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Clinical Biomechanics xxx (2006) xxx–xxx

CLINICAL BIOMECHANICS

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Decline eccentric squats increases patellar tendon loading compared to standard eccentric squats

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Received 9 January 2006; accepted 6 March 2006

Abstract

Background. Recent studies have shown excellent clinical results using eccentric squat training on a 25° decline board to treat patellar tendinopathy. It remains unknown why therapeutic management of patellar tendinopathy using decline eccentric squats offer superior clinical efficacy compared to standard horizontal eccentric squats. This study aimed to compare electromyography activity, patellar tendon strain and joint angle kinematics during standard and decline eccentric squats.

Methods. Thirteen subjects performed unilateral eccentric squats on flat—and a 25° decline surface. During the squats, electromyography activity was obtained in eight representative muscles. Also, ankle, knee and hip joint goniometry was obtained. Additionally, patellar tendon strain was measured in vivo using ultrasonography as subjects maintained a unilateral isometric 90° knee angle squat position on either flat or 25° decline surface.

Findings. Patellar tendon strain was significantly greater ($P < 0.05$) during the squat position on the decline surface compared to the standard surface. The stop angles of the ankle and hip joints were significantly smaller during the decline compared to the standard squats ($P < 0.001$, $P < 0.05$). Normalized mean electromyography amplitudes of the knee extensor muscles were significantly greater during the decline compared to the standard squats ($P < 0.05$). Hamstring and calf muscle mean electromyography did not differ, respectively, between standard and decline squats.

Interpretation. The use of a 25° decline board increases the load and the strain of the patellar tendon during unilateral eccentric squats. This finding likely explains previous reports of superior clinical efficacy of decline eccentric squats in the rehabilitative management of patellar tendinopathy.

Keywords: Patellar tendon strain; Knee extensor loading; Eccentric squat; Decline eccentric squat

1. Introduction

Patellar tendinopathy is an defiant overload injury of the patellar tendon that is highly prevalent among athletes performing jumps and fast decelerations (Kannus, 1997; Khan et al., 1998; Lian et al., 1996, 2003). The condition is often recurrent and limits athletic performance (Khan et al., 1998; Sandmeier and Renstrom, 1997). Even though the prevalence of patellar tendinopathy can be as high as 50% among elite jumping athletes (Lian et al., 2003), the scientific documentation regarding effective rehabilitation regimes and medical treatments is scare (Cook and Khan, 2001; Peers and Lysens, 2005; Sandmeier and Renstrom, 1997).

The conservative treatment of patellar tendinopathy is predominantly empirically and clinically founded, and there is a profound lack of randomized and standardized clinical studies (Cook and Khan, 2001; Peers and Lysens, 2005; Sandmeier and Renstrom, 1997). Nevertheless, the use of eccentric exercise training in the conservative

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doi:10.1016/j.clinbiomech.2006.03.004

management of patellar tendinopathy has shown promising clinical results. Jensen and Di Fabio (1989) demonstrated significant pain reduction following an 8-week eccentric exercise program. Likewise, Cannell et al. showed that 12 weeks of drops-squat exercises reduced the pain and increased the return to sport in patients with jumpers knee (Cannell et al., 2001). Most recently Jonsson and Alfredson (2005) has reported impressive clinical improvements in patients with patellar tendinopathy following 12 weeks of eccentric quadriceps training performed on a 25° decline board (a flat surface board large enough for both feet that is angled 25° from the surface of the floor).

