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Patellar tendinopathy - on evaluation methods and rehabilitation techniques

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Stockholm 2006

Published and printed by Karolinska University Press
Box 200, SE-171 77 Stockholm, Sweden ISBN 91-7140-994-7

Varmt tack för visat stöd under avhandlingsarbetet.

"Life is a mystery to live and enjoy
Not a problem to be solved"

Osho

Abstract

Background:

Patellar tendinopathy is an increasingly common overuse and degenerative injury for recreational and elite athletes. The management of this injury is often difficult and frustrating and the treatment may take a long time. There is therefore a need for efficient and well-evaluated treatment protocols based on evidence based rehabilitation training. The aim of this thesis was to evaluate and develop new training techniques and treatment protocols for active patients with patellar tendinopathy.

Material, Methods and Results:

Outcome evaluation instrument such as the VISA- P score for patellar tendinopathy, which are easily administrated, clinically and scientifically standardized and allow systematical follow-up of chronic symptoms are important and useful. The VISA-P questionnaire has been translated and culturally adapted to be the sensitive for changes during treatment. The translated score showed good test-retest reliability when used to evaluate symptoms of patellar tendinopathy and for tests of physical activity.

A new eccentric overload device Bromsman® in which controlled and safe training can be performed may play an important role for the development of new rehabilitation protocols. The device can handle different heavy loads on a barbell and showed a load- and resistance dependency and no significant difference between test-retest. A direct feed-back system of force under each foot is a new feature and can make rehabilitation very specific when suffering from a unilateral injury.

The load on the patellar tendon during four different eccentric squat exercises was measured on the decline board and in Bromsman®. Eccentric work, mean force and peak patellar force and angle at peak force were greater for squats on a 25 degree decline board compared to horizontal surface, but higher knee load forces for the same measurements were observed in Bromsman®.

In a prospective randomized study two eccentric training methods; the eccentric overload device Bromsman® and the 25 degree decline board; were compared. The clinical evaluation of both training techniques improved the VISA-P outcome score for patients with patellar tendinopathy problem. There was no difference between the groups. The number of patients in this study was limited.

Conclusions:

The VISA-P questionnaire is useful for research and clinical evaluation of patients with patellar tendinopathy. The new eccentric overload device Bromsman® is safe for high performance and rehabilitation training with eccentric overload for multi-joint movement. There are different biomechanical loading pattern on the knee during different squat exercises. It is therefore important to individualize and to be more precise when designing a rehabilitation program. After 12 weeks eccentric overload treatment in the new device or a decline board the majority of patellar tendinopathy patients could be regarded as more or less symptom free.

Key words:

Biomechanics, Bromsman®, decline board, eccentric training, Patellar tendon load, prospective randomized study, VISA-P score.

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ISBN 91-7140-994-7 Stockholm 2006

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Eur J Appl Physiol. 2005 May; 94(37): 168-74

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Submitted to Clin Biomech, 2006

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Submitted to Br J Sports Med, 2006

LIST OF ABBREVIATIONS AND DEFINITIONS

Biomechanics	The use mechanics to study biological systems
CMJ	Counter movement jump
Conc	Concentric muscle action, muscle shortening while producing force
Ecc	Eccentric muscle action, muscle lengthening while producing force
Force	A mechanical interaction between an object and its surroundings. The SI unit for force is Newton (2)
Isokinetic	A movement in which the angular velocity of the displacement body segment is constant
Moment arm	The shortest distance from the line of action of a force vector to an axis of rotation
Moment of force	The rotary effect of a force; torque. The SI unit is Nm
MRI	Magnetic Resonance Imaging
Overload	A training principle that states there is a threshold point that must be exceeded before an adaptive response will occur. >1 RM
Power	The rate of doing work; the rate of change in energy; the product of force and velocity. The SI unit is J/s or Watt
Reliability	Measure of reproducibility of a measurement
Responsiveness	Control if instrument is sensitive to changes in health and can be assessed using distribution based and anchor based approach
ROM	Range of motion, the maximum angular displacement about a joint
Tendinopathy	A syndrome of tendon pain, localized tenderness, and swelling that impair performance
Validity	Degree to which a questionnaire, instrument or test measure what it is intended to measure
VAS	Visual analog scale
VISA-P	Victorian Institute of Sports Assessment- Patellar questionnaire
Work	Describes the extent to which a force can move an object in a specified direction; its SI unit of measurement is the joule (2)

INTRODUCTION

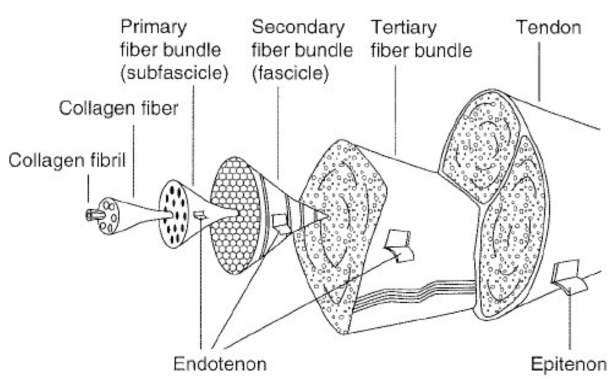
Patellar tendon injury is a major problem in competitive as well as recreational sports (21, 32, 48). In sports with excessive jumping, cutting and hill running patellar tendinopathy seem to be an increasing recurrent problem and an overuse problem (21, 32, 50). Recreational athletes not participating in vigorous activities may also be subjected to tendinopathy. Poor fitness and lack of regular and strategic training may contribute to this as part of a gradual increase in the incidence of degenerative changes in the active tendons. Chronic tendinopathy also accounts for 50 % of occupational illnesses (9).

The management of patellar tendinopathy is difficult and time consuming and often frustrating for both the athletes and the medical team (81). The current management involves exercise with a gradual increase in load as an important element in the treatment concept (55, 57). This thesis includes discussion of different types of overload eccentric exercise programs including a new overload eccentric exercise device and of how the condition can be valuated.

Tendon

For planning adequate treatment and rehabilitation a basic understanding of the patellar tendon structure and function is needed (47). The tendon consists of packed collagen fibres, which are parallel to one another (Figure 1)(78). The fibers of a tendon are formed by fibrils, which are constructed by tropocollagen units where the nerves and blood vessels run. A thin sheath called paratenon surrounds the tendon (49). Between the tendon and paratenon there may be fluid that decreases the friction.

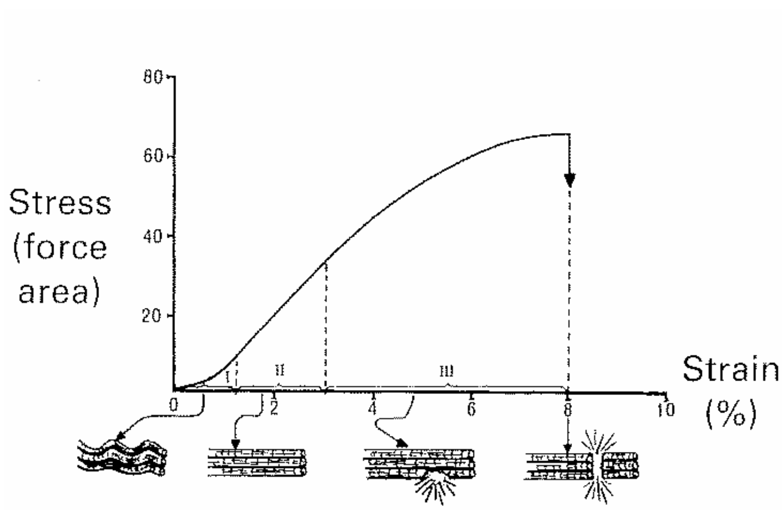
Figure 1. Organization of tendon structure. From Tendon injuries. Eds Maffulli, Renström, Leadbetter, Springer, London, 2005 with permission.



The tendon is an integrated part of the muscle-tendon unit. The primary roles of tendons are to transmit contractile forces into muscles and bones and to create joint movement. Tendons have good ability to withstand tensile and stretching forces and less capacity to endure shear and compressive force (41). The mechanical properties on the patellar tendon can be illustrated by the stress-strain curve (Figure 2)(78).

The tendon fibers have a wavy configuration at rest (0-2 % strain). When the tendon is strained about 2%, the wavy configuration disappears, the fibers are straightened and the tendon shows a linear response to stress. The fibers become parallel and if the tendon is not strained more than 4% it may return to its original length. Continuous increased stress causing strain of over 4% may result in a partial rupture. If there is a strain over 8 % a total rupture often occurs. A patellar tendon force during walking is 0,5 kN, while the force may reach 8 kN during landing, 9 kN during running and 14,5 kN during competitive weight lifting (87, 104). During squat jumping the patellar tendon force was estimated to 3,2 kN (33).

Figure 2**.** Stress-strain curves for tendons, From Peterson, Renström, Injuries in Sports, Dunitz, London, 2001 with permission.



Tendon injuries are common in sports such as basketball, volleyball, athletics, soccer and tennis (Kujala, 1986 #116). Chronic injury in the patellar tendon occurs typically in sports characterized by high demands on force and power of the leg extensor muscles. Patellar tendinopathy is mostly occurring as a result of overuse and 30-50 % of all sports injuries are by some, considered to be overuse injuries (48).

Tendon healing

There are three stages of tendon healing: inflammation, repair and remodelling.

