Contribution of pelvic floor muscles to stiffness of the pelvic ring

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Abstract

Study design. A biomechanical study in embalmed specimens, on the relation between applied tension in the pelvic floor muscles, stiffness of the pelvic ring and generation of movement in the sacroiliac joints.

Objective. To gain insight into the effect of tension in the pelvic floor muscles on stiffness of the pelvic ring.

Background. According to a model on selfbracing pelvic floor muscles have the capacity to stiffen the sacroiliac joints. However, this capacity has not been demonstrated in vitro yet.

Methods. In 18 embalmed specimens an incremental moment was applied to the sacroiliac joints to induce rotation of the innominate bones in the sagittal plane. After assessment of the relationship between rotation angle and moment, springs were applied to the pelvis to simulate tension in the pelvic floor muscles. During the simulated tension the measurements were repeated. Differences in stiffness before and after applying springs were tested for significance.

Results. In females, simulated tension in the pelvic floor muscles stiffened the sacroiliac joints with 8.5% ($P < 0.05$). In males no significant changes occurred. In both sexes a backward rotation of the sacrum occurred due to simulated tension in the pelvic floor muscles ($P < 0.05$). The sacroiliac joints of female specimens were more mobile in comparison to male specimens ($P < 0.05$).

Conclusions. In females, pelvic floor muscles have the capacity to increase stiffness of the pelvic ring. In addition, these muscles can generate a backward rotation of the sacrum in both sexes.

Relevance

The ability of pelvic floor muscles to increase stiffness of the pelvic ring is of importance in patients with impairment of pelvic stability, especially in pelvic pain patients. Increased activity of these pelvic floor muscles might compensate for loss of pelvic stability by stiffening the pelvic ring and restoring proper load transfer through the lumbopelvic region.

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1. Introduction

Pelvic floor muscles, in particular specific parts of the levator ani muscles, have the capacity to constrict the lower end of the rectum and the urethra and in addition to form a muscular diaphragm supporting the pelvic viscera (Delancey, 1994; Williams and Warwick, 1986; Sapsford and Hodges, 2001). Furthermore, together with the coccygeus muscles, the levator ani muscles form a muscular diaphragm opposing the downwards thrust due to increased intra-abdominal pressure (IAP) (Williams and Warwick, 1986). Actually, the pelvic floor muscles are capable to generate and control IAP together with other muscles surrounding the abdominal cavity (Bernstein, 1997; Hemborg et al., 1985; Hodges...
et al., 1997). Activity of these muscles can lead to increased IAP (Bernstein, 1997; Hemborg et al., 1985), whereas increased IAP is related to increase of spinal stiffness (Hodges et al., 1997; Shirley et al., 2003; Essendrop et al., 2004; Cholewicky et al., 1999a,b). In this way pelvic floor muscles indirectly contribute to lumbar spine stiffness.

Being part of the muscular system surrounding the sacroiliac (SI) joints, certain pelvic floor muscles can contribute to SI joint stiffness as well. Snijders et al. (1993a,b) introduced the pelvic floor muscles in a model on adding stiffness to the pelvic ring by force closure. Force closure refers to increase of SI joint stiffness due to compressive forces on the joint surfaces (Snijders et al., 1993a,b; Vleeming, 1990; Vleeming et al., 1990). Force closure depends on the contribution of muscles in two ways: (a) muscles can generate a direct compressive force on the SI joint increasing stiffness and (b) muscles can change the position of the joint leading to increased tension in the ligamentous structures (Snijders et al., 1993a,b; Vleeming, 1990; Vleeming et al., 1990). Force closure depends, in addition, on the size and texture of the contact area of the SI joint surfaces (Vleeming, 1990; Vleeming et al., 1990). A larger contact area of the surfaces implies greater resistance against movement. The resistance against movement is enlarged by the presence of ridges and grooves (Vleeming, 1990) and a rough coarse texture (Bowen and Cassidy, 1981). The overall sum of compressive forces (by ligamentous structures, muscles and gravity) and the size of the contact area of the joint surfaces determine the force closure of the SI joint.

