Knee immobilization : techniques and evaluation

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volgens het besluit van het College van Dekanen,
in het openbaar te verdedigen
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Jan Willem Veldhuizen

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Chapter 1

Introduction

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1.1 General introduction

The recovery after a knee injury follows the concept of tissue healing. The conditions for healing are: approximation of torn structures, sufficient healing time, clearance of debris and supply of nutrients. From a historical point of view 'rest' of the injured extremity is generally advised. Immobilization provides this 'rest'. Besides to the potentially beneficial effect of immobilization there is also a deleterious effect on the surrounding tissues resulting in atrophy and dystrophy. This tissue degeneration can be observed in cartilage (49,52,137,214), tendons and ligaments (2,3,23,66,138,169,202,239), bone-tendon and bone-ligament junctions (125,169,214), and bone (119,136,141). It also causes capsular and pericapsular contractures (49,137,251). The speed and the extent of these unwanted adaptations are tissue specific. Muscular tissue reacts more quickly to inactivity than other tissues. Because of the large muscle mass and its reactivity thigh muscle atrophy is clearly observable, in contrast to the changes in ligaments and tendons. Especially the vasti muscles of the m. quadriceps are susceptible to the harmful effects of immobilization, more than other muscles around the knee joint (91,142,242). This has serious implications for the patient with a knee injury. Coordination and strength of the thigh muscles play a major role in the stability of the knee during all leg activities in human life (84,147,188,204). Especially sporting activities characterized by 'cutting-movements' confront the patient with a deficit in the thigh muscle function (71,208). Thus immobilization of an extremity after trauma has serious side effects on healthy surrounding tissues caused by the imposed inactivity. Besides to the consequences for the injured individual, the surgeon also must consider the socio-economical effects such as costs of medical treatment and loss of labor (146). Therefore more attention is given to early active rehabilitation after a knee injury to prevent muscle atrophy (51,210,222). This stresses the importance of research concerning the different current therapeutic immobilization techniques and the evaluation of measurement of the knee and quadriceps function. The next parts of the introduction will give an overview of the literature on the following subjects: (in-)stability (epidemiology, signs and symptoms, treatment), quadriceps atrophy and immobilization techniques. This will give a better understanding of the aims of the investigations in this thesis.

1.2 Epidemiology of knee injuries

Accidents in and around the house are the most frequent causes of injuries (26%), followed by accidents at work (19%) and in sports (17%). In men 11% of all sports injuries are sprains of the knee. A knee injury is the most expensive type of injury (145,146). Several sports are mentioned in literature as having a high incidence of knee injuries; American football, soccer, downhill skiing, and ice hockey. However,

it is obviously difficult to compare the injury profiles of various sports because of differences in injury-reporting strategies (174,240).

In the Dutch population 8.7% of all sports injuries involve the knee (223). Soccer is the most popular sport in the Netherlands. Swedish research shows that the injury risk from playing soccer in adults is 7.6 injuries per 1000 training hours and 16.9% in matches. Twenty percent of all soccer injuries involve the knee (48). In Sweden soccer is responsible for 58% of all knee injuries in men and of 27% of the knee injuries in women. The majority of serious soccer injuries in men consist of knee injuries (145).

The type of knee injury depends on the mechanism of injury and therefore to some extent on the type of sports, but also on age and gender (40). Of all knee injuries in skiing 60% involve the ACL (55), while the majority of knee injuries in American football involve the MCL (76,96,195,228). Isolated injuries of the MCL are seldom observed, most injuries are combined lesions. Meniscal pathology is found in 86-89% of all patients presented with a chronic ACL lesion (131,241). Recent MR imaging studies have shown that an ACL rupture is often associated (80%) with subchondral lesions (bony bruises) (221). Injuries to the PCL have a much lower incidence rate. The most common causes are sports-related trauma and motor-vehicle accidents (115).

1.3 Instability

1.3.1 Mechanical instability

An injury to the passive stabilizers results in mechanical instability. Especially ruptures of the ACL and the combined injuries of the ACL lead to instability, since the ACL will not heal spontaneously (4,16,18,116,171). Although the ACL plays only a limited role in the control of the passive stability of the knee (149), a complete rupture may result in early or late functional complaints and complications (16,18,59,184). Noyes showed that a large number (82%) of patients with an ACL rupture resumed their sports activities at first, but within two years 51% suffered a reinjury and five years after the initial injury only 35% still participated in strenuous sports (170). Also more optimistic results are reported (154). Isolated injuries of the PCL usually do well when treated nonoperatively (61,182), while combined injuries do not (234). Injuries to the collateral ligaments do tend to heal, although the quality of the scar may never reach normal ligament characteristics (63).

The active stabilizers can to some extent compensate for instability due to dysfunction of the passive stabilizers. Extensive thigh muscle atrophy on the other hand will lead to dynamic instability even in the presence of normal passive stability. Due to the abnormal motion in the chronically unstable knee, especially with concomitant

meniscectomy, the remaining ligaments and active stabilizers are stressed more. This can be observed as muscle hypertrophy e.g. of the hamstrings. It can also result in a situation of wear and tear with pain, recurrent effusion, possible cartilage and meniscal damage and finally osteoarthritis (16,41,59,155,166,170,171).

1.3.2 Testing mechanical instability of the knee

Testing the stability of the knee is limited to the examination of the passive stabilizers. The injured side is compared with the uninjured side. Most studies show consistent symmetry (38,254), however, differences between the left and right knee for laxity and stiffness are reported in uninjured people (150). Various tests are used to show different types of instability (single ligament, combination of ligaments or combinations with capsular structures and iliotibial tract). The tests used are: valgus-varus testing in full extension and in 20° flexion position, drawer sign in neutral position and endo- and exorotation, the posterior drawer test, the Lachman test and the pivot shift test (58,105,129,213,233). Tests are combined to obtain a complete view of the injuries to the passive stabilizers (103). The specificity of these tests is limited (122,175,176,241). The specificity is better in isolated lesions and poor in case of two or more lesions, as is seen in about 50% of all knee injuries (178). The sensitivity and specificity in diagnosing knee injuries is improved by examination of the patient under general anesthesia. The diagnostic process is preferably completed by arthroscopy (6,36,43,109).

More objective tests, mainly applied for scientific investigations, are instrumental testing devices and radiographic examination of manually or instrumentally stressed knee joints (183). Instrumented testing is practically preferable because it requires no radiology. Some testing equipment is now commercially available (KT-1000/KT-2000, Genucom, CALT, KLT). The reproducibility of the measurements and the sensitivity and specificity for ACL lesions are shown in several studies (6,38,90, 98,133,197).

Magnetic resonance imaging of the knee can provide useful information after a knee injury. It makes it possible to identify and evaluate the cruciate ligaments, menisci, collateral ligaments, and the cartilage and the subchondral bone (72,79,144,160).

1.3.3 Functional anatomy

The poor congruency of the tibiofemoral joint enables a fairly large freedom of motion in this joint. This motion is guided and limited by intra- and extra-articular structures (163). These structures are commonly referred to as active and passive stabilizers.

Muscles as the hamstrings, the quadriceps muscles and less importantly the popliteus muscle are the *active stabilizers*. The *passive stabilizers* are the joint capsule, the cruciate ligaments, the collateral ligaments, and the menisci, but the iliotibial tract

can also be considered. This classical distinction between active and passive stabilizers is too simplistic since there are many connections between muscles and ligaments and between ligaments, capsular structures and menisci (224). The musculature reinforces stability by tightening the contact between the joint surfaces and by the dynamisation of the passive stabilizers (147,188). The interaction between the active and the passive stabilizers depends on intact proprioception.

The term instability refers to either *mechanical instability* or *functional instability*. Mechanical instability is the result of loosening of the joint due to disfunction of either the passive stabilisers or the active stabilizers. Functional instability is the feeling of instability as described by the patient.

1.3.4 Functional instability

In the acute knee injury symptoms of pain, haemarthros, joint effusion and inability to move predominate. In a chronic phase the patients primary complaint is instability, resulting in episodes of pain, joint effusion and disability (59,148,155,170,184). The patient describes this instability as a feeling of giving-way. Falling or loss of body support is reported with various physical activities, because of an unexpected collapse of the affected knee, not precipitated by pain, locking, or weakness. Pain, joint effusion and soft tissue swelling will subside over 7-10 days. If pain and swelling last longer, or the symptoms are caused by a specific trauma, the accident is considered to be a reinjury. Giving-way is generally associated with chronic ACL-deficiency.

The degree of functional disability caused by a knee injury can be assessed by means of functional scoring scales. Such scoring scales are made up of subjective complaints (148), complaints in relation to the activity level (226), or complaints and tests of joint laxity at physical examination (151). Functional tests are also used to assess the function of the knee after an injury. Two-leg tests, figure-of-eight test, and the stairs-running test can provide information on daily function. One-leg tests, the triple jump test, and the new stairs hopple are correlated to knee instability (192). Posttraumatic functional instability has a variety of causes. Careful questioning about symptoms and examination of the knee can lead to one of the following underlying mechanisms of functional instability:

- mechanical instability
 - disfunction of the passive stabilizers
 - disfunction of the active stabilizers
- impaired proprioception
- pain
- locking
- psychogenic factors

Mechanical instability due to ACL-deficiency is often combined with disfunction of the active stabilizers. Muscle atrophy is especially seen in the quadriceps muscle.

The hamstrings are generally less affected (86,170,225,231). Muscle atrophy has serious effects on knee function as measured with functional scores. A training program to increase muscle strength in these patients can result in better functional scores (12,208,225,227). There is, however, some evidence that mechanoreceptor activity in the joint capsule in ACL-deficient knees results in reflex inhibition of the quadriceps (216).

Mechanoreceptors have been identified in the cruciate ligaments (128,205,206), capsule, collateral ligaments (132), and menisci (256). With the muscle mechanoreceptors (muscle spindles) they account for the joint *proprioception*, defined as the extraction of any information regarding body position and movement (97). Proprioception was found to be impaired in the ACL-deficient knee (17,20). The clinical relevance of this finding remains uncertain, but it is suggested that the impaired proprioceptive function contribute to the complaints of functional instability (132). Meniscal tears will also affect the motor control in submaximal activities (44).

Many complaints of functional instability after knee injury are of patellofemoral origin. Acute *pain* inhibits muscle function and subsequently results in loss of body support. Patellofemoral pain, often called Anterior Knee Pain, is thought to be caused by patellofemoral instability due to atrophy of the quadriceps muscle. Also (traumatic) chondromalacia and overuse are major causes for patella-femoral complaints (65,104).

Locking can also cause functional instability. Locking is the result of impingement of remnants of a ruptured ACL, a loose body or a meniscal tear. Locking often results in joint effusion.

Next to the physical causes of functional instability *psychogenic factors* may play a role. Many patients are anxious to use their knee after injury. In the past surgeons stimulated this fear prescribing long-lasting immobilization for the healing of the ligamentous repair. Functional treatment regimens overcome immobilization and overprotection of ligamentous repairs. On the other hand the patient may suffer more pain during early mobilization. This may interfere with effective early mobilization (13). In a patient, who is mentally sensitive to pain, a cascade of pain, immobility, muscle atrophy, functional instability and as a result more pain will occur (51).

1.4 Treatment of instability

1.4.1 Treatment of mechanical instability

The aim of treatment of knee ligament injuries is to restore the stability. For most surgeons this means restoration of the passive stabilizers. This is best achieved through anatomical reconstruction of the injured structures (179). However, various tissue structures like the cruciate ligaments cannot be reconstructed easily. Healing

of collateral ligaments can last a long time. Moreover, surgical exploration of the injured structures may lead to substantial damage. Next to ligamentous reconstruction thigh muscle rehabilitation and restoration of coordination are important parts of the treatment of knee ligament injuries.

Cruciate ligaments

The natural course of ACL lesions is unfavorable, and an ACL lesion is called 'the beginning of the end of the knee'. This clinical observation has led to the development of reconstructive surgical procedures. It is thought that operative reconstruction of the ACL can reduce the complaints and increase the level of activity, and can also reduce the risk for secondary osteoarthritis (59). Several extra-articular repairs for the treatment of cruciate ligament ruptures have been advocated in the past (62,93, 213) next to simple suturing or reinsertion (179). Both good (152) and poor results of these procedures (54,64) are reported. Nowadays it is accepted that primary repair of an intrasubstance tear of a cruciate ligament is inferior to reconstruction. By the introduction of arthroscopic reconstructive surgery, it is possible to reduce the surgical damage and achieve better anatomical reconstruction under direct vision (26,31,110,173,189). The major problem still to solve is to find the optimal material for replacement of the cruciate ligament. Some prostheses are not able to withstand the forces applied to the ligament eventually (19,70,78,173,245). Rejection phenomena are also reported (8). Patellar bone-tendon-bone autografts, allografts and augmented prosthetic replacements are the most promising so far (1,30,37,112, 117,140,158,172,193,194,199,211).

Collateral ligaments

An injury to the collateral ligaments can heal spontaneously. The conditions for healing seem to be adequate approximation, limited stress on the ligament and sufficient time to heal. In theory healing requires longstanding immobilization. Animal experiments in MCL-healing show that the biomechanical properties of the healing ligament are inferior even after 40 weeks (63). Exposure of the ligament to limited stretching and movement (74) and surgical approximation (32) improve the quality of healing, with better organized collagen structure. Similar findings were reported for the LCL (180). Therefore, there are three possibilities of treatment for collateral ligament ruptures:

- 1) cast-immobilization (112,198)
- 2) partial immobilization to restrict unwanted range of motion, but permitting beneficial tissue stress through motion (107,118,161,207,227)
- 3) surgical treatment through an anatomical or extra-anatomical reconstruction (57,102,198)

All treatment regimens will eventually result in an almost complete restoration of function.

Muscle rehabilitation

Thigh muscles play an important role in knee joint stability. Quadriceps activity reduces the strain produced on the MCL and reduces the anterior-posterior translation when the knee is stressed (73,235,243). Hamstring activity reduces strain on the ACL (191). It is also stated that the gastrocnemius muscle is also a primary stabilizer of the knee in case of ACL-deficiency (139,249). Disfunction of the passive stabilizers can partially, or even completely, be compensated for by well-balanced support of the active stabilizers (12,71,171,225,227,238). An ACL-deficient knee can be asymptomatic.

There is discussion concerning the method of muscle rehabilitation after cruciate ligament injury or surgery. Especially the isokinetic training programs prove to be efficient and effective (232). Such exercises will induce strain on the ACL, but the clinical relevance of this phenomenon seems limited (101). Axial loading, on the other hand, will limit anterior tibial displacement. Therefore, squat exercises are the safest way to train the thigh muscles after an ACL injury (162,252). Based on theoretical, biomechanical considerations some authors stress the importance of training the hamstrings, since they work synergistically with the ACL to prevent anterior displacement of the tibia on the femur (7,71,124,162,191,218,219,231,238).

1.4.2 Treatment of functional instability

The treatment of functional instability does not consist of a ligamentous reconstruction alone. Not all patients with ligamentous instability suffer from giving-way. Good (71,154,184,198) and poor (4,18,59,170) results of functional treatment are reported in studies comparing operative and nonoperative treatment of ACL ruptures. Therefore, the treatment of ACL ruptures is still discussed among surgeons (116). The outcome of treatment can be improved by ruling out and treating the other causes of functional instability: locking or clenching, muscular atrophy, Anterior Knee Pain Syndrome, impaired proprioception, and psychogenic factors. This means that after initial diagnosis and treatment an adequate effort is put in *muscular rehabilitation*. A training program of 6-12 weeks is usually effective to improve the muscle condition. Quadriceps strengthening is also recommended for all patients with Anterior Knee Pain, leading to recovery in most cases (126).

