Acute effect of Prone Trunk-Extension on the biomechanical properties of lumbar and dorsal lower limb muscles

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Research Article

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Abstract

**Background:** Fascia attaches to and wraps around muscles throughout the body to expand the range of action and redistribute force transmission. However, specific data on the myofascial tensegrity network of the lumbar and lower limbs are lacking.

**Objective:** This study investigated the effect of the prone trunk extension test (PTE) on muscle stiffness in the lower limbs, explored the optimal angle for lumbar muscle training, and analyzed the mechanical conduction patterns of the lumbar and lower limb muscles in the myofascial tension network.

**Design:** This was a laboratory-based experimental study.

**Method:** Twenty healthy young females were recruited for this study, and the stiffness of the erector spinae (ES), semitendinosus (ST), biceps femoris (BF), the medial head of the gastrocnemius (MG), and lateral head of the gastrocnemius (LG) was measured by MyotonPRO under four angular PTE conditions (0° horizontal position, 10°, 20°, and 30°).

**Results:** With the increasing angle, the stiffness of ES decreased gradually, while ST and BF increased first and then decreased. The stiffness of MG and LG increased first and then decreased and then increased. There was a negative correlation between ES stiffness variation and ST (r=-0.819 to -0.728, p<0.001), BF (r=-0.620 to -0.527, p<0.05), MG (r=-0.788 to -0.611, p<0.01), and LG (r=-0.616 to -0.450, p<0.05).

**Conclusions:** Horizontal PTE maximizes activation of ES. There is a tension transfer between ES, hamstrings, and gastrocnemius, mainly between ST and LG. The study provides data to explore the myofascial tensegrity network between the lumbar and lower limb muscles.

1. Introduction

Previous theories of muscle anatomy referred to the "muscle isolation theory," in which skeletal muscle was considered to exist independently, ignoring its superior and inferior connections (Edith M. Arnold et al., 2010; Thomas W. Myers, 2014). Numerous studies suggest that myofascial continuity (MC) exists between the limbs and trunk. Myofascia is composed of muscles and a network of connective tissue that surrounds them throughout the body. MC (Thomas W. Myers, 2014) plays an important role in transferring loads and coordinating movements between body regions. The presence of fascial chains demonstrates the existence of tensegrity networks. Wilke et al (Jan Wilke et al., 2016) showed in a systematic evaluation that the existence of myofascial chains as proposed by Myers (Thomas W. Myers, 2014) was well supported by evidence. Joshi et al (Durga Girish Joshi et al., 2018) found that distal release of the plantar fascia and suboccipital fascia increased hamstring flexibility, confirming the "anatomical continuity" from the head and neck to the plantar aspect of the foot in practical treatment. Stecco et al (Antonio Stecco et al., 2009) found "anatomical continuity" between the muscles and fascia involved in upper extremity flexion movements, verifying the constant propagation of myofascial tension.
in a specific direction. However, there is still a lack of specific data supporting the tensegrity network of fascial tension in the trunk and lower limbs, thus necessitating clinical trials on the overall network of tension in the human trunk and lower limbs.

