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ORIGINAL ARTICLE

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Stabilization of the sacroiliac joint in vivo: verification of muscular contribution to force closure of the pelvis

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Abstract A model of sacroiliac joint (SIJ) function postulates that SIJ shear is prevented by friction, dynamically influenced by muscle force and ligament tension. Thus, SIJ stability can be accommodated to specific loading situations. The purpose of this study was to examine, in vivo, whether muscles contribute to force closure of the SIJ. SIJ stiffness was measured using a verified method combining color Doppler imaging with induced oscillation of the ilium relative to the sacrum in six healthy women. SIJ stiffness was measured both in a relaxed situation and during isometric voluntary contractions (electromyographically recorded). The biceps femoris, gluteus maximus, erector spinae, and contralateral latissimus dorsi were included in this study. Results were statistically analyzed. The study showed that SIJ stiffness significantly increased when the individual muscles were activated. This held especially true for activation of the erector spinae, the biceps femoris and the gluteus maximus muscles. During some tests significant co-contraction of other muscles occurred. The finding that SIJ stiffness increased even with slight muscle activity supports the notion that effectiveness of load transfer from spine to legs is improved when muscle forces actively compress the SIJ, preventing shear. When joints are manually tested, the influence of muscle activation patterns must be considered, since both inter- and intra-tester reliability of the test can be affected by muscle activity. In this respect, the relation between emotional states, muscle activity and joint stiffness deserves further exploration.

Keywords Sacroiliac joint · Stabilization · Emotions · Doppler · Electromyography

Introduction

This study was initiated to demonstrate in vivo that muscles contribute to force closure of the sacroiliac joint (SIJ). According to the model of form and force closure, shear in the SIJs is prevented by increased friction due to a combination of two factors:

1. Specific anatomic features increase the friction coefficient (form closure) and
2. Tension of muscles and ligaments crossing the SIJ lead to higher friction and hence stiffness (force closure) [16, 20, 23, 24]

Thus, stabilization of the SIJs can be dynamically accommodated to the specific loading situation [16, 17, 21, 22, 24, 26, 27, 29, 30, 31]. Stability of the SIJs is partly realized by tension of ligaments due to SIJ motion [16, 21, 23, 24, 27, 28]. The model assumes that for effective transfer of load from the spine through the pelvis to the legs, muscles acting on the pelvis must be activated to increase force closure of the SIJ [17, 29, 30]. Research on joint stability in general and SIJ stability specifically is mainly focused on quantitative measurements, including recording of the range of motion [10, 12, 15, 18, 19, 20, 25]. No studies were found on qualitative measurements such as establishing the stiffness of the SIJ or determining the ability of the SIJ to resist shear forces. The need for a reliable and non-invasive method to quantify SIJ stability in vivo resulted in the development of a measuring technique, combining color Doppler imaging (CDI) with excitation of the pelvis by means of an oscillation device [1, 2, 3]. With this method, force closure of the SIJ can be measured in vivo as a function of the amount of SIJ friction.

Experimental application of this method on an artificial mechanical model of the pelvis showed reproducible results [1, 2, 3]. Further validation of this method was performed in three different studies: on embalmed specimen, on healthy subjects, and a comparative clinical study demonstrating this technique to be objective and reproducible in determining SIJ stiffness (reliability coefficients: left SIJ 0.97, right SIJ 0.94) [1, 2, 3].

Previous anatomical in vitro studies have identified specific muscles that could contribute to SIJ stabilization. Biceps femoris and gluteus maximus muscles could increase force closure of the SIJ, through their specific and massive attachments to the sacrotuberous ligament [21, 22, 30]. Gluteus maximus and latissimus dorsi were found to be partially coupled by the posterior layer of the thoracolumbar fascia, creating a compressive force acting perpendicular to the SIJ. This was confirmed by a study of Mooney et al. [13]. Finally, it was shown that the tendinous aponeurose of the erector muscle was closely linked to the sacrum and posterior superficial SIJ ligaments [28].

The present study attempts to determine whether muscles contribute to force closure in vivo. This study combines CDI and artificially generated oscillation of the SIJ with controlled activation electromyography (EMG) of specific muscles, applied to a group of healthy volunteers. Because of their assumed role in force closure of the SIJ, this study focused on the effect of unilateral activation of the biceps femoris, gluteus maximus and erector spinae, and contralateral activation of the latissimus dorsi muscle [13, 21, 22, 29, 30]. It was expected that the null hypothesis that muscles cannot stabilize the SIJs would be disproved.

