

The Relation Between the Transversus Abdominis Muscles, Sacroiliac Joint Mechanics, and Low Back Pain

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Study Design. Two abdominal muscle patterns were tested in the same group of individuals, and their effects were compared in relation to sacroiliac joint laxity. One pattern was contraction of the transversus abdominis, independently of the other abdominals; the other was a bracing action that used all the lateral abdominal muscles.

Objectives. To demonstrate the biomechanical effect of the exercise for the transversus abdominis known to be effective in low back pain.

Summary of Background Data. Drawing in the abdominal wall is a specific exercise for the transversus abdominis muscle (in cocontraction with the multifidus), which is used in the treatment of back pain. Clinical effectiveness has been demonstrated to be a reduction of 3-year recurrence from 75% to 35%. To the authors' best knowledge, there is not yet *in vivo* proof of the biomechanical effect of this specific exercise. This study of a biomechanical model on the mechanics of the sacroiliac joint, however, predicted a significant effect of transversus abdominis muscle force.

Methods. Thirteen healthy individuals who could perform the test patterns were included. Sacroiliac joint laxity values were recorded with study participants in the prone position during the two abdominal muscle patterns. The values were recorded by means of Doppler imaging of vibrations. Simultaneous electromyographic recordings and ultrasound imaging were used to verify the two muscle patterns.

Results. The range of sacroiliac joint laxity values observed in this study was comparable with levels found in earlier studies of healthy individuals. These values decreased significantly in all individuals during both muscle patterns ($P < 0.001$). The independent transversus abdominis contraction decreased sacroiliac joint laxity (or rather increased sacroiliac joint stiffness) to a significantly greater degree than the general abdominal exercise pattern ($P < 0.0260$).

Conclusions. Contraction of the transversus abdominis significantly decreases the laxity of the sacroiliac joint. This decrease in laxity is larger than that caused by a bracing action using all the lateral abdominal muscles. These findings are in line with the authors' biomechanical

model predictions and support the use of independent transversus abdominis contractions for the treatment of low back pain. [Key words: exercise, biomechanics, low back pain, sacroiliac joints, abdominal muscles] **Spine 2002;27:399–405**

There are numerous conservative treatments for low back pain (LBP). The challenge has been put forward to all those interested in health care, that treatments for LBP must have scientific evidence of their effectiveness.

Although general exercises for the whole body and encouraging the patient to stay active have been shown to be beneficial for the patient with chronic LBP,¹⁴ in recent years increasing emphasis has been placed on giving more specifically directed exercises for the spinal muscles in addition to the general exercise programs. These more specific exercises were developed to target the muscles that are associated with lumbar–pelvic stability with the aim of developing more effective and efficient exercise programs for LBP.¹⁹ In this article we define stability as mechanical control of the joint, including the muscles limiting or controlling unwanted movement, and preventing injuries of ligaments and capsules.

■ Specific Exercises Designed to Stabilize the Segments of the Spine and Pelvis

Specific spinal exercises were developed to target the local muscles of the lumbar–pelvic region. The local muscle system includes deep muscles such as the transversus abdominis and the lumbar multifidus that are attached to the lumbar vertebrae and sacrum and are capable of directly controlling the lumbar segments. By contrast, the global muscle system encompasses the larger and more superficial muscles of the trunk that are more concerned with producing and controlling trunk movements (*e.g.*, the external oblique and erector spinae muscles).² Whereas conventional exercises generally work to increase the strength of the global muscles, the specific exercise approach aims to improve the dynamic stability role of the local muscles in providing stiffness to the segments of the spine and pelvis during functional postures and movements.

The concept that has become the basis of the specific exercise treatment techniques¹⁹ is the ability to cocontract the transversus abdominis and the lumbar multifidus independently of the other larger trunk muscles. This exercise is based on evidence of the stability roles of the

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muscles^{5,13} as well as on evidence that the transversus abdominis functions independently of the other global abdominal muscles.¹¹ The active cocontraction of these muscles is completed at a very low level of muscle activity and has been variously described as forming a deep muscle corset¹⁹ or performing self-bracing.²² Progression of treatment has consisted, in principle, of increasing the patient's efficiency at performing this independent deep corset action while at the same time minimizing the contribution of the global trunk muscles.