In conjunction, two recent studies by Purdam et al. (2004) and Young et al. (2005) investigated the clinical effect of eccentric unilateral squat performed on a 25° decline board compared to that of a standard eccentric unilateral squat performed on flat surface in patellar tendinopathy patients. Although these studies suffer from the lack of randomization and poorly controlled exercise loading, the findings indicates that the decline eccentric squat protocol offers superior clinical outcomes compared to a standard eccentric squat protocol. Both studies hypothesized that the superior effectiveness of the decline eccentric squat protocol may be the result of the 25° decline board reducing calf muscle tension, allowing better isolation of the knee extensor mechanism (Purdam et al., 2004; Young et al., 2005). However, neither of the two studies has investigated the physiological or the biomechanical mechanisms potentially related to the two modes of eccentric squats. Therefore it remains unknown if decline eccentric squats yields greater load on the knee extensor mechanism and if this may explain why decline eccentric squats offer a superior clinical effect on patellar tendinopathy compared to eccentric standard squats.

Consequently, the purpose of this study was to compare electromyography activity (EMG), patellar tendon strain and joint angle kinematics during a standard and a decline eccentric squat protocol. It was hypothesized that the decline squat protocol would impose patellar tendon strain loading that was different from those of traditional squatting regimes.

2. Methods

2.1. Subjects

Seven men and six women volunteered to participate in the study. Males; body mass 80.8 (SEM 2.2) kg, height 185 (SEM 2) cm, age 26 (SEM 3) y. Females; body mass 66.2 (SEM 2.1) kg, height 172 (SEM 2) cm, age 26 (SEM 3) y. All subjects gave their informed consent to the procedure of the study. None of the subjects had any history of previous hip, knee or ankle injury and all subjects had a score >90 in the Victorian Institute of Sport Assessment (VISA) questionnaire for knee injury (Visentini et al., 1998). All subjects were moderately physically active (3–6 h sports activity pr. week). The study was approved by the local ethics committee in compliance with the Helsinki II declaration.

2.2. Squat procedure

One week prior to the experiment, all subjects underwent a complete series of familarization trails. Initially joint electrogoniometers (Penny & Gilles, G180, Biometrics, Gwent, UK) were positioned at the ankle, knee and hip joints of the dominant leg. Following the attachment of the electrogoniometers calibration samplings were obtained at 0° and 90° knee joint angle (0° = full extension). Thereafter, EMG electrodes were placed on eight representative muscles of the subject’s lower extremity (described in details below).

Following a 10 min warm up on a stationary bicycle subjects performed, in a randomized order, three unilateral standard squats and three unilateral squats on a 25° decline board with their dominant leg. All squats were performed in a movement range from complete knee extension to approximately 95° knee angle and back to extended knee. Subjects were instructed to complete each squat in approximately 5 s. Each squat was separated by a 2 min rest period. During the squat procedure subjects received visual feedback from the knee-angle goniometer via a portable goniometer-amplifier (Penny & Gilles, Biometrics, Gwent, UK) to ensure that a full range of motion (0° → 95° → 0° knee angle, extended knee = 0°) was achieved in each squat. Data were recorded in the descending/eccentric phase of the squat movement (0° → 95°).

2.3. EMG measurements

EMG signals were obtained during the performance of the standard eccentric unilateral squat and the unilateral eccentric squats performed on a 25° decline board with the subject’s dominant leg. After a careful preparation of the skin (shaving, abrasion and cleaning with alcohol) bipolar surface EMG electrodes (Medicotest A/S; M-00-S, Oelstykke, Denmark) were placed with a 1.8-cm inter-electrode distance on the medial portion of the vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), biceps femoris (BF), semitendinosus, (ST), gastrocnemius medialis (GM), soleus (SOL) and tibialis anterior (TA) muscles of the subjects dominant leg. The signals were lead to custom-built differential instrumentation amplifiers with a bandwidth of 10–10,000 Hz and a common mode rejection ratio >100 dB (Aagaard et al., 2000). After initial preparation it was checked that neither passive movements nor tapping the leg produced any visible artifact oscillations of the EMG signal.