The value of specific *proprioceptive training* in case of ligamentous lesions of the knee has not been well established so far, although its popularity is growing and satisfying results have been reported in some patients even after ACL reconstruction (33,255). Closed Kinetic Chain Functional Training is a method that allows for

task-specific application, speed/intensity manipulation, and incorporation of these motor learning concepts (177).

Patients trapped in the *spiral of pain, fear and muscular atrophy* should be given an intensive, supervised rehabilitation schedule. In these patients operative treatment of ligamentous lesions is not the first choice of treatment.

The problems described above lead to the following treatment schedule in patients suffering from complaints of functional instability of the knee after a ligamentous lesion. The patient should undergo an arthroscopy with stability testing under anaesthesia. Locking as a cause of functional instability can be dealt with at arthroscopy. Additionally isokinetic muscle strength testing is recommended. Next a treatment schedule should be instituted with emphasis on regaining the strength and coordination of the thigh muscles. The patient should learn to deal with mechanical instability (135). Bracing a knee for a given period or for certain stressful events (eg. sports) is a useful part of the nonoperative treatment (185,212). Operative treatment is considered when this rehabilitation fails and the patient is significantly impaired (26,170,171).

1.5 Atrophy of the quadriceps muscle after immobilization

1.5.1 Definition of muscle atrophy

Muscular function depends on intact innervation, mechanical loading, mobility of the joints, and adequate blood supply for nutrients and oxygen. Deterioration of any of these factors will result in an adaptation of muscle tissue known as muscle atrophy. Muscle atrophy is defined as shrinking of muscle fibers because of diminished intracellular substance. The term atrophy should be used descriptively to denote a decrease in size and not, like degeneration to denote dynamic mechanisms responsible for adverse cellular reactions (34). Atrophy is commonly seen as a physiological reaction to sub-optimal conditions, or changes in conditions such as denervation, inactivity or malnutrition.

1.5.2 Quantifying muscle atrophy

The most informative way to evaluate muscle atrophy *in vivo* in humans is the microscopical analysis of biopsy specimens. This enables the measurement of the fiber diameter, and permits histological and histochemical evaluation of atrophy in different muscle fiber types. Measurement of fiber cross sectional area, however, is not free of errors. These errors include muscle cuts not made perpendicularly to the muscle fibers as well as alterations in fiber size caused by fixation and staining procedures.

The macroscopical evaluation of muscle atrophy includes techniques such as Computer Tomography (CT), Ultrasound, and Magnetic Resonance Imaging (MRI). These techniques allow differentiation between large muscle groups (e.g. hamstrings and quadriceps), bone, and subcutaneous fat (108,253). They cannot discriminate between different muscle fiber types, nor between the relative changes in intramuscular substance as the connective tissue fraction and fat tissue. This includes an error in the evaluation of true muscle atrophy considering that intramuscular connective tissue increases with immobilization (34,92,120,247).

The thigh circumference is generally used in medical practice as a measure for muscle atrophy. Next to the shortcomings as mentioned for the other macroscopical evaluation techniques, it cannot differentiate between quadriceps and hamstrings, and muscle tissue and subcutaneous fat. Since subcutaneous fat increases with immobilization (86), and considering that the measurement of thigh circumference is not very reliable and reproducible, this method is obviously only a rough estimate (11).

1.5.3 Histology and histochemistry

Muscle tissue has a high metabolic rate and adjusts specifically to different functional demands. In case of immobilization this results in atrophy. The fiber diameter decreases, and there is an increase of intramuscular connective tissue, both endomysially and perimysially (120,121). Capillary blood supply is impaired due to the increased intramuscular connective tissue, but also due to a decreased capillary density (34,120). In animal experiments also more dramatic effects are observed such as fiber disruption and fiber splitting (34), and fiber necrosis (9). Also fiber regeneration takes place, most likely from satellite cells (9,10). The number and size of mitochondria decrease and mitochondrial damage is observed (9,34,130). Nuclei become irregularly shaped and some are no longer located in the periphery, but in central parts of the fiber (9). There is also an increase in autophagic activity and an increased number of phagocytes (9,34,120). This is not reported in human studies after immobilization.

Biochemical analysis of muscle tissue after immobilization reveals a rapid decrease in protein synthesis (25,203). Muscles with predominantly type I fibers (slow-twitch, oxidative) show a more rapid decrease in protein turnover than muscles with more type II fibers (fast-twitch, glycolytic) (120,203). Myofibrillar protein mass and concentration decrease (95). Signs of catabolism can be shown after immobilization by a negative nitrogen balance. Also, the skeletal muscles become diabetic-like with a decreased ability of insulin to stimulate glucose uptake and glycogen synthesis (167). The oxydative enzymatic activity remains the same or decreases. The glycolytic enzyme activity is essentially unchanged. The findings in literature are not completely unanimous concerning changes in energy stores or enzymatic activities (table 1). This is probably due to different measurement techniques, studies in

Table 1: Effect of immobilization on energy stores and enzymatic activity as reported in different studies (= unchanged values, ↓ decreased values).

	Effect	References
<i>Energy stores</i>		
Creatine	=	156
CP	=	77
	↓	24,156
ADP	=	156
ATP	=	77,156
	↓	24
Glycogen	=	47
	↓	24,156
<i>Oxidative enzymes</i>		
SDH	=	45,47,80,82
	↓	35,88,100
Citrate synthetase	↓	14,111,244
<i>Glycolytic enzymes</i>		
Phosphofructokinase	=	80,82,88,111
Phosphorylase	=	45,47
Lactodehydrogenase	=	45,77,111
	↓	100

different species, different muscles, limited numbers, and inadequate establishment of reference values in studies concerning patients.

A shift in muscle fiber typing toward more type II fibers is reported in some studies (45,83,87,95,106), but these findings are still controversial (11,106). When comparing the results of studies concerning the topics of muscle atrophy, enzymatic activity, and shift in muscle fiber typing, one has to consider the different mechanisms of muscle atrophy and degeneration induced by different methods as immobilization, suspension, tenotomy, and denervation.

The development of muscle atrophy is influenced by different factors:

- duration of immobilization

The rate of atrophy is more pronounced during the first week of immobilization and less after that (9). It is not known if there is a maximum to this decrease. A variety in the degree of muscle atrophy is reported (Figure 1).

- method of immobilization

Immobilization of a leg can be either weight bearing or non-weight bearing. Non-weight bearing immobilization has some resemblance to suspension, and several studies have shown that suspension will also result in muscle atrophy, but some differences to immobilization are noted (56,91). Immobilization of a leg results in complete or partial immobilization of the individual muscles, i.e. mono- versus bi-articular muscles in knee immobilization (142).

Fig. 1: Immobilization induced muscle atrophy as reported in different studies. (References in figure: 9,14,21,27,28,34,69,77,80,81,82,87,94,95,106,108,142,143,157, 159, 168,186,203,217,244,247)

- denervation

Denervation results in impressive muscle atrophy, which is different from atrophy induced by immobilization (34,202).

- muscle fiber typing

Muscles with predominantly type I fibers are more sensitive to immobilization (9,80,81,82,186,201). On the other hand, a greater atrophy in type II fibers after immobilization is also reported (47).

- muscle length at immobilization

Immobilization in a shortened position will result in a more pronounced atrophy than immobilization in a lengthened position (94,203).

- preimmobilization state

Well-trained muscles show a lower rate of atrophy (9).

The development of muscle atrophy induced by immobilization can be opposed in different ways:

- isometric contractions (196)
- electrical muscle stimulation (14,50,69,75,215,244).
- administration of growth hormone (28).
- administration of calcium entry blocking drugs (217).

In case of a knee trauma or surgery the following measures can be taken to restrict muscle atrophy:

- partial immobilization techniques (80).
- preimmobilization training (9,127).
- reduction of surgical damage (173)..
- limitation of tourniquet application (68,181).
- prevention of joint effusion (39,53,220).
- pain relief by NSAID's (15) or Transcutaneous Neural Stimulation (TNS) (113), although the effectiveness is subject to discussion (5,165).
- Continuous Passive Motion (CPM)(42,67,209).
- Exercise with the contralateral leg (123).

It was shown that muscle atrophy caused by immobilization is fully or nearly fully restored by training. Even fiber regeneration can be observed, probably from satellite cells (9,10). It was also shown that muscles with predominantly type I fibers regenerate quicker than type II muscles (24). The functional recovery after immobilization seems to take about the same period as the immobilization phase itself or longer (24,60). Recovery after trauma or surgery with subsequent immobilization is hindered or delayed by:

- mechanical instability (218)
- joint effusion (53)
- reflex inhibition (216)
- fear resulting in disuse through relative immobility pain.

1.5.4 Functional testing of muscle atrophy

Based on its unique contractile properties muscle tissue can develop tension between its origin and insertion. A contraction can be concentric, eccentric, or isometric. The ability to contract gives rise to some measurable parameters of its function, namely strength and endurance. Current research concerning muscle atrophy has focused mainly on concentric muscle strength, being the most obvious ability.

Muscle strength

Physiological considerations: The contractile behavior of the muscle is best characterized by the force-velocity relation. The highest force can be achieved at lower velocities, and force and maximal work decline with inclining velocity (99,246). The force- velocity relation of a muscle depends on the muscle fiber typing. Muscles with predominantly FT motorunits and muscle fibers can develop a higher torque at high angular velocities, than ST muscles. At lower angular velocities there is no relation between muscle fiber composition and force development (229). Under eccentric loading the muscle is considerably stronger than in concentric or isometric contrac-

tions. With increasing stretching velocity the eccentric force-velocity relation becomes steeper (46). A muscle can counteract an external force exceeding its isometric maximum force by 40%-50% without considerable lengthening. This enables active shock-absorption under conditions of fast cyclic motion.

Isokinetic dynamometry: With the development of isokinetic dynamometers it is possible to measure torque as a function of angular velocity. Another advantage of the isokinetic dynamometer over isotonic measuring devices is that it allows for optimal loading over the full range of motion. The peak torque (PT; Nm) is the highest torque during a Maximal Voluntary Contraction (MVC). The measurement of PT is thus dependent on the cooperation of the subject, which clearly limits its value. However, a surprisingly high reproducibility of PT is reported (114,153,230).

The Cybex II (Lumex, N.Y.) is a commonly used isokinetic dynamometer. It allows for measurements of the torque at isometric and concentric contractions of muscles around major joints at angular velocities up to 300 deg.s^{-1} . The standard configuration is meant for torque measurements of knee flexion and extension with the subject in sitting position. Applications for measurements of movement in other major joints are available. Isokinetic dynamometry has many pitfalls, which can be divided in subject, protocol, and device errors.

- Subject related problems are due to the fact that PT measurement requires a maximal contraction, which depends on skill and motivation. Sensations of pain can also interfere with PT measurements especially at low angular velocities in patients with anterior knee pain.
- The protocol of PT measurement must give the subject the opportunity to get used to the isokinetic movement before starting the actual measurements. The test protocol must also provide sufficient rest between different tests in the same leg.
- The Cybex II dynamometer does not correct its measurements for the effect of gravity acting on the lever arm and limb. This results in a considerable error in measurements done in the vertical plane, e.g., knee flexion and extension. It is suggested to correct this error by calculating the gravitational torque of the limb-lever arm system based on an actual measurement during passive knee flexion (164), or placement of an accelerometer (248). Another source of error results from overshoot in torque recordings (200).

The test protocol for PT measurement should consist of sufficient training before the actual measurements. It is recommended to perform two preceding training sessions. The subject must be optimally motivated. PT is recorded at different angular velocities because of individual differences in torque-angular velocity curves due to muscle fiber typing, and to evaluate the motivation of the subject. Working with the Cybex II means accepting the overshoot in speed and torque, and either adequate correction for gravity with the use of an accelerometer, or no correction. Without correction for gravitational forces the results of the tests are still valuable for

left-right, and test-retest comparisons, but useless for intersubject comparisons and hamstring-quadriceps ratio determinations.

Muscle strength in muscular atrophy: Muscle strength decreases significantly after immobilization. The decline in muscle strength is greater than the observed muscle atrophy (89,157,159). However, the number of studies that allow this comparison is limited. The greater decrease in muscle strength than in muscle or fiber diameter is thought to be the result of deterioration in the neural activity of the muscle. This decline in the electrical activity of the muscle at MCV after detraining has been observed in EMG studies (85,250).

Muscular endurance

Physiological considerations: Endurance is the ability to maintain an isometric contraction, or to continue repeated dynamic contractions, and thus to resist fatigue. There is no consensus to what the parameters of endurance are. The term endurance must therefore be defined carefully within the context of the specific movement patterns and the metabolic and physiological requirements of an activity. Endurance testing refers to the capacities of the various energy transfer systems. The immediate energy system (ATP-CP) is tested by means of very intense exercise of short duration, e.g., the stair-stepping power test. The short-term energy system (anaerobic system) is tested through all-out-exercise with a duration up to three minutes, e.g., Wingate test and Katch test. The isokinetic fatigue tests measuring the decline of PT after a given number of MCV's, or the time in which PT of repeated MCV's declines to 50% must also be considered as tests of the anaerobic energy system. Important information about the capacity of the long-term energy system (aerobic system) is provided by the maximal oxygen uptake capacity (VO_2max). This has become the fundamental measurement in exercise physiology. VO_2max can be measured by exercise that activates large muscle groups with sufficient intensity for longer periods. The VO_2max test usually consists of graded exercise until exhaustion. No such tests for the aerobic energy system of single muscles or muscle groups have been reported.

Endurance testing and muscular atrophy: Traditionally rehabilitation is focused on muscular strength, and the training programs have only little emphasis on endurance (35). This is surprising because it is known that the oxidative enzyme activities decrease after immobilization (see Table 1), but so far no research on the subject of functional effects of immobilization on the aerobic energy system has been reported. Some research is done on the effects of immobilization or injury on the anaerobic energy system showing no effect of shortterm voluntary immobilization (159), and no effect of surgery and subsequent immobilization (89) on fatigue. The dynamic endurance as tested on an one-legged bicycle is reported to be decreased by 27% in

operated patients, but not in non-operatively treated patients being immobilized (89). It can be concluded that the sparse data concerning the effects of immobilization on the anaerobic energy system are not conclusive. The negative effect of immobilization and atrophy on the aerobic energy system is known from changes observed in the oxidative enzymes, but is not yet confirmed by functional measurements.

1.6 Immobilization techniques

1.6.1 Materials

Originally cotton wrappings sprinkled with plaster were used for the immobilization of limbs. Nowadays, Plaster of Paris is still the most commonly used casting material, but more and more new casting materials are introduced. These are based on polyesters or glassfibers impregnated with polyurethane. Also thermoplastic materials are applied. These new materials are lighter, often waterproof, less vulnerable, and have better X-ray translucency. Disadvantages are the less easy application, and the higher costs. In case of immobilization for longer periods and for special indications, these 'plasterless' casting materials are favoured. Next to the casting materials as mentioned above there are also prefabricated splints for immobilization.

1.6.2 Techniques

There are different techniques for immobilization and stabilization of the knee, each with its own indications and rigidity c.q. level of stability:

- a) external fixation crossing the joint
- b) long leg cast
- c) walking or cylinder cast
- d) hinged cast-brace
- e) knee brace
 - rehabilitation
 - functional

ad. a) The *external fixation* crossing the knee joint is solely applied in cases of serious injuries or infections, requiring rigid immobilization and optimal access to the joint.

ad. b) The *long leg cast* is applied from the toes to the groin, resulting in a nearly rigid immobilization of the knee. Flexion and extension are virtually impossible, but valgus-varus, rotational, and anterior-posterior movements are still possible to a considerable degree (134). Isometric muscle contractions are of course possible, and it must be kept in mind that the bi-articular thigh muscles are also not immobilized. The cast can be made suitable for weight-bearing with a minor application under the foot.

ad. c) The *walking or cylinder cast* is a circular cast applied from the malleoli to the groin. The ankle joint remains free. This results in a less rigid immobilization of the knee due to increased activity of the gastrocnemius muscle, a slightly increased flexion and extension movement, but more important increased freedom of rotatory movements.

ad. d) A *hinged cast-brace* consists of two circular casts, one around the lower leg from the malleoli to the tuberositas tibiae, and one around the upper leg from just above the patella to the groin. Both parts are connected with two hinges, one medial and one lateral with their axes of movement as close as possible around the center of the joint. Rotation and sliding down are opposed by means of a heel support connected to the lower leg cast with two hinges, allowing movement in the ankle joint. A hinged cast-brace is used in full or partial weight-bearing conditions, according to the indication. Motion in the knee is possible from full extension to about 100° flexion, but it can be limited by stops in the hinges.

ad. e) A *Rehabilitation knee brace* is a prefabricated hinged cast-brace. The brace has bars and shells on the upper and lower leg fixed with velcro strips or straps. This allows the patient or the physician to remove the brace when needed. The rehabilitation brace has the same indications as the cast-brace, but the immobilization is less rigid. These braces significantly reduce translations and rotations (29).

