 ± 48.2 N respectively; $P < 0.05$). The myosin heavy chain (MHC) composition was determined electrophoretically. The proportion of MHC I isoform decreased from 59.35% to 47.97% ($P < 0.05$).

Key words Arthroscopy · Muscle · Atrophy · Muscle biopsy · Isometric strength

Introduction

The function of the knee joint is closely linked to the integrity of the joint structures, ligaments and coordinated action of the surrounding muscles. Even isolated lesions of ligaments and joint surfaces or menisci can lead to loss of strength that may be associated with muscle atrophy and the presence of abnormalities in the muscle activation profiles of the knee extensor muscles [24]. Knee ligament injuries are reported to occur in up to 40% of acute knee injuries [9]. Arthroscopic methods in the knee are used for diagnostic procedures and offer the surgeon a minimally invasive method for repairing a wide variety of both acute and chronic injuries of the knee [17]. Atrophy of the thigh muscle (especially m. vastus medialis) is the major problem in rehabilitation following knee injury and surgery. Such factors as pain and joint effusions, which lead to disuse of thigh muscles, are thought to be responsible for the development of quadriceps atrophy [3, 12, 14].

It is a well-known but still empirical finding that quadriceps atrophy in knee-injured patients is difficult but possible to reverse. (Human m. vastus medialis), a knee extensor, is an antigravity muscle and consists mainly of oxidative muscle fibers and the slow myosin heavy chain (MHC) isoform MHC I [10, 19]. The changes in skeletal muscle morphology and protein metabolism during and after a period of inactivity due to immobilization have been well studied, but they can be different from changes seen after disuse without immobilization [10, 19]. Changes in specific body measures may influence strength, movement mechanics and physiological parameters. Morphological factors are known to directly influence human perfomance [8, 26]. Thigh girth measurement is used to determine signs of atrophy in the muscles and soft tissues surrounding the knee joint. Several techniques are available to analyze the changes in skeletal muscle morphology and protein metabolism. To estimate the effect on the skeletal muscle of atrophy due to disuse, it is important to analyze different functional characteristics and determine changes in the contractile apparatus at the molecular level.

Table 1 Anthropometric patient data (mean ± SE)

Parameter	Men (n = 8)	Women (n = 5)
Age (years)	24.9 ± 3.1	22.5 ± 2.53
Body mass (kg)	79.4 ± 4.3	64.2 ± 2.3
Height (cm)	1.82 ± 3.0	1.68 ± 2.0
Body mass index (kg/m^2)	24.04 ± 1.14	22.80 ± 1.06
Period of pain before the operation (months)	3.3 ± 1.4	16.0 ± 6.3

The aim of this study was to investigate the influence of disuse due to knee injury on the functional characteristics of m. vastus medialis and on its MHC composition.

Materials and methods

Thirteen patients diagnosed with a medial meniscus lesion participated in this study, after giving written informed consent. The study was approved by the Ethical Committee of the Medical Faculty, University of Tartu. The main characteristics of the subjects are listed in Table 1. No actively competing athletes were included, but the majority of subjects had participated in regular leisuretime sports activity. They had no orthopedic limitations or contraindications for exercise testing or training.

No patient had a history of knee injury. All patients were instructed to perform standard isometric exercises [18] to restore quadriceps muscle strength. All patients were treated arthroscopically by resection of the ruptured part of the meniscus; there were no complications. Measurements were performed and biopsies taken bilaterally before and 6 months after knee arthroscopy.

The characteristics of the knee extensor muscles were estimated using the methods outlined below.

Thigh girth measurement

The circumference of the thigh muscles was measured at 10 cm superior to the adductor tubercle on a line connecting the tubercle with the anterior superior iliac spine [15]. Each measurement was made with patient standing with the heels about 10 cm apart and weight evenly distributed between both feet. An inelastic tape measure (Lufkin, USA) was positioned horizontally around the hip in complete contact with the skin but without compression of the soft tissues. Measurements were performed in triplicate and the median value recorded [26].

Isometric strength testing

An electromechanical dynamometric chair was used to measure isometric maximum voluntary contraction of the knee extensor muscles. Patients were positioned in the chair with the knee and hip angles at 110°, with a stabilization strap at the level of the waist. The sliding cuff of the dynamometer was positioned proximal to the malleoli. Subjects were instructed to extend the leg against the cuff, which was fixed to a strain gauge system [16, 27]. Three trials were performed for the isometric test, and the trial showing the highest output was recorded.

Biopsy

The biopsy from the vastus medialis muscle was taken with a Bergström needle [7], 6–8 cm proximal to the patella. The muscle samples were immediately frozen in liquid nitrogen and stored at –70° C until further analysis. Frozen muscle samples were pulverized in liquid nitrogen and homogenized 1 : 7 (mass/vol) in phosphate buffer according to Sugiura and Murakami [28]. The protein concentration of homogenates was determined according to Lowry et al. [21]. The myosin heavy chain isoforms were separated electrophoretically using the 5%–8% gradient SDS-PAGE method of Bär and Pette [5]. The gels were stained by the method of Oakley et al. [25]. Densitometric evaluation was used in order to quantify the ratio of different MHC isoforms.

Statistics

All data are presented as means ± SD. One-way analysis of variance was used to determine the atrophy effect. Student's t-test was used to evaluate differences between the operated and the nonoperated extremities. The $P < 0.05$ confidence level was chosen to indicate statistical significance.

Results

Thigh girth

There was a minimal tendency to decreased thigh girth at 10 cm superior to the adductor tubercle in the operated extremity (Table 2).

Isometric strength testing

The maximum voluntary contraction of the knee extensor muscles was considerably lower in the injured limb than in the non-injured limb (mean values 548.2 ± 54.1 N and 705.4 ± 48.2 N respectively, $P < 0.05$; Fig. 1).

MHC isoforms

The normal m. vastus medialis in our experiment contained 59.35 ± 2.02% MHC I, or slow, isoform and 24.3 ± 11.85% MHC IIa and IIb, or fast, isoforms. After the in-

Table 2 Thigh girth (cm) in the operated and non operated extremities before and after arthroscopic knee surgery (mean ± SE)

	Operated extremity	Non-operated extremity	Difference
Men			
Before surgery	41.33 ± 1.26	41.69 ± 1.32	0.36 ± 0.35
After surgery	41.28 ± 1.44	41.49 ± 1.34	0.21 ± 0.34
Women			
Before surgery	41.23 ± 0.75	41.52 ± 0.53	0.28 ± 0.27
After surgery	41.30 ± 0.70	41.63 ± 0.70	0.33 ± 0.17

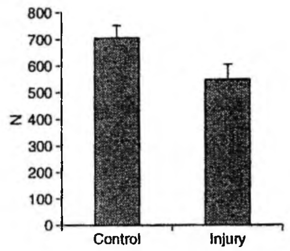

Fig. 1 Isometric maximum voluntary contraction values of knee extensor muscles before and after knee arthroscopic surgery (mean ± SE, * $P < 0.05$)

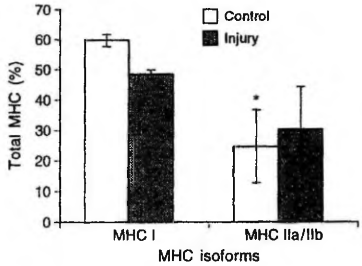

Fig. 2 MHC composition in the m. vastus medialis of the operated and the nonoperated extremity (mean ± SE, * $P < 0.05$)

activity period, m. vastus medialis contained 47.98 ± 1.51% MHC I isoform and 29.74 ± 14.15% MHC IIa and IIb isoforms. The proportion of MHC I isoform decreased from 59.35% to 47.98% ($P < 0.05$; Fig. 2).