The proposed superficial back line (SBL) fascial chain (Thomas W. Myers, 2014) indicates the presence of continuity between the lumbosacral and lower extremities. Weisman's (Martin H. S. Weisman et al., 2014) team concluded that there was a significant correlation between muscle activation along the SBL. We previously study (B. Chen et al., 2021) demonstrated a strong correlation between lumbar tissues and lower limb muscles by isometric plantar-flexion with different resistances, so we speculate that changes in lumbar muscle strength may also have an inverse effect on lower limb muscles. The lumbar muscles are one of the most important structures for maintaining lumbar spine stability, and the ES is the most important trunk extensor muscle, whose main role is to maintain an upright posture and to assist lateral flexion, rotation, and lumbar extension movements (Daniel SANCHEZ-ZURIAGA et al., 2010). Weak ES may lead to a malfunction of the vertical force line of the spine, which eventually leads to abnormal loading of the spine, which may lead to low back pain. Strengthening the muscles of the low back helps maintain and enhance the stability of the lumbar spine, thus delaying the process of lumbar strain degeneration, which can effectively prevent acute and chronic lumbar injuries and low back pain. (Colado JC et al., 2011) PTE is a recognized isometric stabilization exercise. Isometric contraction maximizes back muscle recruitment. Lumbar stiffness (Stuart McGill, 2002) both eliminates joint micromotion to avoid pain and tissue degeneration and also enhances limb athleticism and speed. Studies have shown a strong linear relationship between muscle stiffness and strength (Thomas Lapole et al., 2015; Yasuhide Yoshitake et al., 2014), and increased muscle activation increases short-range muscle stiffness (Friedl De Groote et al., 2017), the stiffness caused by deformation of the attached actin-myosin cross-bridge and the accompanying force generated, so muscle stiffness can be used as a surrogate indicator of changes in muscle force production.

Normal muscle stiffness is critical to the dynamic stability of the body (H. Wagner R. Blickhan, 1999). It is very important to study the stiffness of ES and the lower limb dorsal muscles and the correlation between the stiffness percentage change of them during lumbar muscle extension for training lumbar muscles, preventing low back pain, and clarifying the regulation strategies and tension transmission processes of different muscles during trunk extension. The purpose of this study was to assess the effect of PTE on the biomechanical properties of lumbar and lower limb muscles.

2. Materials And Methods

2.1. Participants

This study received approval from the ethics committee of the Guangdong Provincial Hospital of Chinese Medicine (YF 2021-223-01). This study followed the principles of the Declaration of Helsinki. Twenty healthy adult females (mean age: 19.55 ± 1.15 years; mean height: 1.61 ± 0.05 m; mean mass: 51.15 ± 3.65 kg; BMI: 19.64 ± 0.61 kg/m²) were recruited. The inclusion criteria were (1) right hand and foot were
the dominant sides; (2) could follow the instructions of the measurer and voluntarily participate in this trial; and (3) no pain or trauma to the lower back, lower extremities, or feet that interfered with normal life and work for at least the past 6 months. Exclusion criteria were: (1) those with skin breakdown or a tendency to bleed in the low back and lower limbs; (2) neuromuscular disease or joint disease; (3) scoliosis; (4) BMI > 24 kg/m²; and (5) during pregnancy. All participants were fully informed about the safety of MyotonPRO, the basic rights of the participants, the procedure, and the purpose of the trial, and they signed informed consent in writing before the trial. They were asked to avoid strenuous activity for 48 hours before the start of the trial.

2.2. Equipment and Parameter Settings

The equipment used in this study was MyotonPRO (produced by MyotonPRO AS in Estonia). The MyotonPRO is a handheld device that enables non-invasive quantitative assessment of soft tissue stiffness. It has excellent reliability (ICC > 0.93) with a small Coefficient of Variation (CV) during isometric muscle contraction (Oseph P. Kelly et al., 2018). This trial required the rapid acquisition of stiffness parameters from multiple muscles, and the MyotonPRO is able to quantify the metrics quickly compared to the shear wave elastography previously used by our team.

MyotonPRO was used to measure the stiffness of the right ES, ST, BF, MG, and LG. The operator marked the measured muscles with an oil pencil and first palpated the spinous process of the fourth lumbar vertebra (L4) and then the spinous process of the third lumbar vertebra (L3) according to the body surface markers, with the ES measured at 2.5 cm to the right of the spinous process of L3. The MG is measured from the popliteal fossa to 30% of the length of the lateral ankle, and the LG is measured from the lateral popliteal fossa to 30% of the length of the medial ankle. (Fig. 1)

