A BIOMECHANICAL INVESTIGATION OF A SPANISH SQUAT: THE EFFECT OF TRUNK INCLINATION AND LOAD ON QUADRICEPS ACTIVITY AND PATELLAR TENDON FORCE

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The Spanish squat targets the knee extensor muscles and has been suggested to be an appropriate rehabilitation exercise for patellar tendinopathy. This study provides novel empirical data on the effect of trunk inclination and load on quadricep muscle activity and patellar tendon load while performing the Spanish squat. The findings of this study informs on the progression and regression of the Spanish Squat and provides evidence to support the application of the Spanish squat in progressive tendon loading strategies in the treatment of PT.

KEYWORDS: Patellar Tendinopathy, Spanish squat, quadriceps, patella tendon force

INTRODUCTION: Patellar Tendinopathy (PT) is a chronic condition that is characterised by pain localised to the inferior pole of the patellar tendon (Malliaras et al., 2013). While PT has a multifactorial aetiology, the development of PT is linked with the mechanical overload of the patellar tendon via the repetitive and accumulative storing and release of energy in a spring-like manner, which is associated with activities such as jumping, landing, pivoting, and cutting movements (Rutland et al., 2010).

Over the last two decades, conservative rehabilitation strategies to treat PT have concentrated on the application of eccentric exercise due to the high musculotendinous loading placed on the quadriceps muscles and patellar tendon. For instance, patellar tendon force while performing the single leg decline squat (SLDS) can progress from 6 to 8x bodyweight as knee flexion angles increase from 60° to 90° (Zwerver et al. 2007). However, since the SLDS can often provoke symptoms, this exercise is now utilised as a clinical test to isolate and to monitor the patellar tendon's response to load (Agergaard et al., 2021; Millar et al., 2021). Recently, the use of the SLDS combined with sport specific exercises has demonstrated inferior VISA-P scores and a lower rate on return to sport when compared to a progressive tendon loading exercise rehabilitation program that consisted of isometric, isotonic, energy storage, and sport specific exercises (Breda et al., 2021).

Alternatively, the “Spanish squat” (SpS) is a bilateral quadriceps exercise that has been shown to reduce pain and improve function in people presenting with PT (Rio et al., 2019). In addition, the SpS can trigger an analgesic response through isometric contractions that makes it a popular in-season exercise for travelling athletes suffering with PT (Rio et al., 2019). Knowledge on the biomechanical demands of the SpS is limited to a single study. Based on the findings of Needham et al. (2019) modifying SpS trunk angle results in kinetic changes that implies a progression and regression to the SpS. For example, a vertical trunk posture produces greater knee extensor moment and mechanical work of the quadriceps during both eccentric and concentric contractions compared to a 45º trunk inclination. As no research exists, this preliminary study aims to examine the effect of additional load and different trunk inclinations while performing the SpS on patellar tendon load. This information could further inform practitioners on load management strategies when utilising the SpS in the treatment of PT.

METHODS: Five physically active males with no pain or known musculoskeletal disorder participated in this study (mean age 23 years, height 1.76 m, mass 76 kg). Ethical approval was granted by the University Research Ethics. All participants provided written informed consent. An 18-camera optoelectronic motion capture system (Vicon, Oxford, UK) was used to collect marker trajectory data at 100 Hz. Reflective markers were attached on the thorax, pelvis, and lower limbs using double-sided adhesive tape in accordance with the Istituto Ortopedico Rizzoli models (Leardini et al., 2007; Leardini et al. 2011). Force plate data were collected at 2000 Hz using two AMTI force plates (Advanced Mechanical Technology Inc MA, USA). A wireless surface electromyography (sEMG) system (Trigno, Delsys Inc., Boston, MA) recorded quadriceps muscle activity at 2000 Hz. Trigno sensors were placed on rectus femoris, vastus lateralis, and vastus medialis on the left and right legs in accordance with SENIAM guidelines. The bilateral SpS is performed with assistance of rigid straps placed posteriorly below the knee joint anchored to a rigid frame. With a vertical shank posture, participants performed the SpS to an angle of 90° of knee flexion at two trunk inclinations 45° (SpS45) and 90° (SpS90). The SpS was also performed with a 90° trunk angle while holding a 20 kg dumbbell in the upper sternum i.e., Goblet Squat position (SpS90L). For the bodyweight squat the feet were placed shoulder width apart and were angled approximately at 20° laterally; participants were asked to squat to an angle of 90° of knee flexion. Knee joint angle was standardised using real-time analysis of a three-point planar angle between markers on the greater trochanter, lateral epicondyle of the femur and lateral malleolus. Trunk angle was standardised to the horizontal using real-time analysis of a four-point planar projection angle between the 2nd thoracic vertebral spinous process and 5th lumbar vertebral spinous process relative to two virtual markers along the anterior-posterior axis of the laboratory. A metronome was used to standardise a three second count for the eccentric and concentric phase. The raw kinetic and kinematics data were exported to Visual3D (C-Motion, Inc, Germantown, MD) for processing. Force and marker coordinate data were filtered using a fourth-order, low-pass Butterworth filter using cut-off frequencies of 25 Hz and 6 Hz, respectively. To remove any offset, EMG data were zeroed before a band-pass filter with a high-pass filter of 20 Hz and a low-pass filter of 500 Hz was applied (Richards et al., 2008). The integrated EMG (i-sEMG) was estimated on full-rectified data, which represents the total mechanical work of the quadriceps over the entire movement. Patellar tendon load was determined by dividing the knee extensor moment by the estimated patellar tendon moment arm. The patellar tendon moment arm was quantified as a function of the sagittal plane knee angle for each participant, by fitting a 2nd order polynomial curve to the data provided by Herzog & Read (1993). Three trails were collected for each squat condition.