These new specific spinal exercises have already been shown to be effective for patients with acute idiopathic LBP. The influence of this exercise approach on muscle size and function as well as on recurrence of symptoms has been investigated.^{7,8} Individuals in the intervention group performed gentle coactivation of the multifidus and transversus abdominis muscles with real-time ultrasound imaging as feedback. There were significantly fewer recurrences in the intervention group than in the control group.^{9,19}

In addition, the specific exercises are effective in the treatment of patients with LBP associated with a specific diagnosis. O'Sullivan et al¹⁸ have demonstrated decreased pain and disability in patients with chronic LBP who have a radiologically confirmed diagnosis of spondylolysis or spondylolisthesis. The exercises are also proving beneficial in LBP conditions arising from the pelvic region. The specific cocontraction of the transversus abdominis and the multifidus is recommended on the basis of a biomechanical model of the stability of the lumbosacral region.²²

■ Mechanism of Action

With evidence of the clinical effectiveness of the specific exercise program, an increasing number of research studies have been designed to demonstrate the mechanisms by which the specific deep muscle contractions can relieve pain and disability in the patient with LBP.^{6,10} This information is needed to help refine the exercise model so as to optimize its effectiveness and efficiency for treatment.

A biomechanical model has been proposed by the Snijders group^{12,20-22} that can explain how specific exercise may help in the conservative management of problems associated with the mechanical control of the sacroiliac joints (SIJ). The almost flat SIJ are protected against dislocation by a strong ligamentous system, but the viscoelastic ligaments are liable to creep under prolonged load. Therefore, we hypothesize that in all loading situations, extra muscle force is needed to press the sacrum between the ilia, which raises friction to resist shearing. We speak of force closure when such a continuous force is needed to hold an object in place.²² If no extra force is needed, we speak of form closure. The extra muscle activity is called self-bracing. At present it is not possible to quantify these different contributions in healthy individuals and in patients. Several muscles with a transverse orientation can produce forces that cross the SIJ in the

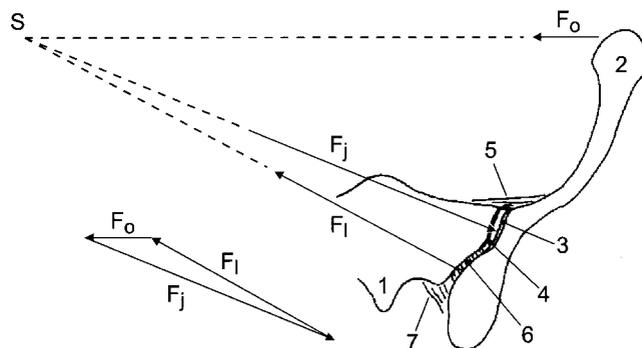


Figure 1. Cross-section of the pelvis at the level of the sacroiliac joints. Force application by the transversely oriented abdominal muscles (F_o), in combination with stiff dorsal sacroiliac ligaments (F_l), compresses the sacroiliac joints (F_j). Because the lever arms of muscle and ligament force are different, the joint reaction force is much greater than the muscle force. 1 = sacrum; 2 = iliac bone; 3 = joint cartilage; 4 = joint space; 5 = ventral sacroiliac ligament; 6 = interosseous sacroiliac ligaments; 7 = dorsal sacroiliac ligaments; S = intersection of forces lines of action.

appropriate direction to produce force closure. They especially include the transverse abdominal, the middle part of the internal oblique abdominal, the piriformis, and the coccygeus muscles. The external oblique abdominal and rectus abdominis muscles are not transversely oriented.