Discussion

The results of this experiment demonstrate the effect of decreased mechanical load on the functional characteristics and MHC composition in human m. vastus medialis. The main finding of the study was that the proportion of slow MHC isoforms decreased and the proportion of MHC fast isoforms increased simultaneously in consequence of altered functional conditions. Restriction of movement also caused atrophy of thigh muscles, as revealed by the minimal reduction in thigh girth. Maximum voluntary contraction in the injured leg decreased compared with the nonoperated leg. This finding is in full accordance with the results of previous investigations which demonstrate that restricting the movement of the lower limbs after orthopaedic surgery or in the conservative treatment of sports injuries leads to atrophy of muscle with concomitant loss of strength [22, 23]. Prolonged periods of time spent with diminished or no weight bearing have a deleterious effect on skeletal muscle function, with decreased protein synthesis, loss of muscle mass, and loss of voluntary strength [6, 11].

Several factors are thought to be responsible for the development of quadriceps atrophy – pain, joint effusion, and, probably the most important, immobilization [4, 12, 14]. Clinical observations show that atrophy of skeletal muscle occurs as a consequence of immobilization and is caused by the altered functional conditions in the muscular system. Skeletal muscle function depends on intact proprioceptive activity, motor innervation, mechanical load, and joint mobility. If one of these factors is altered, the muscle will undergo adaptation. As increased muscular activity leads to enhancement of the structures involved in contraction, inactivity or disuse is followed by reduction of the muscle mass [2, 3].

Alterations of biochemical parameters and changes at the ultrastructural level of the contractile apparatus are considered to be characteristic of atrophied muscles. The effect of disuse on the skeletal muscle depends on the fiber type composition of the muscle. The degenerative changes in disused muscles at the ultrastructural level have been shown to be most severe in slow oxidative muscles [3]. The antigravity muscles which maintain posture and which are permanently loaded consist mainly of slow oxidative muscle fibers. Lieber et al. [20] suggested that the most vulnerable muscles were antigravity muscles crossing a single joint. M. vastus medialis, examined in our experiment, belongs to this group of muscles. The changes observed in our study confirm the high susceptibility of this muscle to the effects of inactivity due to disuse. M. vastus medialis consists mainly of slowly oxidative and oxidative-glycolytic muscle fibers and the MHC isoforms MHC I and MHC IIa, thus being very susceptible to the effects of disuse. The properties of muscle contraction which depend on the MHC isoform composition decrease in atrophied skeletal muscle [19]. Contractile activity can induce differential expression of myosin protein isoforms in skeletal muscle. MHC composition has an important regulatory role in myosin ATPase activity and muscle fiber shortening velocity [13]. Prolonged inactivity causes alterations in the MHC isoform composition. A decrease in the mechanical load stimulates the conversion of slow myosin in muscles of mixed fiber type composition [30], whereas a decrease in the weight-bearing load results in a decrease in slow myosin content [29].

In conclusion, the properties of muscle contraction which depend on MHC isoform composition decrease in atrophied skeletal muscle.

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III

Gapeyeva H., Pääsuke M., Ereline J., Pintsaar A., Eller A.
Isokinetic torque deficit of knee extensor muscles
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Isokinetic torque deficit of the knee extensor muscles after arthroscopic partial meniscectomy

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Abstract Isokinetic torque deficit of the knee extensor muscles in the operated leg was measured in 21 male patients (mean age 26.4±1.9 years) who had undergone arthroscopic partial medial meniscectomy. The isokinetic torque testing was performed 1, 3, and 6 months postoperatively using the Cybex II dynamometer according to standard technique. Isokinetic knee extension peak torque (PT) at angular velocities of 60° and 180°/s was determined in both legs, and the proportional PT deficit in the operated leg was compared with that in the nonoperated leg. A significant ($P<0.001$) isokinetic PT deficit in the operated leg in testing with angular velocity of 60° and 180°/s was observed at 1 month (28.6% and 31.0%, respectively) and 3 months (19.8% and 15.8%, respectively) postoperatively. At 6 months postoperatively a significant ($P<0.001$) isokinetic PT deficit (18.2%) of the knee extensor muscles in the operated leg was observed only in testing with angular velocity of 60°/s; no significant differences ($P>0.05$) in isokinetic PT between the operated and nonoperated leg in testing with angular velocity of 180°/s was found 6 months postoperatively. Thus in patients with arthroscopic partial meniscectomy the postoperative recovery of isokinetic strength of the knee extensor muscles in the injured leg is closely related to testing velocity, while it is more delayed at low than intermediate angular velocities.

Keywords Arthroscopy · Partial meniscectomy · Knee extensor muscles · Isokinetic testing

Introduction

Knee meniscal injuries, as a consequence of sporting and occupational activities, have a high incidence and economic relevance. Thigh muscle atrophy and strength deficit is the major problem in rehabilitation following various types of knee injuries, including meniscectomy [8, 15]. It has been observed that meniscectomy leads to impaired function of the menisci with regard to their load transmission capability and stability, frequently resulting in osteoarthritis [4, 14, 20, 30]. Pain and joint effusions, which lead to disuse of thigh muscles, are thought to be responsible for the development of atrophy in the knee extensor muscles [1]. Even isolated lesions of ligaments and joint surface or menisci that may be associated with atrophy and the presence of deficiency in activation of the knee extensor muscles can lead to loss of muscle strength [10, 15]. Muscle strength plays an important role in the function and stability of the knee joint. Reduced muscle strength may be caused by a lack of adequate rehabilitation, or it may occur if the patient avoids normal use of the extremity as a result of pain or instability of the knee extensor muscles after meniscal injuries. Good muscle strength can partially compensate for a lack of stability [2]. Rehabilitation of muscle function is therefore an important goal after knee injuries or surgery.

Isokinetic dynamometry does not mimic natural movements and has been generally accepted as a safe and reliable method for testing neuromuscular performance, training, and rehabilitation. The most frequently used isokinetic parameter is peak torque (PT). Isokinetic testing has been used in assessment of neuromuscular performance to identify deficit in maximal voluntary dynamic force generating capacity of muscles following injury or surgery. If results of preparticipation isokinetic testing are not available, the PT deficit in the injured leg may be calculated and compared with the noninjured leg. Several authors have shown the significant isokinetic PT deficit of the knee extensor muscles in the injured leg in patients with arthroscopic meniscectomy [6, 13, 15, 24, 25, 26]. However, the postoperative isokinetic PT deficit in testing with various angular velocities (speed of contraction), remains unclear.

The aim of this study was to investigate isokinetic strength deficit of the knee extensor muscles in the operated leg at slow and intermediate angular velocities in patients with arthroscopic partial medial meniscectomy following 6-month postoperative recovery.

Materials and methods

Subjects

The subjects were 21 male patients aged 20–34 years with arthroscopic partial medial meniscectomy, who gave written informed consent to participation in the study. Their mean age was 26.4± 1.9 years, height 179.0±1.7 cm, and and weight 77.5±3.0 kg. Patients with concomitant injuries, such as lesions of the lateral meniscus, cruciate ligaments, osteochondral injuries, and chondral damage in other components, were excluded. The mean period of pain before the operation was 3.5±1.6 months. The arthroscopic operation for all patients was performed by the same surgeon at Tartu University Hospital. The subjects were moderately physically active, and no professional athletes were included. They had no orthopedic or neurological limitations or contraindications for exercise testing or training. Immediately after the surgery and throughout the 3rd postoperative week multiple-angle isometric and cocontraction exercise plus straight leg raising (in supine position, 20–70° knee flexion, approximately during 10 s up and 10 s down, 5 min, with rest period 1 h, 10–12 time per day) were used to limit thigh muscle atrophy. Ergometry on stationary bicycle was recommended 4–8 weeks postoperatively. After 9 weeks the therapeutic exercise procedures were progressed gradually from submaximal to maximal to ensure normal ranges of movement of tibiofemoral and patellofemoral joint, and closed kinetic chain exercises were introduced [28]. Isokinetic knee extension PT in the operated and nonoperated leg for all patients was tested 1, 3, and 6 months postoperatively. The study carried out with the approval of the Ethics Committee of the University of Tartu.

