Load application to the sacrotuberos ligament; influences on sacroiliac joint mechanics

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Summary

In the embalmed human pelvis, the connections between sacrum and fifth lumbar vertebra were spared together with most of the ligaments. The effect of load application to the sacrotuberos ligament was studied on rotation in the sacroiliac joint. It was shown that load application along the direction of hamstring and gluteus maximus muscles significantly diminished ventral rotation of the sacrum. The results imply that loading the sacrotuberos ligament restricts nutation of the sacrum. Consequently, muscles which attach to the sacrotuberos ligaments, such as the gluteus maximus, and in certain individuals the long head of the biceps, can dynamically influence movement and stability of the sacroiliac joints. The importance of sacrotuberos ligaments and sacroiliac joints as parts of the kinematic chain is emphasized.

Relevance

Demonstration that certain muscles can influence the sacrotuberos ligaments and, consequently, the sacroiliac joints is of importance for understanding and treating low back pain.

Key words: Sacroiliac joint, sacrum, joint instability, pelvic bones, anatomy, spinal injuries, intervertebral disc

Introduction

Up to 1934 the sacroiliac (SI) joints were thought to be the chief cause of low back pain. With the study on the invertebral discs of Mixter and Barr1 a better understanding of ischialgia and low back pain became possible.

However, the SI joints are often neglected as part of the low back2, and as late as 1983 Lavignolle et al.3 described the joints as an enigma. Literature on coupled motions of the SI joint is particularly scarce. This may be due, at least in part, to the regional approach by which the lower vertebral column (like many other systems) is taught in most medical courses. Particularly for the musculoskeletal system, we regard this approach as a handicap in understanding such a complex system.

For clinical reasons we are interested in whether abnormal displacement between sacrum and ilium can be responsible for abnormal displacement or stress of the lumbar vertebrae. Being part of the complex kinematic chain between legs and spine, even a small displacement of the sacrum or ilia may have important effects. Displacement of sacrum relative to ilia simultaneously affects the SI joints, the intervertebral joints at L5, S1, and the intervertebral disc of L5 and S1. Ilium displacement relative to the sacrum affects the SI joints and symphysis4.5. Since the iliolumbar ligaments connect the ilium and lumbar spine, ilium displacement can generate stress on the lumbar vertebrae. When muscle action is taken into consideration, the situation is more complex.
In an anatomical study of the sacrotuberous ligament (ST ligament) it was shown that the ST ligament can be tightened dynamically. It was suggested that the muscles attached to the ST ligament have a function in stabilizing the SI joint.

In a biomechanical study we developed a method for testing the mobility of intact SI joints in preparations from elderly people. By loading the joints, mobility could be confirmed in most specimens.

The present study concerns the effect of load application to the ST ligament on SI joint displacement. Support for such an effect would highlight the potential importance of muscles attached to the ST ligament in stabilizing the SI joints. Possibly, it could also clarify why certain aspecific surgical approaches to the SI joint were shown to have favourable effects. One of these (obsolete) approaches concerned operating on the SI joint and performing arthrodesis for curing ischialgia. Direct relief of pain was described before any consolidation of the two joint parts occurred.

Materials and methods

Part of the materials and methods concerning the instrumentation will be briefly dealt with. See Vleeming et al. for details and discussion.

Four cadavers were embalmed by vascular perfusion with a medium containing 2.2% formaldehyde. Their age and sex were (A) 73, female; (B) 75, male; (C) 83, female; (D) 77, female. The pelvis was removed leaving vertebrae L_3 and L_4 intact. The femora with joint capsules were removed. Blunt dissection followed, leaving the iliolumbar, sacroiliac, sacrotuberous and sacrospinous ligaments intact. The vertebral foraminae of L_3–L_5 were slightly widened and a tapering steel rod was fitted in the foraminae as far as the caudal part of L_4. Each pelvis was mounted on an inner frame, which was connected to an outer frame (Figures 1 and 2). The acetabula were chosen as points of force transfer. Stainless steel rods were fitted from lateral to medial through the acetabula (Figure 2–3). Through small holes in the rods, steel wires (Figure 3–1) were passed through the external acetabulum holes. Acetabulum and vertebral rods were centred and stabilized with a two-component industrial hardening resin. Steel wires were connected to four power units (Eltrac 471-1471.905, Enraf Nonius) generating gradual adjustable tensile forces on the acetabula.