Materials and methods

Volunteers

Fifteen female volunteers (aged 15–30 years) participated in this study. They were all in good physical health with no recent complaints of spine, pelvis or hip joints. To increase the sensitivity of the CDI method, only pelves that exhibited considerable motion were included. Joint stiffness was initially measured three times with CDI during application of oscillation to the pelvis. Only in six volunteers (average age 22, SD 2.6 years) were threshold values of the CDI high enough to be included in the study (see Results). Average height and weight of the subjects were respectively 170 (SD 4.1) cm and 62 (SD 4.9) kg. Preliminary tests showed the protocol to be fairly straining to the subjects. Because testing both sides may have led to unreliable results due to fatigue [11], during the experiment, tests were performed unilaterally (four right side, two left side).

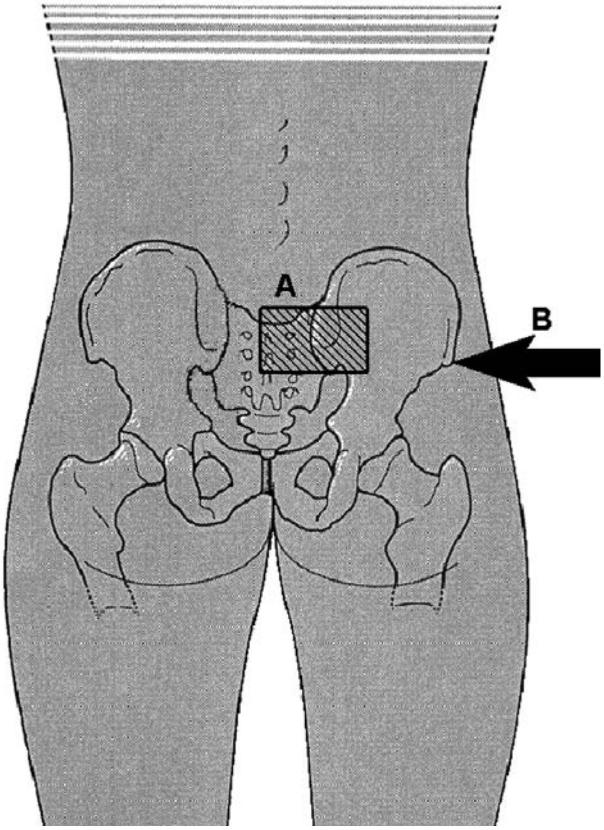


Fig. 1 Outline of test position for combined color Doppler imaging (CDI) and electromyographic (EMG) measurements. **A** Location of the CDI probe over both sacrum and ilium on one side of the pelvis. **B** Positioning of the oscillator plate against the anterior superior iliac spine

Testing procedure

Volunteers were positioned prone with the anterior superior iliac spine in contact with the oscillator plate (Fig. 1). Before the measurements, a maximal voluntary contraction (MVC) of each separate muscle was recorded, using isometric muscle test procedures with manual resistance as described by Kendall et al. [9].

Each measurement started with determination of SIJ stiffness without any muscle activation using CDI. The volunteers were then asked to activate only one particular muscle for the period of the measurement, using the technique as for the MVC test. However, in contrast to the MVC test, no maximal voluntary contraction but only slight effort of the tested muscle was pursued (>10% of MVC), with no or only minimal coactivation of other muscles (<10% of MVC) and minimal disturbance of the initial posture. Since only minimal exertion was required, no manual resistance (in contrast to the MVC test) was applied during the tests.

During each test, EMGs of all four muscles were recorded simultaneously to test for co-contractions. Sustained muscle contractions with an average duration of 10 s were required to analyze SIJ stiffness by means of the CDI method.

The test sequence was repeated three times with biceps femoris, gluteus maximus, latissimus dorsi and erector muscles tested in randomized order for each subject.

Finally, to verify that EMG signal quality did not change during the measurements, a second maximal voluntary contraction test, similar to the initial MVC test was performed for each muscle.

EMG recording

Electrode location was determined as described by Delagi et al. [4, 7, 11]. Volunteers were instrumented with surface EMG electrodes (Meditrace pallet electrodes) after the skin had been scrubbed and cleaned with alcohol. EMG signals were amplified and 10–2 kHz filtered (bipolar EMG amplifier PS-800, Twente Medical System). The signals were rectified, low-pass filtered (10 Hz) and simultaneously fed to a computer with a sample frequency of 50 Hz. Preliminary studies showed no interference of the vibration device with the EMG recordings.