Isokinetic dynamometry

Isokinetic concentric knee extension PT was measured using a Cybex II dynamometer and manual (Lumex, Ronkonkoma, N.Y., USA). Prior to testing each subject underwent a 10-min warming-up period that consisted of submaximal leg ergometry followed by stretch exercises. After calibration of the dynamometer subjects were seated in the adjustable chair and thigh, hip, and chest were stabilized using straps. The axis of rotation of the knee joint was aligned with axis of the dynamometer lever arm. The force pad was placed 3–4 cm superior to the medial malleolus with the foot in plantigrade position. The knee of the measured leg was positioned at the flexion of 90°. Range of motion during testing was set using the goniometer through an arc from 90° knee angle to full extension. Subjects were instructed to hold their arms across the chest to further isolate knee joint extension movements. During the testing the subjects were asked to produce knee extension as forcefully and quickly as possible through a complete range of motion. Verbal encouragement was given during every trial. Three attempts were carried out at low (60°/s) and intermediate (180°/s) angular velocities, and the one with the highest PT value was used for further analysis. The trial proceeded from the lower angular velocity to the higher velocity. The nonoperated leg was examined first. A rest period of 1 min was allowed between the attempts. All torque measurements were gravity corrected. The proportional isokinetic knee extension PT deficit in the operated leg was calculated in relation to the nonoperated leg.

Statistics

Data are presented as means and standard errors (±SEM). One-way analysis of variance for repeated measures followed by Tukey's post hoc comparisons was used to evaluate differences between the operated and nonoperated legs and between the different testing periods. A level of $P<0.05$ was selected to indicate statistical significance.

Results

The results of the present study are summarized in Table 1. Isokinetic PT of the knee extensor muscles in testing with angular velocity of 60°/s was significantly lower ($P<0.001$) in the operated leg than in the nonoperated leg 1, 3, and 6 months postoperatively. The isokinetic PT deficits in the operated leg were 28.6%, 19.8%, and 18.2%, respectively. Isokinetic PT in testing with angular velocity of 180°/s was significantly lower ($P<0.001$) in the operated leg than in the nonoperated leg also 1 and 3 months postoperatively, which represented PT deficits in the operated leg of 31.0% and 15.8%, respectively. No significant differences ($P>0.05$) in isokinetic PT in testing with angular velocity of 180°/s were found between the operated and nonoperated legs 6 months postoperatively.

Table 1 Postoperative isokinetic peak torque (N) of the knee extensor muscles at angular velocities of 60°/s and 180°/s in patients with arthroscopic partial meniscectomy

Post-operative period	60°/s		180°/s	
	Operated leg	Nonoperated leg	Operated leg	Nonoperated leg
1 month	163.8± 8.7**	229.5±7.6*	73.4±6.7**	106.3±5.6*
3 months	190.4± 9.2	237.4±9.2*	94.5±6.1***	112.2±6.1*
6 months	194.6±10.1	237.8±9.2*	104.7±6.2	113.8±6.6

*$P<0.001$ vs. operated leg, **$P<0.001$ vs. to 3 and 6 months postoperatively, ***$P<0.05$ vs. 6 months postoperatively

Discussion

The isokinetic PT was measured to monitor potential alterations in maximal voluntary force-generating capacity of the knee extensor muscles in this study. The results indicate a significant isokinetic PT deficit of the knee extensor muscles in the operated leg 1 month after knee arthroscopic surgery, which varied in testing with low (60°/s) and intermediate (180°/s) angular velocities from 28.6% to 31.0%. This finding is in general agreement with those previously published by Stam et al. [24]. These authors observed in patients with meniscectomy a PT deficit in the knee extensor muscles of the operated leg compared with the nonoperated leg in testing with angular velocity of 90°/s 1 month and 3 months postoperatively of 30% and 21%, respectively. However, Patel et al. [19] has found markedly lower isokinetic PT deficit of the knee extensor muscles in the operated leg (12%) in patients with arthroscopic meniscectomy 1 month postoperatively. It has been reported that the acceptable muscle strength deficit in the operated leg as the threshold for clinical significance is 10–15% [11, 31].

The isokinetic peak torque deficit in the injured leg following early postoperative period may be caused by several factors. Knee extensor muscles are closely related to the anatomy of the knee joint (the patella and patellar tendon from a part of the knee joint), and instability within the knee can directly affect the quadriceps femoris muscle [2]. Arthroscopic surgery, as well as the partial removal of menisci, is less traumatic for the knee joint than open surgery or total meniscectomy [5, 14, 20]. However, after surgery the muscle function is generally impaired as a result of joint effusion, pain, fear of moving, surgical damage to joint and muscles, and muscle damage because of tourniquet application.

It is known that persistent symptoms after knee injuries lead to a thigh muscle strength deficit in the affected leg [18, 22]. The immobilization is the main cause of muscle atrophy in patients after knee injury and surgery [12, 29]. Surgery and immobilization are associated with immediate atrophy of slow-twitch muscle fibers, while after long-term disuse of the knee the atrophy of fast-twitch muscle fibers may become more dominant [8, 17]. Only part of the strength deficit of the injured leg can be attributed to muscle structural atrophy.

Muscular force production is determined not only by muscle cross-sectional area and muscle mass but also by central excitatory drive. Full development of potential muscle tension requires maximal recruitment of the motoneurons of agonists and synergists and effective inhibition of the motoneurons of antagonists [21]. Several researchers [7, 16] have shown that short-term training can result in enhanced voluntary muscle torque production without concomitant increase in muscle size. This evidence suggests that neural adaptation mechanisms are unrelated to muscle size and may influence muscle force generating capacity.

Reduced muscle strength may occur if the patient avoids the normal use of the extremity as a result of pain or instability of the knee. Pain and swelling of a joint can reflexively inhibit the muscles around joint, resulting in decrease in isokinetic PT values of the knee extensor muscles [3, 23]. Thus the postoperative maximal voluntary isokinetic muscle torque deficit is to a large extent due to an impaired central excitatory drive.

The major finding of this study is the markedly higher difference in isokinetic PT of the knee extensor muscles between the operated and nonoperated legs between 3 and 6 months postoperatively at low rather than intermediate testing velocities. Isokinetic PT at low (60°/s) testing velocity was significantly lower in the operated leg than in the nonoperated leg 3 months (19.8%) and 6 months (18.2%) postoperatively. At moderate (180°/s) testing velocity, significant isokinetic PT deficit in the operated leg was found to last for 3 months (15.8%) but not 6 months postoperatively. Thus the present study clearly indicates that the postoperative recovery of force-generating capacity of the knee extensor muscles in the injured leg is more delayed in cases of lower than higher speed of contraction.

The difference in postoperative isokinetic PT deficit of the knee extensor muscles of the injured leg in testing with different angular velocities may be caused by several factors. It has been observed that the earlier period of rehabilitation after knee surgery is characterized by particular immobilization of joint and is associated with atrophy of slow twitch muscle fibers [8, 17], which play an important role in force generation of the whole muscle during slow speeds of contractions [9, 32].

It is known that slow- and intermediate-velocity concentric isokinetic contractions differ by recruitment of the motor units. During slow-velocity concentric contractions the high resistance induced by isokinetic dynamometer implies maximal muscle activation for a given velocity throughout the range of motion [31], and a great number of both slow and fast motor units are recruited [9, 27]. In contrast, during intermediate-velocity concentric isokinetic contraction the lower resistance induced by isokinetic dynamometer limits significant muscle activation that is involved primarily only at the beginning (agonists) and end (antagonists) of the range of motion [31]. At faster speeds of contraction, force production is closely related to the proportion of fast motor units within a mixed muscle [9, 29, 32]. An impaired central drive would therefore be associated with reduced isokinetic muscle performance in the operated leg more at slower than higher testing velocities.

In conclusion, the results of this study indicate that postoperative recovery of isokinetic muscle strength in the operated extremity after arthroscopic partial meniscectomy is closely related to testing velocity, while it is more delayed at low than intermediate angular velocities.

