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A functional-anatomical approach to the spine-pelvis mechanism: interaction between the biceps femoris muscle and the sacrotuberous ligament

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Une approche anatomo-fonctionnelle de la mécanique pelvi-rachidienne: interaction du muscle biceps fémoral et du ligament sacro-tubéral

Résumé. On pense rarement au dysfonctionnement de l'articulation sacro-iliaque comme cause possible de "lombalgie". Cela est dû au fait que l'on a recours bien souvent à des modèles anatomiques incomplets. D'un point de vue cinématique, les modèles habituels d'anatomie topographique sont généralement insuffisants car ils individualisent le pelvis, la colonne lombaire inférieure et les membres inférieurs comme des entités distinctes. Cette étude anatomo-fonctionnelle centre son intérêt sur la question de savoir si les relations anatomiques entre le muscle biceps fémoral et le ligament sacro-tubéral sont cinématiquement utiles. Les forces appliquées au tendon du muscle biceps fémoral, semblent influencer la tension du ligament sacro-tubéral. Comme la tension du ligament sacro-tubéral influence la cinématique de l'articulation sacro-iliaque, l'entraînement des ischio-jambiers pourrait influencer l'articulation sacro-iliaque et ainsi la cinématique du rachis lombaire. Les applications cliniques concernant la rétraction des ischio-jambiers, l'instabilité pelvienne et la marche sont discutées.

Mots-clés: Pelvis – Ligament sacro-tubéral – Muscle biceps fémoral – Stabilité articulaire – Articulation sacro-iliaque

Summary. Sacroiliac joint dysfunction is often overlooked as a possible cause of low back pain. This is due to the use of reductionistic anatomical models. From a kinematic point of view, topographic anatomical models are generally inadequate since they categorize pelvis, lower vertebral column and legs as distinct entities. This functional-anatomical study focuses on the question whether anatomical connections between the biceps femoris muscle and the sacrotuberous ligament are kinematically useful. Forces applied to the tendon of the biceps femoris muscle, simulating biceps femoris muscle force, were shown to influence sacrotuberous ligament tension. Since sacrotuberous ligament tension influences sacroiliac joint kinematics, hamstring training could influence the sacroiliac joint and thus low back kinematics. The clinical implications with respect to 'short' hamstrings, pelvic instability and walking are discussed.

Key words: Pelvis – Sacrotuberous ligament – Biceps femoris muscle – Joint Stability – Sacroiliac joint

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For successful treatment of pelvic and spinal disorders, it is essential to have a clear insight into the morphology and function of the connections between spine and pelvis, i.e. the sacrum and its joints. As a rule, discussions on low back pain are based on classifications used in topographical-anatomical models. In these models spine, pelvis and lower extremities are considered as separate entities. However, from a neurophysiological, biomechanical and functional anatomical point of view these structures are fully coupled. The topographical-anatomical approach is shown by reductionistic terminology as in the word back muscles. After all, these muscles are not only connected to head and ribs but also to pelvic structures such as the iliac crests, sacrum and sacroiliac ligaments [2, 10, 11, 12, 17]. Obviously, parts of the back muscles act directly and indirectly at the sacroiliac (SI) joints. Consequently, neglecting SI joint dysfunction as a cause of low back pain may well be the result of the use of reductionistic anatomical models leading to an artificial classification.

Earlier studies [18–21, 24] dealt with the intertwined relationship between pelvis and spine. Specific symmetrical roughening patterns on the surface of the SI joints, already commencing in the pubertal period, were considered as functional adaptations, increasing stability [20]. As shown in a biomechanical study, the specific roughening of the SI joint surfaces goes with a higher friction coefficient. Furthermore, it was shown that the stability of the SI joint was increased by a larger wedge-angle of the joint. As a result, less ligament force is required for bearing the upper part of the body. Vleeming et al. [21] described this as the self-bracing effect of the SI joint. This refers to the dynamic mechanism by which the internal friction in the SI joint can be increased.

Since the sacrotuberous ligament influences the self-bracing mechanism, muscles connected to the ligament could play an important role in obtaining SI joint stability [18, 19, 24]. Connections between the gluteus maximus muscle and the sacrotuberous ligament were found [18]. In the same study the sacrotuberous ligament was shown to be fused with the tendon of the long head of the biceps muscle in six out of twelve cadavers, in four cases even bilaterally.