2.3. Experimental Protocol

The experiment was performed as follows: (1) Before the test began, the participants were asked to lie prone on the anterior descending treatment bed, with the anterior superior iliac spine moved to the junction of the anterior and posterior segments of the treatment bed, hands placed on either side of the body, a pillow padded at the ankle joint and kept in a neutral position, and three non-elastic seat belts were added to immobilize the ankle joint, popliteal force, and greater trochanteric plane, respectively, to minimize the participant's discomfort. To ensure that the muscles of the low back and lower limbs were in a relaxed state, the participant was relaxed in a prone position on the treatment bed for 5 minutes (MAUD CREZE et al., 2017), and the operator used MyotonPRO to measure and record the muscle stiffness of the participant's right lower back and lower limbs in the resting state. (2) The operator lowered the anterior section of the bed, and the participant was asked to keep the neck in maximum flexion, the gluteal muscles contracted to maintain pelvic stability (O. Shirado et al., 1995), and the arms were crossed close to the chest (C. Juan-Recio et al., 2018). The participant's upper body was suspended over the edge of the treatment bed and kept horizontally extended. An assistant holds an inclinometer placed on the spinous process of the eighth thoracic vertebra (T8) of participants (Kyung-Hee Park et al., 2015; P. Malliou et al., 2006) to provide position feedback. After the pointer pointed to 0° and stabilized for 5 seconds (Carlos...
Murillo et al., 2019), the operator measured the stiffness of the participant's ES, ST, BF, MG, and LG, and the assistant verbally reminded the participant to remain in the required position. In addition, to avoid the effect of breathing-induced abdominal fluctuations, we measured muscle stiffness at the end of expiration to ensure consistency of the test results. (3) After the measurement, the operator raised the front end of the treatment bed to the starting position, and the participant dropped the upper body back to the bed surface and rested sufficiently until the muscle stiffness returned to step (1). (4) Subjects maintained PTE at 10°, 20°, and 30° and the operator measured the stiffness of ES, ST, BF, MG, and LG using MyotonPRO (the order of PTE angle and measurement site was determined randomly). (Fig. 2) Measure 2–3 positions at a time, and repeat step (3) between measurements. Each measuring position was measured three times, and the average value was taken for analysis.

2.4. Statistical Analysis

Statistical analysis was performed using SPSS 25.0 software (version 25.0, Chicago, IL, USA). The Shapiro-Wilk test showed that the data all conformed to a normal distribution, expressed as mean ± standard deviation (SD). One-way ANOVA was performed with angles as independent variables and muscle stiffness (same measurement position) as the dependent variable. When the results of ANOVA were significant, post-hoc Tukey was performed to determine whether there were differences in muscle stiffness under different angles (Fig. 3). The significance level of statistical differences was set at p = 0.05.

Pearson correlation was used to calculate the correlation coefficient (R-value) for the percentage change in stiffness of different muscles. Taking into account individual differences and the stiffness properties of the muscle itself, the percentage change in stiffness was used to reflect the effect of different angles on the muscle itself. Stiffness percentage change (%) = (measured stiffness − original stiffness) / original stiffness × 100%. The percentage change in muscle stiffness at each measurement location was compared with ES under the same test conditions (Table 2). The correlation strength of the R values was set to r < 0.3 for weak correlation, 0.3 ≤ r ≤ 0.6 for moderate correlation, and r > 0.6 for strong correlation. The level of statistical significance was set at p = 0.05.