1. Inflammatory phase: The inflammatory response begins direct when the injury occurred whereas a hematoma is formed, the hemostatic is activating the vasodilators and new fibroblasts initiate growth of a capillary network. This stage lasts for 2-7 days (100).
2. Repair phase continues from day 5 –21, where cells produce type III collagen, which optimizes the collagen synthesis.
3. Remodelling phase starts after 21 days and can last for up to a year. The new tissue alignment is optimized and collagen fibrils alignment is increased. The longitudinal tendon structure as well as the elasticity and tensile strength are improved (101). The treatment during this phase is often progressive tensile loading.

Tendon healing takes a long time since the tendon has a slow metabolic rate. Tenocytes producing collagen with have a turnover time of 50-100 days (72). If a tendon is given inadequate time to repair the tenocytes may die due to excessive strain. It is therefore recommended to allow time for the treatment and avoid overusing the tendon.

Patellar tendinopathy

The prevalence of patellar tendinopathy is high in sports characterized by high demands on speed and power for the leg extensors, specially volleyball and basketball (32, 63, 71). Men has higher incidence of this injury compared to women (19, 22, 66).
Chronic overload is generally accepted as the main cause of patellar tendinopathy with excessive loading and tensile strain (54). The combination of pain, swelling and impaired performance indicates the clinical diagnosis tendinopathy (16, 67). The clinical symptoms can be severe and may often result in long-standing impairment of athletic performance.
There is no or little inflammation (10, 56, 74) which is indicated by normal prostaglandins investigated by microdialysis in Achilles tendinopathy (6). It is important to understand that absence of inflammatory modulators at end stage of a chronic disease does not mean that they are not present in early stage of a chronic disease. This could be a factor in the cause of tendinopathy. It has become clear that chronic patellar tendon overuse syndrome, so called patellar tendinopathy, is a degenerative condition mostly located at the posterior aspect of the proximal patella tendon where it inserts in the distal pole of the patellae (47). There is a

mechanical, a vascular and a neural theory for the cause of the degenerative process in the tendon.

History and careful clinical examination will most often indicate the diagnosis (73). The main symptom caused by patellar tendinopathy is pain during activity affecting the function of the athletes. The pain often occurs during jumping activity, walking in stairs (51) and squatting and can easily be provoked during palpation over the inferior pole of the patella (24) with straight knee and the quadriceps relaxed. A skilled clinician can categorize the pain as mild, moderate or severe (24). Stiffness around the knee in the morning may be another dominant symptom.

These symptoms often recur and may cause functional problems for the athletes. It affects the ability to perform optimally in many sports especially sports involving jumping and cutting activities. These functional problems may last over a long time and may often cause frustration for the athlete and the treatment team. It should be pointed out that mild patellar tendon tenderness should not be over interpreted, as it may be a normal finding in athletes (53).

Sometimes the clinical diagnosis needs to be verified. Ultrasonography (2) is valuable for setting the diagnosis and evaluating a patellar tendinopathy (22, 40). MRI will verify the diagnosis. In the Achilles tendon, MRI detects abnormal tissue with greater sensitivity than US (69). MRI and US show however only moderate correlation with clinical abnormality at the beginning of the tendinopathy process (23, 36, 53). It is however important to point out that imaging gives only anatomical, but not functional or symptomatic information, and is only added help to the history and physical examination in verifying the diagnosis (22, 24).

Tendon injury management

Both physiological and mechanical principles must be considered in managing patellar tendinopathy. Corrections of intrinsic and extrinsic risk factors, flexibility and biomechanical abnormalities are very important to analyze. The knowledge of the load on the muscle-tendon unit is an evidently a corner stone in the rehabilitation of the patellar tendinopathy. Submaximal loading can cause microscopic injuries to collagen fibers and more susceptible to tendon failure (58). Initially the cause of the problem such as negative external forces and factors such as external pressure must be identified and removed. Thereafter the treatment regime should match the stages of healing. In managing tendinopathy a key question is how we best can stimulate a chronic tendinopathy to recover, and allow an athlete a quick return to sport during a reasonable time. It is hypothesized that overuse injuries is a result of mismatch between a mismatch between adaptation of collagen and mechanical load (64). Exciting research by Kjaer and co-workers (31) shows that loading exercises initiates a good healing response of the diseased tendon (60). Human tendon tissue responds to mechanical loading both with a higher metabolic and circulatory activity as well as with an increased extra cellular matrix synthesis (63) (63). These changes contribute to the training induced adaptation in mechanical properties. Resistance to loading is altered and tolerance towards strenuous exercise can be improved and injuries avoided (59). Exercise increases the collagen synthesis and cross sectional area of the tendon and results in enlargement of the tendon diameter (101).

Eccentric training as treatment

An eccentric action is an activation of the muscle at the same time as it elongates (31). The musculo-tendinous complex lengthens, the muscle shortens and the tendon elongates (42). Eccentric exercise is regularly used as treatment for chronic tendinopathy and it seems that eccentric training does not affect the metabolism the same way in healthy and effected tendon (63).

The principle of specificity suggests that training modes and testing techniques should stimulate the functional demands as closely as possible. The use of eccentric training will optimally prepare the person during moments when an eccentric action is required for efficient and safe sports or functional demands. Eccentric training has a role in numerous training populations, from geriatric joint dysfunctions to elite athletic training programs, and clearly applies to a host of rehabilitation challenges (25).

Multiple studies (8, 14, 27, 45, 87) have reported specific eccentric based principles in the lower extremity, with common references to patellar tendon dysfunction and management. In addition, Garrett el al has stressed the role of eccentric loads in the causation of muscle strains and tears and the importance of specific preventive eccentric training programs (39).

A tendon is exposed to larger loads during eccentric loading especially when the movement occurs rapidly (52). The tendon is maximally strained during eccentric activity, which may explain the connection between eccentric loading and tendon injury (104) (104). Some clinical and empirical references stress the important role of eccentric loading to both the etiology and proposed treatment of tendon patellar problems (16, 87). Stanish and Curwin initiated the concept of eccentric exercises and rehabilitation for patients with tendinopathy(87). There are however a few studies evaluating different eccentric treatments of patellar tendinopathy available (18, 20, 24, 45, 46, 75, 88, 102). The clinical dose of the eccentric treatment exercise is not known which remains a major concern. The symptoms must therefore be related to tensile loading. The most common cause for failure is incorrect program progression and incorrect diagnosis (26). The gradual development of the exercise protocol is based on load and speed, which should be carefully monitored and slowly increased with jumping activity during a pain monitoring model (90).

Eccentric overload device - Bromsman®

The rapid movement toward specialization within the health science professions has produced exciting new equipment, continued growth of the knowledge based on therapeutic exercise, and an emerging emphasis on clinical and experimental research regarding the effects of exercise on the musculoskeletal, neuromuscular, and cardiovascular system. Clearly, the appropriate application of research to clinical and sports training settings will power the growth and evolution of exercise training into the next decade.

The main components of the eccentric overload device, Bromsman®® are shown in Figure 3.. The machine was constructed by Leif Larsson and Ulf Arnesson for high performance training at the National Swedish Sports Complex, Bosön, Lidingö, Sweden, utilizing the ability for eccentric training with high loads (up to 550 kg). The device consists of a barbell that can be moved up and down a chosen distance at a preset speed by a hydraulic machine. The machine has variable velocity and visual feedback of the load distribution. Thus it is useful for technique training. Athletes at national and international levels in alpine skiing, tennis, ice hockey, football, track and field, and weight lifting have used the machine to train squat, bench press and heel rises under control. No apparent injury or overuse problems have occurred during these training sessions. Thus, the machine appears to provide a highly safe way to apply eccentric overload in healthy athletes (37).
It was therefore considered valuable to start a validating study of the machine to be able to use it for further studies. A prospective and randomized study was also started after the initial good clinical results for treating patients with patellar tendinopathy problems. The actual load on individual joints and muscles while performing squats in the machine are unknown and has also been the topic for investigations.

Exercise on a decline board

Eccentric training, on a the 25 degree decline board as treatment for patients with patellar tendinopathy is nothing new but has now shown superior results compared to squatting on horizontal surface (46, 75). It is also indicated that the decline squat protocol offers greater clinical gain, during rehabilitation for patellar tendinopathy in athletes, who continue to train and play volleyball with pain (102). On the contrary there is however one study that showed no effect on knee function from a 12-week program with eccentric training on a decline board among a group of volleyball players with patellar tendinopathy who continued to train and compete during the treatment period (98).

Thus, exercise on a decline board seems to be efficient in managing patellar tendinopathy. It was therefore considered to be of interest to compare this training technique with the eccentric overload training device - Bromsman®.

Evaluation of the VISA-P score

The only published clinical questionnaire for patellar tendinopathy problems (38) was developed in Australia by the Victorian Institute of Sport Assessment in Melbourne (97). This score assesses symptoms, simple tests of function and ability to play sport related to patellar tendinopathy.

This score has increasingly been used as a valuable tool in the evaluation of patients with patellar tendinopathy (11, 46, 102, 104). In order to be able to use this score in further studies it is of importance to have a translated and culturally adapted version (13).

Rationale

Considering the high incidence of patellar tendinopathy in sports such as basketball, volleyball and tennis the difficulty in managing the sport specific patellar tendinopathy and the long time it takes to return to sport (73, 76, 77). Therefore there is a great need for investigating all available treatment options. The most promising treatment regime includes eccentric exercise with increasing load (11, 87). This thesis was therefore initiated to evaluate different aspects; techniques and effects of overload eccentric exercise of the complicated clinical problem, patellar tendinopathy.

AIMS

Overall aims

The overall aim of this thesis was to study and evaluate the results of two different eccentric rehabilitation methods for patients with the diagnosis patellar tendinopathy.