In several *in vitro* and *in vivo* studies we found evidence to support our model.²⁰⁻²² In this respect, the issue is not SIJ disease but the understanding of load transfer at the base of the spine, in which the SIJ stability problem points to interesting muscle actions.

The beneficial effect that contraction of the transversus abdominis, especially, can have on the stability of the SIJ is illustrated in Figure 1. The considerable effect on SIJ compression of transversely oriented muscle force follows from two aspects: (1) The SIJ cavity is almost parallel to the sagittal plane, while the transversus abdominis force acting on the ilia is more or less perpendicular to the sagittal plane. (2) The abdominal muscle force (F_o in Figure 1) produces a counterclockwise moment with respect to the SIJ. A clockwise moment for equilibrium can be realized by tension in the stiff interosseous sacroiliac ligaments (F_l). Because the lever arm of these ligaments is considerably smaller than the lever arm of the transversus abdominis, a force magnification mechanism exists, which can be compared with the principle of a nutcracker. In Figure 1 this situation is illustrated by a graphic analysis. The proportion of the forces is given in the triangle.

This compression can be compared with the strong effect of closed packed positions seen in body support by the tarsal bones. The arch of the foot provides foot protection against shear of the rather flat and vertically oriented tarsal joint surfaces. This mechanism has been further developed for the pelvic arch.²² The mechanical action of a pelvic belt in front of the abdominal wall at the level of the transversus abdominis corresponds with



Figure 2. The color Doppler imaging monitor is to the left of the photograph. The probe is placed dorsal to the left sacroiliac joint. The monitor in the middle displays real-time abdominal muscle activity changes, as shown in Figure 3. This photo also shows the electrode positioning for EMG recording of erector spinae muscle activity.

the action of this muscle. A tension in the pelvic belt of only 4 or 5 kg is sufficient to obtain the required clinical effect.^{15,17}

Aim of This Study

The aim of the study was to demonstrate the significant effect on the laxity of the SIJ of a low-effort activation of the transversus abdominis alone, as predicted by the above model.

■ **Materials and Methods**

Study Participants. Individuals without a history of LBP were selected for this study to ensure that an optimal pattern of muscle contraction could be attained. They included eight men and five women with a mean age of 26 years (SD = 4.3), mass 74 kg (SD = 13), and body height 1.78 m (SD = 0.08). Their mean scores for activity levels were sport, 2.6; leisure, 3.1; and work, 2.5.¹ The measurements were performed in the University Hospital Rotterdam, Dijkzigt.

Equipment and Measurements

Measures of Laxity of the Sacroiliac Joint. Vibrations with 200 Hz of frequency (vibrator Derritron VP3; Derritron Electronics Ltd., Hastings, East Sussex, England) were applied unilaterally to the anterior superior iliac spine of the individuals in prone position with relaxed muscles. The vertical vibrations propagated in the ilium up to and beyond the SIJ area. At the dorsal side, the vibrations of the ilium and the adjacent sacrum were picked up by a color Doppler imaging transducer (Philips Quantum Angio Dynograph 1; Philips Ultrasound Inc., Santa Ana, CA, USA), which covered both sides of the SIJ (Figure 2). Colored pixels resulting from vibration of the sacrum and ilium appeared simultaneously on the monitor at high threshold values (dimension dB). First, a threshold value was found at which the Doppler color image of the vibrating sacrum disappeared and changed to a gray scale. In the same way, a second threshold value was found for the ilium. Because the threshold value was directly related to the vibration velocity of the bone, a large difference between threshold values of the ilium and sacrum

indicated a large difference of vibration velocity (and therefore amplitude) at both sides of the SIJ, which meant that the joint was not stiff. A small difference indicated a stiff joint. This method of measurement was chosen because SIJ stiffness values with the dimension N/m or Nm/rad cannot, at present, be determined *in vivo* noninvasively.