Color echo Doppler imaging (CDI)

The application of CDI in combination with generated oscillation and the subsequent validation of this method has been described in detail in previous studies on SIJ stiffness [1, 2, 3]. Vibrations with a frequency of 200 Hz (using a Derritron VP3 oscillator) were unilaterally applied to the anterior superior iliac spine. The vibrations from ilium and sacrum were measured by a Philips Quantum AD1 CDI transducer, covering both sides of one SIJ (see Fig. 1).

Table 1 Mean electromyography levels of muscles as percentages of maximal voluntary contraction and mean decrease of threshold difference (THD) during specific tests when compared to THD measured in the relaxed situation (*n*=6)

Test for	Biceps Mean (SD)	Gluteus Mean (SD)	Erector Mean (SD)	Latissimus Mean (SD)	THD Mean (SD)
Biceps	54 (22)**	9 (6)	27 (23)	6 (4)	2.5 (0.5)**
Gluteus	19 (5)**	47 (22)**	42 (27)*	18 (14)	2.7 (0.8)**
Erector	10 (6)	8 (3)	46 (19)**	14 (10)	2.7 (1.5)**
Latissimus	13 (8)	9 (9)	27 (21)	34 (13)**	1 (0.6)**

$^{*}P<0.05$; $^{**}P<0.01$; *P*-values are calculated with a paired *t*-test, for muscles: H0:$\mu=10$, for THD H0:$\mu=0$

The threshold indicates the necessary signal power to display perceived vibration in color. The height of the threshold is set by the operator by means of the threshold button on the control panel of the CDI apparatus. During a measurement the threshold is precisely set to the level were no vibrations are visible on the CDI screen. A large difference between the thresholds (threshold difference; THD) set at the sacrum and ilium indicates little stiffness of the SIJ. A small or absent THD indicates a stiff joint [1, 2, 3]. In this study, differences between THD in the relaxed position and the THD during a muscle test were used as a measure for change in SIJ stiffness. A decreased THD during the muscle test indicates that the joint has become more stiff.

Analysis

To determine changes in SIJ stiffness during muscle activity, THDs found during muscle tests were subtracted from THDs found during relaxed postures for each individual. The muscle tests were: (1) the biceps femoris test, (2) the gluteus maximus test, (3) the erector spinae test and (4) the latissimus dorsi test. From the three repetitions of each muscle test the mean THD was calculated. The statistical significance of mean differences between THD during relaxed postures and the THD during each muscle test was determined using a paired two-sample *t*-test.

To quantify the activity level of each muscle during the tests, the recorded EMG signals were averaged. From the three repetitions of each muscle test, the mean activity level was calculated. To compare between subjects, the muscle activity levels are presented as percentages of the MVC for each muscle.

Muscle activity (in percentage of MVC) during relaxed position and during the muscle tests was compared using a paired *t*-test. A muscle was considered active when the activity level during the tests was more than 10% of MVC. *P*-values less then 0.05 were considered significant.