Functional knee braces are made of shells for upper and lower leg, fixed with straps, or of bars and straps. The upper and lower leg parts are connected with one or two hinges. The braces allow the full range of motion in the knee joint, but limitation of both flexion and extension is adjustable. The functional knee braces are not used for immobilization, but for stabilization of the knee. Biomechanical testing reveals that shell type braces provide more mechanical stability than bar-strap type braces (22,236). Functional knee braces are applied in cases of mechanical instability with functional instability and in (secondary) prevention of knee joint injuries. On prescribing a functional knee brace one has to consider the activities at which the brace is worn, the build of the patient, the patient's ability to place and remove the brace properly, and the weight of the brace (especially in top athletes) (187). Level and type of stabilization depends on factors like fit and type of brace, length and material of the shells or bars-straps, and the hinges (29,190,236).

1.7 Aims of the study

Immobilization of the knee joint is a hot topic in (sports) traumatology. A ligamentous knee injury gives rise to symptoms (pain, joint effusion, giving-way) forcing the patient to spare the leg, resulting in immobility. This results in disuse atrophy

and disfunction of the stabilizing muscles. The complaints of pain and joint effusion will subside gradually during the process of healing. During the recovery the effect of muscle atrophy, especially of the quadriceps muscle, can become more prominent, giving rise to symptoms of instability.

The treatment of knee ligament injury is successful when the rehabilitation process results in complete functional recovery. Often recovery is incomplete and the patient is left with complaints of functional instability. In these cases muscular atrophy is frequently observed, and difficult to treat. It is therefore important to prevent or to limit the muscle atrophy in the treatment of knee injuries. There are many factors contributing to the development of posttraumatic muscle atrophy. Immobility (disuse) is the key factor. Therapeutic immobilization causes the extreme form of immobility. Thus, abolition of immobilization seems to be the answer to the problem of muscle atrophy. However, it is unknown to what extent the posttraumatic muscle atrophy is due to immobilization. It is also unknown whether and to what extent the alternatives of treatment with partial immobilization will lead to muscle atrophy. The effect of immobilization cannot be distinguished from all the other atrophy inducing factors, that are present in patients with a knee injury. These interfering factors can only be ruled out in healthy subjects. Therefore we used healthy subjects to examine the effects of some immobilization techniques. This also allows the evaluation of the effects of the immobilization techniques on thigh muscles by functional testing. These functional tests apply to the major abilities of the thigh musculature: strength and endurance. Strength is tested by means of an isokinetic dynamometer, which is a safe and reliable method. Endurance, however, is not clearly defined, and so far no tests for the aerobic endurance capacity of an isolated muscle or muscle group have been described. To develop a meaningful parameter of endurance a new test procedure for the maximal aerobic capacity of the quadriceps is described in chapter 2. We studied the effects on the thigh muscles of cast-immobilization and two of the most commonly applied partial immobilization techniques: hinged cast-bracing and a functional knee brace. A functional knee brace may be a helpful tool in the rehabilitation phase after a knee injury or surgery, and in cases of chronic instability. Sportsmen, however, are reluctant to use these knee braces since it is thought that they 'weaken the knee'. To evaluate the effects on thigh muscle performance the brace is worn by healthy subjects for four weeks (chapter 3). Hinged cast-bracing may be an alternative to cast-immobilization in the treatment of knee joint injuries, or in the post-operative phase. It is felt that this will lead to less muscular atrophy. The quantitative effects of hinged cast-bracing and cast-immobilization on the thigh muscle performance are not yet known. Therefore we studied the effects of their application during a clinically relevant period of four weeks (chapter 4 and 5, respectively). In chapter 6 the results are discussed of a functional treatment regimen with shortterm cast-immobilization and hinged cast-bracing in patients with a grade III lesion of the MCL.

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Chapter 2

Isokinetic aerobic power testing of the quadriceps muscle

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Summary

A stepwise increasing exercise protocol to measure the maximal aerobic power of the quadriceps muscle is introduced. Sixteen healthy volunteers performed isokinetic knee extension/flexion exercises at an angular velocity of $180^{\circ} \cdot s^{-1}$. The protocol consisted of stages of 200 knee movements from 100° flexion to full extension, starting at 10% peak torque (PT) and increasing by 10%PT each following stage until exhaustion. Quadriceps work, oxygen uptake, heart rate, plasma lactate concentration and surface electromyography were monitored. Quadriceps power (P_{ext}) was highly related ($r=0.95$) with the extension torque at which the subjects were instructed to exercise. The test-retest ($r=0.82$) and left to right ($r=0.94$) correlations of maximum quadriceps power (P_{max}) were good. Both sexes (males 43 ± 9 W, females 36 ± 8 W) achieved their P_{max} at 47%PT. Oxygen uptake ($r=0.85$) and EMG-amplitude ($r=0.88$) were linearly related to P_{ext} . Mechanical efficiency and plasma lactate concentration showed a large variability between work stages and between subjects. In conclusion: P_{max} as assessed by the proposed test is an useful measure of muscular endurance capacity.

Introduction

Rehabilitation after a knee injury is a major problem in (sports)medicine. Muscular performance in particular of the knee extensor muscles deteriorates significantly after knee injury, surgery, and/or immobilization (6,16), and recovery can be difficult. Rehabilitation programs are all focussed on regaining muscular strength of the thigh muscles. Consequently, strength testing of the thigh muscles is nearly common practice in rehabilitation after eg. knee injuries, but endurance with emphasis on aerobic metabolism is generally forgotten. There is, however a demand for endurance testing both in sports medicine and in rehabilitation since endurance is an important factor for physical activity as well.

Endurance is somewhat unclear defined as the ability to resist fatigue, while fatigue is defined as a failure to maintain force or power output, the cause and characteristics of which vary according to the nature of the activity performed (3). Endurance performance depends on adequate supply of oxygen and essential nutrients to the active muscle cell on the one hand, and on eliminating heat and waste products on the other. There are no general accepted parameters for endurance of isolated muscles, and therefore endurance is not easily tested. Some studies on isokinetic muscle fatigue testing have been published. In general, two methods are used: the decline in strength of a series of Maximal Voluntary Contractions (MVC) in a given period of time (12), or the number of MCV's (8,11,15)(Fatigue Index, FI) until the

torque has declined to a certain percentage of the previously established maximum (usually 50%)(2,7). However, repeated MCV's are associated with anaerobic metabolism and will therefore result in local accumulation of lactate, and in fatigue. This will quickly impede muscular function, resulting in poor judgment of the aerobic muscular endurance capacity. In this view it is not surprising, that not all subjects are able to perform the above described isokinetic fatigue tests (7,11). So there is a need for tests which evaluate the maximal aerobic power of local muscles or certain muscle groups. The aim of the present study is to develop a graded exercise protocol for the use in sport- and rehabilitation settings to measure the maximum aerobic power of the quadriceps muscle. The proposed test procedure is validated by test-retest and left-right comparisons, and correlations of power output and physiologic and electromyographic parameters. Finally, suggestions are made for its application in general practice.

Subjects and Methods

Subjects

Sixteen healthy volunteers, eight males and eight females, participated in this study after giving their written informed consent. None of the subjects suffered from complaints of the knee, nor had a history of knee injury. They were all sedentary and not accustomed to isokinetic testing. The physical characteristics of the subjects are presented in Table 1.

Table 1: Characteristics of the subjects (means $\pm$ S.D.)

sex	males (n=8)	females (n=8)
age	22.4 $\pm$ 1.7	21.4 $\pm$ 1.3
height	178.9 $\pm$ 5.8	167.5 $\pm$ 5.4
weight	72.6 $\pm$ 7.4	63.0 $\pm$ 7.4

Test procedure

In two practice sessions prior to the tests the subjects were accustomed to exercising on the isokinetic dynamometer (Cybex II, Lumex, N.Y.), and to the testing procedure. The subjects were placed on the chair of the isokinetic device, and the thigh, pelvis and upper body were fixed. They were allowed to support the arms. Prior to the test sessions a venous catheter was inserted into an antecubital vein. Next the peak torque (PT ; Nm) was determined at an angular velocity of 180°·s⁻¹, being the highest value

in two bouts of five knee extensions with maximal effort. PT was not corrected for gravity.

The range of motion on the dynamometer was set from full extension to 100° flexion, and was checked with an audio-visual feedback system. The demanded as well as the delivered torque were shown on a monitor placed in front of the subject. The speed of the dynamometer was set at 180°.s⁻¹. The subjects were instructed to perform 200 knee extensions with a demanded torque (T_{dem} ; Nm) of 10%PT. The instruction was also to alternate the knee extensions with passive knee flexions. After completing the first stage T_{dem} was increased by 10%PT each stage, until exhaustion. The test ended when the subject could no longer produce T_{dem} , or as soon as the quadriceps power of the last completed stage turned out to be lower than the previous one. The time (s) for completion of each stage was recorded. Both legs were tested with a two hours recovery period between the tests for allowing complete recovery of plasma lactate and heart rate. Four weeks later a retest was performed to assess the test reliability.

Data gathering

The torque of knee flexion and extension was registered by means of an Apple II computer with an AD-chart sampling at 50 Hz. Custom made software calculated the work of the knee extensions for each stage of 200 movements (ΣJ_{ext} ; J). The work of the knee flexions, due to gravity acting on the mass of the leg plus unintended active flexion activity, was also calculated (ΣJ_{flex}). Finally the delivered power of the knee extension movement and the power of the complete knee movement were calculated ($P_{ext} = \Sigma J_{ext} \cdot s^{-1}$, $P_{tot} = (\Sigma J_{flex} + \Sigma J_{ext}) \cdot s^{-1}$).

Oxygen uptake (VO_2 ; l.min⁻¹) was measured continuously by means of a pulmonary metabolic apparatus, the EOS Sprint (Jaeger, Würzburg, Germany). Heart rate (HR) was recorded by means of an ECG recorder (Hellige, Freiburg, Germany). Plasma lactate values were determined from a blood sample obtained at the end of each stage (PLa; mmol.l⁻¹, Lactate Analyzer 640, Kontron, Zürich, Switzerland). Mechanical efficiency (ME ; %) was calculated according to the following equation: $ME = (60 \times P_{tot}) / (20934 \times VO_2) \cdot 100\%$.

Electromyography

At each exercise stage, starting at the 100th movement, raw surface electromyography signals (EMG) were obtained from the vastus medialis during 10 s using Beckmann Ag/AgCl surface electrodes. The data were digitalized at a sample frequency of 1000 Hz (Labmaster ADC), and were stored on computer hard disc for further analysis.

The electromyographic bursts were selected manually from the raw signal (1024 points). The data were filtered (Blackman window) and Fourier transformed. The

amplitude (mV) of the 512 frequency components were summed. The amplitude of the interburst interval was determined in the same way and subtracted from the burst amplitude. The data were normalized per subject by setting the average of the amplitudes of the completed stages in each test at 50%, and recalculating the amplitudes of the separate stages accordingly. Computerized analyses were made using the Asystant⁺ software package.

Statistical analysis

Data for left to right and test- retest comparisons of quadriceps power were statistically analysed using the Student-t-test for paired data. The Pearson correlation coefficient was used to compute the relationship between power and physiologic and electromyographic parameters. The data were analysed by means of the SPSS/PC⁺ statistical package, and are presented as means $\pm$ SD. The level of significance was set at $p < 0.05$.

Results

Technical aspects of the test

All subjects completed four or five exercise stages. Pext showed a linear increase with Tdem ($r=0.95$, Figure 1). $\Sigma Jflex$ was not constant over all exercise stages. It

Fig.1: Quadriceps power as delivered in relation to the torque level as demanded ($r=0.95$)

increased from 1.8 ± 1.0 kJ at stage 1 (10%PT) to 3.5 ± 1.6 kJ at stage 4 (40%PT) ($p < 0.001$). The contribution of flexion to the total work produced decreased from 48% at stage 1 to 21% at stage 4. The duration of exercise stages declined from 285 ± 22 s for stage 1 to 260 ± 20 s for stage 4. The myoelectric bursts of knee extension also lasted shorter (767 ± 103 ms in stage 1 to 593 ± 81 ms in stage 5). The two hours of rest between testing of both legs was sufficient as was judged by measurements of HR, PLa and VO_2 at rest.

Reliability of the test

The peak power of knee extension (P_{max} ; W) showed no significant differences between the test- and retest situation (39.2 ± 10.1 W and 39.6 ± 8.3 W, $r = 0.82$). The mean variability of P_{max} was 12%. P_{max} of the right leg (39.1 ± 9.5 W) did not differ significantly from the left leg (39.6 ± 9.0 W). The comparison between males and females as another indication for the test reliability showed, that P_{max} was reached at the same exercise stages between 40%PT and 50%PT in both sexes (average males $46.7 \pm 7.6\%$ PT, females $46.9 \pm 7.8\%$ PT).

Test performance and physiologic correlates

Males reached a significantly higher PT ($p < 0.001$) and P_{max} ($p < 0.001$) than females (PT; males 138.6 ± 24.1 Nm, females 110.0 ± 29.9 Nm, P_{max} ; males 43.4 ± 9.2 W, females 35.6 ± 7.6 W). The difference between both sexes in peak oxygen consumption (VO_2 ; males 1.50 ± 0.38 l.min⁻¹, females 1.26 ± 0.38 l.min⁻¹) was correlated to the difference in P_{tot} . The peak heart rate in females (156 ± 21 beats.min⁻¹) was significantly ($p < 0.05$) higher than in males (142 ± 20 beats.min⁻¹). Peak plasma lactate concentrations were lower than commonly found in VO_2 max testing on treadmill or bicycle ergometer ($8\text{--}10$ mmol.l⁻¹), and there were no statistically significant differences between males (6.9 ± 3.7 mmol.l⁻¹) and females (5.8 ± 2.2 mmol.l⁻¹).

VO_2 at each stage was plotted against P_{ext} (Figure 2). The relationship appeared to be linear in the submaximal stages ($r = 0.85$) with a tendency to incline at the maximal stage. When the calculated mechanical efficiency was plotted against the relative work delivered (Figure 3), the best fit of the relationship was a curve with its optimum around 60% peak power, and a correlation coefficient of $r = 0.54$. The relative oxygen consumption was linearly related ($r = 0.74$) to HR. Plasma lactate concentration showed a curvilinear relation with VO_2 with a correlation of 0.71 (Figure 4). PLa remained at resting levels until 50-60% of the peak oxygen consumption, then it increased exponentially, with peak values ranging from 2.1 mmol.l⁻¹ to 15.6 mmol.l⁻¹.

Surface electromyography from the vastus lateralis was applied to identify the relationship between the electrical activity of the quadriceps and the work performed

Fig. 2: Oxygen consumption ($\text{l}\cdot\text{min}^{-1}$) for quadriceps power as delivered (Watt). Overall correlation is 0.85; correlation for submaximal stages only is 0.87.

Fig. 3: Mechanical efficiency (%) for relative power delivered in both flexion and extension movements (%). Maximal power level is set at 100%.