Specific aims

- To translate and evaluate the VISA-P score for patella tendinopathy pain and activity level for reliability, reproducibility as well as culturally adaptation.
- To investigate the characteristics and test-retest reproducibility of the new eccentric overload training device Bromsman®.
- To estimate the load on the patellar tendon in different types of squats.
- To compare two eccentric treatment protocols for patellar tendinopathy.

SUBJECTS

Table 1. Summary of subjects in the studies

Study	N	Age	Male/Female	Comments
I	17	24± 6	8/9	Healthy students, control group
	17	26± 3	17/0	Male national basketball team, risk group
	17	22± 5	17/0	Patellar tendon patients, patient group
II	7	38±11	7/0	Fire fighters
	13	40± 9	13/0	Fire fighters
III	11	36± 9	11/0	Fire fighters
	13	39±10	13/0	Fire fighters
IV	11	26± 8	9/2	Patellar tendon patients (B-group), Bromsman®
	9	28± 8	7/2	Patellar tendon patients (C-group), decline board

Study I

Fifty-one subjects were recruited for test-retest evaluation of the VISA-P score. Three different groups were tested at two different occasions and subjects were picked from three different areas to cover extreme values. The control groups were students from Swedish Sport Confederation College (Bosön), and the patient group were referred to the study by physicians and physiotherapists during ongoing treatments at the Bosön Top Sports Clinic. The patients had a history of pain from around the patellar tendon, acute as well as chronic. The third and last group named “risk group” was male basketball players from the Swedish national team tested during a training camp at Bosön.

Study II and Study III

To test-retest the new overload device Bromsman® as well as to calculate the patellar tendon load in different types of eccentric squats, fire fighters were recruited as healthy well trained men from Lidingö fire station, Sweden. They daily train, have high physical demands resembling athletes and are highly motivated for excessive training.

Study IV

After an information letter, colleague physicians and physiotherapists referred patients with the clinical diagnosis patellar tendinopathy to the Swedish Sports Confederation Clinic. To be included in the study, the athletes had a characteristic history of patellar tendinopathy, continuously for at least 3 months, or recurrent for at least 6 months. Verification of patellar tendinopathy was required using either Magnetic Resonance Imaging (6) or Ultrasonography (2). Exclusion criteria were local corticosteroid injection the last 3 months, previous ACL injury or reconstruction, diabetes, chronic inflammatory or rheumatic joint disease, or back pain during the last 3 months.

METHODS

A translation and evaluation of the VISA-P questionnaire (Study I)

The VISA-P score consists of eight questions, of which six questions concern pain experienced during a range of everyday activities (97). Two questions deal with the ability to engage in sport activities. All questions are answered on separate scales (97), where a higher score indicates a lower level of pain or impairment (see Appendix A and B in study I). The maximal total score is 100 points, which would indicate that the person has no knee pain, good function and can perform fully in sports. The theoretical minimum score is 0 points. The translation process followed the method described by Beaton et al (13). This method is currently used by a number of organizations, including the American Association of Orthopaedic Surgeons (AAOS) Outcomes Committee, as they coordinate translations of the different components of their outcome batteries (13). The translation process is divided into five different stages: I. Translation; II. Synthesis; III. Reverse translation; IV Expert committee review and V. Pre-testing.

Initially, two physiotherapists performed two independent translations (2) from English into Swedish. A synthesis (4) of these translations was made, and the consensus of the two translated Swedish versions was documented. Reverse translations (11) were performed independently by three native Anglophones fluent persons in Swedish. One of the reverse translators was a physiotherapist, one was an economist and the third was a teacher. The three physiotherapists in the expert committee (2) then made a semantic and idiomatic equivalence analysis between the original source and target Swedish version of the VISA-P questionnaire. The translated questionnaire was pre-tested (2) on 12 individuals, six patients with patellar tendinopathy and six physical education students.

The Swedish VISA-P score was administrated to all 51 participants at Bosön, the Swedish National Sports Confederation Complex (Lidingö, Sweden). Three different groups completed the questionnaire twice within an interval of one week (range 4-7 days). The principal investigator administrated the questionnaires at all test occasions, with the exception of six of the tendinopathy patients.

An eccentric overload device - Bromsman®® (Study II)

Loads are applied on an Olympic barbell (20 kg), which is supported by two galvanic steel wires (Gunnebo Lifting, Östersund, Sweden). The barbell can travel a distance of 1.70 m, i.e. between 0.40 m and 2.10 m above the support surface. The wires are attached to a hydraulic cylinder. A hydraulic pump generates the pressure needed to lift the barbell and an adjustable hydraulic valve controls the velocity of the barbell. One of the wires runs past the wheel of a rotary sensor, which measures the displacement of the barbell. The hydraulic valve can be continuously adjusted. Fully open valve corresponds to a velocity of 0.6 ms^{-1} with a heavy load on the barbell (320 kg). The vertical component of the ground reaction force under the sole of each foot is measured using two industrial scales.

A PC controls the machine and provides real-time feedback by means of a screen showing two bars that indicate the vertical component of the ground reaction force under each foot. The purpose of this feedback is to enable a controlled distribution of the load, e.g. to target the weaker limb. This information is also presented to the operator. Vertical components of the ground reaction force and the movement of the barbell were recorded with the built-in displacement sensor in the machine and using a motion capture system.

Experiments were performed to investigate not only the machine, but also how the barbell and the resistance of an individual influence the velocity during lowering the barbell. Test-retest reliability was also investigated were the subjects were tested for maximal eccentric leg extensor strength in squatting on two occasions with two weeks apart.

Figure 3. Bromsman® -the eccentric overload device

Kinetics

Motion capture (Study II-III)

A motion capture system (Qualisys AB, Gothenburg, Sweden) was used for study II, to evaluate the Bromsman® machine and study in III to study the load on the patellar tendon.

In study II, to validate the displacement sensor in Bromsman®[®], the velocity was measured at twenty different levels between 0.08 ms^{-1} and 0.4 ms^{-1}. The movement of the barbell was recorded both with the built-in displacement sensor in the machine and using the motion capture system with three cameras. A single reflective marker was attached to one end of the barbell. The trajectory of the marker spanned most of the field of view. The 3D movement of the marker was captured at 150 Hz, and low-pass filtered at 40 Hz using a zero-face 8^{th} order Butterworth filter. The velocity was then estimated using the central difference ($v(t) = (x(t+1) – x(t-1)) / 2\Delta t$, $\Delta t = 0.0067s$). The phases of initial acceleration and of constant velocity were identified by visual inspection of the velocity plot. The durations of the phases were recorded, and the average velocity was computed for the constant velocity phase. The vertical velocity was also estimated from the recordings of the displacement sensor. The velocity was calculated via the central difference, ($\Delta t = 0.061s$) and the constant velocity region identified visually.

The squatting movement in study III was recorded using six or seven cameras (at two different test situations) which were positioned around the measurement volume at horizontal distances ranging from 2.6 m to 5.7 m from the origin of the coordinate system, which was located at the right rear corner of the force platform under the left foot. The cameras were positioned at heights ranging from 0.3 m to 2.5 m above the force platforms. The cameras have a field of view of 43° horizontally and 33° vertically. A total of 24 spherical reflective markers (∅ 19mm) were attached bilaterally on the body. Single markers were attached using double-sided tape on the following landmarks: the most posterior aspect of the heel (on the shoe), the anterior-superior aspect of the second toe (on the shoe), the lateral malleolous, and the lateral side of the femoral epicondyle. Slightly curved styrofoam plates with three markers on each were attached using flexible tape (Blenderm, 3M, St Paul, USA) to the anterior shank and lateral thigh. A belt was strapped to the pelvis over the iliac crest. Four markers were attached to the belt approximately at the posterior superior iliac spines and the anterior superior iliac spines.

Decline board (Study III)

The test on the tendon load and the one-legged decline squat protocol were performed on a 25 degree decline board, according to the recommendations by Curwin and Stanish (27, 87). The decline boards consisted of two identical wooden boxes with high friction strips glued onto the surface to avoid slipping. The subjects' feet were placed on each board such that the entire sole of the foot rested on the declined surface.

The subjects performed squats holding a weight (barbell disc) of 10 kg in against the chest. The squats were carried out both bilaterally and unilaterally on each leg with the feet shoulder width apart. During the unilateral squat the subjects descended on a single leg, with the contra lateral foot touching the floor, but without bearing weight. For the ascending phase the subjects used both legs. A metronome assisted the subjects in keeping a standardized movement velocity similar to that applied in the tests on the Bromsman® device.

Kinematics (Study III)

Marker data collected in study III were low-pass filtered with cut-off frequency at 6 Hz using a zero-phase 4^{th} order Butterworth filter. The data were analyzed using custom written code (Matlab, The Mathworks, Inc, MA, USA) and commercial software for biomechanical analysis (Visual3D v3.21, C-Motion Inc, MD, USA). A total of seven body segments were defined; the feet, the shanks, the thighs and the pelvis. Local coordinate systems for the thighs and shanks were defined with the origin in the center of the respective proximal joint. The orientations were defined with one axis pointing from the proximal to the distal joint center (longitudinal direction) and one axis pointing in the direction of the dominating joint axis (medio-lateral direction). The position of the joint centers of the ankle, knee and hip joints, as well as the direction of the dominating axis of rotation, were estimated individually for each subject based on the method recommended by Ehrig et al. (28), and using data from a bilateral squat movement. This means that the joint centers were estimated by the center of rotation occurring in that joint. The local coordinate system of the feet was defined similarly as for the shanks and thighs, except that in the absence of a distal joint, the marker on the toe was used to define the distal end of the segment. Thus, the longitudinal direction of the foot was from the center of the ankle joint to the marker on the second toe.