The anatomical findings were substantiated by a biomechanical study: when minor loads in the direction of the gluteus maximus and biceps femoris muscles were applied bilaterally to the sacrotuberous ligament, ventral rotation (nutation) of the sacrum, as a result of simulated bodyweight, diminished significantly. Since in some cases the long head of the biceps femoris muscle is connected to the sacrotuberous ligament, it is hypothesized that force from this muscle can influence sacrotuberous ligament tension, and in doing so can dynamically influence stability of the SI joints [19].

This article deals with the question whether biceps femoris muscle force indeed influences sacrotuberous ligament tension.

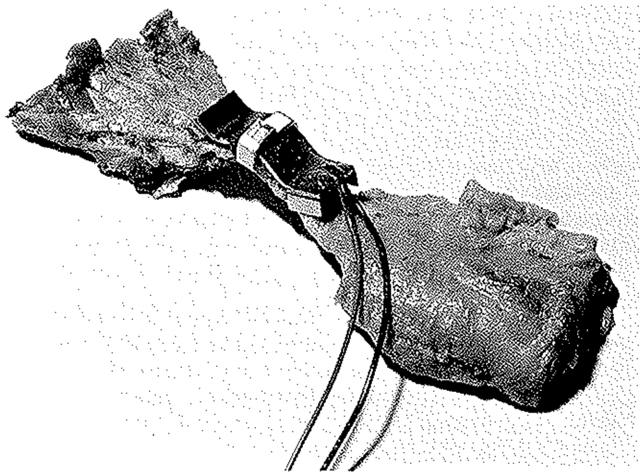

Fig. 1. Buckle-transducer attached to sacrotuberous ligament. Ligament dissected from pelvis after measurement for calibration

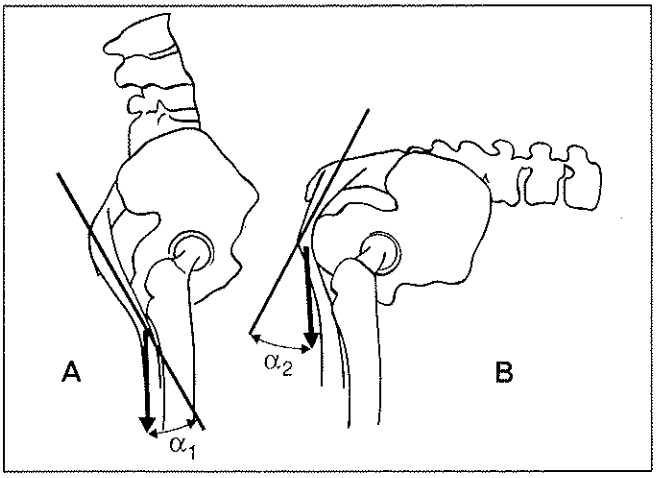

Fig. 2A, B. From erect stance (**A**) to flexed stance (**B**) the angle between the sacrotuberous ligament and the biceps femoris muscle changes from α_1 to α_2

Materials and methods

Six human bodies (two male, four female) at the ages of 70–90 years were embalmed by vascular perfusion with a medium containing 2.2% formaldehyde. The skin, gluteus maximus muscle and soft tissue covering the sacrotuberous ligament were carefully removed, leaving the sacrotuberous ligament unimpaired. In addition, the distal part of the biceps femoris muscle was removed, leaving intact its proximate tendon and adjacent muscular tissue originating from the ischial tuberosity. Special attention was given to the course of the fibres of the sacrotuberous ligament. Based on the macroscopic findings the sacrotuberous ligaments were classified as either *totally* or *partially* fixed to the ischial tuberosity.

In a previous study the effect of increased sacrotuberous ligament tension on SI joint mobility was demonstrated under loaded conditions of the lower lumbar spine and pelvis, to simulate trunk weight [19]. This study focuses on the influence of biceps femoris muscle force on sacrotuberous ligament tension. Body weight was not simulated. The specimens were lying prone and anchored to the table to prevent sliding. Ligament tension was recorded by means of a custom-made buckle-transducer (Fig. 1), as described by Peters [14] and Barry and Ahmed [1]. The dimensions of the transducer were adapted to fit a sacrotuberous ligament: 8 × 12 × 34.5 mm. (Strain gauge: Micromeasurements EA-09-062-AP). The buckle-transducer could be applied to the sacrotuberous ligament without affecting its anatomical integrity. Biceps femoris muscle forces from 0 to 100 N with a 10-N increment were simulated with weights. As site of impact, the biceps femoris muscle tendon was chosen 5 cm caudal to the ischial tuberosity.