Low back and pelvic pain disorders can be related to hampered load transfer through the lumbopelvic region due to impairment of force closure (Snijders et al., 1993a; Mens et al., 1999; Pool-Goudzwaard et al., 1998; Richardson et al., 2002). In these patients enhancement of force closure of the SI joints can be relevant. In vitro (Vleeming et al., 1992) and in vivo (Damen et al., 2002), enhancement of force closure have been demonstrated by a pelvic belt, stiffening the SI joint. Theoretically, several pelvic muscles have the capacity to increase force closure as well, e.g. the piriformis and coccygeus muscles (Snijders et al., 1993a,b). However, this capacity of pelvic floor muscles is not demonstrated in vitro nor in vivo.

In the present study we focus on the role of the pelvic floor on stiffness of the pelvic ring. For several reasons these muscles are of interest: (a) since the pelvic floor muscles, and especially the coccygeus muscle, cross the SI joints these muscles might produce compressive forces to the pelvis (Snijders et al., 1993a,b), (b) altered motor control patterns of the pelvic floor muscles have been reported in subjects with a clinical diagnosis of SI joint pain (O’Sullivan et al., 2002; Avery et al., 2000) and (c) voiding dysfunctions have been demonstrated in a group of patients with SI joint pain (O’Sullivan et al., 2002; Avery et al., 2000; Pool-Goudzwaard, 2003).

In addition, we focussed on the capacity of pelvic floor muscles to generate movement in the SI joint. Regarding the topography of the pelvic floor muscles we expect these muscles to rotate the sacrum backwards moving the caudal part of the sacrum forwards coined counternutation in the SI joint.

2. Methods

To test SI joint stiffness the following set-up was used: 18 embalmed specimens (9 female and 9 male; average age 77 years, SD 14.4 years), were carefully dissected by blunt dissection and consisted of pelvis, L4 and L5, with all ligaments intact. In these specimens the moment–rotation relationships in the SI joints were studied. The sacrum was secured in a custom made rig (Pool-Goudzwaard et al., 2003). A metal plate was screwed to each of the innominates (Fig. 1A). To enable the application of a moment to the iliac bones in the sagittal plane, each plate was connected to a steel axle. To allow three-dimensional translations of the iliac bones, the axle contained two universal joints (Fig. 1B) and a prismatic sliding joint (Fig. 1C). The torque on each axle (left and right) was realised with a string around a pulley (Fig. 1D), fixed at the end of the axle. Tension in the string was applied bilaterally with a custom made traction device, equipped with a control system. The moment applied to the iliac bone was measured with two torque transducers, one at each pulley (Fig. 1E).

In order to measure the position of the bones, 12 light reflecting markers were fixed on three screws, four on each screw. These screws were placed on the left iliac crest, the right iliac crest and the base of the sacrum. The markers were illuminated by an infrared light source mounted on two CCD video cameras (HCS Vision Technology MX5). The video images of these markers were digitised by a computer that was equipped with a

![Fig. 1. Fixation of the iliac bone to the pulley. A: plate fixed to the iliac bone, B: axle with two universal joints, C: torque transducer, D: pulley, E: prismatic sliding joint.](image-url)
frame grabber (Vision Dynamics VCS-II). The image coordinates from the cameras were combined to three-dimensional spatial coordinates using direct linear transformation (Abel-Aziz and Karara, 1971). With custom made software we calculated the amount of rotation in the sagittal, frontal and transversal plane.

During each test an incremental moment was applied to the SI joints. Each load increment of 3 Nm was applied slowly in 5 s. The angular movements due to each load step were registered after 5 s. The relation between the applied moment and the measured counternutation and nutation was displayed in a load deformation curve (Fig. 2). We define a forward rotation of the innominate with respect to the fixed sacrum as a relative counternutation in the SI joints and a backwards rotation of the innominate as a relative nutation in the SI joints.