2.4. Signal processing

Synchronous sampling of goniometer signals and EMG signals were performed at 1000 Hz analog-to-digital conversion rate using an external A/D converter (dt2801-A, Data Translation, Marlboro, MA, USA) (Aagaard et al., 2000). During the subsequent EMG analysis, all raw EMG signals were smoothed using a linear envelope (Aagaard et al., 2000), which consisted of digital high-pass filtering at a cutoff frequency of 5 Hz followed by full-wave rectification and subsequent low-pass filtering at a 10-Hz cutoff frequency. All filtering procedures were based upon fourth order, zero-lag Butterworth filters (Winter, 1990). The goniometer signals were converted to geometric joint angles by use of the calibration samplings. Mean EMG amplitude for each muscle was identified in the knee angle interval of 85°–90° and subsequently used for analysis. Start and stop angles for the ankle, knee and hip joint and the knee angle velocity were registered for the three decline and the three standard squat movements.

To compare individual muscle mean EMG signal amplitudes, mean EMG amplitudes were normalized (%) relative to the peak EMG amplitudes obtained during either of three maximal 4 s isometric contractions of the respective muscles i.e. knee extension, knee flexion, dorsal flexion and plantar flexion (Aagaard et al., 2000). Peak EMG amplitudes during the maximal isometric contractions were measured in a 60° knee angle for the knee extensors (VL, VM & RF), in a 45° knee angle for the knee flexors (ST & BF) and in a 0° knee angle and 0° ankle angle for the plantar and dorsiflexors (GM, SOL & TA). These respective joint angles were chosen since they approximately corresponds to the joint angles in which the respective muscles can develop the greatest torques (Horstmann et al., 1999; Kues et al., 1992; Narici et al., 1992).

The mean EMG amplitudes, joint angle movements and the mean angle velocity of the knee joint from the three decline and the three standard squats respectively were calculated and used in the statistical analysis.

2.5. Measurement of tendon elongation and calculation of tendon strain

An external marker (Micropore™ Surgical Tape, 1530-1, 3M™, Neuss, Germany) was applied transversely on the subjects skin approximately 2 cm distal to the patellar apex (Fig. 1A) (Reeves et al., 2003). Next, subjects were placed on a rigid chair with their legs hanging freely and relaxed in a 90° knee angle (Fig. 1A). Subsequently a 7.5 MHz linear array ultrasound transducer (Sonoline Sienne, Siemens, Issaquah, WA, USA) was positioned in the sagittal plane over the patellar tendon so that the patellar tendon apex and the proximal edge of the external marker shadow were visible in the ultrasound B-mode picture, and a B-mode ultrasound picture was captured and saved (Fig. 1A). Following this, subjects maintained a unilateral isometric 90° knee angle squat position, on either the flat or decline surface, whereupon a B-mode ultrasound picture was obtained and saved for analysis (Fig. 1B and C). Subjects randomly maintained the unilateral isometric 90° squat position on the flat or the decline surface. The patella tendon elongation was measured in an isometric setting since it was not possible to completely fixate the ultrasound transducer to the skin of the subjects during a dynamically performed squat movement. It is obvious that the isometric obtained strain values can only be an estimation of the patellar tendon strain values occurring during a dynamically performed eccentric squat since no vertical acceleration or deceleration of the body segment is present during the isometric squat position. However, the subjects of this study were instructed to perform the eccentric squat movements with a constant slow speed reducing the amount of vertical acceleration or deceleration of the body. Two ultrasound pictures were recorded in each isometric position and the mean of the two measurements of patellar tendon elongation for the specific position (flat or decline surface) was calculated and used for analysis. The distance from the patellar apex to the proximal edge of the external marker shadow was measured in each picture using Scion Imaging software (www.scioncorp.com) and patellar tendon elongation was subsequently calculated. All ultrasound pictures were blinded to the experimenter who performed the imaging analysis.