Fig. 4: Plasma lactate concentration (mmol.l⁻¹) in relation to the relative oxygen consumption. Peak oxygen consumption at the isokinetic endurance test is set at 100%.

Fig. 5: EMG amplitude in relation to quadriceps power. Both variables are normalized at 50% for each test of consecutive stages to compensate for differences in electrode placement.

by the quadriceps. The relationship between EMG amplitude after normalization, and quadriceps power appeared to be linear ($r=0.88$) with a tendency to increase at peak power (Figure 5).

Discussion

The present study evaluates a stepwise increasing isokinetic loading protocol to measure maximal aerobic power of the quadriceps muscle.

Technical aspects

A significant, but constant error in the measurements is included because no correction for gravity has been applied. However, because gravity, mass of the leg, and movement cycle remain the same during the test, the error in measurement of ΣJ_{ext} and ΣJ_{flex} is constant within each subject. This means that extension strength and work are underestimated due to gravity acting on the mass of the leg and lever arm, while flexion strength and work are overestimated to the same extent. Because the mass of the leg is a variable in this measurement of extension power, the results of the test can only be used for intra-subject comparisons with intact limbs.

In the ideal situation the work recorded in passive knee flexions is constant over all exercise stages. However, unintended muscular activity may cause an increase of the power of flexion with increased quadriceps loading. This increase is relatively small, from 6.3 ± 3.5 W at 10%PT to 13.5 ± 6.2 W at 40%PT, but differences between the subjects are noted. The increased flexion activity never interferes with the extension exercise as can be judged from the limited power that is obtained. In addition the subjects stated that exhaustion was always the result of quadriceps fatigue.

A remarkable finding was that the time needed for completing each stage decreased with increased quadriceps loading. Since the speed of the dynamometer is fairly constant during movement, as well as the range of motion, this means that the alternation of movement is swifter. This might be the result of changes in motor control. These changes are observed with surface EMG as a decreased duration of the myoelectric bursts with increased loading. The decrease in time needed for completing each stage can to some extent also be attributed to technical shortcomings of the Cybex II dynamometer, since the preset limit of the angular velocity can be exceeded at the impact of the leg and lever arm (14). Due to this technical shortcoming the absolute values of torque and power measurements are device specific.

Angular velocity was set at 180 deg.s^{-1} . This velocity was chosen because it is well tolerated by the subjects and it is usually applied in other studies examining fatiguability (2,7,8,15). It is, however, shown that fatigue is velocity dependent (12). This means that the results of this test are velocity specific as well.

The Cybex II isokinetic dynamometer does not have the feature of an adjustable external loading, the apparatus merely accommodates to forces applied to it and makes them measurable. In order to allow stepwise increased quadriceps loading the subjects are therefore instructed to deliver a given torque at each stage. In doing this they are aided with visual feedback to keep the variation in torque output within range. However, fluctuations in torque during each stage are inevitable, and the expected increase in the delivered work can only be assessed retrospectively since the actual work delivered is only calculated after completing the exercise stage. The high correlation between T_{dem} and P_{ext} at each stage ($r=0.95$) demonstrates that even though fluctuations in torque output occur, this does not influence the work produced over the entire stage.

Reliability

The test- retest correlation for maximal performance is fairly good ($r=0.82$ with a mean variability of 12%). This is in accordance with a test- retest correlation of 0.85 found in an isokinetic anaerobic power test at 180 deg.s^{-1} (2). Nevertheless, the test-retest correlation is less than in aerobic power testing on the treadmill ($r=0.96$)(17) and the variability is higher than in bicycle ergometer exercise (4.79%) (9). Poor muscular coordination with this unaccustomed movement, and the poor training status of our sedentary subjects may be responsible for this lower correlation and higher variability.

Test-performances and physiological correlates (P_{max} , VO_2 , HR, PLa , EMG)

The average P_{max} is 39.2 ± 10.1 Watt, and is delivered at an average of 47%PT. This is in accordance with findings of Komi et al. (8), who reported a maximal torque output of 44% after 100 Maximal Voluntary Contractions (MCV): 51% in subjects with predominantly ST fibers and 38% in those with predominantly FT fibers.

As expected, males have a higher P_{max} than females. In both sexes P_{max} is linearly related to PT. No left to right differences are noted for PT or P_{max} . This is in accordance with the findings of Gilliam (5). This natural equality between both legs makes the test suitable for use in rehabilitation settings, comparing the injured leg with the healthy leg.

At submaximal exercise stages oxygen uptake is linearly related to P_{ext} ($r=0.85$) and to P_{tot} ($r=0.89$), but it inclined at the maximal performance stage. This extra oxygen consumption may be the result of coactivity of various muscle groups (e.g. arms, back, neck, abdomen), at peak performance, which are likely present during the test. The maximal capacity of the heart is not fully exploited in this test as shown in the submaximal peak heart rates. This is due to the limited active muscle mass during one leg knee extension/passive knee flexion exercise. During the progressive exercise protocol the maximal blood flow capacity of the active muscles is most probably

approached and anaerobic energy sources contribute progressively to the energy delivery demanded. This process is reflected in the increase of the plasma lactate concentration at the final stages.

In the present study, the amplitude of the EMG is well related to P_{ext} ($r=0.88$). It is shown both in submaximal isometric contractions (13), as in submaximal bicycle ergometer exercise (1), that iEMG is linearly related to strength. The same linear relationship between contractional work and EMG activity is demonstrated in isokinetic exercise of the human triceps surae by Fugl-Meyer (4). The present isokinetic quadriceps loading protocol reveals a linear relationship between muscle power and amplitude of EMG up to about 75% P_{max} . At higher power levels the amplitude increases more exponentially. This exponential rise in EMG activity in maximal exercise is also reported by Kuroda in isometric quadriceps contractions (10).

Applications

P_{max} can be a valuable measure in the evaluation of local muscular endurance capacity in sports medical practice and in rehabilitation settings. A simple and reliable test procedure is important. We feel that the test procedure described above can be simplified. At first, a reliable assessment of P_{max} can be done without measurement of ΣJ_{ext} with the additional computer and software due to the strong correlation between T_{dem} and P_{ext} . Secondly, the protocol can be shortened by starting at 20%PT since all subjects were able to complete at least the 30%PT stage. The suggested simplified protocol to assess P_{max} consists of stepwise loading of the knee extensors at 180 deg.s⁻¹, starting at 20%PT and increasing with 10%PT each consecutive stage, until exhaustion.

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Chapter 3

The effects of a supportive knee brace on leg performance in healthy subjects

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Summary

Eight healthy volunteers were fitted with a supportive knee brace (Push Brace® 'Heavy') to one knee for the duration of four weeks wherein they were tested before, during and after the application to establish the effect of bracing on performance. The tests consisted of isokinetic strength measurement of knee flexion and extension, 60 meter dash, vertical jump height and a progressive horizontal treadmill test until exhaustion (V_{max}) with determination of oxygen uptake, heart rate and plasma lactate concentration. Wearing the brace for one day, the performance indicators showed a decline compared with the tests before application (base values). Sprint time was 4% longer ($p < 0.01$), and V_{max} 6% slower ($p < 0.05$). Peak torque of knee flexion at 60 and 240 deg. sec^{-1} was 6% ($p < 0.01$) respectively 9% ($p < 0.05$) less. Peak extension torque at 60 deg. sec^{-1} was 9% less ($p < 0.05$). While wearing the brace for four weeks, the test performances were practically identical to their base values. After removal of the brace, all test parameters were statistically similar to the base values. Heart rate at submaximal exercise levels was even lower ($p < 0.05$). In conclusion, performance in sports with testlike exercise patterns is not affected by the knee brace tested. Bracing does not 'weaken the knee' as it is widely believed in sports practice.

Introduction

The main reasons for a sportsman to wear a supportive knee brace are symptomatic knee joint instability and secondary prophylaxis after a previously encountered knee ligament lesion. Particularly, athletes make high demands upon supportive braces. On the one hand, the brace must compensate for joint instability and must lower the risk of re-injury, but on the other hand, it should not interfere with performance. A number of studies demonstrate that in laboratory settings knee braces are capable of reducing undesired valgus/varus, rotational and anterior/posterior movements to a certain extent (1,2,6,9,12,14). Functional evaluation of bracing in case of instability shows that bracing only reduces the occurrence of swelling, pain and giving-way (3,4,11).

Recent publications concerning the prophylactic use of knee braces give rise to serious doubt regarding their injury-preventive effect (5,7,8,13,15). In addition, in sports practice it is generally assumed that when a brace is worn for preventive purposes, the joint stability relies less on muscular function. This will lead to muscular atrophy and consequently decreased performance. Supportive for this view are the findings of Houston et al. (10) and Zetterlund et al. (17), who concluded that a knee brace affects muscle strength and aerobic capacity. Thus the gain in passive

stability may be counterbalanced by decreased muscular stability and lower leg performance. However, it is not known to what extent preventive bracing does induce muscular atrophy and decrease performance. Especially for use in sports, a supportive knee brace (Push Brace® 'Heavy') has been developed. The use of this brace is indicated in patients with complaints of chronic medial or lateral instability and is assumed to increase stability and not to decrease performance or muscle strength. The aim of the present study is to evaluate the direct and long-run effects of this knee brace on leg performance.

Materials and Methods

Subjects

In order to eliminate all injury-related bias, the study was performed in healthy subjects. Eight healthy volunteers participated in this study after giving their informed consent (Table 1). The participants did not have a history of knee injury and were all active in sports.

Brace

In all subjects the Push Brace® 'Heavy', a supportive knee brace, weighing 300 grams, was used. This brace has elastic strappings and a series of lateral and medial built-in hinges preventing valgus and varus movement (Figs. 1a and 1b). Knee flexion and extension are possible over the full range of motion. The brace was randomly assigned to the right or the left leg. The subjects were instructed how to tie the brace to the previously selected knee during daytime hours for a period of four weeks. Application of the brace was regularly checked during the period of this study and before testing.

Table 1: Characteristics of the subjects

Subject	Sex M/F	Age yrs	Height cm	Weight kg	Braced knee R/L	VO ₂ max l.min ⁻¹	Sports
1	F	23	180	56	R	2.58	fitness
2	M	26	180	75	L	5.08	triathlon
3	M	39	176	75	L	3.64	soccer
4	F	19	168	64	R	2.67	jogging
5	M	19	185	81	L	4.41	jogging
6	M	21	188	82	R	4.05	soccer
7	M	25	185	73	L	3.74	soccer
8	M	22	183	75	R	4.23	jogging
mean		24	181	75		3.80	
S.D.		6	6	9		0.85

Figs. 1a and 1b: The Push Brace® 'Heavy'.

Testing protocol

The tests series examining changes in leg performance were taken three days before application of the brace, at day one and at day 28 during the bracing period, and again one day after removal. The results of the test before application were considered as base values. In both test series at day one and at day 28 during the bracing period, the subjects were wearing the brace. The test series included isokinetic muscle strength measurements, 60 meter dash, vertical jump height testing and treadmill running. Prior to the study, the subjects were familiarized with the dynamometer and treadmill. Strength of knee flexion and extension was measured as maximal torque output using a Cybex II isokinetic dynamometer (Lumex, N.Y.). Maximal torque was registered for both knees at an angular velocity of 60, 120, 180, 240 and 300 deg. sec^{-1} from a series of five movements with maximal effort. Dynamometry was followed by a vertical jump height testing and manually clocked 60 meter dash. After a 30-minute rest period the subjects performed a horizontal treadmill test which consisted of a warm-up at a speed of 10 km. h^{-1} . Every three minutes the speed was increased two km. h^{-1} until volitional exhaustion (V_{max} ; km. h^{-1}). Oxygen uptake (VO_2 ; l. min^{-1}) and heart rate (HR ; b. min^{-1}) were continuously monitored by means of an automatic pulmonary metabolic apparatus (EOS Sprint®, Jaeger, Würzburg, Germany) and E.C.G. recorder (Hellige, Freiburg, Germany). At the end of each workload a blood sample was drawn from a catheter in an antecubital vein for plasma lactate analysis (PLa ; mmol. l^{-1} ; Lactate Analyzer 640®, Kontron, Zürich, Switzerland).

Statistics

The data during submaximal exercise at 10, 12 and 14 km.h⁻¹ were statistically analysed by two-way analysis of variance with repeated measures using the four test situations (16). For statistical analysis of the results of the 60 meter dash, high-jump and Vmax, the Wilcoxon test was used. The level of significance was set at 0.05.

Results

During the first three days of wearing, some of the subjects complained about pinching of the knee. After this initial habituation period the complaints ceased. The physical activities of the subjects in terms of duration and level of performance in sports were not affected by the brace.

Strength measurements

Peak torque values for knee extension and flexion at 60 deg.sec⁻¹ and of flexion at 240 deg.sec⁻¹ were 9% ($p < 0.05$), respectively 6% ($p < 0.05$) and 9% ($p < 0.05$) lower on the first day of the application period (Figs. 2 and 3). Four weeks later the outcome of the strength measurements were again equal to the base values.

Sprinting, high jump and Vmax

The results of vertical jump height tests, 60 meter dash and Vmax are shown in Table 2. The results of the vertical jump height tests showed a large variation over all test trials and therefore no significant differences. The running time of the 60 meter dash was 4% longer 4% ($p < 0.01$) on the first day of application of the brace (test 2). After four weeks there were no significant differences compared with the base values. Testing Vmax, while wearing the brace on day one and day 28, resulted in a decrease of 6% ($p < 0.05$) and 4% ($p < 0.05$), respectively.

Table 2: Results of 60 meter dash, vertical jump height test, and maximal speed on the treadmill in the successive test trials. Values are means $\pm$ S.D. (* $p < 0.05$ as compared with base values).

	Sprinting (s)	Jump height (cm)	Vmax (km.h ⁻¹)
Before application	8.74 $\pm$ 0.35	47.1 $\pm$ 7.2	16.6 $\pm$ 2.6
Day 1 of application	9.05 $\pm$ 0.44*	45.1 $\pm$ 8.2	15.6 $\pm$ 1.8*
Day 28 of application	8.91 $\pm$ 0.55	47.4 $\pm$ 7.0	16.0 $\pm$ 2.7*
After removal	8.86 $\pm$ 0.56	45.8 $\pm$ 6.7	16.8 $\pm$ 2.7

Fig. 2: Knee flexion

Fig. 3: Knee extension

Figs. 2 and 3: Mean values of isokinetic strength of knee flexion and extension in the eight subjects at angular velocities of 60, 120, 180, 240 and 300 deg.sec⁻¹.

Test 1 taken 3 days before application of the brace, test 2 the first day of application, test 3 the 28th day after application, and test 4 the day after removal of the brace. (* $p < 0.05$ as compared with base values.)

Table 3: HR, VO₂, and PLa at 10, 12 and 14 km.h⁻¹ on the treadmill at the four successive test trials. Values are means ± S.D.. Level of significance is set at 0.05, ^a denotes a significant difference as compared to test 1, ^b as compared to test 2, and ^c as compared to test 3.