Firstly, the moment was applied up to maximal counternutation (trajectory a in Fig. 2). Next, the load was released, so that the iliac bones returned to their neutral position and then increased to maximal nutation (trajectory b in Fig. 2), directly followed by the same procedure (release to neutral position and increase of load) to maximal counternutation (trajectory c in Fig. 2). Maximal counternutation and nutation were reached when visually no or negligible additional counternutation or nutation occurred during three incremental load steps.

To answer the question whether pelvic floor muscles have the capacity to increase SI joint stiffness we focused on the coccygeus muscles (see A in Fig. 3) and two separate parts of the levator ani: the iliococcygeus and pubococcygeus muscles (see resp. B and C in Fig. 3). Tension in each muscle was simulated by applying the following springs on either side of the pelvis:

- two springs were attached bilaterally to two rings fixed on the fixation plate (on each side one) at the height of the junction between sacrum and coccyx (see 1 in Fig. 4) and the pelvic surface of the ischial spine (see A in Fig. 4), simulating tension in the coccygeus muscle,
- two springs were attached bilaterally between the rings on the fixation plate and the pelvic surface of ischial bone (see B in Fig. 4), simulating tension in the iliococcygeus muscle according to the working line of the central part of this muscle and
two springs were attached between the rings on the fixation plate and the dorsal side of the pubic bones (see C in Fig. 4), simulating tension in those fibres of the pubococcygeus muscle deriving from the pubic bones and inserting on the coccyx and sacrum.

The load of each spring was calibrated to be 50 N. On each specimen five subsequent tests were performed:

Test 1. no intervention, followed subsequently by,
Test 2. with two springs attached to the pelvis, simulating either the left and right coccygeus, iliococcygeus or pubococcygeus muscles,
Test 3. with two springs attached (left and right side), simulating one of the two remaining muscles not tested yet,
Test 4. with two springs attached (left and right side), simulating the not tested muscle,
Test 5. with six springs attached, simulating all three pelvic floor muscles.

Tests 2–5 were performed in random order. Subsequently, the incremental moment of force was applied, resulting in a load deformation curve. After each load test the specimen was carefully examined for structural damage.

To demonstrate the ability of pelvic floor muscles to stiffen the SI joints all five load deformation curves are compared. An increase of stiffness of the SI joint is expected to result in a less steeper load deformation curve (see Fig. 5, thick S-curve), compared to the load deformation curve with no springs applied (see Fig. 5, thin S-curve). The slopes of the linear regression lines of these S-curves are considered as a measure for the stiffness of the SI joints (dotted lines in Fig. 5).

To compare the data of all five load deformation curves of each specimen, we used an equal load range for data analysis (Fig. 6). To determine an equal load range around the same neutral position for all curves we corrected for the initial displacement caused by the application of springs. For this purpose, the joint displacements and moments in experiments with simulated muscle force were calculated with respect to the neutral position as registered without spring forces and external moment.

For data analysis the first loading trajectory of each loading curve from neutral position to maximal counternutation was discarded. Furthermore, to avoid disturbance of data analysis due to the hysteresis loop, both ends of the load range were not used for data analysis (thin lines in Fig. 6). Data analysis was performed on the remaining two trajectories of each load deformation curve: (1) the trajectory between maximal counternutation and maximal nutation and (2) the trajectory between maximal nutation and maximal counternutation (see bold trajectories in Fig. 6). For both trajectories one mean slope was calculated by linear regression. A decrease in slope was considered to reflect increased SI joint stiffness. A mixed model ANOVA (proc mixed of SAS, version 6.12) was used to test whether the changes in slope by intervention were significant. The dependent variable slope was analysed after natural logarithmic (ln) transformation, due to positively skewed distribution of the slopes. The explanatory factors were: gender (two levels), side (two levels), type
(four levels: the pubococcygeus, the iliococcygeus, the coccygeus muscle and the three muscles combined), and a side-specific baseline measurement of the (ln) slope as continuous covariate. The side by type and gender by type interactions were tested. No structure was imposed upon the residual correlations. By using a one-way ANOVA the initial differences between baselines measurements and hence stiffness between male and female were tested.