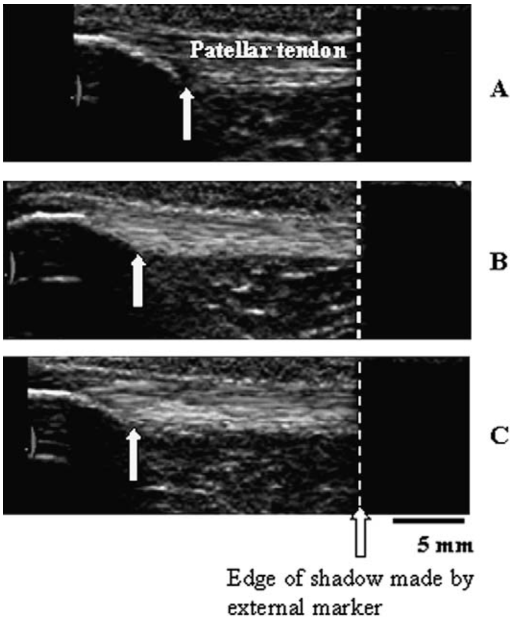

Fig. 1. Sagittal plane scans of the patella tendon at rest (A), during 90° isometric squat position on flat surface (B) and during 90° isometric squat position on decline surface (C) for one subject.

Initial patellar tendon length was assessed from sagittal-plane ultrasound images obtained with the knee hanging freely and relaxed in a 90° angle. Patellar tendon length was measured as the distance from the apex of patellar to the superior aspect of the tibial tuberosity (obtained by a single saggital ultrasound scan of the patellar tendon). Finally, patellar tendon strain was calculated as the ratio (%) of tendon elongation relative to initial length during the isometric squat position on either flat or decline surface.

The reliability of the patellar tendon strain measurement was assessed by measuring tendon length and elongation in identical squatting conditions on two separate days, in a sub sample of nine subjects. The patellar tendon elongation measurements taken on separate days by the same experimenter showed a correlation coefficient of $r = 0.89$ ($P < 0.001$) and a CV of 8.1%.

2.6. Statistical analysis

All values are presented as mean (standard error of the mean). Normality of data was determined by the Kolmogorov–Smirnov test of normality. Paired samples Student's *t*-tests were used to analyze for differences in patellar tendon strain, mean EMG amplitudes, joint angle movements and knee angle velocity during eccentric squats performed on flat and decline surface. All tests were carried out as two-tailed with a chosen level of significance of 0.05. The statistical analyses of the data were performed using the statistical software package GraphPad Prism® Version 4.01 (2004).

3. Results

3.1. Patellar tendon strain

During the performance of the decline unilateral isometric 90° knee angle squat position a patellar tendon strain of 9.4 (SEM 1.1) % was obtained (Fig. 2). Correspondingly a patellar tendon strain of 7.4 (SEM 0.8) % was obtained during the squat position on the flat surface (Fig. 2). As a result, patellar tendon strain was significantly greater ($P = 0.032$) during decline eccentric squatting than eccentric standard squatting.

3.2. Muscle activity

For the standard squats the normalized mean EMG amplitudes of the knee extensor muscles (VL, VM & RF) were 56 (SEM 6) %, 58 (SEM 6) % and 41 (SEM 5) % for the VL, VM and RF respectively. During the decline squats, normalized mean EMG amplitudes of the knee extensors were 65 (SEM 7) %, 68 (SEM 6) % and 66 (SEM 6) % for the VL, VM and RF respectively, which was significantly greater than that of the standard unilateral eccentric squat (Fig. 3) ($P = 0.048$, $P = 0.004$, $P = 0.001$ for VL, VM & RF respectively). There were no significant differences in the normalized mean EMG amplitudes of the triceps surae muscles (GM and SOL) between the decline squats and the squats performed on the flat surface (Fig. 4). Similarly normalized mean EMG amplitude of the biceps femoris did not differ between the standard and decline squat (21 (SEM 4) % and 23 (SEM 3) % respectively), and neither did the normalized mean EMG amplitude of the semitendinousus (9 (SEM 2) % and 8 (SEM 1) % respectively). Normalized mean EMG amplitude of the tibialis anterior was significantly greater for the standard squat (69 (SEM 8) %) compared to the decline squat (53 (SEM 7) %) ($P = 0.009$).