3. Results

3.1. Effect of different trunk extension angles on muscle stiffness

Figure 3 shows the relationship between angle and muscle stiffness. One-way ANOVA showed differences in muscle stiffness at different angles. With the increasing angle, ES stiffness gradually decreased, ST and BF stiffness showed a trend of increasing and then decreasing, with the highest stiffness at 20°, and MG and LG stiffness showed a trend of increasing and then decreasing and then increasing. The post-hoc Tukey test showed that ES stiffness was significantly different at 0° and 10°, 0° and 20°, 0° and 30°, 10° and 20°, and 10° and 30° (p = 0.0086, p < 0.0001, p < 0.0001, p = 0.0105, p < 0.0001),
and ST and BF stiffnesses were significantly different at 0° and 20° (p = 0.0002, p = 0.0013), MG stiffness was different between 0° and 30° (p = 0.0105), LG stiffness was different between 0° and 10° and 0° and 30° (p = 0.0373, p = 0.0027), and there was no significant difference in muscle stiffness between the remaining angles (p > 0.05) (Fig. 3).

### 3.2. Characteristics of the percentage change in muscle stiffness at different angles

The characteristics of the changes in muscle stiffness percentages are shown in Table 1. The changes in stiffness percentages increased and then decreased for ES, ST, and BF, and decreased and then increased for MG and LG. The stiffness percentages increased more for ST than for BF from 0° to 20° and decreased more for BF from 20° to 30°. The stiffness percentages changed more for LG than for MG from 0° to 30°.

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Position</th>
<th>0°-10°</th>
<th>10°-20°</th>
<th>20°-30°</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES</td>
<td></td>
<td>-11.34 ± 5.25</td>
<td>-12.21 ± 6.67</td>
<td>-11.00 ± 5.19</td>
</tr>
<tr>
<td>ST</td>
<td></td>
<td>9.99 ± 4.67</td>
<td>13.24 ± 7.70</td>
<td>-8.95 ± 10.35</td>
</tr>
<tr>
<td>BF</td>
<td></td>
<td>7.95 ± 2.94</td>
<td>11.54 ± 5.30</td>
<td>-9.27 ± 4.09</td>
</tr>
<tr>
<td>MG</td>
<td></td>
<td>8.61 ± 3.33</td>
<td>-0.02 ± 4.46</td>
<td>4.08 ± 4.89</td>
</tr>
<tr>
<td>LG</td>
<td></td>
<td>10.60 ± 2.86</td>
<td>-3.83 ± 3.46</td>
<td>7.06 ± 3.29</td>
</tr>
</tbody>
</table>

SD, standard deviation (N/m); ES, erector spinae; ST, semitendinosus; BF, biceps femoris; MG, medial gastrocnemius; LG, lateral gastrocnemius.

### 3.3. Correlation between lumbar and lower limb muscle stiffness under different angles

The percentage of muscle stiffness at each measurement location was compared with that of ES under the same test conditions (Table 2). The results showed a strong negative correlation between ES and ST (r = -0.819, p < 0.001), BF (r = -0.620, p = 0.004), and MG (r = -0.752, p < 0.001) at angles of 0° to 10°. Strong negative correlations existed between ES and ST (r = -0.728, p < 0.001), MG (r = -0.788, p < 0.001), and LG (r = -0.616, p = 0.004) for angles from 0° to 20°, and moderate negative correlations existed between ES and BF (r = -0.527, p = 0.017). There was a high negative correlation between ES and MG (r = -0.611, p = 0.004) and a moderate negative correlation between ES and LG (r = -0.450, p = 0.047) for angles of 0° to 30°.
Table 2
The correlation of the stiffness percentage changes between ES and other muscles (mean ± SD, %)