To assess whether the pelvic floor muscles have the capacity to counternutate in the SI joint, we compared the position measured directly after application of the different springs with the neutral position (no springs attached and no moment of force applied to the pelvis). Forward rotation of the cranial part of the iliac bones, with respect to the sacrum, in the sagittal plane is considered to be evidence for the pelvic floor muscles to generate counternutation in the SI joint. We used the paired samples t-test to analyse these data for significance.

Since three specimens were lost (broken fixation plate, ventral capsular tear and one specimen with an ankylosis of the SI joint), 15 specimens were available for data analysis. In these 15 specimens no visual damage occurred during the load tests.

3. Results

SI joint stiffness tested by the one-way ANOVA of the baseline measurements showed a significant steeper slope (P < 0.05) in female pelvises in comparison to male pelvises, respectively 0.13 (SD 0.08) and 0.06 (SD 0.06).

In female pelvises, the slope of the regression line of the S-curve decreased significantly (P < 0.05) by 8.5% due to simulated tension in the pelvic floor muscles acting as a group (six springs attached), resembling an increase of stiffness of the SI joints. In male pelvises there were no changes (P > 0.05, see Table 1).

In female pelvises a significant increase (P < 0.05) of the slope of the S-curve of 16.1% occurred, resembling a decrease of stiffness of the SI joints, during simulated tension in exclusively the iliococcygeus muscles. No changes occurred in males. In neither of the sexes a change occurred during simulated tension in the pubococcygeus or coccygeus muscles (P > 0.05). The percentual changes in geometric mean slopes and 95% confidence per sex and type are shown in Table 1. The mixed model ANOVA showed a significant interaction of gender by type (P < 0.05). No interaction of side by type occurred.

For both sexes the T-test showed a significant counternutation (P < 0.05) in the SI joint when tension was simulated in the coccygeus muscles, the pubococcygeus muscles and all three pelvic floor muscles combined (see Table 2). This in contrast to simulated tension in the iliococcygeus muscle (P > 0.05).

4. Discussion

In females, we demonstrated an increase of SI joint stiffness due to simulated tension in the pelvic floor muscles acting as a group. Although springs, used to simulate tension in the pelvic floor muscles, never do right to the correct anatomical attachments we mimicked the workline of the three pelvic floor muscles as carefully as possible. We used one combined insertion site for the springs at the height of the junction of the sacrum and coccyx to take into account the attachment of the pelvic floor muscles to both coccyx and lower end of the sacrum. Since we have tried to simulate the workline of the muscles correctly, the conclusion that pelvic

<table>
<thead>
<tr>
<th></th>
<th>Sex</th>
<th>GMS</th>
<th>Ch%</th>
<th>95% Cl</th>
<th>Sig</th>
</tr>
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<tbody>
<tr>
<td>Iliococcygeus</td>
<td>F</td>
<td>0.070</td>
<td>−16.1</td>
<td>5.5–27.7</td>
<td>0.00*</td>
</tr>
<tr>
<td>Muscle</td>
<td>M</td>
<td>0.066</td>
<td>−8.3</td>
<td>−1.2–18.7</td>
<td>0.08</td>
</tr>
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<td></td>
<td>B</td>
<td>0.068</td>
<td>−12.7</td>
<td>3.9–22.2</td>
<td>0.00*</td>
</tr>
<tr>
<td>Coccygeus muscle</td>
<td>F</td>
<td>0.068</td>
<td>−11.7</td>
<td>−3.0–28.6</td>
<td>0.12</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>0.063</td>
<td>−4.5</td>
<td>−8.6–19.6</td>
<td>0.49</td>
</tr>
<tr>
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<td>B</td>
<td>0.066</td>
<td>−8.5</td>
<td>−1.5–19.6</td>
<td>0.09</td>
</tr>
<tr>
<td>Pubococcygeus</td>
<td>F</td>
<td>0.067</td>
<td>−10.9</td>
<td>−4.2–28.4</td>
<td>0.15</td>
</tr>
<tr>
<td>Muscle</td>
<td>M</td>
<td>0.064</td>
<td>−5.0</td>
<td>−8.6–20.7</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0.066</td>
<td>−8.5</td>
<td>−1.8–19.8</td>
<td>0.10</td>
</tr>
<tr>
<td>Pelvic floor</td>
<td>F</td>
<td>0.055</td>
<td>+8.5</td>
<td>−6.1–12.4</td>
<td>0.05*</td>
</tr>
<tr>
<td>muscles as a</td>
<td>M</td>
<td>0.063</td>
<td>+3.5</td>
<td>−4.7–12.4</td>
<td>0.39</td>
</tr>
<tr>
<td>group</td>
<td>B</td>
<td>0.059</td>
<td>+3.0</td>
<td>−8.8–3.2</td>
<td>0.31</td>
</tr>
</tbody>
</table>