Digital Mitutoyo displacement meters (type IDU 25 575-113 and IDU 25E 575-103-5) were connected to the inner frame (Figure 3). The meters were coupled with a Mitutoyo UB5 Multiplexer 011028 to the registration unit (Mitutoyo Digimatic miniprocessor DP-1 DX264-501-1).

To record displacement, a Perspex plate (5×90×40 mm) was fitted to the centre of the sacrum with bone screws. The plate could not be fitted to the lateral side of the sacrum without destroying part of the sacroiliac ligaments. Another Perspex plate with the same dimensions was connected to the posterior superior iliac spine (Figure 3–3). The two plates were adjusted to lie in the same plane and were fixed with hardening resin.

Two sets of two displacement meters, all lying parallel to each other and connected to the inner frame (Figure 3–2), were adjusted in the sagittal plane, perpendicular to plates on the ilium and sacrum. The meters of one set were located at a distance of 40 mm. The meters were calibrated to the zero position. Since the plates on the sacrum and ilium were inclined to the frontal plane, the meters were adjusted to this new plane. The
new values of the meters were used in a correction calculation and the meters were again calibrated to zero.

For measuring sagittal plane rotation of the sacrum relative to the ilium, the following calculation was used. In Figure 4, one set of meters (M1 and M2) is shown located on an ilium (compare with Figure 3). Line N shows the neutral position of the meters. Line P shows the position of the meters adjusted to the Perspex plate on the sacrum or ilium. Line O represents a possible position of the meters after displacement of sacrum and/or ilium. The values first registered (c1 and c2) are used as a correction factor and, consequently, line P is considered as the zero position. The difference between P and Q is registered (m1 and m2). For calculating rotation between lines P and Q, the following procedure was used. By subtracting c1 from both c1 and c2, the original line P now, as line P', intersects line N at point 0. The value of meter M1 for line P (at the position of line P') becomes zero and the value of meter M2 for line P becomes c2-c1. For the position at line Q, the same procedure is followed. Thus, c1+m1 are subtracted from the values at Q. As a result of this calculation, line Q (as line Q') intersects line N also at point 0. The value of M1 for line Q' now becomes zero and the value of M2 for line Q becomes (m2+c2)-(m1+c1).

The angle between line Q and line P (representing the angle displacement from line P to Q) can be calculated from angle Q'0P' = angle Q'0N - angle P'0N.

Angle P'0N is calculated from:

$$P'0N = \arctan \left( \frac{(c2-c1)}{a} \right)$$

Angle Q'0N is calculated from:

$$Q'0N = \arctan \left( \frac{(m2+c2)-(m1+c1)}{a} \right)$$

Subtraction gives the angle between line Q and P. This calculation is repeated for the other set of meters located on the sacrum and registering sacrum displacement. These displacement angles are subtracted from each other.

As stated before, the acetabula were chosen as force transfer points. To induce ventral rotation (as part of nutation) the following loads were used: F cranial bilateral 200 N; F ventral bilateral 100 N.

To induce dorsal rotation (as part of contranutation) the following loads were used: F dorsal bilateral 200 N; F caudal bilateral 100 N.

To avoid destruction of material by the large number of measurements, the loads were smaller than those used in a former study.

The cranial force was chosen to reproduce gravity. The rigid top plate transforms this force into a compressive force on the specimens. The caudal force was necessary since the rigid top plate transforms part of the dorsal force into a compressive force, resembling gravity. To exclude this compression, the caudal force was introduced. Excluding gravity appears to be a prerequisite for contranutation (Weisl; Egund et al.; Lavignolle et al.).

The rotation of sacrum and ilium relative to each other was tested as a function of loading the ST ligament. For this reason the ST ligament was fixed to a specially developed string (Figure 5). The string was connected to a steel wire running over a pulley to a traction unit. The ST ligaments were loaded bilaterally, each side with 50 N. Since the gluteus maximus muscle and in some individuals, the long head of the biceps femoris muscle, are connected to this ligament, a laterocaudal direction of loading was chosen (Figure 5). Then, the applied loading of the ligament is approximately perpendicular to the ventral and middle part of the SI joint (Dijkstra et al.).