Euler angles were computed for each joint with the first angle corresponding to a rotation about the dominating joint axis. We refer to this joint angle as flexion angle. The definition of the hip flexion angle differs from the knee and ankle flexion angles. For the hip joint, the flexion angle is zero when the subject is standing neutral, whereas for the knee and ankle joints, the flexion angle is computed between the longitudinal direction of the segment distal and proximal to the joint. For the knee 0° flexion is a straight leg, whereas for the ankle, 180° flexion means a plantar flexed foot to a position where the longitudinal axes of the shank and foot are aligned.

The descending phase, in the following referred to as the eccentric phase of the squat, was detected separately for the left and right leg. The beginning was defined as the instant when the angular velocity of the knee joint exceeded a threshold of 5 °/s and was maintained at >5 °/s for at least 0.5 s. The threshold had to be somewhat greater than 0 because many subjects (in the free weights test) exhibited a continuous, slow knee flexion velocity during the shift of weight towards one leg occurring prior to the squat. The end of the eccentric phase was defined as the instant of maximum knee flexion. The range of angular motion (ROM) at the hip, knee and ankle were calculated from the start to the end of the eccentric phase.

Figure 4**.** Experiments during tendon loading

Force plates (Study III)

In both test situations in study III, two force platforms, each 0.60 x 0.40 x 0.10 m (Kistler AG, Winterthur, Switzerland) were placed in parallel on the floor with a distance of 0.45 m center to center. Reaction forces were measured in 3D. A decline board was firmly attached with double-sided adhesive tape on top of each of the force platforms.

Force data were recorded at 1 kHz on the same computer where marker data were captured.. The data were low-pass filtered with cut-off frequency at 6 Hz using a zero-phase 4^{th} order Butterworth filter.

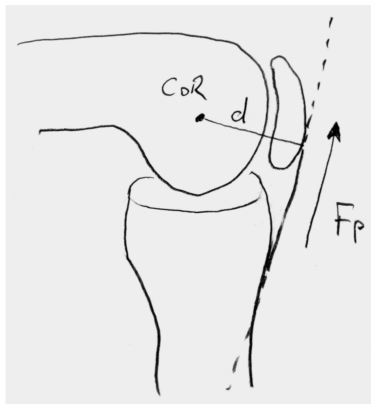
EMG (Study III)

Muscle activity was recorded in study III with electromyography (EMG) after shaving and cleaning the skin with alcohol. Pre-gelled surface electrodes (Blue Sensor, Ambu A/S, Ballerup, Denmark) were placed in pairs bilaterally (interelectrode distance 2 cm) on the most prominent part of the following muscles on both legs; medial quadriceps (vastus medialis), lateral hamstrings (biceps femoris) and medial triceps surae (medial gastrocnemius). Synchronously, the EMG signals were collected at 1 kHz on a separate computer. The start of data collection on one computer triggered the data collection on the other computer A notch-filter (50Hz) was applied to the EMG signals followed by a 4^{th} order Butterworth high-pass filter with cut-off frequency at 10Hz before rectification. Muscle activation was quantified by taking the average of the rectified EMG signal between the beginning and the termination of the eccentric phase.

Inverse dynamics and patellar tendon force (Study III)

In study III, the method called inverse dynamics (99) was used to calculate the knee joint moments for each leg. Inverse dynamics uses Newton's equations of motion treating the joint moment and joint force as the only unknowns. In order to obtain an estimate of the force acting on the patellar tendon, we assumed that the net knee moment was due only to an extending moment produced by the quadriceps, thus neglecting any possible (negative) contribution from the knee flexors. To get from the joint moment produced by the quadriceps to the patellar tendon force, we needed also the length of the patellar tendon moment arm. This length is both angle specific and subject specific, and published studies have found a range from 20mm to 54mm using different methods and definitions (93). As an approximation to the true moment arm, we chose to use results from (86). For each data point, the knee moment was divided by the patellar tendon moment arm, specific for the corresponding to knee flexion angle, to obtain the force acting on the patellar tendon.

Figure 5. Fp is the patellar tendon force, d is the patellar moment arm i.e the distance from center of rotation (CoR) to the line of action of the patellar tendon. The moment of Fp with respect to CoR equals Fp times d.



From the normalized and averaged patellar tendon force and angular displacement, the peak force, the angle at which the peak force occurred, and the mean force were extracted. Moreover, the knee joint power (joint moment multiplied by joint velocity) was integrated from the start to the end of the eccentric phase to obtain the eccentric work at the knee. This is the same as the area under the moment-displacement curve.

Testing and evaluation (Study IV)

Isokinetic testing

A Biodex® dynamometer (Biodex Multi-Joint System 2, Biodex Medical System, USA) was used for isokinetic testing. Maximal voluntary concentric knee contraction was performed on each leg and the peak torque was chosen for the tests. The protocol included five maximal concentric quadriceps/hamstring contractions at 90º/sec, and 25 endurance contractions at 240º/sec. A single series of each velocity was tested. All subjects were familiarized with the test procedure. The subjects were seated in 110º angle between the back support and the seat. The upper thigh was strapped onto the chair while the lower thigh was strapped to the padded lever arm of a dynamometer. The non-tested leg was hanging freely, and (68) the upper body was secured and fastened with two diagonal straps and one horizontal strap over the trunk.

The palpated center at the knee-joint was aligned with the axis of rotation of the lever arm. Verbal encouragements were given during all tests.

Functional tests

The vertical jump tests were measured using a timer-equipped infrared contact mat (IVAR IR-Matta®, LN Sport Konsult HB, Habo, Sweden). The contact mat was used for estimation of the time the patients were in the air, with a precision of 0.001 sec, that was converted to jump height.

Squat jump (SQJ): The SQJ was performed on one and two legs, respectively. The starting position was semi-squatting with 90º of knee flexion, with the hands fixed on the waist, followed by a maximal vertical jump. The subjects performed three approved trials, first using both legs, followed by three single leg trials, alternating the right and left leg, always starting with the uninjured side. The best value of each leg was registered.

Five-repetition counter movement jumps (CMJ x 5): The starting position of the CMJ x 5 was upright, with the arms directed upwards towards the ceiling. At the sudden knee bending to approximately 90° of knee flexion followed by the maximal vertical jump, swinging arms were used to help the jumping movements. Sets of five repetitions were performed three times, and the mean value of the best result in each of the three trials was registered (61).

One-leg single hop test: Allowing free arm swing through the movement, the subjects were instructed to jump as far as possible landing on the same leg. The landing had to be steady for at least two seconds on the landing foot. The distance from the toe at the push-off to the heel mark in the landing was measured, and the best of three technically approved jumps was used. The legs were tested alternatively, always with the uninjured leg tested first (12, 70).

One-leg triple hop test: The test was performed as above, but with three repetitive long jumps straight forward, landing on the same foot. The legs were alternatively tested, starting with the uninjured and the best value of three trials was registered (17, 78).

Range of motion

Ankle (talo-crural joint): Passive ROM of ankle dorsal flexion was measured with the patient standing with the foot to be measured on a chair (standardized height, 48 cm). A standard goniometer (Model G 300, Whitehall manufacturing), was placed with the center at the most prominent point of the lateral malleolus, and one lever arm directed towards the fibular head, and the other along the line towards the head of the fifth metatarsal. The patient was asked to move the knee over the foot as far as possible, without lifting the heel from the surface. The measurement was repeated three times, using the maximal value in the analysis (68).

Flexibility tests

Quadriceps muscle flexibility: The quadriceps muscle flexibility was tested in a prone position, with the hip of the leg to be tested extended on the bench, and the other leg vertically flexed over one side. While stabilizing the pelvis manually, the heel of the investigated leg was passively brought as close as possible to the ipsilateral buttock. Using a goniometer, the degree of the knee flexion was measured and recorded. One standardized measurement was performed (96).

Hamstring muscle flexibility: The patient lies supine, the hamstring muscle flexibility was tested with a straight leg raise test. While the contra-lateral leg was kept straight on the bench, the measured straight leg was slowly extended towards the ceiling. The goniometer was placed over the hip and the angle between the trunk and the raised leg was recorded.
To reduce inter-tester variability, the same of two physiotherapists tested the same patient at both occasions (29).

Visual analog scale (VAS)

Pain during eccentric exercise is debated. In this study the exercise were not supposed to increase the patient’s symptoms and the pain was allowed during the exercise program according to the pain- monitoring model Thomeé 1997. The exercise was only increased if the above conditions were pain-free, if not, the patients were told to return to the previous level and contact the physical therapist (90).

Eccentric treatment protocols (Study IV)

Eccentric treatment was given in both groups twice weekly starting with a standardized warm up on a stationary bicycle for 15 min at 100 W. Each rehabilitation session consisted of eccentric strength training treatments (group B or C, as below), alternated with trunk and foot stability training. The trunk training consisted of 3 x 15 sit-up movements and the foot stability training consisted of one leg stance 3 x 1 min on each leg.

This implied an active rest of 4 min between each eccentric strength series. Each training session lasted for about 70 min, and was rounded off with standardized stretching of the quadriceps and hamstring muscles, complemented with an icepack over the painful patellar tendon for 20 min. All patients ceased participating in sport and other training activities for the first six weeks. During the last 6 weeks of the protocol, participants slowly resumed supervised jogging and plyometric jump training, guided by Thomee's pain-monitoring (90, 91)

Randomization

The patients were randomized to either one of two treatment groups by random draw of a sealed envelope that contained the group assignment.