3.3. Joint kinematics

Joint movement characteristics for the standard and the decline squat are presented in Table 1. There were no differences in knee joint start or stop angle between the standard and the decline squat performance and hence no significant difference in knee joint range of motion (ROM).

The ankle joint start angle in the standard squat procedure was significantly more dorsiflexed ($P = 0.001$) than in the decline squat. Correspondingly, the ankle joint stop angle in the standard squat was significantly more dorsiflexed ($P = 0.001$) than in the decline squat. The ankle joint ROM was not significantly different between the decline and standard squat procedure.

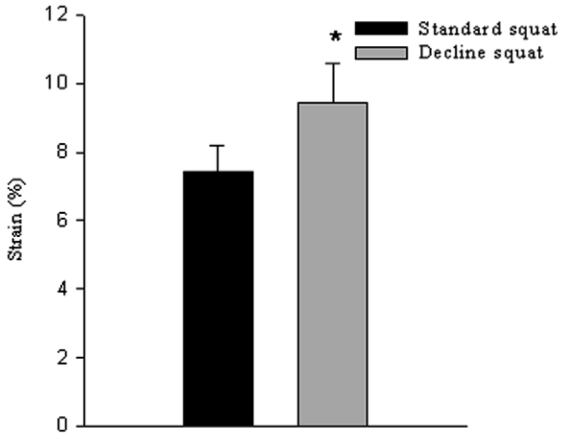

Fig. 2. Patella tendon strain measured during unilateral isometric 90° knee angle squat position on flat (standard) and on a 25° decline surface. Values are mean (SEM). *Significantly ($P = 0.03$) higher than strain on flat surface.

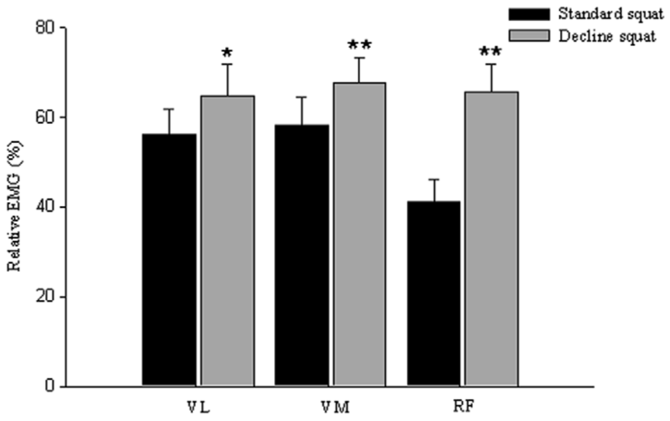

Fig. 3. Relative peak EMG of the vastus lateralis (VL), vastus medialis (VM) and the rectus femoris (RF) during the eccentric phase of unilateral squat performed on either flat (standard) or 25° decline surface. Values are mean (SEM). *Significantly higher peak EMG than standard squat ($P < 0.05$). **Significantly higher peak EMG than standard squat ($P < 0.001$).

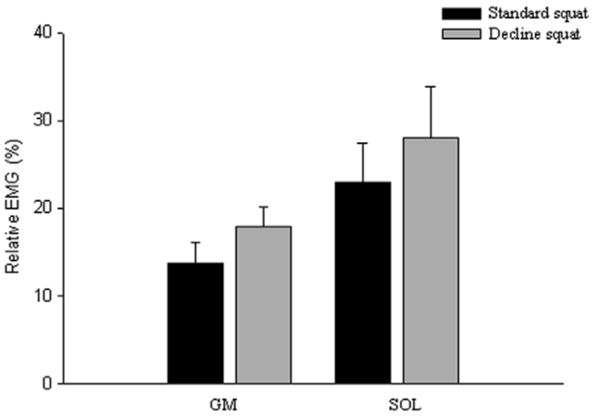

Fig. 4. Relative peak EMG of the gastrocnemius medialis (GM) and the soleus (SOL) during the eccentric/descending phase of unilateral squat performed on either flat (standard) or a 25° decline surface. Values are mean (SEM).