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Position</th>
<th>0°-10°</th>
<th>R (p-value)</th>
<th>0°-20°</th>
<th>R (p-value)</th>
<th>0°-30°</th>
<th>R (p-value)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Percentage change</td>
<td></td>
<td>Percentage change</td>
<td></td>
<td>Percentage change</td>
<td></td>
</tr>
<tr>
<td>ES</td>
<td>0°-10°</td>
<td>-11.34 ± 5.25</td>
<td>1(-)</td>
<td>-22.27 ± 6.45</td>
<td>1(-)</td>
<td>-30.67 ± 8.46</td>
<td>1(-)</td>
</tr>
<tr>
<td></td>
<td>0°-20°</td>
<td>9.99 ± 4.67</td>
<td>-0.819 (0.000**)</td>
<td>23.69 ± 8.52</td>
<td>-0.728 (0.000**)</td>
<td>12.03 ± 9.04</td>
<td>-0.057 (0.812)</td>
</tr>
<tr>
<td></td>
<td>0°-30°</td>
<td>7.95 ± 2.94</td>
<td>-0.620 (0.004**)</td>
<td>20.36 ± 5.33</td>
<td>-0.527 (0.017*)</td>
<td>9.16 ± 6.29</td>
<td>-0.396 (0.084)</td>
</tr>
<tr>
<td>ST</td>
<td></td>
<td>8.61 ± 3.33</td>
<td>-0.752 (0.000**)</td>
<td>8.50 ± 3.57</td>
<td>-0.788(0.000**)</td>
<td>13.77 ± 5.41</td>
<td>-0.611 (0.004**)</td>
</tr>
<tr>
<td>BF</td>
<td>0°-10°</td>
<td>10.60 ± 2.86</td>
<td>0.127 (0.593)</td>
<td>6.29 ± 2.43</td>
<td>-0.616(0.004**)</td>
<td>13.75 ± 3.07</td>
<td>-0.450 (0.047*)</td>
</tr>
<tr>
<td>MG</td>
<td>0°-20°</td>
<td>9.16 ± 6.29</td>
<td>-0.396 (0.084)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LG</td>
<td>0°-30°</td>
<td>10.08 ± 2.54</td>
<td>0.127 (0.593)</td>
<td>6.29 ± 2.43</td>
<td>-0.616(0.004**)</td>
<td>13.75 ± 3.07</td>
<td>-0.450 (0.047*)</td>
</tr>
</tbody>
</table>

SD, standard deviation(N/m); ES, erector spinae; ST, semitendinosus; BF, biceps femoris; MG, medial gastrocnemius; LG, lateral gastrocnemius. ** indicate p < 0.01; * indicates p < 0.05.

4. Discussion

We found the following characteristics of muscle stiffness changes: (1) ES stiffness gradually decreased with increasing angle, ST and BF stiffness showed a trend of increasing and then decreasing, MG and LG stiffness showed a trend of increasing and then decreasing and then increasing, that is, the best angle for training ES was 0° horizontal position; (2) there was a tension transfer between the hamstrings and gastrocnemius, mainly between ST and LG; (3) lower limb muscle and ES stiffness percentages were moderately to strongly correlated.

The PTE training used in this study originated from the Biering-Sørensen Test (BST)(Biering-Sørensen F., 1984). The postural movements of the PTE exert a greater load on the ES, which mobilizes more neuromuscular control and ES recruitment to maintain stability in the lower thoracic region. Plamondon et al(Zachary J. Domire et al., 2009) showed that intermittent PTE exercises in the horizontal position were effective in increasing the level of low back muscle activation and fatigue. They also studied ES activation levels at 0, 30, and 60 degrees of trunk forward flexion and showed that extension torque increased with increasing flexion angle, with the strongest ES contraction at 60 degrees of forwarding flexio(A. Plamondon et al., 1999). Michael et al.(MICHAEL L. POLLOCK et al., 1989) mentioned that the larger and stronger hamstrings and gluteals performed most of the movement in back extension without
proper pelvic stabilization. Therefore, the pelvis should be restrained during PTE exercises to maximize
the activation of the trunk extension muscles. Cresswell et al. (A. G. Cresswell & A. Thorstensson, 1989)
investigated the electromyographic activity of ES and isometric trunk torque during 60 degrees of trunk
flexion to 30 degrees of extension in the lateral recumbent position and found that torque decreased with
increasing trunk extension. Roy et al. (A. L. Roy et al., 2003) used dynamometry and Surface Electro-
Myography (EMG) to quantify trunk extensor activity and isometric extension torque from 50° of trunk
flexion to 20° of extension in the standing position, and also found that extensor EMG activity increased
linearly with increasing flexion angle and suggested no significant differences in extensor activity by
gender. All of the above studies support our findings. Park et al. (Kyung-Hee Park et al., 2015) investigated
the effects of PTE horizontal and hyperextension extension on the ES of the thoracic and lumbar spine,
and the results showed that there was no difference in the anterior lumbar convexity curve between the
hyperextended and horizontal positions, which further demonstrated the safety of PTE training in the
hyperextended position. There are many studies investigating the flexion and extension of the trunk in
different positions, but few studies on the effects of different angles of the trunk from horizontal to
extended position on ES and lower limb muscles in the prone position, so this trial investigated the
aspects of the optimal PTE angle for activating ES and lower limb muscles.