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IV

Gapeyeva H., Pääsuke M., Vaher V., Ereline J., Pintsaar A., Eller A.
Recovery of knee extensor muscle contractile properties
after arthroscopic partial meniscectomy.
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Recovery of Contractile Properties of the Knee-Extensor Muscles After Arthroscopic Partial Meniscectomy

Helena Gapeyeva, Mati Pääsuke, Jaan Ereline, Vallo Vaher, Aivar Pintsaar, and Aalo Eller

Context: Contractile characteristics of the knee extensors after arthroscopic meniscectomy are poorly understood. ***Objective:*** To measure the recovery of knee-extensor-muscle contractility after arthroscopic partial meniscectomy. ***Design:*** Single-group repeated measures. ***Setting:*** Kinesiology and biomechanics laboratory. ***Subjects:*** Fourteen patients with arthroscopic partial medial meniscectomies. ***Main Outcome Measures:*** Maximal isometric voluntary contraction (MVC) force, rate of force development ($MRFD_{ES}$), and half-relaxation time (HRT_{ES}) of evoked tetanic contraction preoperatively and during 6 months postoperatively. ***Results:*** Two weeks postoperatively, a reduction in MVC force of 27.1% and in $MRFD_{ES}$ of 17.8% and a prolongation of HRT_{ES} of 34.0% in the injured leg were found. A significant MVC-force deficit (17.5%) was observed 3 months postoperatively. ***Conclusions:*** The recovery of knee-extensor-muscle voluntary strength is more delayed than are evoked tetanic-contractile characteristics after partial meniscectomy. The rehabilitation protocol seems to be insufficient to attain effective recovery of knee-extensor-muscle voluntary strength. ***Key Words:*** meniscus injuries, knee extensors, electronically evoked tetanic contractions

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There is a high rate of incidence of meniscus injuries resulting from different activities at work and in sport. Partial meniscectomy leads to impairment of the function of the menisci with regard to their load-transmission capability and stability.[1-5] It has been observed that even isolated lesions of ligaments, joint surfaces, or menisci can lead to loss of muscle strength that might be associated with atrophy and the presence of abnormalities in the activation profiles of the knee-extensor muscles. Thigh-muscle atrophy and strength deficit are the major problems in rehabilitation after meniscectomy.[6-9] The contractile properties and neural coordination of the

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knee-extensor muscles play an important role in the function and stability of the knee joint. Rehabilitation of muscle function is therefore an important goal after knee injuries. Most studies on the changes in force-generating capacity of the knee-extensor muscles after arthroscopic meniscectomy have focused on maximum voluntary isometric or isokinetic strength deficit in the injured leg in relation to the uninjured leg.[1,6-12] Less attention has been paid to the changes in electrically evoked contractile characteristics of the knee-extensor muscles after arthroscopic meniscectomy. Electrically elicited twitch or tetanic-contraction characteristics, however, can be used to measure force-generating capacity and time course of contraction and relaxation within the muscles, independent of volition, skill, and motivation of the subjects.

The purpose of this study was to measure the changes in contractile properties of the knee-extensor muscles in patients with arthroscopic partial medial meniscectomies during their 6-month postoperative recovery. We were especially interested in examining the isometric maximal voluntary contraction (MVC) force, as well as force-time and relaxation-time characteristics of the electrically evoked submaximal tetanic contraction, which corresponded to 25% of MVC force. All characteristics of the injured leg were compared with those of the uninjured leg.

Methods

Subjects

The subjects were 14 male patients age 21–33 years with arthroscopic partial medial meniscectomies who, after giving written informed consent, participated in this study. The mean (± SEM) age, height, and body mass of the patients were 26.4 ± 2.3 years, 179.6 ± 2.1 cm, and 77.4 ± 3.5 kg, respectively. Subjects had no previous knee injuries. Patients with concomitant injuries (eg, lesions of the lateral meniscus or cruciate ligaments, osteochondral injuries, or chondral damage in other components) were excluded. The period of duration of knee pain before the operation was 3.7 ± 1.2 months. One surgeon at Tartu University Hospital performed the arthroscopic operation for all patients. The subjects were moderately physically active—no competing athletes were included. They had no orthopedic or neurological limitations or contraindications for exercise testing or training. Immediately after the surgery and throughout the 3rd postoperative week, multiple-angle isometric and cocontraction exercises plus straight-leg raises (in supine position, 20° to 70° knee flexion, approximately 10 seconds up and 10 seconds down for 5 minutes, with a rest period of 1 hour, 10–12 times per day) were used to limit thigh-muscle atrophy. Four to 8 weeks postoperatively, ergometry on stationary bicycle was recommended. After 9 weeks the therapeutic exercises were progressed gradually from submaximal to maximal to ensure normal range of motion of the tibiofemoral and patellofemoral joints, and closed kinetic chain exercises (leg presses, semisquats) were introduced.[13]

Isometric MVC force and electrically evoked tetanic-contraction characteristics of the knee-extensor muscles in the injured and uninjured leg for all patients were recorded preoperatively and 2 weeks and 3 and 6 months postoperatively. Postoperatively, during every test session pain and swelling were registered.[7] The subjects were asked to report their complaints of pain in general and during the strength test. In both cases pain was scored on a 5-point scale: 0 = *no pain*, 1 = *occasional moderate pain*, 2 = *continuous moderate pain*, 3 = *occasional severe pain*, and 4 = *continuous severe pain*. Knee swelling was scored before strength testing took place. A 4-point scale was used to rate swelling: – = *no clinical signs of intra-articular effusion*, ± = *clinical signs of intra-articular effusion*, + = *patellar tap sign after compression of the suprapatellar pouch*, and ++ = *patellar tap sign without compression of the suprapatellar pouch*. The study carried the approval of the university's ethics committee.

Measurement

We gave the subjects instructions and demonstrated the strength-testing and electrical-stimulation procedures 24–48 hours before collecting the first data. This was followed by a practical session to familiarize the subjects with the procedures. Before testing, each subject underwent a 10-minute warm-up (submaximal leg ergometry during 6 minutes at low intensity, followed by stretch exercises).

During measurement, the subjects were seated in a specially designed dynamometric chair[14] with knee and hip angles at 90° and 110°, respectively. Three Velcro™ belts placed over the chest, hip, and thigh secured the body position. Knee-extension force was recorded by a standard strain-gauge transducer mounted inside a metal frame, which was fastened around the distal part of the ankle above the malleoli using a Velcro belt. The electrical signals from the strain-gauge transducer were digitized on-line (sampling frequency 1 kHz) via a personal computer. The digitized signals were stored on hard disk for further analysis.

Each subject was asked to perform a knee extension against the belt of the strain-gauge system while the isometric MVC force was recorded. The MVC was held for approximately 3 seconds. The force-time curves were analyzed on a personal computer, and the best result from 3 attempts was taken as the MVC force. Before each isometric contraction, subjects were instructed to "push as hard as possible." Visual on-line feedback was also used to help motivate the subjects. A rest period of 1 minute was allowed between attempts.

The position of the subjects during the recording of force-time and relaxation-time characteristics of the electrically evoked tetanic contraction of the knee-extensor muscles was the same as during MVC-force measurements. Two large (23- × 7-cm) carbon-rubber electrodes (Nemectron, Germany) were used. The skin over the quadriceps muscle was washed with liquid soap and water to reduce electrical impedance. The anode was placed approximately 10 cm proximally from the patella and the cathode 10 cm proximally from the anode (Figure 1). Transcutaneous electrical stimulation from a standard electrostimulator (Medicor, Hungary) with a frequency of 50 Hz, impulse duration of 1 millisecond, and train duration of 1 second was performed. The electrical impulses were monophasic rectangular waves. The stimulation voltage was adjusted to provide the initial force of about 25% of the isometric MVC force of the knee-extensor muscles. The interval between the final MVC trial and the start of the electrical-stimulation trials was 5 minutes in order to minimize the effects of muscle fatigue. Before stimulation, subjects were instructed to relax their muscles. The force-time curves of the electrically elicited tetanic contraction were analyzed on a personal computer. The following characteristics of the submaximal tetanic contraction were recorded: maximal rate of isometric force development ($MRFD_{ES}$), which is the first derivate of force development (dF/dt), and half-relaxation time (HRT_{ES}), which is the amount of time to half of the decline in tetanic force.