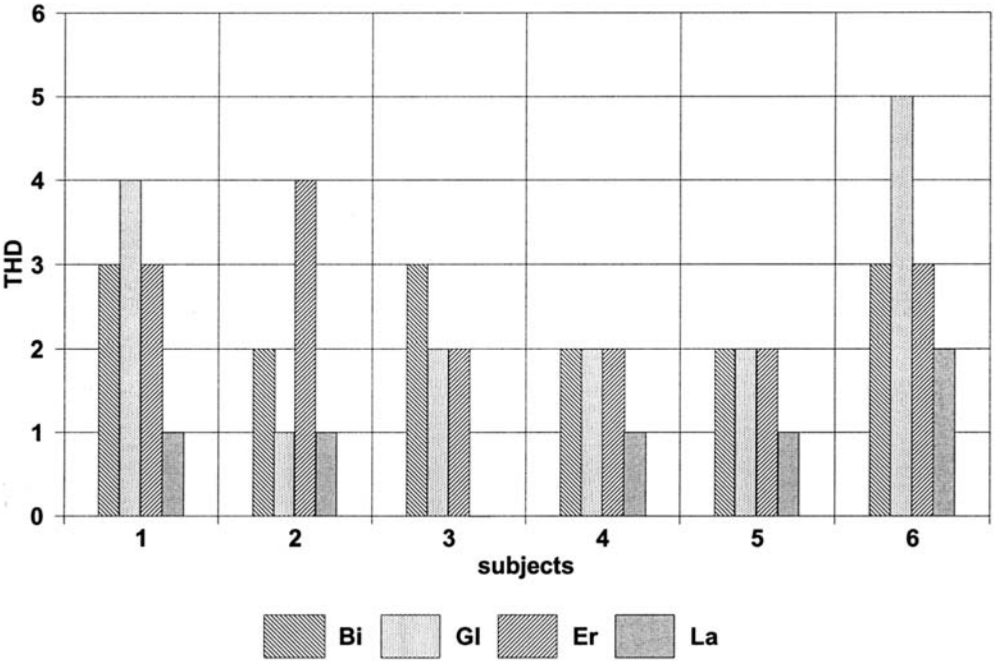


Fig. 2 Mean decrease in threshold level (THD) for each muscle test clustered by volunteer (*Bi* biceps femoris, *Gl* gluteus maximus, *Er* erector spinae, *La* latissimus dorsi)

Fig. 3 Mean (3 repetitions) EMG activity of all muscles as percentage of maximal voluntary contraction (MVC) for each volunteer during the biceps test

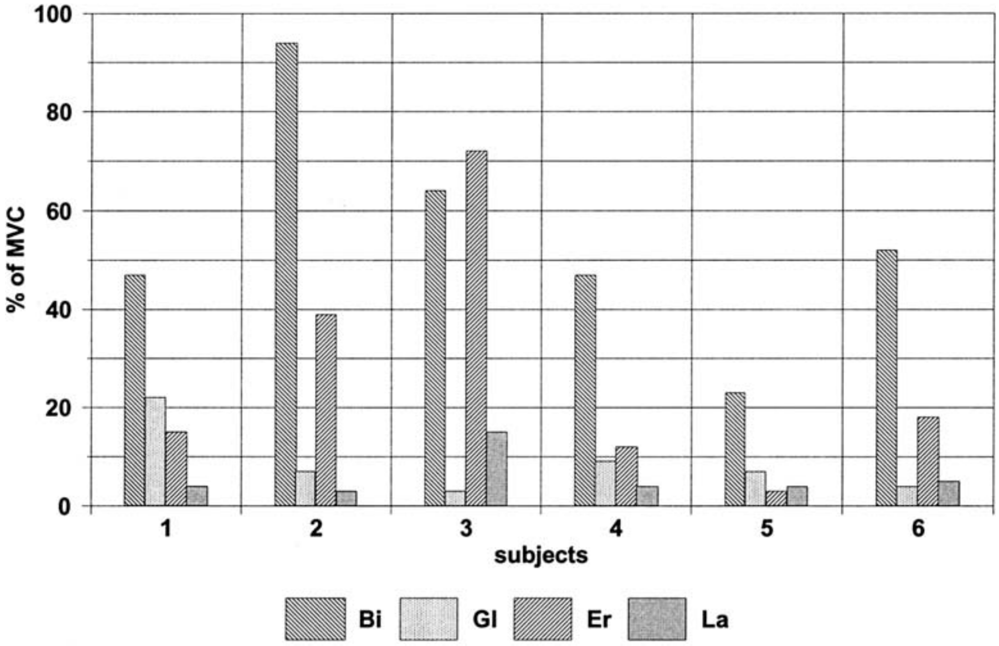
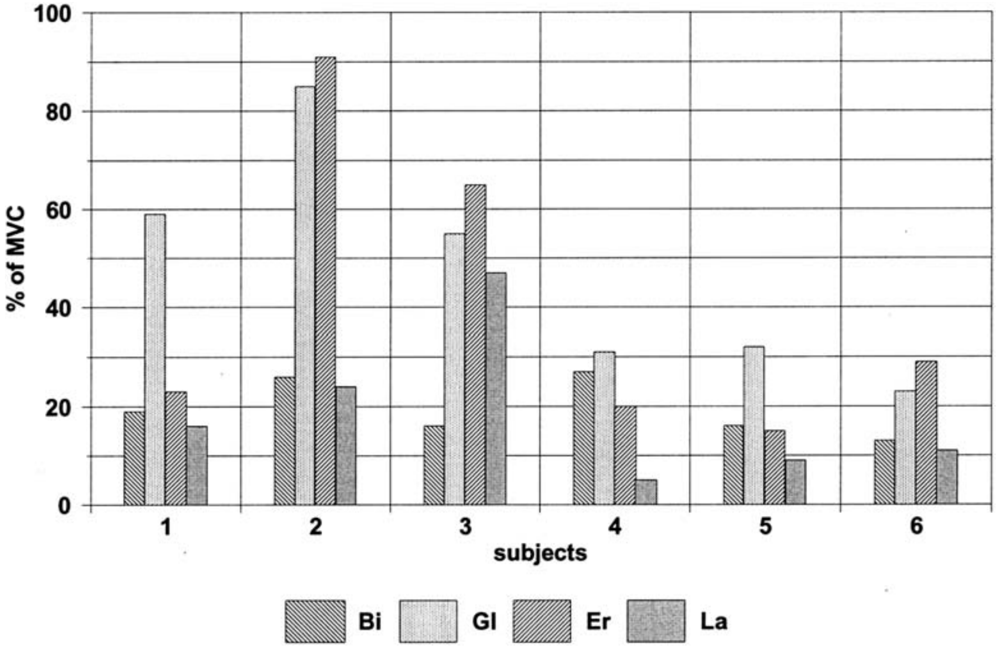