	Speed km.h ⁻¹	Test 1 before	Test 2 day 1	Test 3 day 28	Test 4 removed
HR b.min ⁻¹	10	166 ± 19	160 ± 20 ^a	161 ± 21	156 ± 18 ^{a,b,c}
	12	175 ± 18	173 ± 18	173 ± 19	169 ± 19 ^{a,b,c}
	14	180 ± 15	178 ± 13	180 ± 17	175 ± 17 ^a
VO ₂ l.min ⁻¹	10	2.67 ± 0.40	2.72 ± 0.40	2.67 ± 0.40	2.54 ± 0.39 ^{a,b,c}
	12	3.02 ± 0.44	3.12 ± 0.54	3.09 ± 0.47	2.92 ± 0.42 ^{b,c}
	14	3.43 ± 0.47	3.54 ± 0.67	3.53 ± 0.58	3.40 ± 0.49
PLa mmol.l ⁻¹	10	3.1 ± 1.1	3.3 ± 1.6	3.2 ± 0.8	2.9 ± 1.0
	12	4.1 ± 2.0	4.6 ± 2.9	4.4 ± 2.1	3.7 ± 1.8 ^c
	14	5.0 ± 2.2	5.7 ± 2.8	5.5 ± 2.3	4.5 ± 1.7

Treadmill tests

HR, VO₂ and PLa at submaximal exercise on the treadmill are shown in Table 3. HR showed only slight variation between the test trials, except for the test one day after removal. HR at 10, 12 and 14 km.h⁻¹ was then 6% ($p < 0.05$) respectively 3% ($p < 0.05$) and 3% ($p < 0.05$) lower in respect to base values. VO₂ was slightly, but not significantly increased while wearing the brace at submaximal treadmill running. After removal of the brace VO₂ at 10, 12 and 14 km.h⁻¹ declined below base values. PLa at submaximal exercise showed the same pattern as VO₂, i.e. slightly elevated levels during brace application (n.s.) and 6% to 10% reduction after removal (n.s.) as compared with the test results before brace application.

Discussion

When comparing the results of the four test trials, performance appears to be impaired on the first day of application of the brace. Isokinetic strength of knee flexion and extension declined, sprinting was slower, and exhaustion at the progressive treadmill test was achieved at a lower velocity. After wearing the braces for four weeks, the test results were again similar to the base values. However, both VO₂ and PLa at submaximal exercise remained elevated. These findings indicate some mechanical impediment of knee movement due to the brace. One day after removal of the brace, VO₂, PLa and HR at submaximal treadmill exercise appeared to be declined below

base values. This might indicate a slight training effect, probably induced by the mild hindrance of the brace mimicking resistance training.

Both Houston et al. (10) and Zetterlund et al. (17) investigated the effects of wearing a supportive knee brace on performance in patients accustomed to wearing a brace. In order to compare their results to those of the present study, the 'brace-condition' in their tests is considered similar to the test at day 28 of brace application. The 'non-brace condition' is compared with the test the day after removal of the brace. Houston et al. found that wearing a brace gave rise to a 41% increase in PLa after a fifteen-minute ride on a bicycle ergometer at a load established to elicit a heart rate of $170 \text{ b} \cdot \text{min}^{-1}$. PLa in our subjects rose 11.9% at $10 \text{ km} \cdot \text{h}^{-1}$ (n.s.), 18.9% at $12 \text{ km} \cdot \text{h}^{-1}$ ($p < 0.05$), and 22.3% at $14 \text{ km} \cdot \text{h}^{-1}$ (n.s.) when comparing brace condition with the test results after removal. Houston et al. also found isokinetic strength to be 12% to 30% lower, compared to a maximum of 6% in our subjects. Zetterlund et al. revealed that patients wearing a Lennox Hill® brace had 4.6% higher VO_2 and 5.1% higher HR at a treadmill test at $9.7 \text{ km} \cdot \text{h}^{-1}$. In our subjects treadmill running at $10 \text{ km} \cdot \text{h}^{-1}$ whilst wearing the brace resulted in a 5% higher VO_2 ($p < 0.05$) and a 3% higher HR ($p < 0.05$) as compared with the test after removal.

In order to understand the effects of a supportive knee brace on leg performance itself, without interference of a traumatic lesion, we used healthy subjects in our tests. Testing in patients can give rise to false findings in 'non-brace-conditions' caused by reticence, resulting in an underestimation of the impediment caused by bracing. Tegner et al. (14) reported, that wearing certain types of supportive knee braces will interfere with the results of functional tests. Our protocol enables us to reveal both direct and structural effects on leg performance of wearing the brace. Muscular strength is tested by isokinetic strength measurements, vertical jump height testing and 60 meter dash; muscular endurance and the aerobic capacity by the treadmill tests. A follow-up period of four weeks during which time the brace was constantly worn, was considered to be sufficient in comparison with medical practice, where bracing is advised for a limited period, or during sports, where a brace is worn intermittently.

In conclusion we can say that the knee brace tested does impair performance slightly but significantly during the first day of application. After familiarization only a slight mechanical hindrance remains, with little or no effect on performance, but which gives rise to some resistance training effects. For optimal performance in sports, it is important to get accustomed to bracing in training sessions. After removal of the brace, signs of muscular atrophy were not demonstrated. The present study does not give any indications to support the believe that bracing 'weakens the knee'. In the case of athletes with symptomatic knee instability, the effect of an appropriate supportive brace on performance might well be positive, when mechanical hindrance is outweighed by functional improvement. More effort should be considered in functional testing of braces used by sportsmen.

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Chapter 4

Effects of cast-bracing of the knee on physical performance in healthy subjects

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Summary

Effects of application of a hinged cast-brace on thigh muscle strength and physical performance tests were studied in eight healthy volunteers. The cast-brace was applied to one leg for four weeks. The subjects were free to move around. The extra loading by the cast-brace was determined in a progressive uphill walk test on a treadmill with measurements of oxygen uptake, heart rate and plasma lactate concentration. Submaximal oxygen uptake in the uphill walk test was raised significantly (average 9%) on the day after application. After four weeks of cast-brace wearing the submaximal oxygen uptake in the uphill walk test had decreased, but remained elevated (average 4%) even one day after removal. Heart rate was significantly higher (average 7%) during cast application and after removal. Plasma lactate concentration, however, was not influenced. To investigate the effect of four weeks cast-bracing various performance tests to judge the thigh muscle function were taken before application and after removal. No significant changes in peak torque of knee flexion and extension, in physiologic variables at submaximal running pace during treadmill exercise, maximal running speed, 60 m dash, or in jump height were found. In conclusion, cast-bracing of a healthy knee for four weeks has no significant effects on physical performance after removal.

Introduction

Immobilization of the knee joint is indicated in a number of traumatic disorders such as knee ligament lesions, tibial shaft fractures and fractures of the tibial condyle. However, it is known that immobilization of the knee is associated with degeneration of cartilage and ligaments, thigh muscle atrophy and osteodystrophy (3,4,6,8,13,14,15,19). The indication to immobilize the knee joint should be carefully balanced against these adverse effects. Cast-bracing, whenever possible has been advocated to avoid long lasting complete immobilization. The use of a hinged cast-brace is indicated in primary non-operative treatment of knee ligament lesions and post-operative protection after surgically treated knee ligament lesions (1,2,11,16). The range of motion can be adjusted, depending on the lesion. By allowing movement and weight-bearing less degeneration of ligaments is seen (6). Thigh muscle atrophy is also less severe as compared with complete immobilization, but it is still evident. Muscle atrophy observed in patients wearing a cast-brace after knee ligament surgery might be attributed to the partial immobilization or other factors causing a relative immobilization. Such immobilizing factors are pain, discomfort, joint effusion, surgical and/or traumatic damage to joint or muscle-tendon complex, or fear to move the injured leg. Thus the relative immobility may not exclusively be due to the

cast-bracing itself, but can also be influenced by the other mentioned immobilizing factors. The aim of the present study was to assess the effects of cast-bracing alone on physical performance during application of a hinged cast-brace for four weeks and after its removal in healthy subjects.

Materials and Methods

Subjects

Eight healthy volunteers participated in this study after giving their informed consent. Their physical characteristics are given in Table 1. The participants did not have a history of prior knee injury and were all active in sports.

Table 1: Physical characteristics of the subjects.

Subject	Sex M/F	Age yr	Height cm	Weight kg	VO ₂ max.kg ⁻¹ ml.min ⁻¹
1	M	21	184	80	49
2	M	21	198	90	55
3	M	22	174	59	52
4	F	20	174	59	42
5	M	19	191	72	58
6	M	39	176	73	60
7	M	21	179	67	55
8	F	21	178	62	46
median		21	178.5	69.5	55

Cast-brace

A hinged cast-brace (Delta Cast Light®) was applied to one randomly selected leg by an experienced castroom technician for a period of four weeks (Fig.1). The cast-braces weighed 905 to 1260 gram (median 1011 g). Full weight-bearing was allowed. The hinges were set free, enabling normal knee extension and 90-100 degrees of flexion.

Exercise protocol

Test series examining leg performance were executed three days before application of the cast-brace (base values), the day after application (test 2), four weeks after application (test 3), and the day after removal of the cast-brace (test 4). Test 1 and test 4 included isokinetic strength measurements, vertical jump height, 60 meter

Fig. 1: Cast-brace as used in this study

Table 2: Test sequence

	test 1 day -3	Application		Removal
		test 2 day 2	test 3 day 28	test 4 day +1
peak torque	+	-	-	+
60 m dash	+	-	-	+
jump height	+	-	-	+
treadmill level running	+	-	-	+
treadmill uphill walking	+	+	+	+

dash, an incremental level running treadmill test and an uphill walk treadmill test. Test 2 and test 3 were restricted to the progressive uphill walk test because of movement limitations determined by the cast-brace (Table 2). Strength of knee flexion and extension was measured as maximal torque output using a Cybex II isokinetic dynamometer (Lumex, N.Y). Peak torque was registered at angular velocities of 60 ,120, 180, 240, and 300 deg.s⁻¹ from two series of five movements with maximal effort. Dynamometry was followed by a vertical jump height test and a manually clocked outdoor 60 meter dash. After a 30 minutes rest period the subjects performed a level running treadmill test (Quinton 18-50, Seattle, USA). This test

consisted of a warm-up of five minutes at a speed of 10 km.h^{-1} . Subsequently the running speed was increased 2 km.h^{-1} every three minutes until the subject could not keep up with the imposed speed due to exhaustion (V_{max} ; km.h^{-1}). Oxygen uptake (VO_2 ; l.min^{-1}) and heart rate (HR; b.min^{-1}) were monitored by means of an automatic pulmonary metabolic apparatus (EOS SPRINT, Jaeger, Würzburg, Germany) and an E.C.G. recorder (Hellige, Freiburg, Germany), respectively. At the end of each stage a blood sample was drawn from a catheter in an antecubital vein for plasma lactate analysis (PLa; mmol.l^{-1}). The samples were analyzed using the Lactate Analyzer 640 (Kontron, Zürich, Switzerland). After a three hours rest period the subjects performed the treadmill walk test with a constant speed of 6 km.h^{-1} and an increasing slope of 10, 15, 20 degrees. Similar physiologic variables as in the running tests were registered.

Data analysis

Data were statistically analysed using the Wilcoxon test for non-parametric data. An analysis of variance and a postiori test were done on the results of the progressive uphill walking tests. The level of significance was set at 0.05. Because of the limited number of participants the data are presented as medians.

Results

Immediate and late effects of cast-brace application as tested in the uphill walk test

The immediate effect (one day after application) of wearing the cast-brace is demonstrated in test 2 compared to test 1 (Fig.4). Submaximal oxygen uptake in the uphill walk test at subsequent slopes of 10° , 15° and 20° showed an average rise of 9% (range 5% to 12%; $p < 0.05$). A similar effect was found for the heart rate (average rise 7%; range 6% to 9%; $p < 0.05$). Plasma lactate concentration was not affected. The late effects of wearing the cast-brace (four weeks of application) are shown in test 3 as compared to test 2. Submaximal oxygen uptake showed a tendency to decrease (average 4%; range 2% to 5%; n.s.), but it remained elevated compared to the baseline test.

Analysis of variance and a postiori test showed, that the heart rate was significantly higher during both tests wearing the brace (test 2 and test 3) and after removal (test 4).

Effects of four weeks of cast-bracing on various performance tests.

After removal of the cast-brace the subjects did not report any complaints and they were able to resume their usual gait. Peak torque of knee extension at five angular

Fig. 2: Plasma lactate concentration (mmol.l⁻¹), heart rate (b.min⁻¹) and oxygen uptake (l.min⁻¹) in the progressive uphill walk test with slopes of 0°, 10°, 15° and 20°. Test 1 represents the baseline values, test 2 is taken after cast-brace application, test 3 after 4 weeks of cast-brace application and test 4 after removal of the cast-brace. Heart rate was significantly higher in test 2, 3 and 4 as compared with test 1 (ANOVA; $p < 0.05$).

Table 3: Vertical jump height, 60 m dash and maximal speed achieved in graded treadmill running before application of the cast-brace and after removal. Values are medians and range.

	Pre-test day -3	End-test day +1
jump height (cm)	49.0 (34-58)	49.0 (35-56)
60 m dash (s)	8.88 (7.74-10.12)	8.29 (7.56-10.54)
Vmax (km.h ⁻¹)	16.6 (14.0-20.0)	15.1 (14.0-19.7)

velocities was unaffected (Fig.3). Knee flexion strength was also unaffected with the exception of an 8% rise ($p < 0.05$) at 180 deg.s⁻¹ (Fig.4).

The performances at 60 m dash, vertical jump height and the peak running speed in the progressive treadmill test were not significantly different between the pre- and post cast-brace period (Table 3). During the submaximal uphill walking none of the physiological parameters (submaximal oxygen uptake, heart rate and plasma lactate concentration) showed consistent differences between the baseline test and testing after removal of the cast-brace (Fig.2). Also no significant differences of the given parameters were observed during level treadmill running at 10, 12 and 14 km.h⁻¹.

Discussion

A hinged cast-brace of the knee influences the daily use of the leg involved, although this cannot be quantified. The effect of wearing the cast-brace on energy expenditure was tested in an uphill walking test. The late effects after four weeks of application were evaluated with various performance tests. The tests were taken in a relatively small sample population of eight healthy subjects, therefore the results have to be regarded more as tendencies than as absolute values.

Immediate and late effects of cast-brace application as tested in the uphill walk test

All subjects completed the study. Apart from the mechanical hindrance of the cast-brace no complaints were reported. The uphill walk test with the cast-brace was completed by seven of the eight subjects. The oxygen uptake at submaximal exercise, as parameter for energy expenditure, was increased while wearing the cast-brace (test 2). The heart rate, as a parameter for the oxygen transport system, showed a corresponding rise. Plasma lactate concentration remained below two mmol.l⁻¹ at the three lowest stages in both tests, indicating that the energy delivered was covered

Fig. 3: Knee extension strength of the casted leg before application (test 1) and after removal (test 4).

Fig. 4: Knee flexion strength of the casted leg before application (test 1) and after removal (test 4). (* $p < 0.05$)

practically completely by aerobic processes. Only at a slope of 20° was the exercise hard for several subjects, reflected in a rise in PLa (range 1.1 to 9.8 mmol.l⁻¹).

In the literature no studies concerning the effects of cast-bracing on energy expenditure were found. When comparing our data with the effects of less firm functional knee braces similar increases in oxygen uptake and heart rate were reported. Zetterlund et al. revealed that patients wearing the Lennox Hill brace had a 4.6% higher VO₂ and 5.1% higher HR while walking on a treadmill at a speed of 5.7 km.h⁻¹ (20). Highgenboten published similar results for four different functional knee braces and reported a significant rise in energy expenditure of 3-8% (9). The rise in oxygen uptake was dependent on the weight of the knee brace. It was demonstrated by Soule and Goldman that a weight added to a leg has a high mechanical impact with regard to the energy expenditure (17). Additionally Houston demonstrated that athletes wearing a functional knee brace had significantly less knee extension strength (12% to 30%), were slower in unloaded knee extension, performed worse in a stair run and had a 41% higher plasma lactate concentration at submaximal bicycle ergometer loading (10).

Effects of four weeks of cast-bracing on various performance tests

Cast-bracing does restrict the normal use of the leg involved, but mainly for those movements that require a large flexion angle or a high angular velocity. Walking in daily life is acceptable, but running as in sports is practically impossible. It is unfeasible to monitor subjects for several weeks to estimate the difference in physical activity due to cast-brace application. However, it is reasonable to speculate that the overall physical activity has declined during cast-bracing resulting in a detraining effect. On the other hand it can be speculated that a training effect is elicited due to the mechanical hindrance by the hinges of the cast-brace and the extra weight applied to the leg. The results of various performance tests involving the thigh muscles revealed that the subjects were not significantly affected in either direction. This means that cast-bracing alone has no significant effect on the knee function of the thigh muscles.