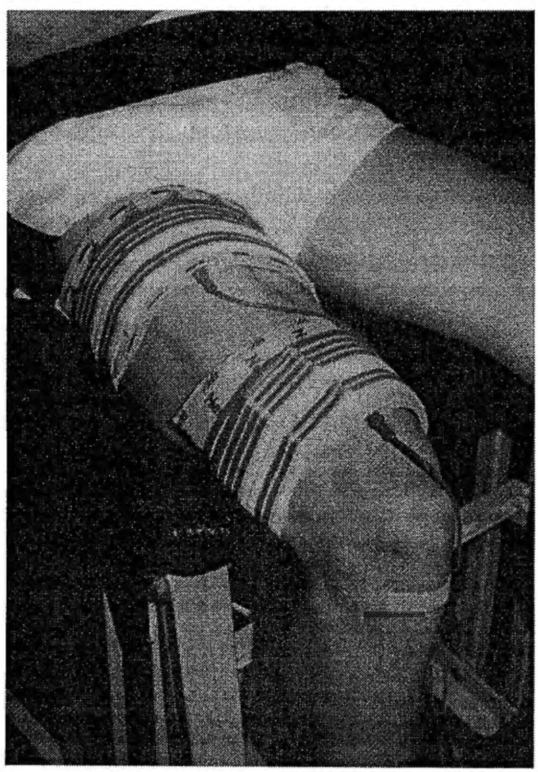

Figure 1 Transcutaneous electrical stimulation of the quadriceps femoris muscle.

Statistical Analysis

Data are presented as means and standard errors (± SEM). One-way analysis of variance (ANOVA) for repeated measures, followed by Tukey post hoc comparisons, was used to evaluate differences between the injured and uninjured legs and between testing periods. The level of $P < .05$ was selected to indicate statistical significance.

Results

The MVC force of the knee-extensor muscles was 14.2% less in the injured leg than in the uninjured leg preoperatively, 27.1% less 2 weeks postoperatively, and 17.5% less 3 months postoperatively ($P < .05$; Figure 2[a]). No significant differences ($P > .05$) in MVC force between the injured and uninjured legs were observed 6 months postoperatively. The $MRFD_{ES}$ of the knee-extensor muscles was 17.1% lower in the injured leg than in the uninjured leg preoperatively and 17.8% lower 2 weeks postoperatively ($P < .05$; Figure 2[b]). No significant differences ($P > .05$) in $MRFD_{ES}$ of the knee-extensor muscles were observed between the injured and uninjured legs 3 or 6 months postoperatively. The HRT_{ES} of the knee-extensor muscles in the injured leg was 14.1% longer than in the uninjured leg preoperatively and 34.0% longer 2 weeks postoperatively ($P < .05$; Figure 2[c]). No significant differences ($P > .05$) in HRT_{ES} were found between the injured and uninjured legs 3 or 6 months postoperatively.

Postoperatively, no patients scored 2, 3, or 4 when asked to rate their pain. Complaints of occasional moderate pain (a score of 1) are distributed in Table 1. Two weeks after surgery, 1 patient experienced occasional moderate pain in general, and 6 patients during strength testing. Three months after surgery, only 1 patient complained of moderate pain during strength testing. Six months postoperatively, none of the patients experienced pain.

Two weeks postoperatively, all patients had moderate to severe symptoms of intra-articular effusion (Table 1). During the period of rehabilitation there was a tendency to a gradual reduction of swelling in the injured knee. There were clinically detectable signs of intra-articular fluid in only 1 patient 3 months after surgery. Six months postoperatively no swelling was found.

Comments

Several authors have reported recovery of the isometric MVC force of the knee-extensor muscles in patients with partial meniscectomies within a period of 2 months.[1,7] The present study indicated significantly lower isometric MVC force of the knee-extensor muscles in the injured leg than in the uninjured leg 3 months after knee-arthroscopic surgery. The rehabilitation program used after partial meniscectomy seems to be insufficient for

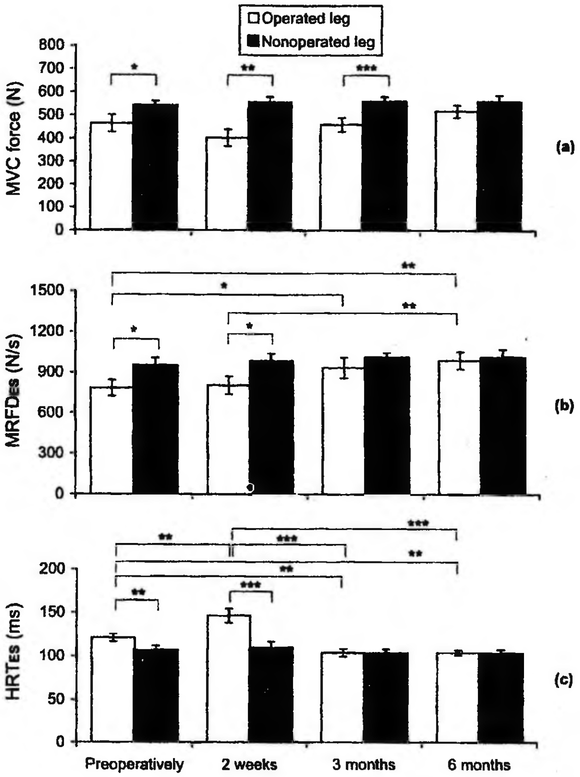

Figure 2 Preoperative and postoperative changes in isometric maximal voluntary contraction (MVC) force: (a) maximal rate of isometric force development ($MRFD_{ES}$) and (b) half-relaxation time (HRT_{ES}) of (c) electrically evoked tetanic contraction of the knee-extensor muscles after arthroscopic partial medial meniscectomy. Data are means ± SEMs.
*$P < .05$; **$P < .01$; ***$P < .001$.

effective recovery of knee-extensor-muscle voluntary strength. The reduction of maximal voluntary force-generating capacity of the knee-extensor muscles might be caused by several factors. Knee-extensor muscles are closely related to the anatomy of the knee joint (the patella and the patellar tendon form a part of the knee joint), and instability in the knee can directly affect the quadriceps femoris muscle.[15] The results of this study indicate that all patients had moderate to severe swelling of the knee during the early phase of rehabilitation (2 weeks) after surgery. This is in agreement with previous reports.[7] These symptoms can inhibit the voluntary expression of muscle strength.

It is known that persistent symptoms of knee injuries lead to thigh-muscle-strength deficits in the affected leg. Immobilization is the main cause of muscle atrophy in patients after knee injury and surgery.[16,17] Surgery

Table 1 Incidence of Complaints of Occasional Moderate Pain and Each of the Scores on a 4-Point Swelling Scale After Partial Meniscectomy (N = 14)*

	Time Postoperative		
	2 weeks	3 months	6 months
Pain in general	1	—	—
Pain during testing	6	1	—
Intra-articular effusion			
–	0	12	14
±	8	2	0
+	6	0	0
++	0	0	0

*– indicates no clinical signs of intra-articular effusion; ±, clinical signs of intra-articular effusion; +, patellar tap sign after compression of the suprapatellar pouch; and ++, patellar tap sign without compression of the suprapatellar pouch.

and immobilization are associated with immediate atrophy of slow-twitch muscle fibers, and after long-term disuse of the knee, the fast-twitch muscle fibers begin to atrophy.[18,19] Only part of the deficit in voluntary muscle strength of the injured leg can be attributed to structural atrophy. Muscle-force production is determined significantly by the central excitatory drive. Full development of potential muscle tension requires maximal recruitment of the motoneurons of agonists and synergists and effective inhibition of the motoneurons of antagonists.[20] Reduced muscle strength can occur if a patient avoids normal use of the extremity because of pain. In this study, approximately 40% of measured patients experienced occasional moderate pain during strength testing 2 weeks after surgery. Thus, postoperative deficit in maximal voluntary force-generating capacity of the knee-extensor muscles in the injured leg is partly a result of an impaired central excitatory drive.