Fig. 4 Mean (3 repetitions) EMG activity of all muscles as percentage of MVC for each volunteer during the gluteus test



Results

Mean results of all subjects are presented in Table 1. Individual results are presented in Fig. 2, Fig. 3, Fig. 4, Fig. 5 and Fig. 6. During the initial SIJ stiffness measurements (no muscle activation), the individual mean THDs were 5.8, 3.0, 3.8, 6.0, 4.0 and 8.3 respectively (mean 5.2, SD 1.94). The THD in the relaxed position between measurements varied in most cases by zero or one level. In one occasion the THD was two levels lower than the initial measurement. During each muscle test the THDs significantly diminished (Table 1). This effect was particularly strong during the erector, gluteus and biceps muscle test; the mean decreases of THD of 2.7, 2.7 and 2.5 respectively came to about 50% of the mean relaxed THD of 5.2. The mean results show a significant increase in SIJ stiffness when muscles were activated. Fig. 2 shows that there was

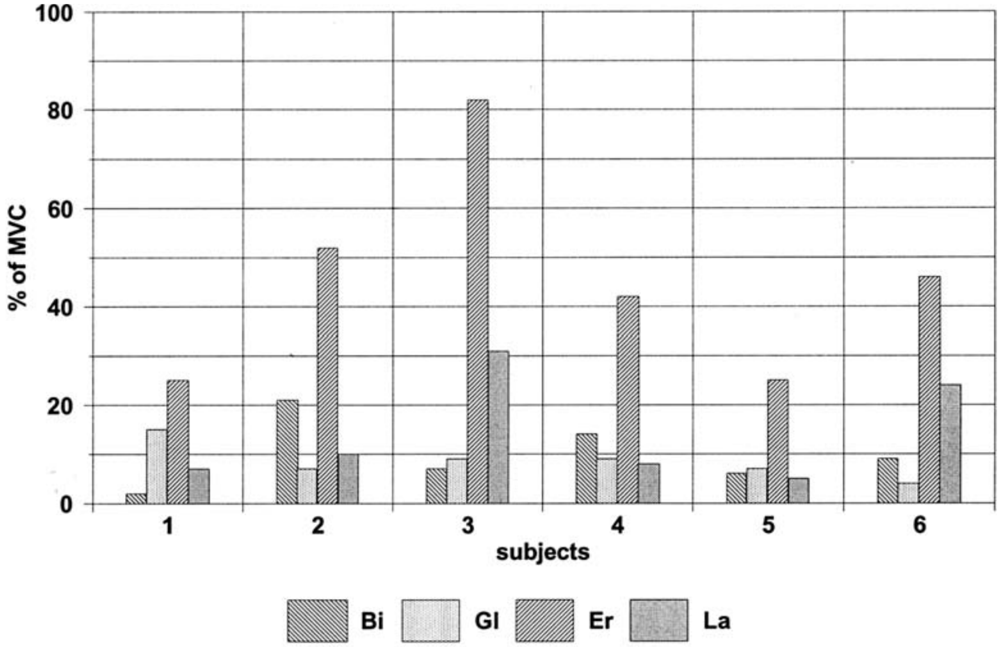


Fig. 5 Mean (3 repetitions) EMG activity of all muscles as percentage of MVC for each volunteer during the erector test