Two-legged eccentric overload training (Bromsman® device, Group B)

For each patient, the descending distance was individually set from a standing straight position to approximately 110° of knee flexion, the barbell was loaded with 320 kg, and the speed was set to 0.11 m/s. Two industrial scales registered the vertical force under each foot, and the patients were given real-time feedback of the forces by means of two bar graphs on a computer monitor. Another computer monitor facing the physiotherapist displayed time series of forces, which were recorded. The patients resisted the movement of the barbell using both legs during 4 sets x 4 repetitions, where the first set was for warming up and the following three at maximal effort. During the ascending phase, the patients followed the barbell without resisting the movement. Pain was assessed after each set using VAS.

One-legged eccentric training on a decline board (Group C)

One-legged eccentric training (26, 27, 75) was carried out on a 25º decline board, with 3 x 15 reps of unilateral squats on the injured leg, holding an extra weight in front of the chest (Figure 3). Both legs were used during the ascending phase. At the start of the treatment no extra weights were added. At each following training session, the patients initially performed a set of 15 reps with the same weight as the previous time. If the VAS score was below three for a set, the load was increased in five kg increments, and if VAS exceeded five, the load was reduced. This group was instructed to train at home (3 sets x 15 reps/day). The pain-monitoring model (cf. above) was also used during the home training program, and the extra load increase was accomplished by adding weights in a backpack or in their hands. The principal investigator (AF) led all training sessions for all patients in both groups being performed at the clinic.

Figure 6**.** One-legged eccentric training on a decline board

STATISTICAL METHODS

All variables were summarized using standard descriptive statistics (mean, median, standard deviation or standard error). A significance level of 5 % was applied for all studies. The specific statistical tests used in the different studies were as follow:

Study I

All variables were summarized according to standard descriptive methods [mean and standard deviation (SD) and checked for outliers. No significant deviations from the normal distribution criterion were found. The test-retest reliability was analyzed according to the method described by Bland and Altman, which yields an intra-class correlation (ICC)(15). Differences between test occasions and groups were analyzed with an ANOVA (analysis of variance for repeated measurements, group * time). In the post-hoc tests of group differences, Tukey's HSD method was applied.

Study II

The Wilcoxon matched-pairs sign rank test was used to test the difference between the test and retest results. Reliability is reported using the correlation coefficient (r), the coefficient of variation (within-subject standard deviation divided by the group mean) and the intra-class correlation (ICC). ICC was computed using a one-way ANOVA model with repeated measurements (84).

Study III

Differences between conditions (horizontal *vs* declined) for the right leg in the Bromsman® test situation were tested using a one-way repeated measures ANOVA. Differences between test conditions (horizontal *vs* declined) and legs (left *vs* right) in the free weight test situation were assessed with two-way repeated measures ANOVA. Differences between the two tests most often used in the clinic, i.e. free weight on a decline board versus Bromsman® on a horizontal surface, were evaluated employing one-way repeated measures ANOVA.

Study IV

Results were analyzed using a three-way ANOVA, with Group (B and C) as the between-subjects factor, and *Time* (before and after treatment) and *Side* (affected leg and unaffected leg) as the within-subjects factors. When an interaction was significant, simple main effects tests were performed, i.e. effects of one factor, holding the other factor fixed. Due to the data level, the VISA-P measurements were analyzed by a generalized estimating equations (GEE) model with the GENMOD procedure in SAS® (Statistica 7.1, StatSoft®, Inc. Tulsa OK, USA). The GEE strategy is a useful approach for repeated measurements analysis of ordered categorical outcomes. The VISA-P measurements was categorized into four categories, 0-50, >50-65, >65-75, >75-100, and this ordinal response ranged from 1 to 4, was then analyzed with a proportional odds model for repeated measurements with the GEE method. The model was set up with the within factor *Time* (0, 3, 6, 9, 12 weeks), and the between factor Group (B and C). The *Group x Time* interaction refers to the statistical test of whether the response profile for one treatment group is the same as for the other group. Fisher's exact test was used to compare the two groups regarding the dichotomized VISA-P score, ≤75, and >75 ("healthy"), and the Sign test was used to analyze the effect within methods for the VAS measurements (79, 89).

ETHICAL CONSIDERATION

All subjects received oral and written information about the purpose and procedure of the study and written informed consent was obtained.

The Ethical Committee at Karolinska Institutet, Stockholm, Sweden, approved the studies I, II and IV; (No.00-103 including a supplement).

Study III was approved by the Ethical Committee at Karolinska Institutet, Stockholm (EPN 2005/338-31/4).

RESULTS

VISA-P outcome score for patellar tendinopathy (Study I)

The participants considered the VISA-P score was easy to use, and it took about five minutes to complete. The expert committee considered the translation and reverse translation satisfactory.

The test-retest of the Swedish VISA-P score showed high reliability and significance (ICC = 0.97, $p<0.001$). There were no significant differences for the total VISA-P score between the first and second test occasions. Each question (Q) was analyzed separately with respect to regarding the reliability. Seven out of eight questions had a reliability of more than ICC=0.8 (range 0.68-0.97). The internal consistency of the total scale was high for the scores both on the first and second occasion, 0.83 and 0.82, respectively.

The principal component analysis yielded a two-factor solution. The communality, i.e. the degree of explained variance, of one of the questions ("sit pain-free?") was below 0.35, and thus not sufficiently explained by this solution. Thus, a three-factor solution was preferred which explained 85% of the total variance, with all communalities above 0.60. The first component comprised of six questions. The second and third components comprised of one question each. This solution showed high stability, being invariant in a second factor analysis of the scores from the second occasion (the amount of explained variance was 83%).

At the first test occasion (A) the mean (± SD) of the VISA-P score in the healthy student group was 83 (±12), in the basketball players 79 (±23), and 47 (±20) in the patient group. In all questions, the patient group had lower scores as compared to the other two groups and statistical significance ($p<0.05$) was observed in all individual questions except the first (Q 1; "sit pain-free"). The questions concerning pain (Q 6; "pain during 10 single leg hops") had the greatest difference between the groups. Both activity questions (Q 7 and 8; "currently undertaking sport" and" pain during activity") showed significant differences between the groups.

Evaluation of the Bromsman®-device (Study II)

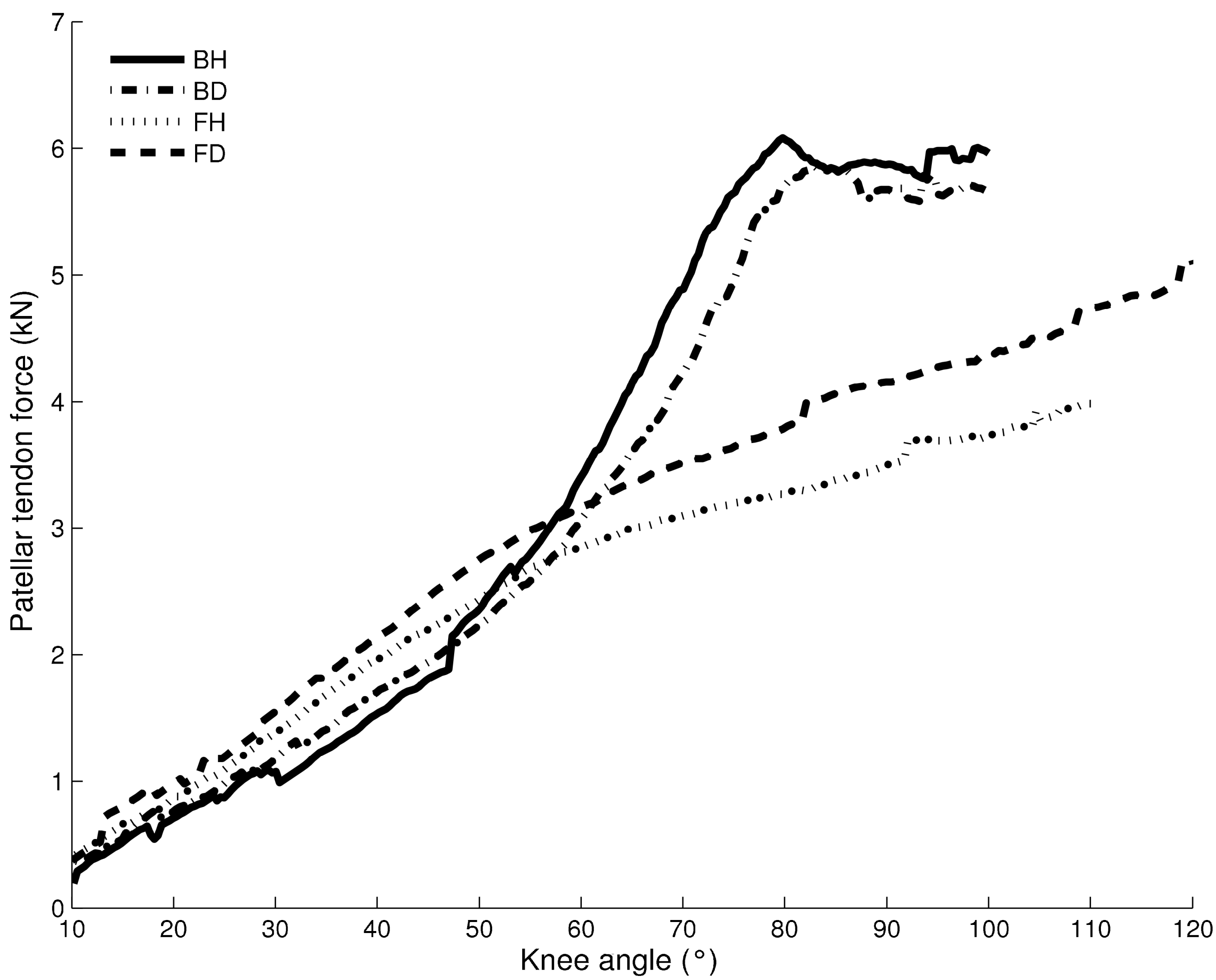
The velocity was more sensitive to the resisting force with a lower load on the barbell and was also dependent the temperature of the hydraulic oil.