In the results section, the effect of loading the ST ligament on dorsal and ventral rotation is shown separately for each SI joint. Specimens 1 and 2 and specimens 5 and 6 are the left and right side, respectively.
of pelvis A and D. Specimens 3 and 4 are, respectively, the right side of pelvis B and the left side of pelvis C. The other sides of pelvis B and C are not shown, since mobility was hardly possible (see Vleeming et al.'). Translation, which represents a relatively small part of the total nutation and contranutation, was not measured in this study.

In preliminary studies, we observed that successive measurements influenced each other. Therefore, the measurements were replicated in pairs consisting of one measurement with and one without loading of the ST ligament; a random order was used within each pair. Sixteen pairs of measurements were made in two sessions of eight. In order to investigate the effect of loading of the ST ligament for each specimen, a three-way analysis of variance was performed for each specimen separately. In these analyses of variance, the factors were ST ligament (loaded or unloaded), order of measurement within the pair (1 or 2) and session (1 or 2).

To investigate the effect of loading for all specimens averaged together, an analysis of variance was performed in which, in addition to the above mentioned factors, the specimen was taken up as a random factor. $P$ values $\leq 0.01$ were considered to be significant.

**Results**

During nutation the amount of rotation was decreased by loading of the ST ligament. This decrease was small but significant in all specimens except no. 4 (see Figure 6). For all specimens averaged, the effect of loading was significant ($P < 0.01$).

The effect of loading during contranutation is not consistent. In specimens 3, 4 and 5, loading of the ST ligament during contranutation gives a slight but significant increase in rotation (see Figure 6). In specimen 2 rotation is slightly (but not significantly) decreased. For all specimens averaged together, the effect of loading was not significant.

By loading of the ST ligament the amount of total rotation (nutation plus contranutation) was significantly decreased in specimens 1, 2, 5 and 6. For all specimens averaged, the effect of loading was significant.

Specimens 5 and 6, which belong to one pelvis, are of special interest, since the long head of the biceps femoris muscle was bilaterally completely connected with the ST ligament and not with the ischial tuberosity. In specimens 5 and 6, loading of the ST ligament decreased the ventral rotation by 14% and 10%, respectively. In specimen 5, dorsal rotation was increased by 3%.

**Discussion**

In this study, sagittal plane movement was measured in the SI joints. In the experimental setup not only was movement in the SI joints possible, but also movement in the intervertebral joints of L5 and S1, as well as in the disc of this level. In our opinion this is a requisite for realistically testing movement in the SI joints.

As we showed in a former study, extensive connections can exist (in addition to those of the gluteus maximus muscle) between the long head of the biceps femoris muscle and the ST ligament. These connections suggest considerable loading of the ligament in certain individuals, but we chose to simulate minimal loading. Since no counter-forces of muscles were present in this experimental setup, larger forces were thought to be unrealistic.

It was expected that loading of the ST ligament would decrease the amount of ventral rotation (part of the nutation). As shown in the results, ventral rotation was indeed significantly decreased in all specimens. In specimen 1 this amounted to 27% and in specimen 3 to 78%, but the actual rotations were very small.

The effect of loading during contranutation was less consistent. In three specimens dorsal rotation (part of contranutation) showed a small but significant increase.

In former studies it was demonstrated that the amount of friction between the articular surfaces of SI joints was related to the degree of macroscopic roughening of the articular surfaces. It was hypothesized that, in general, this roughening is a normal process. Articular surfaces with both coarse texture and ridges and grooves (depressions) showed high friction coefficients.
The influence of ridges and depressions appeared to be greater than that of a coarse texture. Biomechanically we introduced a free body diagram of the symmetrical sacrum where the resultant of the bone-to-bone contact forces in the SI joint is given by $F_N$. The force $F_T$ can be resolved into a force perpendicular to the joint surface ($F_{TN}$) and a tangential force ($F_{TT}$), the latter resulting from friction. The relationship between both forces is given by

$$F_T \leq F_N \tan(\alpha)$$

which becomes, just before the start of sliding of two SI joint parts over each other:

$$F_T = F_N \tan(\alpha)$$

where $\tan(\alpha) = f$, the friction coefficient.