Table 1
Joint kinematics

	Standard squat ($n = 13$)	Decline squat ($n = 13$)
Knee joint start angle (°)	1 (SEM 1)	2 (SEM 1)
Knee joint stop angle (°)	92 (SEM 1)	93 (SEM 1)
Knee joint ROM (°)	91 (SEM 1)	91 (SEM 1)
Ankle joint start angle (°)	92 (SEM 1)*	76 (SEM 2)
Ankle joint stop angle (°)	114 (SEM 1)*	99 (SEM 1)
Ankle joint ROM (°)	22 (SEM 1)	23 (SEM 2)
Hip joint start angle (°)	8 (SEM 2)	11 (SEM 2)**
Hip joint stop angle (°)	91 (SEM 7)***	83 (SEM 6)
Hip joint ROM (°)	83 (SEM 6)***	72 (SEM 5)
Knee joint velocity (°/s)	30 (SEM 2)	31 (SEM 3)

Joint motion characteristics for the eccentric squat movement on flat (standard) and decline surface respectively. Values are mean (SEM). ROM = range of motion. Knee, hip: 0° = full knee extension, neutral hip position (standing). Ankle: 90° = neutral position (standing).

* Significantly greater than decline ($P < 0.001$).

** Significantly greater than standard ($P < 0.05$).

*** Significantly greater than decline ($P < 0.05$).

Hip joint start angle was significantly more flexed in the decline procedure compared to the standard squat procedure ($P = 0.038$). The hip joint stop angle was significantly more flexed during the standard compared to the decline squats ($P = 0.032$) (Table 1). The hip joint ROM was significantly greater during the standard squat compared to the decline squat ($P = 0.031$).

Finally, there was no difference in the mean knee joint angular velocity in the two squat procedures (Table 1).

4. Discussion

The primary finding of the present study was that patellar tendon strain was significantly greater (+27%) ($P < 0.05$) during eccentric squatting performed on a 25° decline board compared to eccentric squatting performed on a flat surface. Also, the addition of a 25° decline board increased knee extensor EMG significantly compared to the knee extensor EMG obtained during the squatting on flat surface.

EMG measurements have previously been extensively used to assess the neuromuscular activity of selected muscles in specific exercises or motor skills. It has previously been shown that contraction speed and type of contraction have a profound influence on the neuromuscular activation of the quadriceps muscle since neuromuscular inhibition is pronounced during maximal eccentric contractions, especially during fast eccentric contractions (Aagaard et al., 2000; Westing et al., 1990). In the present study however no differences in either contraction type nor movement velocity existed between the standard and the decline squats. Thus the finding of elevated EMG amplitudes of the knee extensors during the decline squats compared to the standard squats strongly suggests that force exerted by the knee extensor muscles was greater during decline squatting compared to standard horizontal squatting.

Numerous studies have reported a linear relationship to exist between tendon force and tendon strain using both in vitro tensile tests and in vivo ultrasonography methods (Hansen et al., 2003; Kannus, 1997; Maganaris and Paul, 1999; Magnusson et al., 2003; Reeves et al., 2003). During the last decade the ultrasonography method has been increasingly used to determine mechanical properties of human tendons. However, data on the patellar tendon has been limited. Reeves et al. (2003) reported maximal tendon strain values for the patellar tendon in the range of 5.9–10.3%, using an ultrasonography strain measurement method similar to that of the present study. Additionally, Hansen et al. (2006) have reported patellar tendon strain values of 6.8% using a somewhat different ultrasonography method taking tibial movement during the knee extension contraction into account. Thus, even though the values of patellar tendon strain reported by Reeves et al. (2003) and Hansen et al. (2006) were obtained during maximal isometric contractions (MVC), the patellar tendon strain values of the present study lies well within the range of the values reported in these studies (Hansen et al., 2006; Reeves et al., 2003). Therefore, the significantly higher patellar tendon strain found in the present study during the decline squats compared to the standard squats is consistent with the existence of an increased force production of the knee extensors, and a correspondingly greater strain and loading of the patellar tendon during the decline squats compared to the standard squats.