Earlier we conducted a study with healthy subjects wearing a supportive knee brace for four weeks (18). Muscle strength of knee flexion and extension, sprint time at 60 m dash and jump height were not affected by functional bracing. Running at submaximal speed revealed a slightly decreased heart rate, oxygen uptake and PLa, indicating some training effect due to mechanical hindrance by the brace. In the present study no significant differences were observed between post cast-brace tests and the baseline tests for muscle strength, sprint time at 60 m dash, jump height, or maximal running velocity, nor were there significant alterations at submaximal exercise. This might indicate that in the case of cast-bracing the training effect as observed in functional bracing is compensated for by a detraining effect due to decreased physical activity.

Cast application for four weeks causes considerable loss of muscular strength and endurance capacity which can be observed in healthy subjects as well as in patients (12,19). When comparing cast-brace application with casting in patients after knee ligament surgery, significantly increased muscle atrophy is observed after standard casting (7). Earlier (partial) recovery of muscle strength in patients with a cast-brace has also been reported (11). However, in patients treated with cast-bracing a considerable decrease in muscular function is observed whereas in the present study it was found that cast-brace application in healthy subjects did not result in any decline in muscular performance. Therefore, it must be concluded that the deterioration of muscular performance observed in patients after knee injury receiving surgery and cast-brace application is the result of other immobilizing factors; i.e. pain, fear of movement and joint effusion, and damage to the joint and/or muscle-tendon complex and not cast-bracing itself (5).

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Chapter 5

Functional and morphological adaptations following four weeks of knee immobilization

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Summary

Immobilization of the knee as part of the treatment in bone or joint lesions leads to atrophy and consequently loss of functionality. In patients this atrophy and loss of functionality is difficult to quantify because of interfering symptoms and missing baseline data. In the present study structural and functional changes in thigh muscles were examined in eight healthy volunteers of whom one leg was immobilized in a cast for four weeks. Quadriceps cross-sectional area determined with computed tomography was $21\% \pm 7\%$ diminished after four weeks immobilization ($p < 0.05$). Muscle biopsies from the musculus vastus lateralis revealed an 16% decreased fiber diameter ($p < 0.05$) and no significant shift in fiber types. Isokinetic strength measurements of knee extensors and flexors demonstrated a fall in peak torque of $52\% \pm 9\%$ and $26\% \pm 13\%$ at an angular velocity of $60 \text{ deg} \cdot \text{s}^{-1}$ ($p < 0.01$). Aerobic power in one-leg-cycling exercise was not significantly affected, but isokinetic quadriceps endurance work decreased from 9.1 KJ to 5.6 KJ ($p < 0.05$). Despite the fall in quadriceps performance the subjects had only minor functional complaints for a few days. It is concluded, that immobilization of the knee is an important factor in the development of thigh muscle atrophy in patients and should therefore be diminished as much as possible.

Introduction

Thigh muscle atrophy is a major problem in the rehabilitation following knee injury and/or surgery. Several factors are thought to be responsible for the development of quadriceps atrophy such as pain, joint effusion, tourniquet application during surgery, and probably the most important factor: immobilization (2,3,6,8,9). It is an empirical finding that quadriceps atrophy in knee-injured patients is difficult to restore. Therefore much effort is spent on prevention of this muscle atrophy. Non-Steroid Anti-Inflammatory Drugs (NSAID) are administered to relieve pain and diminish joint effusion. Transcutaneous Neural Stimulation (TNS) may reduce pain, while electromyostimulation can decrease muscle atrophy (10,15,23,26). To avoid immobilization cast-bracing is applied whenever possible (12,22). However, the effect of immobilization alone on thigh muscles in humans has not been examined yet. Several techniques are available to analyze the effects of immobilization. Muscular strength and endurance and motoric skills are functional variables, whereas leg circumference, histology, histochemistry and Computed Tomography (CT) or Ultrasound provide information on muscle structure.

Functional testing is not possible immediately following immobilization in patients, therefore most data refer to passive measurement techniques or are obtained after partial rehabilitation.

Therefore the aim of the present study is to quantify the deterioration of leg performance due to immobilization alone by functional and morphological measuring techniques in healthy subjects.

Materials and Methods

Design

Eight healthy volunteers participated in this study after giving their written informed consent. The main characteristics of the subjects are listed in Table 1.

The participants had no history of prior knee injury and all had a sedentary life style. In two preparatory training sessions they were accustomed to the isokinetic measuring techniques, and a VO_2max test on a bicycle ergometer was performed to determine the VO_2max workload (W_{max}).

A long leg cast (Scotch Cast[®]) was applied to the randomly selected left or right leg for four weeks. Weight bearing on the casted leg was not allowed.

Leg performance and muscular atrophy were examined before and after immobilization.

Table 1: Characteristics of the subjects

Sex	Age	Length	Weight	VO_2max	Peak torque at 180 deg.s ⁻¹ knee extension pre-immob	
					casted leg	control (Nm)
	yr	cm	kg	l.min ⁻¹		
F	21	157	62	2.18	99	95
M	20	179	63	3.11	121	141
F	21	163	56	2.07	89	85
M	23	183	72	2.74	131	165
M	23	184	70	3.18	155	165
M	19	187	84	3.89	137	171
M	20	183	60	3.42	135	113
M	26	176	85	3.46	165	173
median	21	181	66.5	3.15	133	153

Quantification of muscle atrophy

Muscle atrophy was quantified by means of computed tomography (CT) and histological parameters. Immediately before application and after removal of the cast

the cross-sectional area of the quadriceps femoris was measured by means of CT at the mid-thigh-region. The location of the cross-sectional scanning was marked as a given distance from the medial femoral condyle.

Further a biopsy from the m. vastus lateralis was taken with a Bergström needle, ten to fifteen cm proximally from the patella. The muscle sample was mounted on cork and quickly frozen on isopentane, cooled to the melting point in liquid nitrogen. The samples were stored at -80°C until processing. From the frozen samples $10\text{ }\mu\text{m}$ thick serial cross sections were cut in a cryostat at -20°C and mounted on cover glasses for histochemical staining. The samples were stained for ATPase after pre-incubation at pH 4.2 and 4.6 and classified as type I, IIa and IIb. The ATPase stained sections were analyzed for morphometrical characteristics (lesser fiber diameter) using a Kontron Mop Videoplan Digitizer System (Zeiss, Germany) (7).

Leg performance

Test series examining leg performance were conducted some days before application of the cast and three days after removal. Leg performance parameters were strength of the knee flexion and extension movement, and endurance of knee extension. Strength was measured as maximal torque output (PT; Nm) using a Cybex II isokinetic dynamometer (Lumex, N.Y.). PT was recorded for both knees at angular velocities of 60, 120, 180, 240 and $300\text{ deg}\cdot\text{s}^{-1}$ from two series of five movements with maximal effort. Data were not corrected for gravity.

Endurance was tested with one-leg-cycling and an isokinetic knee extension protocol. One-leg-cycling was performed on an electromagnetically braked bicycle ergometer (Lode, Germany) at workloads of 30%, 40%, 50% and 60% of the previously determined maximal aerobic power (W_{max} ; Watt) with two-leg-cycling. Every three minutes the workload was increased stepwise and heart rate (HR; $\text{b}\cdot\text{min}^{-1}$) and oxygen uptake (VO_2 ; $\text{l}\cdot\text{min}^{-1}$) were monitored continuously by means of an ECG recorder (Hellige, Freiburg, Germany) and an automatic pulmonary metabolic apparatus (EOS Sprint, Jaeger, Würzburg, Germany), respectively. At the end of each workload a blood sample was drawn from a catheter in an antecubital vein for plasma lactate analysis (PLa ; $\text{mmol}\cdot\text{l}^{-1}$).

The isokinetic endurance test consisted of bouts of 200 knee extensions. The subjects were instructed to perform extension movements at an angular velocity of $180\text{ deg}\cdot\text{s}^{-1}$ at a given torque level of 20%PT, alternated with passive knee flexion. Range of motion was set from full extension to maximal flexion (100 deg). Torque level was indicated on an oscilloscope placed in front of the subject for visual feedback. After completing this step the torque level was increased with 20%PT to 40%PT and so on, until exhaustion. The test ended when the subject could not meet the demanded torque level or when the cumulative work was less than the previous step. Torque of knee flexion and extension were registered by means of an Apple II computer with an AD-chart sampling at 50Hz. Custom made software provided total work of each

step of 200 movements. HR, VO_2 , PLa and cumulative work (J) were measured during the test.

All leg performance tests were taken on one day. First the strength of knee flexion and extension was measured, next the endurance tests (isokinetic and one-leg-cycling) were taken in random order with $1\frac{1}{2}$ to two hours rest. After this interval no fatigue was indicated by the subjects, irrespective of the test order.

Statistics

The Wilcoxon test (non-parametric) was used for statistical analysis of the pre and post casted data. The level of significance was set at $p < 0.05$. Results of strength and endurance testing are presented as medians with range. Pre and postimmobilization differences are presented as means $\pm$ S.D.

Results

Symptoms after cast removal

During the first and second day after removal of the cast some subjects were hindered by stiffness of knee and ankle joint, impairing normal gait. At day three full range of motion of knee and ankle joint were restored and they were able to walk normally without discomfort.

Quantification of muscular atrophy

Computed tomography of the quadriceps immediately after removal of the cast revealed a $21\% \pm 7\%$ decrease in quadriceps area of the casted leg compared with CT findings before immobilization ($p < 0.05$).

The biopsy specimens of the m. vastus lateralis showed on average 16% decrease in fiber diameter ($p < 0.05$) and 8% more type II fibers (n.s.) after immobilization (Table 2). The fiber area of the type I fibers decreased from 42% to 34% (n.s.). No pathological changes in cell structure were observed.

Leg performance

After immobilization the strength of knee flexion was decreased to maximal $26\% \pm 13\%$ at 60 deg.s^{-1} ($p < 0.01$). The decrease of knee extension strength was much more pronounced: $52\% \pm 7\%$ at 60 deg.s^{-1} , $53\% \pm 9\%$ at 120 deg.s^{-1} , $45\% \pm 12\%$ at 180 deg.s^{-1} , $43\% \pm 10\%$ at 240 deg.s^{-1} and $41\% \pm 9\%$ at 300 deg.s^{-1} ($p < 0.01$), see Figs. 1 and 2. Muscular strength was already returned to pre-immobilization values without specific training when the subjects were examined finally ten weeks after removal of the cast.

Table 2: Muscle fiber characteristics in muscle biopsies taken from the m. vastus lateralis (median and range). *p < 0.05.

	Pre-immobilization	Post-immobilization
<i>type I</i>		
fiber diameter (µm)	63.2 (55.4-90.9)	53.8 (44.5-65.1)*
percentage type I fibers (%)	40.0 (26-67)	35.0 (22-49)
relative area (%)	34.4 (16.4-99.9)	26.7 (17.9-53.9)
<i>type IIa</i>		
fiber diameter (µm)	58.9 (53.7-102.9)	54.7 (45.5-76.0)*
percentage type IIa fibers (%)	26.0 (10-44)	33.0 (20-51)
relative area (%)	20.3 (7.0-43.3)	25.6 (18.8-57.8)
<i>type IIb</i>		
fiber diameter (µm)	71.0 (62.0-102.5)	57.4 (50.8-85.1)*
percentage type IIb fibers (%)	29.5 (16-44)	26.0 (20-46)
relative area (%)	40.1 (15.0-66.7)	30.2 (19.1-55.7)

Fig. 1: Peak torque of knee extension before and after immobilization, median with 75th percentile (n=8).

** p < 0.01

Table 3: HR (b.min⁻¹), VO₂ (l.min⁻¹) and PLa (mmol.l⁻¹) at the progressive one-leg-cycling test at 30%, 40%, and 50% of the previously established two-legged Wmax (Paired samples). Data are medians with range.

Activitylevel (%Wmax)	parameter	Pre-immobilization	Post-immobilization
30% n=8	HR	148 (128-153)	143 (126-172)
	VO ₂	1.28 (0.84-1.64)	1.25 (0.80-1.64)
	PLa	3.0 (2.0-4.7)	3.0 (2.2-4.7)
40% n=8	HR	164 (142-175)	165 (141-184)
	VO ₂	1.75 (0.98-2.01)	1.75 (1.19-2.12)
	PLa	4.4 (3.2-6.5)	5.1 (3.2-6.1)
50% n=6	HR	177 (162-183)	177 (168-191)
	VO ₂	2.07 (1.36-2.49)	2.09 (1.65-2.66)
	PLa	6.05 (4.0-9.1)	6.8 (4.6-9.1)

Fig. 2: Peak torque of knee flexion before and after immobilization, median with 75th percentile (n=8).

** p < 0.01, * p < 0.05

Fig. 3: Cumulative work, Oxygen uptake, Plasma Lactate Concentration and Heart Rate at an isokinetic quadriceps endurance test consisting in 200 repetitions at 40% of quadriceps peak torque at 180 deg.s⁻¹, before and after immobilization, median with 75th percentile.

* $p < 0.05$

W_{max} at one-leg-cycling was 58% ± 4% of the two-leg-cycling W_{max} before immobilization, and 51% ± 8% after immobilization (n.s.). With the non-casted leg the fall was only 1% after immobilization (n.s.). Physiological variables HR, VO₂ and PLa showed no significantly difference in response between pre- and post-immobilization tests of the casted leg at 30%, 40% and 50%W_{max} (Table 3).

At isokinetic quadriceps endurance testing all subjects had the highest mechanical output at 40%PT. The results showed a 27% fall in maximal work delivered in 200 knee extension movements from median 9.1 KJ (range 2.7 - 12.2) to 5.6 KJ (range 1.8 - 9.7) ($p < 0.05$), and a concomitant decrease in VO₂ of 9%, and a rise in HR of 4% and PLa of 18% (n.s.) as shown in Fig.3.

Discussion

The aim of the present study was to quantify the effects of leg immobilization on thigh muscles in healthy subjects and to study the process of muscle atrophy in association with muscle function apart from interfering symptoms as found in patients with knee injuries.

Quantification of muscle atrophy

After four weeks of immobilization quadriceps area was decreased 21%. The muscle fiber diameter was decreased by 16%, resulting in a 29% decrease in mean cross-sectional fiber area. This is in accordance with the findings after immobilization in patients and healthy subjects. As reported by Ingemann-Hansen and Kristensen cast-immobilization for 5 weeks after a knee ligament injury and subsequent surgery resulted in a decrease of 26% in quadriceps area measured by the CT scanning technique (14). Davies found a 10% decrease in calf circumference after three weeks of immobilization and White reported an 8% decrease in calf circumference after two weeks of cast immobilization (5,25).

In the present study no significant change in fiber type distribution was found. Kristensen studied muscle fiber size and composition before and after surgical treatment of a knee ligament lesion with a subsequent cast immobilization of thirty-one days (17). He found a 6.1% decrease in the number of type I fibers and a 8% decrease in type I cross-sectional fiber area and a 5% increase in type II fiber area. The reported shift towards more type II fibers was even more pronounced in the present study, although not significant.

Leg performance

Isokinetic dynamometry does not mimic natural movements. In rehabilitation and sports medicine it has been generally accepted as a safe and reliable method of performance testing. Isokinetic strength is well related with functional scores in patients after knee injury/surgery (24). The results of isokinetic fatigue testing are known to be related to muscle structure (18).

Immobilization has a dramatic effect on quadriceps strength and to a lesser degree on the strength of the hamstrings, resulting in a deterioration to maximal 52% and 26%, respectively, at isokinetic measurements at 60 deg.s⁻¹. The somewhat lower decrease of knee extension strength at the higher angular velocities is an underestimation because the data are not corrected for gravity.