The force direction of the loading of the ST ligament in real life situations creates a force that is approximately perpendicular to the oblique ventral and middle part of the SI joint\(^{11}\). As shown in the present study, loading the ST ligament diminishes the total range of ventral rotation. From the experiments presented here we propose that in real life situations the muscles connected to the ST ligament can dynamically influence $F_N$.

In specimens 5 and 6, loading of the ST ligament could not directly change the position of the sacrum in these specimens since it was radiologically demonstrated that $L_4$ was (bilaterally) fused with the sacrum (see pelvis no. 4 in Vleeming et al.\(^7\)). Since the vertebrae $L_4$ and $L_5$ are rigidly fixed to the inner frame, it can be assumed that the sacrum is immobilized in this pelvis. However, nutation was also diminished in these specimens after loading the ST ligament (see Figure 4). In our opinion this effect can be explained by the cranial connections of the ST ligament with the ilium, and the loading of the ST ligament in combination with the cranial and ventral forces applied to the acetabula. In all probability this leads to increased compression and friction in part of the SI joints. It might well be that the decrease in displacement seen in the other specimens is also caused by increased compression between the ilium and sacrum. When starting this study, loading of the ST ligament was primarily used to diminish nutation of the sacrum with respect to the ilium. The results of specimens 5 and 6 raise, however, the question of whether the loading of the ST ligament in this experiment simulates real life situations. Considering the data obtained from specimens 5 and 6, a better method of simulation of loading may be a transverse cut of the ST ligament and then pulling the sectioned parts to each other.

The gluteus maximus muscle is orientated approximately perpendicular to the ventral and middle part of the SI joint. Therefore, we assume that this strong muscle can compress the SI joint in real life situations and enlarge $F_N$. The connection of the gluteus maximus muscle with the ST ligament is relatively unimportant, since the muscle is extensively connected to the sacrum. We speculate that training of the gluteus maximus muscle can influence rotation in the SI joints, because of the direct connections with the sacrum and ST ligament. This means that the muscle is dynamically influencing $F_N$.

In some individuals, the long head of the biceps femoris muscle is partly or totally connected with the ST ligament, as in the (female) pelvis of specimens 5 and 6. When present in women it is mostly bilateral\(^8\). In individuals with such a connection, shortened hamstrings can directly influence movement in the SI joints. Therefore, stretching or strengthening the hamstrings could influence the kinematic behaviour of the SI joints.

We will speculate on the effect of the surgical techniques of Smith-Peterson\(^8\) which were shown to be sometimes successful in treating ischialgia. First of all, the SI joints are innervated by the same nerves as the lower spine. Therefore, abnormal function of the SI joint may lead to ischialgia pain. Secondly, Smith-Peterson was surprised that ischialgia was cured before arthodesis of the joint was completed. However, by operating on the SI joint, parts of the joint ligaments, as well as the gluteus maximus muscle, will be affected also. In this way the SI joint can be decompressed, creating another kinematic behaviour of SI joint and lower spine. As a result of this surgical technique, compression of an intervertebral disc might have been changed. This speculation serves, at least in part, as an answer to the question of why this operation might have been effective.

On the basis of this and former studies we want to finish with a general statement on diagnosis and therapy. Obviously, the low back region is characterized by large intra- and inter-individual variety. This carries the implication that, apart from the clear pathology usually leading to neurosurgery, it is extremely difficult to reach a well-founded absolute diagnosis in cases of low back pain. Therefore, we consider it wise to evaluate the outcome of kinematic tests during non-operative treatment especially when tests of the SI joints are involved; the therapy has to be continuously adjusted to this evaluation. This approach can preclude one specific, and often unwanted, diagnosis and therapy. Even in the case of an obvious lesion the question remains whether this is the primary cause or just reflects a disturbance in the complex kinematic chain.

At the moment we consider it impossible, with the technology available, to forecast for an individual patient the precise nature and function of the SI joints (see Sturesson et al.\(^1\) and our comments on this study\(^7\)). With the standard methods available, increased or decreased compression in these joints is particularly difficult to judge.

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