In the test-retest reliability study there was no significant difference between the two test occasions of peak force ($p < 0.22$) and position of peak force ($p < 0.17$). The coefficient of variation between the test occasions was 9% for peak force and 22% for position of peak force. The correlation measures were $r = 0.74$ and ICC = 0.81 for peak force, and $r = 0.43$ and ICC = 0.57 for the position of peak force.

Patellar tendon load in different types of eccentric squats (Study III)

Mean curves for the average patellar tendon force versus knee angular displacement during the four different experimental conditions are presented in Figure7.

Figure 7.



The following acronyms will be used to identify the four different combinations of tests and conditions, FD: free weight on declined board, FH: free weight on horizontal surface, BD: Bromsman® with decline board, and BH: Bromsman® with horizontal surface.

Comparing declined with horizontal; FD vs FH and BD vs BH

The main effects of decline board were present for the kinetic variables; all being higher (25-29%) in FD than in FH. Also, in FD, peak force occurred at a more flexed knee. The kinematic analysis also showed the main effects of decline board in that the movement in FD started at a more flexed knee and a more plantar flexed ankle joint and stopped at a less flexed hip, more flexed knee and more plantar flexed ankle joint as compared to the FH condition. The mean EMG was significantly higher in FD than FH for the gastrocnemius (13%) and vastus medialis (6%), whereas there was no difference for the biceps femoris (<1%).

In the Bromsman® tests, there was no significant difference between BD and BH for any of the kinetic variables investigated, or for the knee angle at peak force. The decline board condition resulted in a smaller range of motion at the hip, a more flexed stop angle at the knee, a more plantar flexed ankle both at the start and stop, and a larger ROM for the ankle. The analysis of the effect of a decline board on mean EMG activity showed that there was a significant increase in activation of the gastrocnemius (7%), whereas there were no changes for the biceps femoris (1%) or vastus medialis (7%).

Comparing Bromsman® horizontal (BH) with free weight decline (FD)

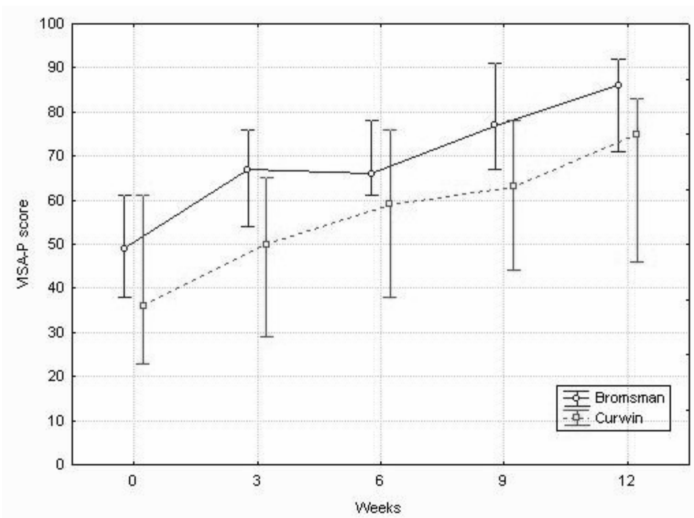
The Bromsman® horizontal test resulted in similar values for work as the free weight decline test. The mean and peak patellar tendon force was higher in BH than in FD and occurred at a less flexed knee angle. The angular excursions were smaller in BH as compared to FD, as demonstrated by lower values in BH for both stop angles and ROMs for all three joints.

Eccentric treatment for patellar tendinopathy- a prospective randomized study of two rehabilitation protocols (Study IV)

All twenty subjects completed the 12-week intervention. There were no significant differences between the groups´ baseline characteristics.

There were no significant differences between the study groups (fig. 4) at any time during the treatment. All patients in both groups improved significantly during the treatment period of 12 weeks ($p< 0.001$ for each group, respectively). Group B increased from median 49 (95% CI 38-61) to 86 (95% CI 71-92) points, whereas the Group C increased from median 36 (95% CI 23-61) to 75 (95% CI 46-83) points (fig. 5). There were no significant differences in the improvement of the VISA-P score between the groups.

Figure 8**.** Visa- P score under 12 weeks for Group B and Group C



At the isokinetic tests at 90º/sec, there were no significant differences between the treatment groups. At baseline, the injured legs in both groups were weaker. After treatment, there was a significant increase for both legs in both groups. At 240°/sec, there were no differences between the uninjured and injured from start or at the end of the treatment. The *group x time* interaction indicated different treatment effects, and the strength of both legs in group B increased approximately 8 %, whereas there were no changes in group C.

The *time x group* interaction was not significant in any of the functional tests below.

There were no differences for the one leg single hop, neither between legs, groups, nor over time. For one-leg triple hop, both groups improved over time, and there were no differences between the legs.

The ROM of both ankle joints increased over time in both groups. The flexibility of the quadriceps increased over time. However, *group x time* interaction indicated different treatment effects and tests for simple effects revealed a significant effect over time for Group C, but not for Group B. The *group x time* was significant for the hamstring flexibility, and there was a significant increase for the injured leg for both groups. Both groups displaced a lower VAS after treatment, from pretreatment values of median 4-6, to median 0-1 after 12 weeks.

DISCUSSION

Patellar tendinopathy is a classic overuse disorder (35). It develops gradually and is often related to high training levels (various combinations of volume, intensity and loads) in both competitive and recreational sport. A healthy tendon is often very strong but weakens with increasing degenerative changes, e.g. insufficient recovery, or anabolic phase, after exercise (60). This makes it vulnerable to repetitive high loads especially in athletes with repetitive exertion of the quadriceps muscle (55). There are two possible solutions to this problem. The tendon can become stronger or the tensile force can be removed (26). Early diagnosis helps to initiate adequate treatment and thereby the decreasing the risk for developing a chronic disorder, which may be difficult to manage.

New ideas and innovative treatment regimes are needed in the management of patellar tendinopathy. Internationally and scientifically accepted standardized outcome measures, such as the VISA-P score, are important so that innovative treatments can be compared and new training methods can be evaluated. Successful treatments should resolve the current symptoms and return the athlete to the pre-injury activity level, but also optimally prevent the athlete from reinjury. New treatment ideas should be based on good science leading to evidence-based medicine, and applied with common sense and clinical experience. Not only are well-designed therapeutic exercise regimes for the impaired tendon needed, but also good clinical judgment, including systematic analysis of the whole body mechanics and function.

Limitations of the studies

In study I, the normal population in the study consisting of physical education students at the Swedish Confederation Center, Sports College, Bosön displayed a VISA-P score of 81-83, about 10 points lower than a similar population in the original investigation (97). This active population in study I may be considered as a population at risk, due to their daily sporting activities. However, in neither of the populations, was the lack of subjective symptoms supported by any US or MRI verification. Also, this may indicate that overuse pain around the knee other than patellar tendinopathy may affect the score values. Furthermore, since patellar tendinopathy is a chronic condition, the symptomatic patients may be in different phases of the impairment, which may affect how the patient scores as well as the relative wide variation in the treatment groups in study IV.

The measurements of the tendon loads for the different types of squats in study III were indirect, with the aid of motion-capture systems and inverse dynamics calculations. Other recently reported techniques to estimate patellar tendon strain recently reported include ultrasonography (indirect) (62) and direct in-vivo measurements using minimal strain gauge transducers (DRVT) (34). Which method is the most valid is not known. Also, the superficial portion of the proximal patellar tendon is reported to be stronger than the deep part, where radiological signs of tendinosis most often can be shown. It could have been of interest to have used patients as test subject while calculating the tendon load but not practical.

In study IV, apparently the patient population is too small to have the power to detect other than dramatic group differences. Choosing the outcome of VISA-P ”normalization” in the present study for power analysis, the study only had a 23 % power at the alpha-level of 5 % to detect any differences between the treatment groups. However, the study population was accepted, since another of the main goals of the study was to secure safety of the new Bromsman® device, and not to worsen the condition. Also, it may be speculated that the isokinetic concentric measurements, performed as secondary outcome in study IV, may have shown other results if eccentric measurements had been performed. However, the equipment for eccentric measurements was not available at the rehabilitation clinic at the time of the study.

VISA-P outcome score for patellar tendinopathy (Study I)

Patient-administered questionnaires are with increased frequency recommended and applied as primary outcome measures in clinical trials (80, 85). The VISA- P is the only questionnaire today specially designed for patellar tendinopathy. It shows good test-retest reliability (ICC = 0.97 in our study). This questionnaire can be considered to be suitable for group and intra-individual comparisons but not beneficial for inter-individual comparison. The difference of the mean VISA-P scores between the patient and the healthy control group in study I was about 35 (35). Compared to the group at risk (male Swedish national team of basketball players), the patients scored lower for all questions and the control group scored higher at all questions except two, respectively.