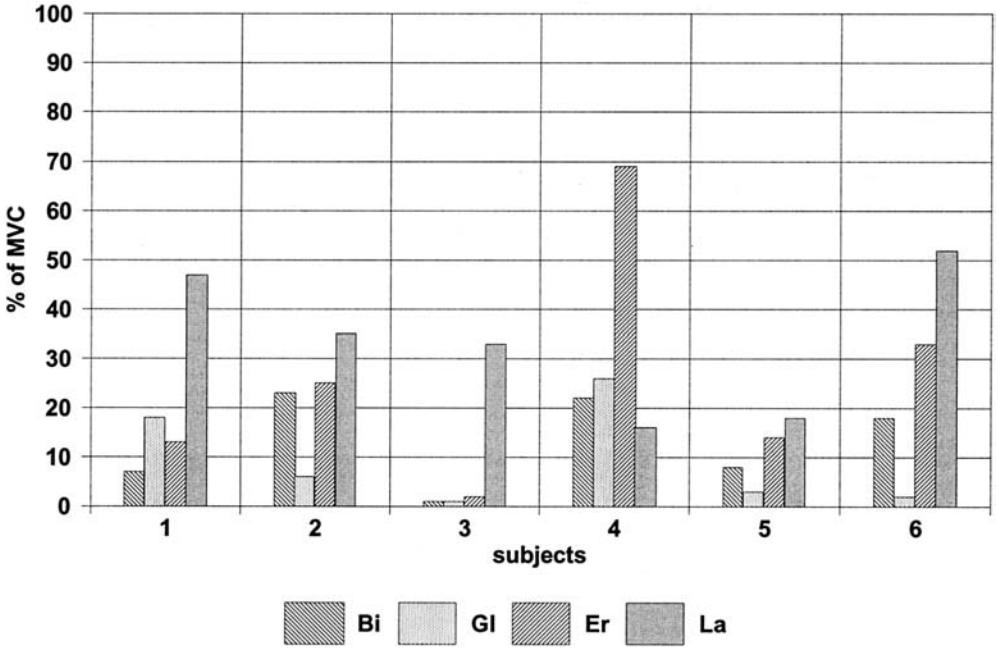


Fig. 6 Mean (3 repetitions) EMG activity of all muscles as percentage of MVC for each volunteer during the latissimus test

no change in THD during the latissimus test for subject 3. The other subjects also showed the smallest decrease in THD for activation of the latissimus dorsi.

With respect to muscle contribution, in all tests the highest mean EMG level was found for the target muscle (Table 1). In some individual tests, however, erector EMG level is higher than the target muscle: this was true during the biceps test for subject 3, during the gluteus test for subjects 2, 3 and 6, and during the latissimus test for subject 4 (Fig. 3, Fig. 4, Fig. 5, Fig. 6). In most individual tests there is more than 10% of MVC EMG activity of other muscles. However, as Table 1 shows, this does not result in significant co-activation. Only during the gluteus test is the mean EMG activity of another muscle besides the gluteus (erector) significantly more than 10% of MVC (42%).

For all muscles the MVC before the test sequence is highly correlated with the MVC after the tests (ICC; biceps: 0.98, gluteus: 0.98, erector: 0.97 and latissimus: 0.92).

Discussion

SIJ motion is characterized by minute movements [18, 19, 21]. Color doppler imaging in combination with pelvic oscillation can be applied to study sacroiliac stiffness in vivo [1, 2, 3]. This method was used to analyze the influence of muscle activity on SIJ stiffness. It showed that contraction of the selected muscles increased SIJ stiffness. The null hypothesis that SIJ stiffness cannot be influenced by muscle activation must therefore be rejected. The erector spinae, the biceps femoris and the gluteus maximus muscles were shown to have the greatest effect on SIJ stiffness. The latissimus dorsi muscle was shown to have a small effect on SIJ stiffness. Subject 3 was able to activate the latissimus dorsi nearly in isolation (Fig. 2, Fig. 6), with no change in SIJ stiffness. It can be argued that the increased SIJ stiffness during the latissimus test in other subjects was due to action of other muscles than the latissimus dorsi. Besides statistical significance of the results, some intriguing inter-individual differences occurred in both muscle activation and decrease of THD (Fig. 2, Fig. 3, Fig. 4, Fig. 5, Fig. 6). These differences may be partly due to individual initial threshold values, but also to individual muscle activation patterns. Therefore the relative contribution of specific muscles to SIJ stiffness needs further study.