RESULTS: An incremental increase in mean i-sEMG across all quadricep muscles (Figure 1A) and knee extensor moment (Figure 1B) was observed during the eccentric and concentric phase for SpS45, SpS90 and SpS90L, respectively, in comparison to the BW squat.

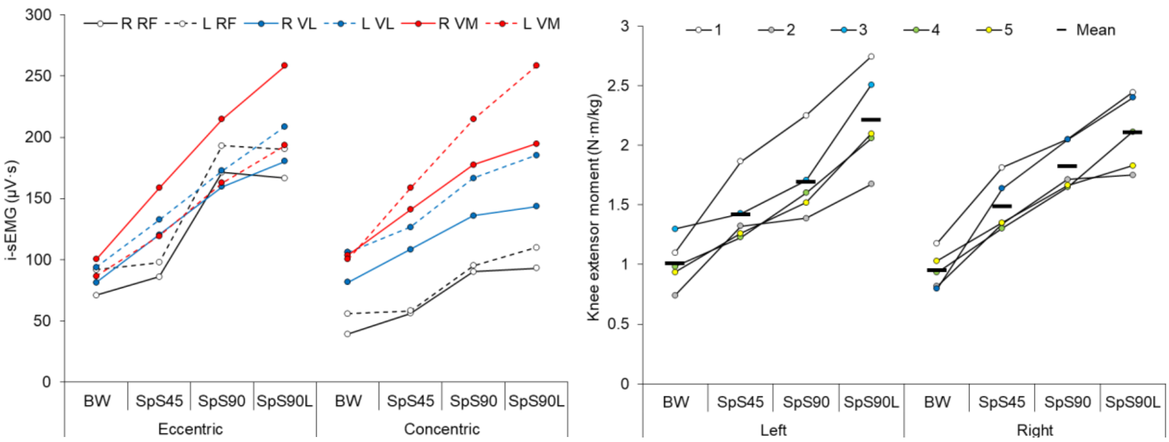

Figure 1: A-Mean i-sEMG for rectus femoris (RF white circle), vastus lateralis (VL blue circle) and vastus medialis (VM red circle) during the eccentric and concentric phase across the BW, SpS45, SpS90 and SpS90L for the right leg (solid line) and left leg (dashed line). B–Mean and individual participant peak knee extensor moment data for the right and left leg.

An incremental increase in peak patellar tendon load and force was observed for the SpS45, SpS90 and SpS90L condition on the left and right limbs, respectively, in comparison to the BW squat (Figure 2A/B).