*P < 0.05.
F = female, M = male, B = both sexes, GMS = geometric mean slope, Ch% = percentual change in stiffness after applying springs (+ = increase, − = decrease), 95% CI = confidence interval of the difference, Sig = Significance (2-tailed).
floor muscles stiffen the SI joint is well defensible. We consider this increase of SI joint stiffness as prove for the capacity of the pelvic floor muscles to stiffen the SI joints, at least in the female. This conclusion seems justified since the results of this study cannot be imputed to the testing protocol. As Pool-Goudzwaard (2003) demonstrated, no significant changes in stiffness occurred after four subsequent load tests in loading conditions similar to this study.

This study demonstrates the presence of a closure mechanism of the pelvic ring in agreement with the theoretical model of force closure of the SI joint, adding stiffness to the pelvic ring by compressive force (Snijders et al., 1993a,b; Vleeming, 1990; Vleeming et al., 1990). The demonstration of this force closure mechanism in vitro is valid for in vivo situations as well, since this mechanism is independent of materials (either fresh, fixed, aged or young specimens). However, we can only speculate about the quantity of this closure mechanism in vivo.

The presence of a force closure mechanism due to muscle tension has also been demonstrated by an in vivo study showing an increase of SI joint stiffness by contraction of the transverse abdominal muscle (Richardson et al., 2002). However, the outcome of that study may well be influenced by simultaneous pelvic floor contraction, since Sapsford and Hodges (2001) demonstrated co-contraction of pelvic floor and transverse abdominal muscles. Unfortunately, Richardson et al. (2002) did not test pelvic floor activity with EMG during their stiffness measurements of the SI joint.

In contrast with the female pelvises, no stiffening and hence force closure was observed when tension was simulated in the pelvic floor muscles in men. This can be due to gender differences in the shape of the pelvis and SI joint mobility since in the present study female SI joints were twice as mobile as male SI joints.

An increase of SI joint stiffness was also expected by simulating tension in the pelvic floor muscles separately. However, no significant effect was seen. There are two possible explanations: (a) these separate muscles are not capable of generating compressive forces and (b) the compressive force of these muscles is counteracted by an alteration of position of the SI joint, due to fixation of the springs, resulting in a smaller contact area. As stated in the introduction a smaller contact implies less resistance against movement.

In females, even a significant decrease of SI joint stiffness occurred during simulated tension in the ilio-coccygeus muscles. Possibly, in the relatively mobile female SI joints, the springs may have led to such a small contact area between the joint surfaces that resistance against movement was nil, resulting in decreased joint stiffness.

Simulated tension in either the coccygeus, the pubococcygeus or the pelvic floor muscles as a group generated significant counternutation in the SI joints. This indicates that pelvic floor muscles can play a role in posture and locomotion. By coordinated co-contraction with muscles leading to nutation in the SI joint (forward rotation of the sacrum moving the caudal part of the sacrum backward), the pelvic floor muscles can control movement of the sacrum. Muscles capable of nutation in the SI joints are the deeper lumbar parts of the erector spinae, the multifidus muscles (Williams and Warwick, 1986; Snijders et al., 1993a,b).