Although the activated muscle was the most electromyographically active muscle during all tests (Table 1), the coactivation of other muscles occurred. The significant co-contraction of biceps femoris and erector spinae muscles during the gluteus maximus test is to be expected, since effective movement requires orchestrated contractions of multiple muscles to evoke tailored joint reaction forces [24]. Co-contractions could have been precluded by using electric muscle stimulation instead of intentional voluntary isometric muscle activation. A reason for not opting for this latter solution is that optimal recording of CDI threshold values, and thus establishing realistic values for SIJ stiffening, requires maximal relaxation of the volunteers. Electric stimulation can be painful, with possible involuntary increase of muscle tone, directly affecting the measurements.

The considerable coactivation of the erector muscle during the biceps, latissimus and gluteus maximus tests, were to be expected, since it has been shown that the aponeurosis and muscle strains of the erector spinae insert on the sacrum, the ilium (PSIS) and partially the long dorsal sacroiliac ligament and sacrotuberous ligament [27, 28]. These anatomical connections explain how the muscle can contribute to stability of the SIJ. This coactivated function of the erector, as described here, is also in agreement with the stabilizing function of the multifidus part of the muscle as described by Hides [5]. The Hides' study shows that the multifidus is coactive with the transverse abdominals and possibly oblique abdominals as primary stabilizers of spine and pelvis [5, 6, 7]. Since in the present study surface electrodes were used, the abdominal muscles could not be included.

During the gluteus maximus test, the activity of erector spinae is particularly high. An additional reason for this activity could be that the subjects were asked to "take the weight of their upper leg from the table," thus activating the erector in the process of stabilizing pelvis and spine.

The influence of muscles on SIJ stiffness as demonstrated in this study could have clinical consequences. In the clinic, joint stiffness is commonly determined by means of the manual skills of the clinician. However, it has been shown that the intra- and inter-tester reliability of manual tests is low [14]. To our knowledge, no studies have been performed to reveal to what extent poor reproducibility of manual tests may be related to variance of muscle tension and hence joint stiffness between tests (in fact intra-joint or patient reliability). The present study showed that SIJ stiffness is influenced by muscle activity and thus by motor patterns. It can be expected that this also holds true for joint stiffness in general. Small variations in the excitation pattern of muscles can lead to differences in joint stiffness. Consequently, during retesting of joints in patients, relatively small postural changes can result in altered muscle contraction patterns and consequently influence the inter- and intra-tester reliability of manual joint play tests.

The use of CDI in combination with bone oscillation gives valid results; however, the method is not easy to use in daily practice [1, 2, 3]. To ascertain valid results in this study, only subjects with a relatively high (>2.5) THD during the relaxed posture were chosen. The aim of the study was only to demonstrate the effect of muscle contraction on SIJ stiffness. Therefore, the small number of included subjects (n=6), as a consequence of the high THD criterion, was considered acceptable for this study. Future studies on specific muscles like the transverse and oblique abdominus, using selective electro-stimulation, are necessary [5, 6, 7, 17].

This study wanted to show that joint stiffness is influenced not only by structural quality and integrity of the joint, but also by the dynamics of muscle activity. It can therefore be assumed that even when no muscle activity is detected on EMG, basic muscle tone already influences joint stiffness. Emotional states are known to influence basic muscle tone and patterning [8]. The effect of emotional states on specific muscle patterns needs to be taken into account when analyzing SIJ function.

In conclusion, this in vivo study showed that stiffness of the SIJ was increased by certain muscle activity. This supported the proposed model that load transfer from spine to legs is enhanced when muscles actively compress the SIJ, thus preventing shear [16, 17, 22, 23, 24]. This agrees with a recent study by Sturesson et al., who demonstrated that in postures with long lever arms, as in stooped positions, SIJ motion became restricted [18, 19].

This in vivo study enhanced our understanding of how muscles dynamically influence SIJ stiffness. The results, however, could have implications for joints in general. When joints are manually tested, the influence of muscle activation patterns must be taken into consideration to recognize how both inter- and intra-tester reliability can be influenced. In this respect, the relation between emotional states, muscle activities, SIJ stiffness and joint stiffness in general deserves further exploration.

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