McDougall, who studied the m. triceps brachii found a decrease in strength of 35% after five weeks of immobilization and 41% after 5-6 weeks (19,20). In a further study the forearm was immobilized for the short period of one week, resulting in a 20% and 13.1% decrease in strength of the m. triceps and m. biceps brachii, respectively (21). Two weeks immobilization of the m. triceps surae resulted in a 24% decrease in strength (25). Animal studies show that atrophy is more pronounced when muscle is immobilized in a shortened position, and that the loss of tissue is most rapid during the first week of immobilization (1,4). Animal studies have also shown that muscles rich in type I fibers are more affected than muscles with mixed fiber typing. These findings seem to contradict the empirical finding that knee extensors are far more susceptible to atrophy than knee flexors, rich of type I fibers

(16). However, three of the four heads of the m. quadriceps femoris are mono-articular, while the hamstrings are bi-articular and thus not completely immobilized in a leg cast.

Maximal power at one-leg-cycling was 7% lower after four weeks of immobilization. Maximal work of the m. quadriceps at 200 knee extensions in isokinetic endurance testing was 27% lower. Endurance has seldomly been tested after a period of immobilization. In general, endurance is tested as aerobic power with progressive exercise testing on a bicycle ergometer or treadmill. Such a protocol is appropriate in evaluation of systemic variables, but not really for regional muscle exercise. Surprisingly, the 7% decrease in W_{max} with sedentary subjects at one-leg-cycling seems to correlate well with data of well trained subjects in whom a 4% decrease in VO_{2max} was observed at treadmill running after one week of immobilization and one week of detraining. However recovery of VO_{2max} to pre-immobilization/detraining values seems to be slow in athletes (13).

One-leg-cycling is thought to be a more specific test for leg performance enabling pre to post and left to right comparisons. In the present study the findings in one-leg-cycling were non-conclusive. The relatively high workloads established in these tests indeed suggest that a vast muscle volume is active during one-leg-cycling. Thigh muscle activity only accounts for a small portion of the work capacity. This test should therefore be considered to be a variety of bicycle ergometry instead of a specific thigh muscle endurance test. Isokinetic quadriceps testing using a stepwise loading protocol has not been used so far. The endurance testing of an isolated movement as used in the present study enables us to quantify deterioration of muscle aerobic capacity next to muscle strength and to make left to right comparisons.

It is known that oxidative enzyme activity decreases in patients suffering a knee injury. As reported by Häggmark the quadriceps succinate dehydrogenase activity (SDH) correlates well with endurance and is decreased 21% after knee surgery and five weeks of immobilization (11). The decreased maximal work capacity of the m. quadriceps at isokinetic testing in this study after immobilization correlates well with the decreased enzyme activity as reported in patients after knee surgery and immobilization.

Clinical relevance

The development of muscle atrophy in patients after knee injury or surgery is considered to be multi-causal. In the present study the effect of immobilization is isolated and studied in a realistic model. Next to atrophy the deterioration of muscle function is also studied. The morphological changes in the present study correlate well with the findings in comparable studies in patients. There are no comparable studies in patients concerning the deterioration of muscle function. It is known that under physiologic conditions strength is linearly correlated with cross-sectional muscle area. However in the present study a 21% decrease in cross-sectional area

was accompanied by a 53% decrease in strength. Apparently, immobilization has not only caused a decrease in cross-sectional area (atrophy), but also the performance of the remaining muscle is decreased. Temporary loss of coordination, an important feature in isokinetic testing, might partly be responsible for this observation.

Conclusions

Four weeks of non-weight-bearing immobilization results in serious deterioration of the m. quadriceps femoris as demonstrated by measurements of strength, endurance, muscle cross sectional area and muscle fiber diameter.

The atrophy observed in the present study after immobilization in healthy subjects is comparable with the atrophy found in patients after injury and/or surgery followed by immobilization. It can therefore be concluded that the effect of immobilization overshadows all other factors known to inflict muscle atrophy.

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Chapter 6

Transposition of the semitendinosus tendon for early repair of medial and anteromedial laxity of the knee

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Summary

In 15 patients with acute medial (n=8) or anteromedial (n=7) laxity of the knee, reconstruction of the torn ligaments was combined with the use of the semitendinosus tendon as a dynamic extra-articular stabilizer. The postoperative regimen consisted of early mobilization in a cast-brace with full weight bearing. An evaluation 1 to 3 years after surgery revealed good results in 14 cases, and one fair result as graded using the Marshall score (mean score 45.3, S.D. 2.9). Isokinetic measurements of knee flexion and extension showed no loss of strength.

Equally good results have been reported in conservatively treated isolated MCL lesions. The operative treatment cannot be considered anything but an alternative in these cases. In case of a combination of a MCL lesion and an ACL lesion the results reported are usually worse. This treatment regimen with emphasis on functional rehabilitation seems to be a good concept in acute anteromedial laxity of the knee.

Introduction

The treatment of complete tears of the medial collateral ligament (MCL) of the knee, isolated or with concomitant ligament damage, has been debated since 1930 (7) and no consensus of opinion exists as how to these lesions should be treated. Initial treatment can be either conservative or operative, and rehabilitation is functional, i.e. short immobilisation with functional early training, or defensive with prolonged immobilisation in a cylinder cast. In 1984 and 1985 we have treated these lesions operatively with a primary repair of the torn ligament, reinforcing it by means of a transposition of the semitendinosus tendon. The overlying tendon is thought to provide an active support to the injured M.C.L. (dynamic stabilisation). This reinforcement allows early mobilization with functional training. The aim of this follow-up study is to compare our results with other series in order to evaluate this treatment.

Materials and methods

In 1984 and 1985 all patients presenting with a fresh rupture of the MCL underwent operative treatment. A total of 15 patients were treated this way. All patients showed complete MCL lesion during operation. Eight patients with a mean age of 33.5 years (range 16-72 years) with isolated MCL lesions were treated by means of repair of the MCL and semitendinosus transfer only. Seven patients with a mean age of 34.8

years (range 22-65 years) suffered concomitant damage, all of which were total anterior cruciate ligament (ACL) lesions, one combined with a small eminentia fracture, which was reinserted with the ACL sutures, and one with a minor tibia condyle fracture treated with internal fixation. After operation all patients were immobilised in a splint for 2 weeks, after which period the stitches were removed and a cast-brace was applied. Full weightbearing was allowed, and in the next weeks the flexion range of the hinges was extended stepwise to the maximum of 100°, the extension range remained limited to 20° throughout this period.

This follow-up study includes all 15 patients treated by this method. The results were scored using both the anamnestic scale of the Lysholm score, and the combined anamnestic and physical examination scale as advocated by Marshall (5,6). Marshall classed the results in four groups i.e. 41-50 good-excellent, 36-40 fair, 31-35 moderate, and less than 30 as poor. Scoring was done by 2 independent physicians. In the final score only the lowest result was used. Maximum dynamic strength of knee extension and flexion were measured in 13 patients using an isokinetic dynamometer (Cybex II, Lumex, N.Y.). The angular velocities studied were 60, 120, 180, 240, and 300°.s⁻¹.

Operative technique

Before the operation started all knees were tested under general anesthesia for concomitant ligament lesions. In the case of a concomitant ACL lesion the operation started with arthrotomy, and continuity of the ACL was restored by suturing. For repair of the MCL a medial Payr incision was used to expose the medial retinaculum. The medial retinaculum was dissected. The tear in the MCL was inspected, and the fibers were approximated. the tendon of the semitendinosus was identified, transposed ventrally, and brought outside the retinaculum, without interrupting its continuity (Fig. 1). The retinaculum was then closed underneath, in such a way that the tendon was positioned over the MCL (Figs 2 and 3). After wound closure a well-padded splint was applied in 20° flexion.

A similar technique for MCL repair was previously described by Bosworth for chronic medial instability (1).

Results

All treated patients were seen for evaluation. Follow-up time was 10 to 33 months (mean 18.5 months). None of the patients experienced a complication of surgery. The mean time between injury and operation was 5.1 days (range 2-11 days). Mean hospitalization was 12.1 days (range 5-23 days). A total of 4 weeks of partial immobilization was used in isolated MCL lesions, and 4-12 weeks (mean 8.7 weeks)

Fig. 1: Identification and transportation of the tendon of the semitendinosus.

in mixed lesions, based on the individual demands of the patient. Subjective results as measured with the Lysholm score were very good ; mean score 94.4, S.D. 8.3 points (max.100) ; in isolated lesions 96 (range 83-100) ; in mixed lesions 92.4 (range 75-100). The combined objective and subjective scoring using the Marshall score was 45.3, S.D. 2.9 (max.50), 14 patients good-excellent, and one fair. The lowest score obtained was 39 in an elderly woman, age 72, who had suffered an isolated

Fig. 2: MCL fibers are approximated. Subsequently the retinaculum is sutured underneath the transposed tendon of the semitendinosus.

Fig. 3: Tendon of the semitendinosus lying subcutaneously.

Table 1: MCL Scores (Marshall) in mixed, and isolated lesions

	Isolated (n=8)	Mixed (n=7)
5 (equal to opposite knee)	2	1
4 (mild instability in flexion)	3	6
3 (moderate instability in flexion)	2	—
2 (instability in flexion and extension)	1	—
1 (gross instability)	—	—

M.C.L. lesion. At follow-up examination there was laxity of the restored M.C.L. in flexion as well as in extension (rated in the score as 2B). She had, however, surprisingly few complains, and therefore she found the end result good. The MCL and ACL stability scores for the two groups (isolated, and mixed) are given in Table 1 and Table 2. Stability scores for ACL are not significantly better for identified 'isolated MCL lesions' compared with the mixed lesions.

All patients but one were able to return to their normal work in 3.8 months (range 1-12 months) after operation. Eleven patients participated in sports at the time of injury, six of them regained full activities, three limited or altered, and two had not regained full activities at the time of follow-up. No difference in strength was found between the affected leg as compared with its control. The results of the strength measurements are given in Table 3.

Table 2: ACL Scores (Marshall) in mixed, and isolated lesions

	Isolated (n=8)	Mixed (n=7)
5 (equal to opposite knee)	1	1
4 (slight jog when tested)	5	5
3 (moderate jog when tested)	2	1
2 (severe instability in neutral)	—	—
0 (severe in neutral and rotation)	—	—

Table 3: Maximum isokinetic strength of knee extension and flexion at different angular velocities (n=13). Values are means ± S.D.

Angular velocity	Affected leg	Control leg
<i>Extension</i>		
60°.s ⁻¹	186.9 ± 64.2	187.9 ± 61.7
120°.s ⁻¹	144.2 ± 53.7	142.8 ± 50.8
180°.s ⁻¹	112.3 ± 44.1	115.7 ± 44.4
240°.s ⁻¹	85.9 ± 36.5	89.7 ± 34.0
300°.s ⁻¹	70.5 ± 31.9	72.3 ± 28.1
<i>Flexion</i>		
60°.s ⁻¹	137.2 ± 61.6	122.5 ± 43.7
120°.s ⁻¹	114.9 ± 49.1	103.8 ± 38.7
180°.s ⁻¹	99.5 ± 41.2	94.6 ± 39.2
240°.s ⁻¹	84.3 ± 37.9	76.3 ± 27.2
300°.s ⁻¹	71.9 ± 33.0	66.0 ± 21.6

Discussion

In our series using the Marshall score, seven patients were graded good-excellent, and one one fair in the group with isolated lesions. These results are in accordance with the study of Indelicato, who had a 88% good-excellent result in operatively treated patients, and a 90% good-excellent result in conservatively treated patients in a population consisting merely of young students (3). For the isolated lesions our results equal those of his concervative treatment, so an operation cannot be considered anything but an alternative to concervative treatment (8). The combination of MCL and ACL lesions forms a generally accepted indication for operative treatment. Even with reconstruction the results are poor, only 39.7% good-excellent (2). The results using this relatively simple technique for the combined MCL and ACL lesions in combination with primary suturing of the ACL, and early functional training seem to be hopeful, with all 7 patients rated as good.

The mild to moderate laxity seems to be of little or no significance to the function of the joint. The good results of the isokinetic strength measurements might be credited for this finding. It supports the concept of knee joint stability as an interaction of both the passive (bone, ligaments, and capsule), and the active stabilizers (thigh musculature). We think that this stresses the importance of a functional rehabilitation, where preservation of muscle strength is the key. This agrees with Tegner in studies of chronic knee instability, who showed that muscular strength has a close relationship with complains, and rehabilitated muscular stability will stay intact even in the presence of passive instability (9,10). Using part of the hamstrings did not decrease its flexion strength (4).

We conclude that non-operative treatment provides good to excellent results in isolated MCL lesions, and with a concomitant ACL lesion the semitendinosus transposition is a relatively simple operation without complications. Laxity after this operation was mild, and not related to dysfunction.

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Chapter 7

General discussion

The integration of therapeutic immobilization and functional treatment in the recovery after a knee injury is complex. On the one hand rest is advised to create optimal circumstances for molecular repair processes, and to protect the joint against reinjury due to poor control. The recovering tissues, on the other hand, need functional stimuli to adjust the molecular repair processes to the right mechanical structure (4). Protection of the joint by immobilization will oblige the surrounding intact structures like muscles, tendons, cartilage, and bone to inactivity, resulting in atrophy and functional deterioration. Both the initial treatment and the rehabilitation program should deal with this dualism of immobilization and functionality. This has led to the development of several partial immobilization and stabilization techniques. The evolution in surgical techniques (arthroscopic reconstructive surgery) towards firmer reconstruction and less surgical damage has led to a more aggressive early functional training after reconstructive surgery. The functional results are promising. The reduction of atrophy seems to play a major role in this success. However, the effects of complete and partial immobilization or stabilization on the functional properties of the leg have not been evaluated properly.

It is impossible to study the various elements of the rehabilitation process separately in patients. The use of the recovering knee joint depends on the severity of the injury, the type and duration of immobilization or stabilization, and also to a great extent on prescribed exercises, psychogenic factors, motivation, pain, or fear. The interference of these complex factors in the rehabilitation process are excluded in healthy subjects (5). Because the functional condition of the right and the left leg is similar, the effect of immobilization or stabilization can be studied by comparing the supported leg with the control leg. In this thesis the effects of three different commonly applied immobilization and stabilization techniques on thigh muscle performance were studied in healthy subjects with functional tests. These tests include walking, running, and jumping, but also isokinetic muscle strength testing. Another aspect in knee rehabilitation, that has got poor attention sofar, is the

endurance capacity of the quadriceps muscle. In this thesis a new protocol is introduced to measure the aerobic power of the quadriceps muscle as a parameter for endurance. The last chapter of the thesis deals with the treatment of knee injuries and the results of a functional treatment schedule.

The first study (**chapter 2**) deals with functional testing in the rehabilitation phase after a knee injury. The isokinetic strength testing has proved to be a safe and reliable method in the rehabilitation after a knee injury. Surprisingly only little attention is given to endurance testing, leading to an underestimation of the problem of deterioration of the endurance capacity (2). The tests described in the literature that deal with endurance are all based on anaerobic exercise. However, the aerobic power is felt to be a better parameter for endurance. The test protocol we describe to measure the maximal aerobic power of the quadriceps (P_{max}) is reproducible (test- retest correlation $r=0.82$) and relatively simple, and can be performed on standard isokinetic equipment. The uninjured leg can be used as the controle, since there is a natural equivalence of both legs (left-right correlation $r=0.94$). The test results are speed and device specific, and since there is no correction for gravity acting on the leg and lever system, the results can only be used for intra-subject comparisons. The measurement of P_{max} increases the insight into the rehabilitation process, and can be used to adjust the individual rehabilitation program.