According to the active length-tension relationship, muscles usually produced the greatest force near the
middle length range and less force when excessively shortened or elongated. In the horizontal position,
ES produces the greatest number of actin-myosin cross-bridges for muscle force, generates the greatest
force, and has the highest muscle stiffness. From the kinetic point of view, force is divided into internal
and external forces, and force multiplied by force arm is equal to force moment. In this test, the external
force refers to the gravity of the upper body, and the external force arm decreases as the angle increases,
while the test is an isometric contraction with equal internal and external moments, so the internal
moment also decreases. From an anatomical point of view, the intrinsic lever arm of the main part of the
ES becomes longer with increasing extension angle, and a longer lever arm minimizes the force required
to maintain the muscle contraction, with a gradual decrease in ES stiffness. ES conditioning exercises
have been shown to increase spinal stability and improve lower back pain (S. M. McGill, 1998). Compared
to lumbar hyperextension, isometric contraction in the horizontal position maximizes ES activation, which
provides a reference for clinical practitioners to choose the appropriate method for training ES.

The fascia connects the various parts of the body to function as a unit, not just the sum of its parts. The
SBL is a chain of two fasciae at the back of the body from the sole to the left and right of the forehead,
with the lower half of the SBL starting at the plantar fascia and the toe dorsiflexors, connecting to the
gastrocnemius via the Achilles tendon, and then to the hamstring via the deep popliteal fascia, which in
turn connects to the sacral tuberosity ligament via the hamstring, which is then connected to the ES and
thoracolumbar fascia (TLF) through the sacral tuberosity ligament. Tuncay et al. (Ibrahim Tuncay et al.,
2009) found fascial bands connecting the gastrocnemius and ST at the knee joint in 23 autopsies, and
Cruz-Montecinos et al. (C. Cruz-Montecinos et al., 2015) found that pelvic motion causes displacement of
the MG deep fascia, suggesting a strain transfer between the popliteus and gastrocnemius. Vleeming et
al. (Vleeming A et al., 1995) suggested that the popliteus is connected to the TLF and ES via the
sacrocollicular ligament, and patients with plantar fasciitis and low back pain also frequently exhibit increased hamstring stiffness (Jonathan M. Labovitz et al., 2011). Willard et al. (F. H. Willard et al., 2012) found that due to ES insertion into the TLF, ES contraction directly stretches the overlying fascia, thereby altering the stiffness of the connective tissue (Thomas M. D. Ph. Findley et al., 2014). Muscle forces can be transmitted through the myofascia (Viviane Otoni Do Carmo Carvalhais et al., 2013) and the force of active ES contraction can be mechanically transmitted through the TLF between the spine-pelvis-lower extremity. Experimental and histological studies have shown (C. M. Eng et al., 2014) that the strain transfer capacity of fascial tissue is highest in the longitudinal plane, which corresponds to the SBL. Latime et al. (J. Latimer et al., 1999) and Plamondon (A. Plamondon et al., 1999) have shown that the level of muscle activation in the hamstrings increases progressively with the repetition of the horizontal position of the PTE. Michael et al. (M. A. Lawrence et al., 2019) also found that the ES activation in PTE exercises with considerable load was accompanied by very high combined muscle activity of the BF and gluteus maximus. These studies demonstrate an interaction between the lumbar tissue and the posterior muscles of the lower extremity. In the present experiment, the interaction between lumbar and lower limb muscles in the myofascial tensegrity network was seen in the changes in lower limb muscle stiffness, with ST, BF, MG, and LG playing a synergistic role in trunk extension.