In recent studies of treatments of patients with patellar tendinopathy (11, 43, 62, 75, 102) and study IV, the mean baseline score values of patients are in the range of 30-60 (see Figure 8). Also, after clinically successful treatment (3 months – 1 year) in these, the mean value ranged from 70-85. This implies that there is room for improvements in the VISA-P score to increase the sensitivity, so that changes during treatment can be followed more accurately. Adaptation of a questionnaire for use in a new setting (language and culture) is time consuming and costly. There are specific criteria that investigators should apply when adapting patient-based outcome measures (13). However, when this has been achieved, larger international data comparisons can be made, increasing the chance for quicker information about treatment effects. Additionally, there is a need for internationally accepted 'golden standards' in outcome scores.

This study shows that the Swedish version of the VISA-P score is an acceptably valid and good contribution in the evaluation of patellar tendinopathy, and can be used both in clinical and scientific work.

Evaluation of the Bromsman®-device (Study II)

The displacement sensor of the Bromsman® device and the scales on the ground gave valid measurements. The low resolution and low sampling frequency of the built-in displacement sensor result in a variance in velocity recordings.
There are two main reasons for the variation of the speed for a given combination of load and valve settings, the pulling force on the wires and the temperature of the hydraulic oil. A large load will lower the natural frequency of the barbell "pendulum", which may affect the squatting technique of the person. A small mass, results in a movement closer to lifting a free weight, more balance and coordination is then required. Involvement of the postural control and activation of the trunk muscles is an essential part of the squat exercise. This may also be influenced by the load applied and may have an effect on the squatting technique.

Replacing the scales with force plates would enable the measurement of forces in three dimensions as well as the centre of pressure. This can be used as visual feedback to control the movement and the bodyweight is then changed through the motion. The power can be used as input for further analysis. The "low" valve setting with moderate load (220 kg) is recommended for rehabilitation training, whereas higher load and velocities are useful for high performance training. The load should be chosen according to the actual strength of the patient or trainee.

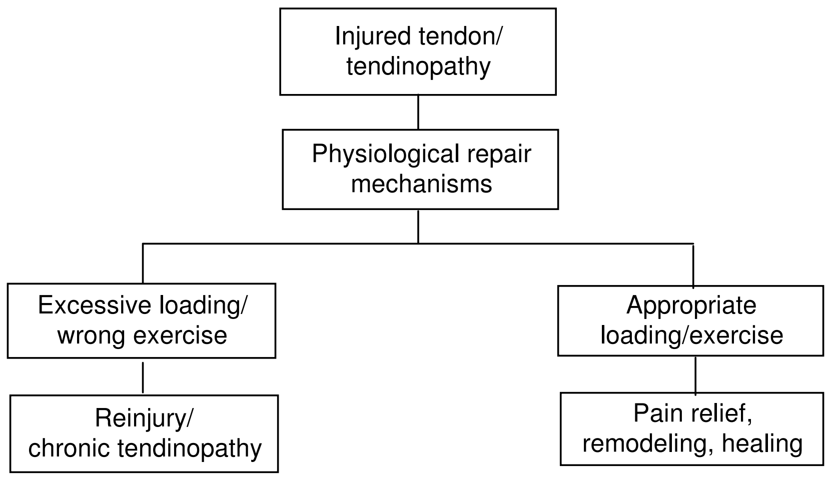
Patellar tendon load in different types of eccentric squats (Study III)

In Bromsman®, the loading patterns at the knee differed substantially from that using free weight. The patellar tendon force reaches its peaks much earlier during the eccentric squat in Bromsman®. In addition, the peak patellar tendon force, as well as the mean force, is substantially higher in Bromsman®, which was expected due to the higher level of voluntary effort. The load on the knee during the free weight tests was about 80% on the decline board and 60% on the horizontal surface of that using Bromsman®, i.e. maximal voluntary effort. These percentages could be somewhat overestimated since bilateral exercises have been shown to produce less strength than adding the unilateral strengths together (30)76).In this context, it could also be remarked that this study was done on relatively fit subjects, for whom a smaller "bilateral deficit" might be expected. The comparison chosen to pursue here was based on the clinical usage of the tests and encompassed free weight on a decline board and Bromsman® on horizontal surface. The difference in patellar tendon and mean force between these two tests averaged approximately 30% in favor of Bromsman®. Due to the generally smaller angular displacements in Bromsman®, the calculated mechanical work at the knee was similar in both tests, despite the higher levels of moment and force in Bromsman®.
The differences demonstrated, both with testing on a decline board and with the new device, Bromsman®, could serve as potential factors to be highlighted when designing and interpreting studies comparing different rehabilitation regimes applied on persons with patellar tendinopathy.

Relevant reliability data for eccentric strength performance during squats are lacking. Test-retest reliability of single-joint isokinetic strength assessment, such as peak knee extension torque, tends to be higher (3, 82) with no major differences between concentric and eccentric actions (83). A larger within-subject variation is to be expected for a multi-joint movement. However, strength performance in a multi-joint movement, such as squat, appears to be more valid from a functional point view.

So, different modalities of the eccentric squat exercise result in different loading patterns on the patellar tendon. The question is what the optimal loading stimulus could be. Evidently, loading of a tendon performed with progressively increased stress under well-controlled conditions leads to improvements of the tendon properties and function (92, 95, 101)(86, 100) see Figure 9.

Figure 9. The pathological and healthy strategy management for patellar tendinopathy



Extrapolating results and loading recommendations into a rehabilitation context is, however, not easy. Calculating patellar tendon force, either via inverse dynamics, as here, or via tendon elongation in static positions, as in the study by Kongsgaard et al. (2006) evidently suffers from several limitations (cf. Methods). Also studying a healthy material, as in both the studies mentioned, is a different situation from applying the tests on persons with tendinopathy, where pain decides to a large extent both loads and movement. Still, studies like this one, offer some insight into the mechanical loading of the knee during various types of clinically used tests. This in turn, provides a more differentiated basis for comparative clinical studies to be made (cf. below).

Eccentric treatment for patellar tendinopathy- a prospective randomized study of two rehabilitation protocols (Study IV)

Eccentric muscle activity, i.e. an activated muscle undergoing lengthening, is an integral part of our athlete's movement repertoire. The function of such an action is to resist an imposed load and to control an ongoing movement. The maximal force produced by a muscle during an eccentric action exceeds that of a concentric, shortening action. This basic knowledge has promoted eccentric actions as an essential part of training programs to improve neuromuscular performance in sports as well as in rehabilitation (1, 2, 65). Even if there is not a complete consensus in the literature, there are a number of studies reporting superiority of eccentric training regimes in improving muscle strength and volume (44, 82). In rehabilitation, evidence is accumulating indicating a beneficial effect of eccentric exercises for tendinopathies of the patellar tendon (18, 20, 87) and Achilles tendon (8, 85).

The present study showed that athletes with patellar tendinopathy improved with both the tested eccentric rehabilitation protocols; one with overload in Bromsman® (Group B) as well as the other on a decline board according to Curwin (Group C) .The groups showed similar trends in the VISA-P score over the treatment period, with no significant difference in the improvement. A recent study comparing eccentric treatment with surgical intervention (11), observed an improvement in mean VISA-P score for the eccentric treatment group from approximately 30 to 50 points after 12 weeks of treatment. This magnitude of improvement is consistent with our results (see Figure.8). In further agreement, Young et al. 2005 observed an improvement in VISA-P score from approximately 62 to 78 points for a 12-week period of eccentric treatment on a decline board. Interestingly, the improvement in VISA-P score is similar for all three studies, even though the baseline mean differs substantially.

The original Australian article (97) found that the control populations of volunteers from the university population and sports clinics patients without jumper's knee had a mean VISA-P score of > 90. However, in study I we found a lower mean score (81-83) in a non-symptomatic population of healthy students. Therefore, there is no clear cut-off value for normality for VISA-P scores, at least not in various at risk non-symptomatic populations. Data in the present study indicates that if a VISA–P score calculates more than ≈ 75 points, the symptoms may be considered as insignificant. In this study, 82% of the Bromsman® group and 44% of the decline group could be considered non-symptomatic at the end point of the study (12 weeks). There was no significant reason for this difference, which may be partly due to lower mean at baseline for group C.

The isokinetic strength tests illustrated that both quadriceps and hamstrings of the injured leg were weaker at both 90°/s and 240°/s for both groups. At the slower speed both groups increased at the second test occasion, but at 240°/s only Group B showed an increase for both legs. Since Group B trained bilaterally this was not an extraordinary result. It can be speculated that overload eccentric training may have a positive effect on high-speed concentric strength. The limitations of the isokinetic testing device are known, especially concerning the ability to achieve higher speeds. It is nevertheless considered reliable.

Of the jump tests, only the results for one–leg triple jump improved. This could be an effect of the supplementary stability training for the trunk and foot, since the triple jump put higher demand on the stability and balance compared to a One-leg jump. The lack of improvement in the other jump tests is in agreement with the findings of Bahr (11), albeit measured at different times after the treatment.

Even if the eccentric descending phase in Group B was performed on two legs, both the mean and peak force in the tendon during a single maximal squat was higher, than for one-legged descents (study III) in Group C. The weekly number of maximal eccentric descents was 24 two-legged in the Bromsman® device, and 315 one-legged (3 x 15 twice a week under supervision, the rest as home exercise) in Group C. Considering the repetitions and the total weekly mean force on the patellar tendon during the treatment (study III), the weekly load in Group C was approximately 10 times higher than in Group B. In spite of this, both groups apparently improved at a similar pace (Figure 8). Hence, the dosage of maximal eccentric challenge on the tendon may be quite different, but still produce similar subjective improvements. Thus, the optimal dose for pain decrease in rehabilitation of patellar tendinopathy, when using eccentric exercises, remains unclear (94, 95).