In **chapter 3** the effect of a *functional knee brace* on the performance of the thigh muscles is evaluated. Many patients with complaints of giving-way benefit from the use of functional knee braces. The number of near-injuries, or symptoms of giving-way are less. Patients feel more secure during sporting activities. Bracing may enhance performance in patients (1). Most of the symptoms of giving-way are encountered at higher levels of physiologic loading, and are therefore related to sports and less to activities of normal daily living. The main function of a knee brace is to support the knee at high physiologic loads. There is a widespread belief in sports and sportsmedicine, that supplying external mechanical support to the knee results in disuse atrophy. The results of the study presented in chapter 3, in the contrary, show that the muscular performance is not impaired by bracing. Only on the first day of application there is a slight decline of the performance parameters. Sprinting time at 60 m dash is 4% slower, and V_{max} is 6% slower. Peak torque (PT; Nm) at isokinetic strength measurements of knee flexion and knee extension are up to 9% lower. While wearing the brace for four weeks the performance parameters return to their base values. After the period of brace application the subjects are retested with similar results at maximal performance. These results contradict the persistent believe in the world of sports, that bracing will 'weaken' the knee.

In **chapter 4** the effect of a *hinged cast-brace* on leg performance is evaluated. A cast-brace is applied in the treatment of some knee injuries as an alternative to a cylinder or long leg cast for some conditions. It provides limited immobilization and external support, limiting the normal function of the subject to some extent. Activities that require a large Range of Motion or movements at high angular velocities are virtually impossible. Wearing a cast-brace will therefore result in some disuse or detraining. The results of the study presented in chapter 4 show that wearing a hinged cast-brace gives rise to an increased energy consumption. Oxygen uptake and heart rate are slightly raised (average 9% and 7%, respectively) at a submaximal uphill walk exercise, probably due to the weight of the cast-brace (approximately 1 kg). After removal of the cast-brace the performance parameters return to their base values. This indicates that the expected decline in performance due to disuse/detraining was negated by the training effect due to carrying the weight of the cast-brace. It is concluded that wearing a hinged cast-brace does not result in muscular atrophy. This is a serious argument for the use of a hinged cast-brace instead of cast-immobilization.

In **chapter 5** the effect of immobilization in a *long leg cast* on the thigh muscles is demonstrated. Cast-immobilization is often applied after knee injury or surgery. Immobilization has serious negative effects on the thigh muscles, resulting in muscle atrophy. This muscle atrophy is related to impaired functional recovery, and is hard to treat (3). The present study shows that four weeks of cast-immobilization has a dramatic negative effect on the thigh muscles; the quadriceps cross-sectional area decreases 21%, the muscle fiber diameter 16%, PT of knee extension 53% and of flexion 26%, and Pmax 27%. Immobilization is the most important factor in the development of muscle atrophy. It overshadows all other factors that induce muscle atrophy after knee injury. Reduction of immobilization time or replacing immobilization with stabilization techniques is therefore the key factor in the prevention of posttraumatic muscle atrophy.

In **chapter 6** we report the results of a functionally-operative treatment of *grade III MCL lesions*, isolated or with concomitant ACL injury. This treatment combines a simple operative technique with a functional rehabilitation, that is focused on maintaining normal function. Cast-immobilization is limited to two weeks, followed by an additional 4-12 weeks of hinged cast-bracing with full weight bearing. Surgical treatment is also limited, but it immediately provides some stability, enabling a fast return to normal function. This treatment regimen results in a successful recovery even in the serious mixed ACL-MCL ligamentous lesions. At follow-up 14 of the 15 patients revealed good or excellent results with no signs of muscle atrophy at final evaluation. This study links the findings of previous studies in healthy subjects and traumatologic practice. It shows that treatment, aimed at functional recovery instead

of mechanical stability, can have a good functional result. The present evolution in surgical skills and materials (arthroscopic surgery) will increase the possibilities of functional rehabilitation, and thus prevent muscle atrophy, and further improve the results of treatment.

Several *functional tests* are used in the evaluation of the immobilization and stabilization techniques. The sensitivity of these test show a wide variation. The tests that specifically load the thigh muscles have a better sensitivity for deterioration of performance. The changes in performance capacity are best shown by the isokinetic strength measurements. The maximal aerobic power is also useful to detect the decline in endurance capacity. The one-leg-cycling test, on the other hand, shows no differences after four weeks of immobilization, and is thus useless to study this effect. The tests that rely on the performance of both legs, and crural, thigh, and gluteal muscle groups (high-jump, sprinting, treadmill running) are not useful to detect small changes in performance due to compensation by other muscle groups. Isokinetic strength and endurance parameters are therefore the best functional indicators of thigh muscle deterioration.

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Chapter 8

Summary and conclusions

Cast-immobilization is frequently applied in the treatment of knee injuries. The indications and consequences of immobilization are discussed in **chapter 1**. To avoid muscle atrophy treatment schedules are adjusted towards shorter periods of immobilization. After that the joint is protected by stabilization techniques. The results of these early functional treatment regimens are promising. In the development of the early functional treatment regimens it is important to know, what the influence of immobilization and these stabilization techniques is on thigh muscle atrophy. The present study quantifies the effects of immobilization and stabilization on the thigh muscles. We used functional tests and isokinetic strength measurements to evaluate the effects on performance. A test protocol to measure the maximal aerobic power of the quadriceps is introduced for the evaluation of the endurance capacity of the quadriceps muscles. Finally the results are reported of a follow-up study of an early-functional treatment regimen in patients suffering a serious knee ligament injury.

The test protocol to measure the maximal aerobic power of the quadriceps as a parameter of the endurance capacity is introduced and evaluated in **chapter 2**. The test consists of a stepwise increase in exercise on an isokinetic dynamometer until exhaustion. The reproducibility of the test is fairly good (test-retest correlation $r=0.82$). The test is especially suitable for use in rehabilitation settings, comparing the injured leg with the uninjured leg (left-right correlation $r=0.94$). Finally recommendations are made for practical application of the test. The effects on thigh muscle performance of two stabilization techniques (functional knee brace and cast-brace), and cast-immobilization are described in **chapters 3-5**. The tests were performed on healthy subjects in order to rule out the interfering effects of injury, and to make pre- and post-application comparisons. The period of application was four weeks in all three studies. The functional knee brace (Push Brace 'Heavy'[®]) impaired performance slightly on the first day of application (Table 1). This effect diminished after familiarization, and after removal of the brace all tests results returned to their base

Table 1: Findings at the tests during and after 4 weeks of application (= no significant changes; ↓ and ↑ significant decrease, respectively increase as compared with base values; np not performed).

	during	after
<i>knee brace</i>		
muscle strength	9% ↓	=
submax treadmill exercise (HR,VO ₂ ,PLa)	=	HR 6%↓
maximal running speed	6% ↓	=
60 m dash	4% ↓	=
jump height	=	=
<i>cast-brace</i>		
muscle strength	np	=
submax horizontal treadmill running	np	=
maximal running speed	np	=
60 m dash	np	=
jump height	np	=
submax uphill walk test	VO ₂ 9% ↑ HR 7% ↑	=
<i>cast-immobilization</i>		
muscle strength	np	quadriceps 53% ↓ hamstrings 27% ↓
maximal aerobic power	np	quadriceps 21% ↓
one-leg-cycling	np	=
quadriceps circumference	np	21% ↓
muscle fiber diameter	np	quadriceps 16% ↓

values. The conclusion was that the brace did not affect performance. Application of a cast-brace (weight approximately 1 kg) resulted in an increased energy expenditure as determined in a progressive uphill walk test on the treadmill (Table 1). Oxygen uptake (VO₂) and heart rate (HR) rose by 9%, and 7%, respectively. VO₂ decreased after four weeks of cast-brace application, but remained slightly elevated (4%). After removal of the cast-brace no negative consequences of the application were observed during the exercise tests. According to expectation cast-immobilization resulted in a measurable muscle atrophy. The mean decreases in quadriceps circumference and muscle fiber diameter were 21% and 16%. Muscle strength decreased considerably more than the morphological parameters (Table 1). The decline of the maximal aerobic power indicated that the endurance capacity of the quadriceps had decreased.

In **chapter 6** the results of the treatment of grade III Medial Collateral Ligament (MCL) ruptures are evaluated, isolated (n=8), or with concomitant Anterior Cruciate Ligament rupture (n=7). The initial treatment consisted of limited surgical treatment with reconstruction of the ruptured ligaments and reinforcement of the MCL by

means of a semitendinosus transfer. The purpose of the semitendinosus transfer was to increase stability, enabling early functional training. Postoperatively a splint was applied for two weeks, followed by 4-12 weeks of cast-brace application to protect the joint. At follow-up 14 of the 15 patients had good to excellent results as graded by the Marshall score and muscle strength testing of hamstrings and quadriceps.

Conclusions

Isokinetic muscle strength and endurance tests are the most sensitive parameters for the evaluation of the functional status of the thigh muscles after injury or immobilization. From these tests we learn that cast-immobilization gives rise to a fast and dramatic deterioration of thigh muscle performance. The extent of the observed deterioration makes it clear that immobilization is the key factor in the development of posttraumatic immobility-induced muscle atrophy. Thigh muscle performance is not impaired by stabilization of the knee allowing weight bearing and movement. This leads to the conclusion that, considering the type of injury and the individual patient, immobilization should be replaced by stabilization to enable early functional treatment. This allows an active treatment of posttraumatic immobility-induced atrophy.

Chapter 9

Samenvatting en conclusies

Gipsimmobilisatie wordt veelvuldig toegepast bij de behandeling van knieletsels. In **hoofdstuk 1** worden de indicaties en de gevolgen van immobilisatie besproken. Gezien het ontstaan van spieratrofie wordt er steeds meer overgegaan tot kortdurende immobilisatie gevolgd door toepassing van stabiliserende technieken. De resultaten van deze vroeg-functionele behandelingen zijn hoopvol. Voor de verdere ontwikkeling van dergelijke behandelingsprotocollen en voor de invulling van het nabehandelingsschema is het belangrijk te weten in hoeverre deze immobiliserende en stabiliserende technieken bijdragen tot het ontstaan van spieratrofie. Dit kwantificerend onderzoek is het onderwerp van dit proefschrift. Bij de evaluatie van de drie onderzochte immobilisatie en stabilisatie technieken hebben wij gebruik gemaakt van functionele metingen van het prestatievermogen. Dit zijn bestaande testen uit de sport en de sportmedische praktijk en een isokinetische spierkrachtmeting. Om de gevolgen voor het uithoudingsvermogen van de geïmmobiliseerde spieren te kunnen meten, hebben we een protocol ontwikkeld voor de bepaling van het maximale aerobe vermogen van de quadriceps. Tenslotte wordt verslag gedaan van een follow-up onderzoek van een vroeg-functionele behandeling van patiënten die een ernstig knieletsel hebben doorgemaakt.

In **hoofdstuk 2** wordt een protocol beschreven en geëvalueerd om het maximale aerobe vermogen van de quadriceps te meten. Het protocol bestaat uit een stapsgewijs oplopende belasting op een isokinetische dynamometer tot opgave. De beschreven test blijkt reproduceerbaar te zijn (test- hertest correlatie $r=0,82$) en is vooral bruikbaar voor links-rechts vergelijking (links- rechts correlatie $r=0,94$). Tot slot worden er aanbevelingen gedaan voor uitvoering van de test en voor toepassing in de revalidatie.

In de **hoofdstukken 3 tot en met 5** worden de effecten van een tweetal stabiliserende technieken en van volledige immobilisatie op de prestatie van de bovenbeensmusculatuur geëvalueerd. De testen zijn steeds gedaan bij gezonde proefpersonen om

Tabel 1: Voornaamste bevindingen van metingen tijdens en na 4 weken interventie. (= geen significante veranderingen ten opzichte van uitgangswaardes, ↓ en ↑ significante daling respectievelijk stijging ten opzichte van de uitgangswaardes, nv niet verricht)

	tijdens	na
<i>kniebrace</i>		
spierkracht	9% ↓	=
loopband submax (HR, VO ₂ , PL _a)	=	HR 6% ↓
maximale loopsnelheid	6% ↓	=
60 m sprint	4% ↓	=
sprong hoogte	=	=
<i>scharniergips</i>		
spierkracht	nv	=
loopband horizontaal submax	nv	=
maximale loopsnelheid	nv	=
60 m sprint	nv	=
sprong hoogte	nv	=
loopband stijgend submax	VO ₂ 9% ↑	=
	HR 7% ↑	=
<i>bovenheensgips</i>		
spierkracht	nv	quadriceps 53% ↓ hamstrings 27% ↓
maximaal aeroboomvermogen	nv	quadriceps 21% ↓
one-leg-cycling	nv	=
quadricepsomvang	nv	21% ↓
spiervezel diameter	nv	quadriceps 16% ↓

voor- en nametingen te kunnen verrichten en om bias door letsel te vermijden. De interventie periode was steeds 4 weken.

De functionele kniebrace (Push Brace 'Heavy'®) blijkt in de eerste periode na het aanleggen een licht negatieve invloed te hebben op de prestatie (Tabel 1). Na gewenning is dit effect verdwenen en na afloop van de interventie periode blijkt bij metingen zonder brace, dat er geen nadelige gevolgen zijn van het dragen.

Het dragen van een scharniergips met een gewicht van 1 kg kost extra energie, zoals blijkt tijdens een stijgend loopband onderzoek (Tabel 1). De zuurstofopname (VO₂) en de hartslag (HR) zijn 9% en 7% gestegen. Na enkele weken neemt dit effect weer wat af en is de VO₂ tijdens belasten nog slechts 4% gestegen. Na afname van het scharniergips zijn er geen nadelige gevolgen meer te meten.

Het dragen van een bovenheensgips leidt geheel volgens de verwachtingen tot spieratrofie. De quadriceps omvang en spiervezel diameter nemen 21% en 16% af. De afname van de spierkracht is nog beduidend groter dan de morfologische achteruitgang (Tabel 1). Het uithoudingsvermogen van de quadriceps verslechtert ook, zoals blijkt uit de achteruitgang van het maximale aerobe vermogen van 21%.

In **hoofdstuk 6** wordt het resultaat geëvalueerd van de behandeling van 15 patiënten met een volledige ruptuur van de mediale collaterale band (MCL; $n=8$), al dan niet in combinatie met een voorste kruisband ruptuur (ACL; $n=7$). De behandeling bestond uit een beperkte chirurgische ingreep met overhechting van de gelaedeerde structuren en een semitendinosusplastiek. Deze ingreep had tot doel om direct een zodanige stabiliteit te krijgen, dat een vroeg-functionele behandeling verder mogelijk was. Deze nabehandeling bestond uit 2 weken gipsimmobilisatie gevolgd door 4-12 weken bescherming met een scharniergips. Bij evaluatie hadden 14 van de 15 patiënten een goed of uitstekend resultaat volgens het Marshall scoringssysteem. De spierkracht van hamstrings en quadriceps was bij nacontrole goed vergeleken met het niet-aangedane been.

Conclusies

Voor de evaluatie van de status van de bovenbeensmusculatuur na een knieletsel of immobilisatie zijn isokinetische metingen van spierkracht en uithoudingsvermogen de meest gevoelige parameters. Hierbij blijkt, dat volledige immobilisatie leidt tot een snelle en dramatische achteruitgang van het prestatievermogen van de bovenbeenspieren. Uit de mate van deze achteruitgang blijkt, dat immobilisatie de belangrijkste factor is in de ontwikkeling van posttraumatische immobiliteitsatrofie. De beide stabiliserende technieken, die hier getest zijn (kniebrace en scharniergips), hebben geen nadelige invloeden op de bovenbeenspieren. Op grond hiervan moet gesteld worden, dat er bij de behandeling van knieletsels gestreefd moet worden naar vervanging van immobilisatie door stabiliserende technieken, dit met inachtnahme van het letsel en de individuele patiënt. Pas dan is een actieve bestrijding van posttraumatische immobiliteitsatrofie mogelijk.

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