In the study by Purdam et al. (2004) they hypothesized that the use of a 25° decline board during the performance of eccentric unilateral squats would decrease force generation of the calf muscles and thereby increase the load imposed upon the knee extensor mechanism including the patellar tendon. In the present study, both the EMG and the patellar strain measurements concurrently confirms a rise in strain loading of the knee extensor mechanism when using a 25° decline board during eccentric squats. However, in the present study no significant difference in calf muscle activity between the standard and decline squat was found (Fig. 4). Contrarily, the activity of the calf muscles tended to be greater during the decline squats compared to the standard squats (Fig. 4). Thus, the increased load placed upon the knee extensor muscles, and therefore the patellar tendon, does not seem to be explained by a decreased calf muscle activity as proposed by Purdam et al. (2004). Instead, the present study found that the use of a 25° decline board during the unilateral eccentric squat performance significantly changed the joint stop angles of the ankle and hip joints (Table 1). It is likely that the less flexed ankle and hip joints observed during the decline squat compared to the standard squat will displace the body's center of mass further behind the knee joint axis which would increase the knee extensor moment and thereby the load on the patellar tendon (Fig. 5).

Altogether the greater load imposed upon the knee extensor mechanism during the decline squat may indeed, as previously hypothesized by Purdam et al. (2004), explain recent findings that decline eccentric squat exercises are more effective than standard eccentric squat exercises in the conservative treatment of patellar tendinopathy (Purdam et al., 2004; Young et al., 2005). Previous studies have consistently demonstrated that both healthy and injured tendinous tissue respond to controlled progressive stress, resulting in progressive increase in tensile strength (Birch et al., 1999; Buchanan and Marsh, 2001; Curwin et al., 1988; Smith et al., 2002; Sommer, 1987; Tipton et al., 1970, 1975, 1986; Viidik, 1969; Woo et al., 1982). Thus the question is if it is the magnitude of loading (i.e. absolute force), and thereby strain, that is decisive for a successful outcome of the conservative management, and whether using the highest load possible will be the most optimal approach to optimize the clinical outcome. Additionally, force is only one parameter that contributes to the total magnitude of load, since the number of repetitions and sets and resting time may also play a role in the total load put upon the tendinous structures. Therefore, future studies are needed in order to investigate the effect of various loads and accordingly if the effect of more heavy types of resistance training in the treatment of patellar tendinopathy will be the most successful conservative treatment.

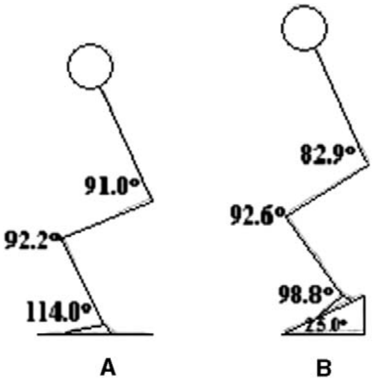

Fig. 5. Drawing of segments and joint angles at the end position of a standard (A) and a decline squat (B) corresponding to the angles reported in Table 1.

5. Conclusion

The results of the present study show that the appliance of a 25° decline board during the performance of eccentric unilateral squats significantly increases strain loading in the patellar tendon. The increased strain load may explain previous study reports of a better superior clinical outcome of decline eccentric squats compared with standard eccentric squats in patients with patellar tendinopathy. Further studies are required to answer if a successful clinical outcome in the conservative management of patellar tendinopathy is solely a matter of the magnitude of load placed upon the knee extensor mechanism.

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