Physically, the difference in threshold values was a measure in dB for the ratio of vibration amplitudes of the ilium and sacrum. The ratio was not affected by a decrease or increase of the vibration input level. Amplitudes were below 0.05 mm. Because a high difference in threshold values implied a high laxity, we used the term *laxity value* rather than *stiffness value*. A laxity value could be regarded as a quantitative noncalibrated indication of joint compression, provided all other factors were constant. A greater SIJ compression force would facilitate vibration propagation across the joint, which decreased the laxity value.

Verification of the Abdominal Muscle Pattern. Two separate measures were used in combination to establish the abdominal pattern used. Real-time ultrasound imaging of the anterolateral abdominal wall was performed with a Siemens Versa Plus using a 5-mHz curvilinear transducer (Siemens, Erlangen, Germany). Surface electromyography (EMG) was performed, and the average integrated signal was measured in microvolts. The equipment used was a Twente Technology Transfer EMG-amplifier, PS-800 (Enschede, the Netherlands).

Features of Draw-in Pattern. The draw-in pattern was a specific contraction of the transversus abdominis, involving the individual drawing in the abdominal wall. Real-time ultrasound imaging of a relaxed abdominal wall (Figure 3A) and during an in-drawing of the abdominal wall (Figure 3B) demonstrated a contraction of the transversus abdominis. Prints of the relaxed state, then the contracted state (taken at the same time as the SIJ laxity measures), verified the changes in shape of the transversus abdominis occurring during the specific abdominal pattern. Surface EMG of the oblique abdominal and erector spinae muscles was used to demonstrate minimal contraction of the global muscles during the specific transversus abdominis contractions.

Features of Brace Pattern. The brace pattern was a general contraction of all the abdominal muscles, involving the individual performing an isometric bracing action. Real-time ultrasound imaging of a relaxed abdominal wall (Figure 3A) and during a brace of the abdominal wall (Figure 3C) demonstrated contractions (increase in depth) of all the abdominal muscles. Prints of the relaxed state, then the contracted state (taken at the same time as the SIJ laxity measures), verified the changes in shape of the individual abdominal muscles occurring during the abdominal bracing pattern.

Surface EMG of both the oblique abdominal muscles and the erector spinae muscles demonstrated higher values during the abdominal bracing contractions than for the draw-in pattern.

Statistics. Differences between laxity values were measured in the resting, draw-in, and brace conditions were statistically tested with mixed model analysis of variance (repeated-measures analysis of variance).

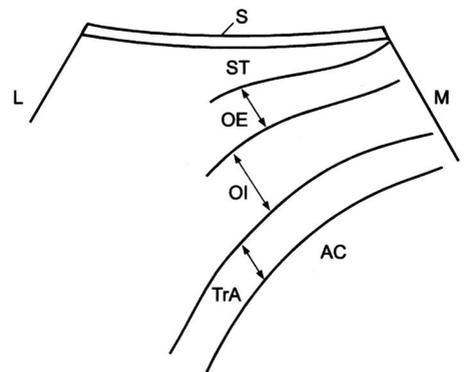
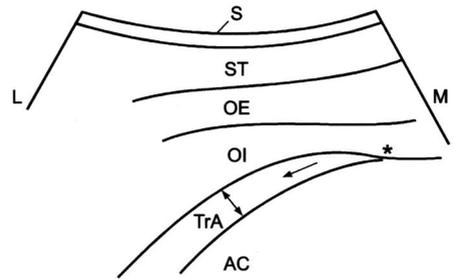
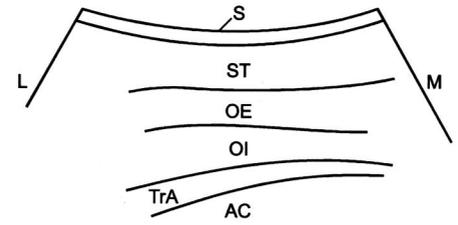