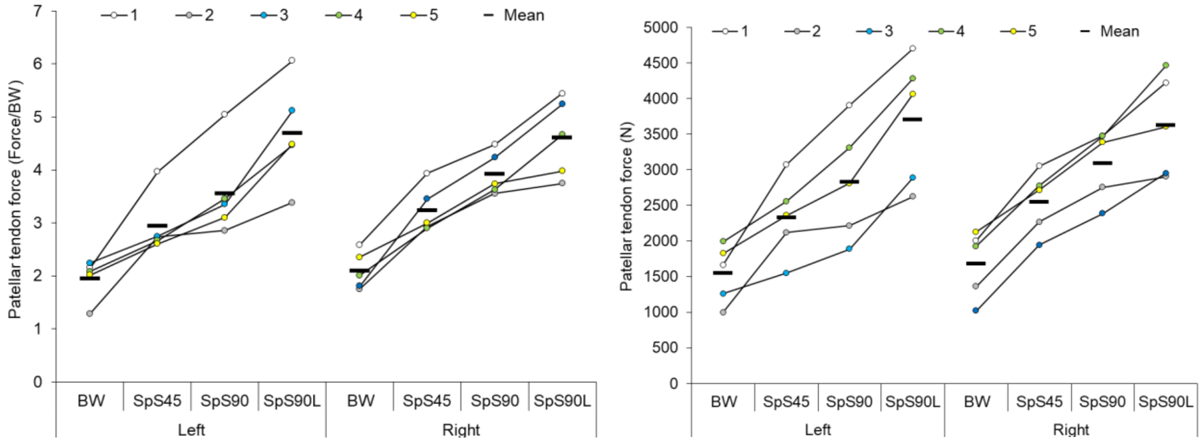

Figure 2: Mean (black rectangles)/individual participant peak patellar tendon load and force for the right and left leg across the BW, SpS45, SpS90 and SpS90L (A–force/bodyweight B–force).

DISCUSSION: Current research on rehabilitation strategies to treat PT emphasise the use of exercises that maximise the mechanical work of the quadriceps. This can be achieved using both weightbearing and non-weightbearing exercises of varying contraction types between 0-90 degrees of knee flexion, although exercise prescription for individuals with PT will be dependent on clinical symptoms (Breda et al., 2021; Malliaras et al., 2013, 2015; Rio et al., 2015, 2019). In the current study, increased quadriceps muscle activity in the SpS90 condition compared with the SpS45 and BW squat condition (Figure 1A) confirms the findings of a previous study (Needham et al. 2019). Furthermore, this study highlights an increase in the biomechanical demands while performing the Spanish squat by the inclusion of additional load (20 kg dumbbell - SpS90L condition), which resulted in a greater knee extensor moment and quadriceps muscle activity in comparison to the SpS90 condition. This novel observation provides further evidence to inform practitioners on the progressive loading strategy when utilising the Spanish squat. Another important observation in the current study for practitioners to consider is on the varying degree of asymmetry between the left and right side across individual participants, which has been noted previously (Needham et al. 2019). Since biomechanical measures can identify asymmetries that were not visually evident, further analysis of kinematic angle data may provide an understanding on compensatory movements associated with performing the Spanish squat with a preferred limb.
The current study is also the first to quantify patellar tendon load while performing the Spanish squat under isotonic conditions, providing findings that reinforce the interpretation of knee extensor moment and quadriceps muscle activity data. Interestingly, peak patellar tendon load during the SpS90L condition was lower (individual participants ranging between 3-6x BW) compared to reported findings on the SLDS (mean peak 8x BW) (Zwerver et al. 2007). Lower patellar tendon load during the continuum of Spanish squat progressions could justify the use of this exercise in the initial stages of a rehabilitation program for individuals with irritable patellar tendon pain, or for in-season athletes who need to manage patellar tendon load. In addition, greater patellar tendon load reported for the SLDS compared to a bilateral squat could help explain the inferior outcomes with the SLDS over progressive loading programs that implemented exercises that had similar biomechanical postures to the Spanish squat (Breda et al., 2021). Reduced patellar tendon load while performing the Spanish squat may also explain why superior in-season outcomes on pain reduction were identified using the Spanish squat (Rio et al., 2019) in comparison to the SLDS (Visnes et al., 2006). However, caution may be warranted on the above interpretation since Zwerver et al. (2007) and the current study used different calculation methods to estimate patellar tendon load. In addition, Zwerver et al. (2007) did not state the duration of the descent and ascent phase. Therefore, differences regarding loading rate may explain differences in peak patellar tendon loads between the exercises.

A low sample size and that the knee extensor moment did not account for co-contraction of the knee flexor musculature are limitations of the current study.

CONCLUSION: The findings of this study inform the nature of the progression and regression of the Spanish Squat and provides evidence to support the application of the Spanish squat in progressive tendon loading strategies in the treatment of PT.

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