Electrical stimulation has been shown to be effective in aiding knee-extensor-muscle force production after anterior cruciate ligament reconstruction.[21] The changes in electrically evoked contractile characteristics of the knee-extensor muscles after arthroscopic partial meniscectomy, however, have been given less attention. This study showed a significant reduction in electrically evoked force-generating capacity of the knee-extensor muscles in the injured leg, as estimated by maximal rate of isometric force development of tetanic contraction, preoperatively and 2 weeks after knee-arthroscopic surgery. It is well documented that the rate of muscle-force development is closely related to the speed of Ca^{2+} release by the sarcoplasmic reticulum and the Ca^{2+} sensitivity of contractile proteins, as well as myosin-ATPase activity and rate of formation of cross-bridges between actin and myosin.[22-25] The preoperative period and earlier recovery period after knee surgery are characterized by reduced muscle loading and immobilization, and thus the associated muscles experience atrophy of the muscle fibers.[18,19] It is well known that immobilization is linked with decreased muscle force-generating capacity. Thus, the reduction in electrically evoked force-generating capacity of the knee-extensor muscles in the injured leg might be caused largely by leg immobilization and muscle atrophy.

In the present study, a markedly longer half-relaxation time of electrically evoked tetanic contraction, as an indication of the time course of muscle relaxation, was observed in the knee-extensor muscles of the injured leg than in the uninjured extremity preoperatively and 2 weeks after knee-arthroscopic surgery. Two main factors have been described as being responsible for the duration and rate of muscle relaxation: sarcoplasmic-reticulum Ca^{2+} uptake and the rate of cross-bridge kinetics.[26] The prolonged half-relaxation time could result from decreased efficiency in the function of the sarcoplasmic reticulum.

In conclusion, this study indicates that in patients who have had arthroscopic partial medial meniscectomies, the recovery of maximal voluntary force-generating capacity of the knee-extensor muscles of the injured leg to the level of that of the uninjured leg is more delayed than is recovery of electrically evoked force-generating capacity and the time course of muscle relaxation. Swelling of the knee joint seems to be an important cause of inhibition of MVC force of the knee extensors during the early phase of recovery from knee-arthroscopic surgery. The rehabilitation protocol that was used in this study was probably insufficient for effective recovery of knee-extensor-muscle voluntary strength. The results of the study support the use of submaximal tetanic electrical stimulation to evaluate the recovery of knee-extensor-muscle contractility during rehabilitation after arthroscopic partial meniscectomy.

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Isokinetic Strength and Tone of Knee Extensors Following Partial Meniscectomy: One-year Study

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Summary

The recovery of knee extensor muscle isokinetic strength and tone in 15 male and 15 female patients aged 17-28 years during one-year period following partial meniscectomy was estimated in comparison with 30 age-and gender-matched healthy subjects as controls. Isokinetic peak torque (PT) of the knee extensors at angular velocities of 1.57, 3.14 and 4.71 rad/s and tone of *rectus femoris* (RF), *vastus lateralis* (VL) and *vastus medialis* (VM) muscles were recorded pre-operatively, 1, 3, 6 and 12 months post-operatively. The isokinetic PT deficit in the operated leg, which was the highest at 1.57 rad/s (41 and 43% for males and females, before the surgery, resp.) has been decreased 12 months after surgery (11% in both groups). The isokinetic PT deficit in the operated leg as compared with that in the non-operated leg was significant 1 month but not 3 months post-operatively. Recovery of the tone characteristics in the operated leg's VM muscle was more delayed than for VL and RF muscles during one-year following partial meniscectomy.

Introduction

Meniscectomy leads to an impairment of the biomechanical function of the menisci of the knee with regard to their load transmission capability and stability, frequently resulting in osteoarthritis (Krüger-Franke et al, 1999). The majority of studies on the recovery of the knee extensor muscle functions after knee meniscus injuries have been focused on voluntary strength deficit between injuried and non-injuried leg (Moffet et al, 1993). Less attention has been paid to the changes of knee extensor muscle tone following knee joint injuries (Gapeyeva et al, 1997). The aim of this study was to estimate the recovery of isokinetic PT and tone of the knee extensor muscles during one-year period after arthroscopic partial meniscectomy.

Materials and Methods

Thirty patients (15 males and 15 females) with partial meniscectomy (aged 17-28 yrs with painful period before operation of 3.3±1.4 and 8.76±2.1 months, resp.) and 30 healthy subjects (15 males and 15 females aged 18-23 yrs without any history of the injuries of lower extremities) participated in the study. The subjects were moderately physically active (3-6 hrs per week), however no competitive athletes were included. After arthroscopic surgery the patients performed isometric exercises for knee extensors to prevent the atrophy of thigh muscles. The unilateral maximal voluntary concentric peak torque (PT) of the knee extensors was recorded using Cybex II dynamometer at angular velocities of 1.57, 3.14 and 4.71 rad/s. The tone of *rectus femoris* (RF), *vastus lateralis* (VL) and

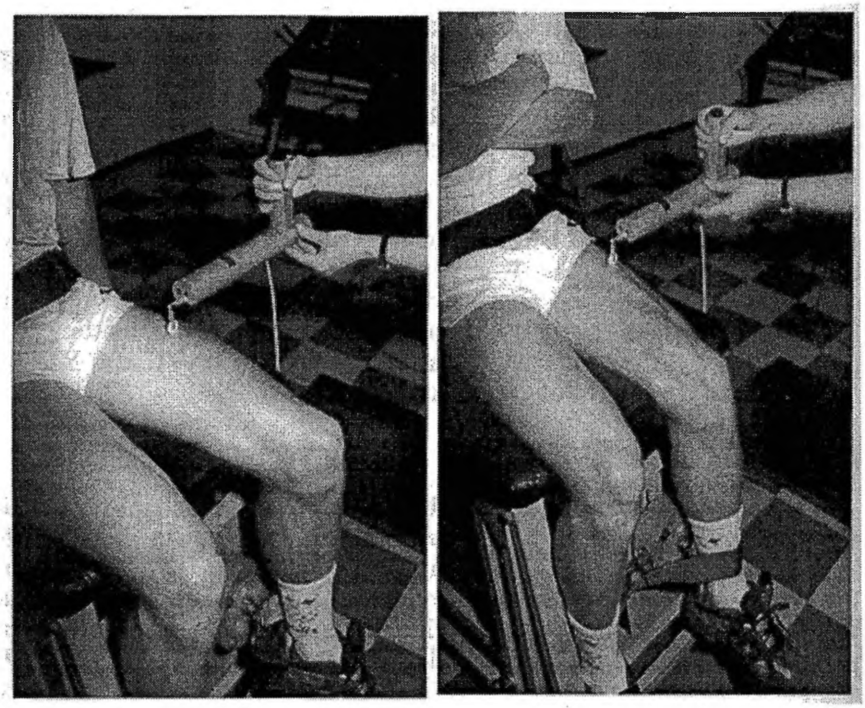

Figure 1. Recording the tone characteristics of rectus femoris muscle at rest (A) and during maximal voluntary contraction (B) by myotonometer.

vastus medialis (VM) muscles at rest and during maximal voluntary isometric contraction (MVC) recorded by computerized myotonometer elaborated at the University of Tartu (Vain, 2000). Muscle tone was characterized by the frequency of damping oscillations elicited by short calibrated mechanical impulse on the muscle belly (Fig. 1). All parameters were recorded pre-operatively and 1, 3, 6 and 12 months post-operatively. Data were mean and standard errors of mean (SEM). One-way ANOVA for repeated measures was used to evaluate differences between the measured characteristics.