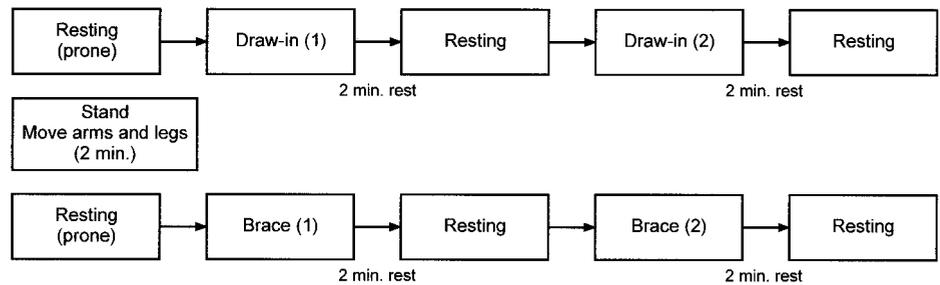
Figure 3. Real-time sonographic appearance of the muscles of the anterolateral abdominal wall in transverse section during relaxed prone lying (A), draw-in test (B), and brace test (C). S = skin; ST = subcutaneous tissue; OE = obliquus externus abdominis; OI = obliquus internus abdominis; TrA = transversus abdominis; AC = abdominal contents.

Procedure

Familiarization Session. At least a day before testing, the study participants attended a familiarization session. Individuals were excluded from the study if they had a history of significant LBP, any history of severe trauma or medical condi-

tions (including respiratory illness such as asthma), surgery to the trunk, pregnancy, obesity (within normal height and weight range), or scoliosis. Those undergoing intensive sports training for competition (*i.e.*, training more than 3 days per week) were also excluded. For inclusion in the study, individuals also had

Figure 4. Schematic representation of the tests performed in this study. Both tests were performed by different individuals in randomized order.



to be able to lie flat in the prone position and be able to perform the two abdominal muscle patterns to be used in the main study. Real-time ultrasound imaging was used to confirm the abdominal muscle patterns. For the draw-in pattern, it was established that the multifidus muscle was contracting with the transversus abdominis.¹⁹ Thirty individuals were considered for the study, but 17 failed to fulfil the inclusion criteria and were excluded from the study. The individuals selected for the main study were asked not to practice the muscle patterns on the day of the testing session to minimize possible fatigue.

Testing Session. The study participants were asked to sign a consent form and complete a physical activity questionnaire.¹ Surface EMG electrodes were then applied (after skin preparation) anteriorly to the left external oblique and the right external oblique just below the rib cage along a line connecting the most inferior point of the costal margin and the contralateral pubic tubercle.¹⁶ Posteriorly, electrodes were attached to the left thoracic erector spinae and right thoracic erector spinae on the muscle bulk at T12. To normalize the EMG recording of the trunk muscles, a standard maneuver of a maximal expiratory volume was undertaken by the individual in the standing position. Readings from a Vitalograph (Vitalograph Inc., Lenexa, KS) were noted during this maximal effort, which was repeated two or three times until the value of maximal expiratory volume was repeatable. An average EMG level could then be taken for the two best efforts. The individual was then assisted into the prone position for testing. The apparatus was arranged for testing of the left SIJ only (Figure 2). The SIJ laxity measures and the real-time ultrasound imaging (to verify patterns) were performed by two individual researchers who were highly skilled at the measurement technique.

Two contractions of each abdominal muscle pattern were performed with real-time ultrasound on the anterolateral abdominal wall and muscle activity (EMG) from the left external oblique, right external oblique, left thoracic erector spinae, and right thoracic erector spinae recorded simultaneously with SIJ laxity (Figure 2). A standard rest period of 2 minutes was given between each test. This was important to ensure that the individuals relaxed fully between each measurement. Visual inspection of the girdle and limb musculature was undertaken to note any signs of increased muscle activity. The order of testing for the effect of the specific transversus contraction and the general abdominal brace were randomized. In between the two patterns tested, the study participants were asked to stand and move the arms, legs, and trunk for 2 minutes. A standard testing order for measures was used for each of the two abdominal patterns tested (Figure 4). As demonstrated in Figure 4, muscle patterns were interspersed with measures of SIJ laxity in the relaxed state. Resting EMG levels were also taken simultaneously with the relaxed state measures.