By analyzing the percentage change of stiffness of each muscle at different angles, we found that the percentage change of stiffness of hamstrings and gastrocnemius increased from 0 to 10 degrees of PTE, and the percentage change of stiffness of LG was the largest, which indicated that hamstrings and gastrocnemius contracted together, and LG was the main generator of tension. From 20 to 30 degrees, the percentage change in stiffness of MG and LG was higher than that of the ST and BF, while the percentage change in stiffness of LG was higher than that of MG, indicating that the contraction of LG in the gastrocnemius was predominant. From the above, it is clear that there is a tension transfer between ES, hamstrings, and gastrocnemius, mainly between ST and LG. By exploring the different regulation strategies and tension transmission processes of lumbar and lower limb muscles during trunk extension, this study can elucidate the role played by muscles and fascia in the peripheral mechanical transmission effects and provide a further reference for our understanding of the overall regulatory pattern of the myofascial tensegrity network.

This study has some limitations. First, for technical reasons, we were unable to measure gluteal muscle stiffness. Secondly, the present experimental results were only applied to the muscle stiffness properties in young women, and it was not possible to determine the stiffness properties during muscle contraction in other populations. Future experiments will be repeated in populations of different ages and genders. Finally, only healthy populations were included in this study, and future studies related to populations with lower back pain will be gradually conducted to explore the specificity of the transmission mechanism of lower back pain from the perspective of peripheral biomechanical transmission.

5. Conclusion
In this study we found different biomechanical behaviors of ES and lower limb muscles during PTE. The flat position was the best position to exercise ES, there was a moderate to strong correlation between ES and lower limb muscle stiffness changes, and tension transfer was mainly present between ES, ST, and LG.

Declarations

Ethics approval and consent to participate: This study received approval from the ethics committee of the Guangdong Provincial Hospital of Chinese Medicine (YF 2021-223-01). This study followed the principles of the Declaration of Helsinki. All participants signed informed consent in writing before the trial.

Consent for publication: All authors agree to the publication.

Competing of interest: The authors declare no competing interests.

Availability of data and materials: The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

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Authors’ contributions: Zhijie Zhang and Chunlong Liu conceived the study, revised the manuscript, Yuting Zhang designed the study and conducted the experiments, performed statistical analysis and drafted the manuscript, Mengtong Chen participated in designing the study and helped draft the manuscript, Yanan He and Yuanchao Li participated in the experiments and assisted in data collection, and Suiqing Yu, Hongying Liang, Junxiao Yin and Pengtao Sun participated in data refinement and statistical analysis. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

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References


Figures
Figure 1

Muscle measurement points: (A) erector spinae, (B) semitendinosus and biceps femoris, (C) medial gastrocnemius and lateral gastrocnemius

Figure 2
Illustration of the four postures. (A) Prone Trunk-Extension 0°, the equipment used for measurement: (1) inclinometer, (2) non-elastic seat belts, (3) towel roll, and (4) pillow; (B) Prone Trunk-Extension 10°; (C) Prone Trunk-Extension 20°; (D) Prone Trunk-Extension 30°

Figure 3

Stiffness variation of each tissue under different degrees. ****, significant intergroup difference (p ≤ 0.0001); ***, significant intergroup difference (p ≤ 0.001); **, significant intergroup difference (p ≤ 0.01); *, significant intergroup difference (p ≤ 0.05); NS, non-significant intergroup difference (p > 0.05)