Results and Discussion

A significant isokinetic PT deficit in the operated leg as compared to non-operated leg was found pre-operatively in males and females at angular velocities of 1.57 and 3.14 rad/s and 1 month post-operatively in males and females at 1.57 rad/s and in males at 3.14 rad/s (Fig. 2). No significant pre- and post-operative PT deficit in injured leg was found in males and females at angular velocity of 4.71 rad/s. The isokinetic PT deficit in the operated leg before the surgery (41 and 43%, 31 and 42%, 31 and 30% at 1.57, 3.14 and 4.71 rad/s for male and female, resp) has decreased 12 months after surgery (11%, 6 and 5%, 3% at 1.57, 3.14 and 4.71 rad/s, resp.). Isokinetic PT of the knee extensor muscles of operated leg recovered to pre-operation level 3 months following arthroscopy. PT of the injured leg differed significantly 12 months post-operatively in male patients at angular velocity of 1.57 rad/s as compared with dominated leg of controls.

There was noted significant decreasing ($p<0.05$) of the operated leg's muscle tone at rest before arthroscopy, 1 month later (for RF, VM and VL), and 3 months later (for VM and VL) in male and female patients as compared with non-operated leg muscles (Fig. 3).

A prolongation of recovery period for tone characteristics of VM muscle was observed for both groups of patients at MVC (Fig. 4) and in females at rest as compared to RF and VL muscles. The tone characteristics of injured leg VL muscle did not differ significantly from the data of non-operated leg.

It has been reported that the reliability of strength test results with patients is, more than in case of healthy subjects, influenced by inhibiting factors, such as pain, joint stiffness and fear of injury (Westers, 1982).

Isokinetic PT of the operated leg following meniscectomy improved rapidly during the 8 weeks of training, and an imbalance of the knee extensors of more than 10% remained after this period (Stam, 1990). Attaining symmetrical knee extensor torque takes more time - Campbell and Glenn (1979) found a 10% deficit for isometric and 16% deficit for isokinetic (60 deg/s) knee extension in 8 patients 5 to 15 months after meniscectomy.

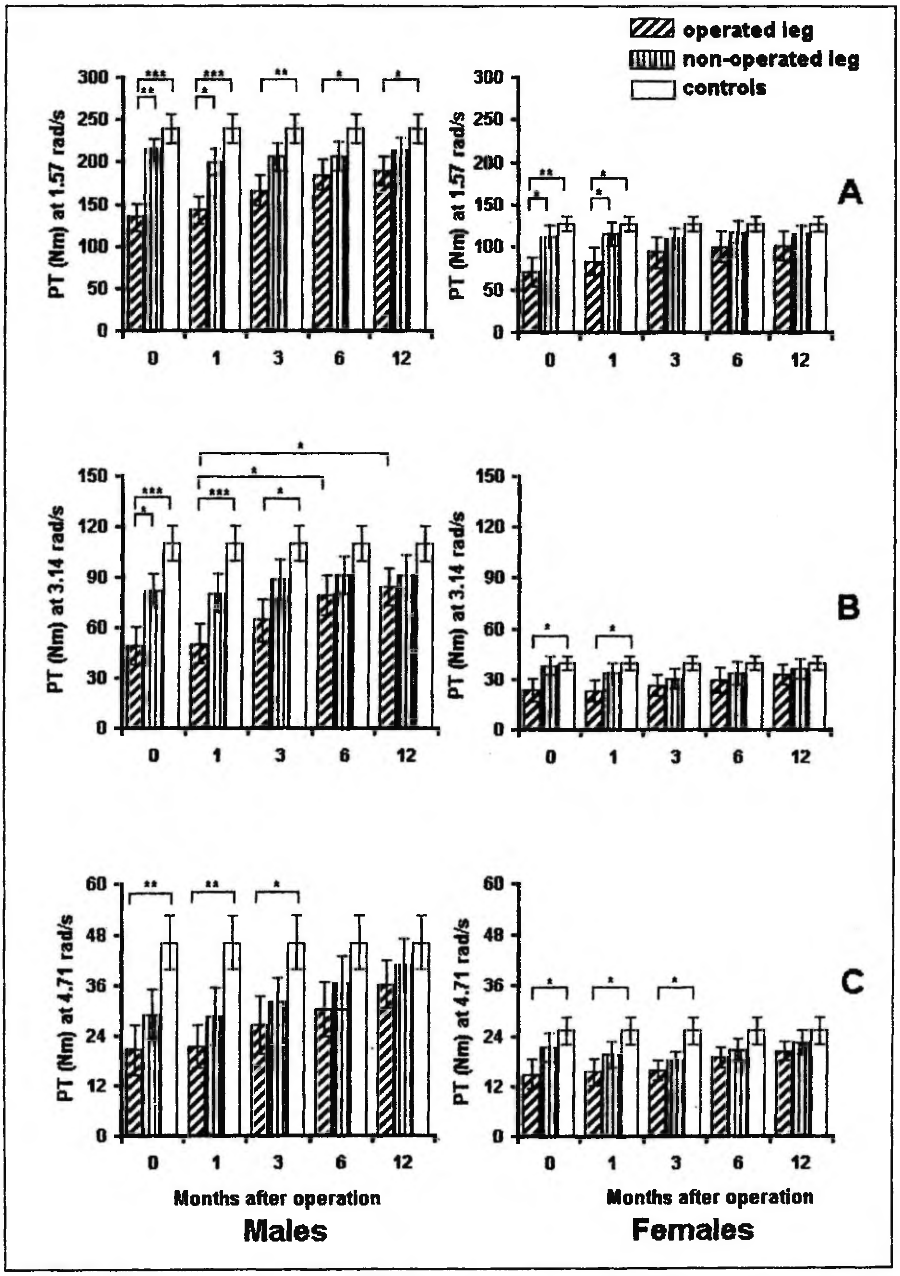

Figure 2. Isokinetic peak torque (PT) of the knee extensors at the angular velocities of 1.57 (A), 3.14 (B) and 4.71 (C) rad/s in patients with partial meniscectomy and controls (mean ±SEM).