■ Results

Figure 3 shows a typical example of the sonographic appearance of the muscles of the anterolateral abdominal wall in transverse section at rest; during drawing-in, showing the specific contraction of the transversus abdominis; and during the abdominal brace, showing the general contraction of all of the anterolateral abdominal muscles. All 13 individuals included in the study could perform these tests.

Figure 5 shows the EMG activity of the external oblique abdominal and erector spinae muscles left and right, recorded at the three different tests, as percentages of the maximum found in a standard maneuver of maximal expiration volume. Electromyographic activity at draw-in was significantly larger than at rest ($P < 10^{-4}$) and during brace action significantly larger than at draw-in ($P < 10^{-4}$). Figure 6 shows the average laxity values observed in the two trials. The lower the value, the stiffer the SIJ. This diagram shows that SIJ laxity decreased as the result of draw-in and of brace action, and that draw-in had even more effect than brace. Mean values determined for all individuals and trials are given in Table 1.

■ Discussion

We have demonstrated that the new concepts of exercise for LBP developed at the University of Queensland, Australia are well matched with the biomechanical model on the transfer of spinal load to the pelvis and lower limbs

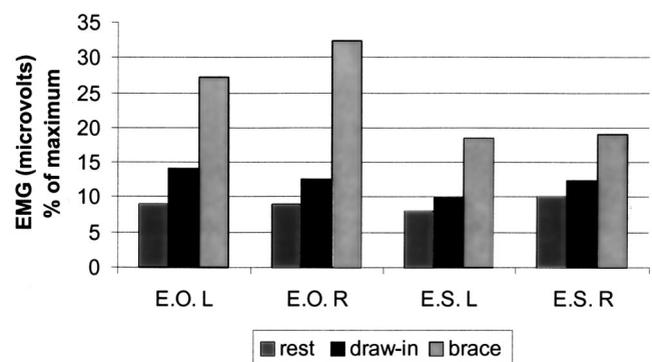


Figure 5. Electromyographic activity from external oblique (EO) left and right and erector spinae (ES) left and right, recorded during rest, the draw-in exercise, and the brace exercise. Average values of all individuals.

that was developed at Erasmus University, Rotterdam, the Netherlands. The results of this study highlight the fact that the transversus abdominis muscle, which is the focus of specific exercise programs for LBP, can significantly decrease the laxity of the SIJ.

The Biomechanical Model

Our biomechanical model is in contrast with other models of spinal loading because it emphasizes transversely oriented abdominal muscles (transversus abdominis and lower portions of the internal oblique) and other transversely oriented muscles such as the piriformis and the pelvic floor muscles, rather than muscles that run more longitudinally, such as the rectus abdominis and the external oblique.^{21,22} Under gravitational load, it is the transversely oriented muscles that must act to compress the sacrum between the ilia and maintain stability of the SIJ. This study helps verify the model.

The measurement of SIJ laxity has recently been introduced and is the first noninvasive objective measure of this entity. It is measured with the individual in a prone position to keep the SIJ in a stationary, neutral, and unloaded position. This quantitative measure is not range of motion but represents a transfer of vibration across the joint, which is best with the joints that are most stiff. In earlier studies, we found a wide range of laxity values in healthy individuals and patients.^{3,4} In the present study, we have demonstrated that the measurement technique is sufficiently sensitive to detect SIJ laxity changes as a result of specific muscle contractions. Reproducibility of the repeated tests was satisfactory, although the rest values of SIJ laxity subsequently decreased slightly, which we ascribe to the fact that these muscles do not completely relax in the 2-minute rest between measurements.