The stiffening effect of pelvic floor muscles in females can be relevant in case of decreased pelvic stability, especially in patients with pregnancy related low back and pelvic pain (Snijders et al., 1993a; Mens et al., 1999; Pool-Goudzwaard et al., 1998; Richardson et al., 2002). Increased tension in the pelvic floor, by a higher level of activity of these muscles might compensate for this decreased pelvic stability, increasing stiffness of the SI joint.

Table 2
Mean counternutation of the sacrum in degrees, per intervention and sex

<table>
<thead>
<tr>
<th></th>
<th>Sex</th>
<th>Mean</th>
<th>SD</th>
<th>95% Cl</th>
<th>Sig</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iliococcygeus muscle</td>
<td>F</td>
<td>0.005 ±0.42</td>
<td>-0.27 to -0.28</td>
<td>0.97</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>0.23 ±0.71</td>
<td>-0.16 to -0.62</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0.13 ±0.61</td>
<td>-0.11 to -0.38</td>
<td>0.27</td>
<td></td>
</tr>
<tr>
<td>Coccygeus muscle</td>
<td>F</td>
<td>0.18 ±0.12</td>
<td>0.10 to 0.27</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>0.20 ±0.25</td>
<td>0.14 to 0.44</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0.24 ±0.21</td>
<td>0.15 to 0.33</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Pubococcygeus muscle</td>
<td>F</td>
<td>0.49 ±0.34</td>
<td>0.26 to 0.72</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>0.29 ±0.36</td>
<td>0.01 to 0.41</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0.33 ±0.38</td>
<td>0.16 to 0.48</td>
<td>0.00</td>
<td></td>
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<tr>
<td>Pelvic floor muscles as a group</td>
<td>F</td>
<td>0.51 ±0.37</td>
<td>0.26 to 0.77</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>0.74 ±0.97</td>
<td>0.20 to 1.28</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>0.65 ±0.77</td>
<td>0.33 to 0.96</td>
<td>0.00</td>
<td></td>
</tr>
</tbody>
</table>

*p < 0.05.
F = female, M = male, B = both sexes, Mean = mean counternutation of the sacrum, SD = standard deviation, 95% CI = confidence interval of the difference, Sig = significance (2-tailed).
joints. However, such a sustained contraction can alter the timing and motor control of these muscles. Indeed, Avery et al. (2000) reported an altered motor control of pelvic floor muscles in subjects with clinical diagnosis of SI joint pain. In addition, O’Sullivan et al. (2002) showed, in patients with SI joint pain, increased pelvic floor descent during low load tasks compared with pain free subjects, also suggesting a change in motor control of the pelvic floor muscles. Sustained contraction of the pelvic floor muscles may well be related to voiding dysfunction, as reported in subjects with SI joint pain (O’Sullivan et al., 2002; Avery et al., 2000; Pool-Goudzwaard, 2003).

Finally, Pool-Goudzwaard et al. (2003) demonstrated frequent occurrence of idiopathic coccygodynia in pelvic pain patients. This also might be caused by sustained contraction of the pelvic floor muscles, pulling the coccyx ventrally. This is in line with two studies (Kim and Suks, 1999; Maigne and Tamalet, 1996) showing in patients with idiopathic coccygodynia an increased angle between the first and last segment of the coccyx. In vitro research has limitations. To test the quantity of the closure mechanism in vivo, EMG registrations of pelvic floor muscles combined with stiffness measurements of the SI joints are necessary.

5. Conclusions

Increase of tension in pelvic floor muscles, viz. the combination of pubococcygeus, iliococcygeus and coccygeus muscles, stiffens the female SI joints and hence the pelvic ring. Such an effect of the pelvic floor muscles could not be demonstrated in male specimens. Most pelvic floor muscles had, in addition, the capacity to counteract the SI joint pain syndrome. In: Proceedings of the 7th Scientific Conference of the IFOMT, Perth, pp. 35–38.

References