* - p<*0.05*, ** - p<*0.01*, *** - p<*0.001*

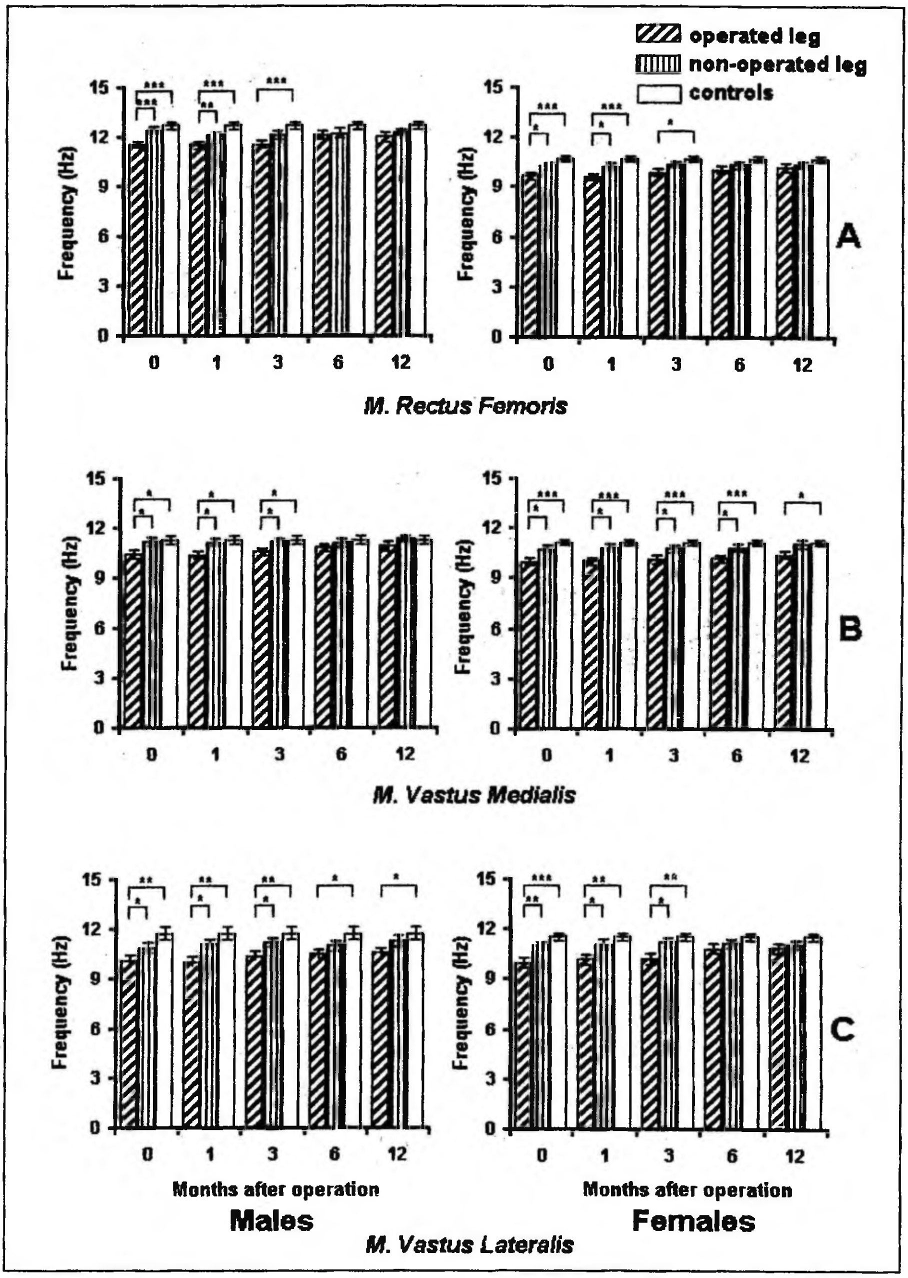

Figure 3. The tone characteristics (frequency of damped oscillations) of rectus femoris *(A),* vastus medialis *(B) and* vastus lateralis *(C) muscles at rest in patients with partial meniscectomy and controls (mean ±SEM).*
* - p<*0.05,* ** - p<*0.01,* *** - p<*0.001*

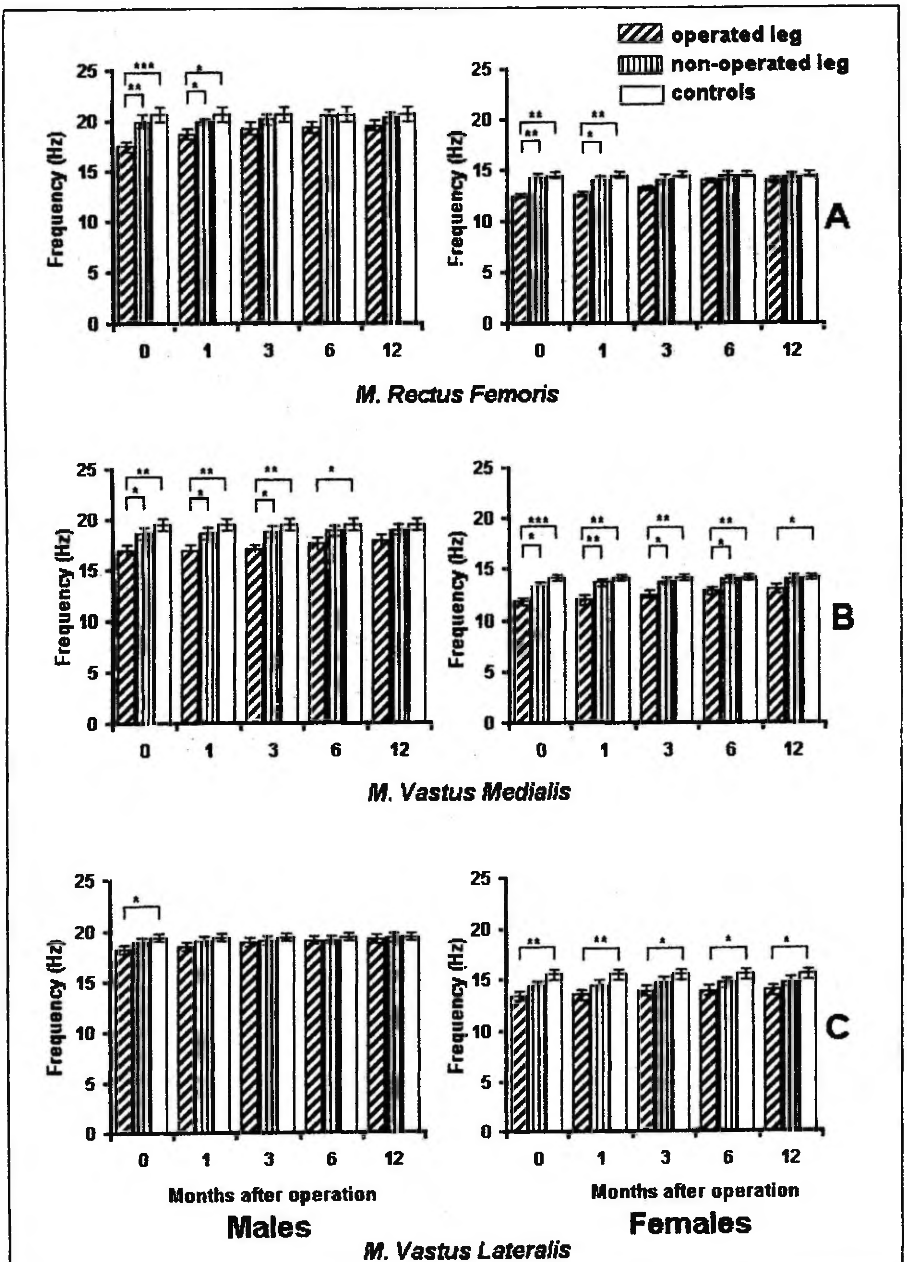

Figure 4. The tone characteristics (frequency of damped oscillations) of rectus femoris *(A),* vastus medialis *(B) and* vastus lateralis *(C) muscles at maximal voluntary contraction in patients with partial meniscectomy and controls (mean ±SEM).*
* - p<*0.05*, ** - p<*0.01*, *** - p<*0.001*

Mean values of frequency of oscillation of RF, VM and VL muscles had a tendency to increase one and three months after operation in comparison with the pre-operative period. In the case of the physiological increase in muscular stiffness the endo-, peri- and epimyseum are under a higher mechanical strain, which increases the elasticity of their collagenous fibres (Purslow, 1989; Purslow and Duance, 1991).

Conclusions

The isokinetic PT deficit of knee extensors in the operated leg, which was the highest at 1.57 rad/s (41 and 43% for males and females before the surgery, resp.) has been decreased 12 months after surgery (11% in both groups). Isokinetic PT of the knee extensor muscles of operated leg recovered to pre-operation level 3 months following arthroscopy. Recovery of the tone characteristics in the operated leg for VM muscle was more delayed than for VL and RF muscles in patients following partial meniscectomy.

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Teadustegevus

Peamised uurimisvaldkonnad:
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- adaptatiivsed muutused närvi-lihassüsteemis kiirusjõu- ja vastupidavustreeningu mõjul;
- lihasväsimus staatilistel pingutustel;
- laste motoorne võimekus pre- ja postpuberteedieas;
- vananemise mõju motoorsetele funktsioonidele.

Kokku on ilmunud 146 teaduspublikatsiooni, sh. 21 artiklit rahvusvahelistes refereeritavates ajakirjades ja kogumikes.

Esinemised konverentsidel: 11 ettekannet rahvusvahelistel teaduskonverentsidel, sh. kaks ettekannet maailmakongressidel ja neli Euroopa konverentsidel.

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