As a pattern, the Group B scored low on VAS for anterior knee pain at the beginning of warming up, but the score decreased during the training session. In most cases, the patients experienced muscle soreness between 1-3 days after training, impressively more in group B. In Group C, there was no regularity of the knee pain, and muscle soreness was less pronounced. However, the muscle soreness was not systematically registered.

The overload descending phase in Bromsman®, resulted in higher peak force on the injured patellar tendon (Frohm et al submitted), and may therefore imply a concern of possible side effects. Our attention during the study was directed towards worsening of the patellar tendinopathy pain with a theoretical possibility of partial or total rupture, back pain or headaches. However, neither the present study, nor earlier clinical experience, revealed any of these or other side effects during the study period. One explanation for the safety of this device may be that the maximal eccentric descent is two-legged and thereby possibly better patient-controlled. Also, the pain-monitoring model (90, 91) in both groups of the present study, apparently seems to be a good tool for guidance during rehabilitation exercises. Thus, we conclude that the use of the new over-load training device (Bromsman®) is safe and effective for rehabilitation of patients with the diagnosis patellar tendinopathy.

As a pattern, the Group B scored low on VAS from the knee at the beginning of warming up, but the score decreased during the training period. In most cases, the patients experienced muscle soreness between 1-3 days after training. In Group C, there was no regularity of the knee pain, and muscle soreness was less pronounced.

CONCLUSIONS

The results of the present study are:

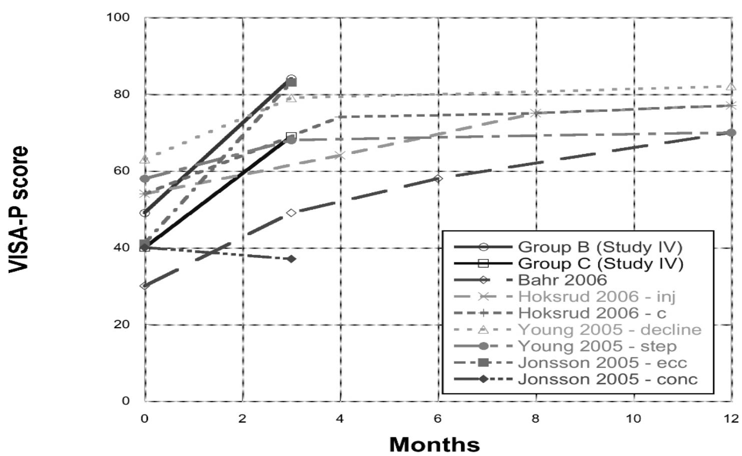
- The translated and culturally adapted Swedish version of the original Australian VISA-P score had satisfactory test-retest reliability when used to evaluate symptoms, tests of function and ability to participate in sports for patients with patellar tendinopathy.
- The new eccentric overload training device Bromsman® provides a safe way to apply eccentric overload and give valid measurements of velocity and vertical force. There was no significant difference between the test and retest in strength testing. Since the machine has variable velocity and provides a valid visual feedback of the load distribution, it is also useful for technique training.
- The load on the patellar tendon was higher (60-80%) in Bromsman® than in Free weight although the eccentric work was similar, due to the deeper squat in free weight. Result for the decline board vs. flat surface: Larger tendon load (25-30%) on decline compared to flat in free weight but not in Bromsman®.
- A prospective randomized study of patients with patellar tendinopathy showed successful short-term results with two eccentric rehabilitation protocols. Two-legged eccentric overload training twice per week, using the new device (Bromsman®), produced improvements comparable to daily eccentric one-legged training using a decline board. Both protocols were safe for the patients.

FUTURE PERSPECTIVES

There is an ongoing paradigm shift in the management of patellar tendinopathy. This has earlier included mostly rest, continues activity and often surgery. Today's management is more directed towards early intervention with a controlled exercise program. Eccentric training was already introduced by Stanish and Curwin 1984 (27, 87). This study has shown this to be a successful short-term alternative in treating this difficult condition. However, there are still questions around the dosage (e.g. load, repetitions and recovery time) the rehabilitation and how much load should be used to reach optimal effect. If the training includes too much load and increases too fast there may be some deleterious effects (figure 9). Also, the time for allowing the athletes safe return to sport after rehabilitation of patellar tendinopathy is still not well known. The present mostly used surgical technique, with excision and closing the tendon leads to long-term rehabilitation. The new longitudinal tenotomy technique may induce revascularization and denervation and possibly quicker return to sport. Recovery after surgery takes a long time regardless of surgical technique. This fact makes it even more important to further develop the current exercise protocols. The routine treatment should be based on evidence based exercise science, and preferably the patient should also be able to carry out the training independently, e.g. home exercises.

Even if eccentric muscle-tendon rehabilitation exercise remains to be one of the cornerstones in the treatment of tendinopathies(91) a few novel treatment regimes for tendinopathies have recently been suggested. Alfredson and co-workers have described a treatment regime with sclerosing injections into remain around the tendinopathy, apparently being most successful for mid-portion Achilles tendinopathy (5, 7), but also promising for tendinopathies at the elbow (103) and the knee (43). However, the latter study as well as a recent study comparing surgical treatment with eccentric training (11), showed short-term (< 3 months) improvements in the VISA-P score at a similar pace as measured in the present study (Figure 10).

Figure 10**.** The evolution with time of the mean VISA-P scores in the various treatments (various forms of excentric training, sclerosing injections, surgery) of patients with patellar tendinopathy reported in four other recently puplished studies (REF Young et al 2005, Jonsson et al 2005, Hoksrud 2006, Bahr 2006) including study IV in this thesis. Except the concentric training group in the study of Jonsson et al (2005), all populations increased their VISA-P score during the 3 first months of treatment in a similar fashion.



Therefore, at present, eccentric exercise rehabilitation can be regarded as successful as surgery. We therefore agree with both Alfredson & Öhberg (5, 7), and Bahr and co-workers (11), that the need for surgery for patellar tendinopathy may be challenged. However, new surgical techniques are presently being investigated, which may change this statement. Regardless of this, both rehabilitation protocols used in this thesis may be used as predictable and successful treatment outcomes for patellar tendinopathy, against which future treatment forms may be compared.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to all friends, here and there, from east to west, who have supported me during my years of work with my thesis. You all are in my thoughts – **THANK YOU!**

Tönu Saartok	My supervisor who tried to introduce me into research already in the 80, sorry some are slow starters. **Never** ending encouragement and support despite long distance.
Per Renström	My professor and “tennis” doctor who always has believed in me as clinician……and as a scientist?,.... who took me on the **big** trips with **big** athletes, both tennis and football.
Kjartan Halvorsen	My young …Norwegian supervisor who **ALWAYS** has been there on the floor with me, during looooong days and with great patience and supported me with biomechanical knowledge.

KI

Annette Heijne	Thank you for **always** being there with your listening sensible heart, sharing your inner thoughts, about life and science. Hope for many OSHO trips!!
Gunilla Sundblad Anna Jansson	Great supporting friendship and valuable scientific and other more important comments about life.
Marita Harringe Linda Swirtun Cecilia Fridén	Your support has been growing with the years, thank you.
Paul Ackerman Daniel Bring	“Tendon-and rat guys” ,thanks for your pep-talks.
Tommy Eriksson Ingrid Canholm Sven Jönhagen	Always sharing crazy ideas and interesting retreats.
Elisabeth Berg Gunnar Edman	Thank you for your professional statistical support and analysis.

Bosön, RF

Britta Kockum Agneta Enblad	Thanks for your supporting this “Bromsman® study”, your measurements but most important, you **never** failing friendship!
Pierre Johansson Leffe Larsson Ulf Arnesson	”MAQ and Bromsman®- grabbsen”, thanks for your inventions, new ideas and new philosophies.

Maja Uebel	What would life be without "communicology?"
Marianne Söderberg Lennart Karlberg	Thank you for starting this unique research process at the Swedish Sports Confederation and at Bosön .
Thanks to **ALL**	My wonderful colleagues at the Swedish Sports Confederation, National Sports Complex for support throughout the years RF-EIC, IFHS, Amica and people at Bosön and GIH.

GIH

Alf Thorstensson	My co-author, - thank you for letting me into your lab and sharing your scientific- and writing knowledge with me. Your support has been **very** valuable.
Anna Bjerkefors	Your bright thoughts and your big heart is **always** there.
Maria, Tony and Calle	Thanks you for always critical comments.
Karin Malmborg-Sørby	Your endless supporting friendship and brilliant encouragement is **always** there, "24 hours a day".
"Lena och Tor"	"Big sister" and House doctors that we always can call in the middle of the night.
Fire fighters	Thanks to all you guys at Lidingö fire station; for always being so willing to exercise and participate in our studies.
Patellar tendinopathy patients	Thank you for your participation in this thesis and giving me your time and knees.
Charlie	My wonderful husband and friend who believes in **endless** love and knows nothing is impossible, always supporting my crazy ideas and helps me when I need it most!
Filippa and Johanna	My flower buds in life! I hope I can nourish you like the flower needs the rain and that you two will slowly become two **wild** flowers listening to the most important in life, your inner voice.
Mamma	My big supporter who has had patience with me **ALL** life and always told I can do IT regardless to what! You have the **biggest** heart in the world!!

FINANCIAL SUPPORT

RF, CIF KI	I would like to express my sincere gratitude for the financial support and participation in the project.

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