Exercise and Low Back Pain

Exercise techniques that promote independent contraction of the transversely oriented abdominal muscles (in cocontraction with multifidus¹⁹) have been demon-

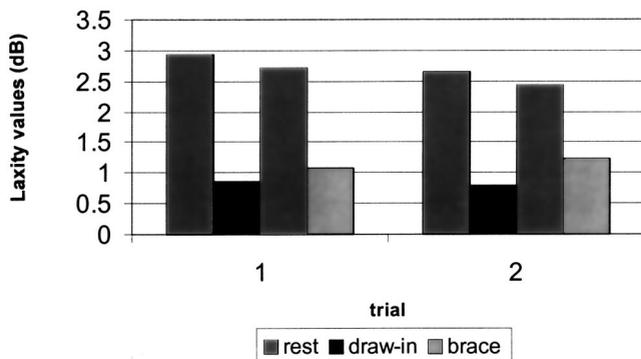


Figure 6. Sacroiliac joint (SIJ) laxity values recorded during rest, the draw-in exercise, and the brace exercise. A lower laxity value represents a stiffer SIJ. The draw-in and the brace test both resulted in laxity decrease, but the draw-in test with independent transversus abdominis contraction was more effective. Average values of all individuals measured in two repeated tests.

Table 1. Mean Values Determined for All Individuals and Trials

		Mean	SE	P Value
1	Resting–draw-in	2.01	0.243	0.0001
2	Resting–brace	1.45	0.236	0.0001
3	Difference 1 and 2	0.56	0.241	0.0260

strated to have beneficial effects in relieving pain and disability in patients with chronic LBP¹⁸ and lowering recurrence rates after an acute pain episode.^{9,19} This study provides some evidence to explain why precise exercise techniques are effective in the relief of LBP.

In all individuals, SIJ laxity was decreased by contraction of the transversus abdominis. This contraction was established by real-time ultrasound imaging, by recording images in the relaxed and contracted state. In addition the independent contraction was verified by EMG recordings of the global muscles. Other muscles of the girdle and limbs were inspected visually during the testing. As expected by model calculations, the transversus abdominis was effective in decreasing SIJ laxity. The drop in the level of average laxity value from approximately 3 to below 1 (Figure 6) meant a reduction to almost complete stiffness. This substantiates the clinical significance of transversus abdominis contraction. This specific contraction was even more effective than the contraction of all the lateral abdominal muscles used in the abdominal bracing maneuver.

This finding is in line with the observations of Hodges and Richardson,¹¹ who used fine-wire EMG to record the patterns of activation of the individual abdominal muscles and observed that the transversus abdominis was controlled independently of the other abdominal and back muscles. It was assumed that its early recruitment before movement during a variety of functional tasks was commensurate with a stabilization role for the spine. It is therefore important that the present study has produced additional biomechanical evidence of the independent functional role of the transversus abdominis in the stabilization of the lumbar–pelvic region. These studies support the argument for LBP exercise treatments to focus on enhancing the stabilization role of the transversus abdominis by precise self-bracing contractions, independently of the other abdominal muscles, rather than general, whole-body exercise programs.

Limitations of the Study and Directions for the Future

One of the limitations of this study was that muscle patterns were activated cognitively. This was controlled to a large extent by the measures of real-time ultrasound imaging and EMG, which provided objective means of verifying the resultant muscle patterns. Furthermore, we cannot exclude other muscles that could have contributed to the decreasing SIJ laxity, in particular the pelvic floor muscles. In addition to the relevance of this study for the conservative management of LBP, these measurement tools may contribute to improved preoperative

testing of patients with severe problems to better predict the outcome of their surgery.

■ Key Points

- The abdominal muscles with transversely oriented muscle fibers, most particularly the transversus abdominis, significantly decrease the laxity of the sacroiliac joints.
- The decrease in laxity as a result of the abdominal wall muscle action is in line with biomechanical model calculations.
- The contraction of the transversus abdominis, independently of the other abdominal muscles, affects the laxity of the sacroiliac joints to a larger extent than a bracing action using all of the lateral abdominal muscles.
- Exercises for lower back pain should incorporate a precisely controlled contraction of the transversus abdominis independently of the global muscles.

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