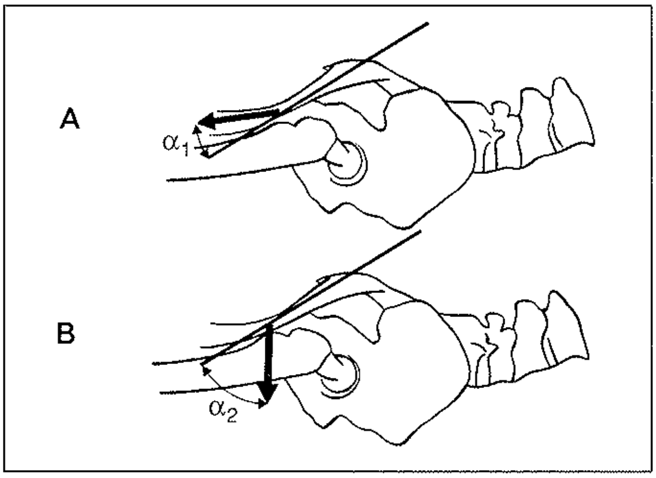

Fig. 3A, B. Angle between sacrotuberous ligament and biceps femoris muscle during measurements. **A** Simulated erect stance and **B** simulated flexed stance. α_1 Approximately longitudinal to the biceps femoris muscle tendon; α_2 vertically downwards

During hip flexion the angle between the sacrotuberous ligament and the biceps femoris muscle tendon changes (Fig. 2). It can therefore be expected that the amount of force transmitted to the ligament is influenced by the pelvic tilt in the sagittal plane. For this reason measurements were taken in two different directions (Fig. 3). Firstly, the direction of the applied forces was approximately longitudinal to the course of the biceps femoris muscle, simulating erect stance, to be referred to as 'erect' or 'upright'. Secondly forces were applied vertically downward to the biceps femoris muscle, simulating hip flexion and to be referred to as 'flexed stance'. To avoid test repetition influence the sequence of force directions was randomized.

To be able to convert the transducer output from millivolts to Newtons the transducer was calibrated for each individual ligament. For this calibration the ligament and transducer were simultaneously removed after the measurements. Calibration was performed twice from 0 to 50 N in steps of 10 N. (Correlation coefficient > 0.995 and mean standard error of estimate = 0.14, range of 0.10).

All tests were repeated three times for each simulated situation. Data of three repetitions were statistically analyzed using two sample ANOVA.

Results

Anatomy

In all preparations the superficial fibres of the sacrotuberous ligament were continuous with the superficial collagenous fibers of the biceps femoris muscle tendon. In six ligaments the deeper part of the ligament was medially connected to the ischial tuberosity. However, the lateral deep part of these ligaments was connected to be the biceps femoris muscle tendon, and no significant fixation to the ischial tuberosity occurred (to be referred to as 'partially fixed' ligaments, Fig. 4).

The deeper parts of the other four ligaments (nos. 1, 2, 9 and 10) did not have any connections with the biceps femoris muscle tendon; they were fully connected to the ischial tuberosity (to be referred to as 'totally fixed' ligaments).

Macroscopic observations showed that the fibres of all sacrotuberous ligaments tested were not arranged parallel but spiral in the course of the ligament. As a result, the medial fibres of the ligament cross to the cranial part of the sacrum, while fibres originating more laterally in the ischial tuberosity region attach to the caudal part of the sacrum. This coiled structure was present in all ligaments.

In both the partially and the totally fixed ligaments the tendon of the long head of the biceps femoris muscle is usually shaped at the level of the ischial tuberosity.

Biomechanics

The results are presented as the ratio of the force applied to the biceps femoris muscle tendon and the force measured on the sacrotuberous ligament (Table 1). In Table 1 every two sequential ligaments belong to one body, except for ligaments 3 and 4 which belong to different bodies. Statistical analysis showed that part of the force applied to the biceps femoris muscle tendon was transferred to the sacrotuberous ligament, in all preparations and in all situations. However, interindividual differences were large (Table 1). Transferred forces tended to be higher during the simulated flexed stance than during simulated erect stance (Table 1), but differences were not significant. Between genders no sigificant differences were not significant. Between genders no significant differences in force transfer could be demonstrated, nor between left and right (Table 1).

More specific results can be summarized as follows:

1. In comparing the sacrotuberus ligaments partially fixed to the ischial tuberosity with the totally fixed sacrotuberous ligaments the following have to be noted: (a) during simulated flexed stance, force transfer to the partially fixed ligaments was significantly higher than to the totally fixed ligaments ($P < 0.01$, Table 2); (b) during simulated erect stance, although not statistically significant, force transfer to the partially fixed ligaments tended to be four times higher than in the totally fixed ligaments (Table 2).

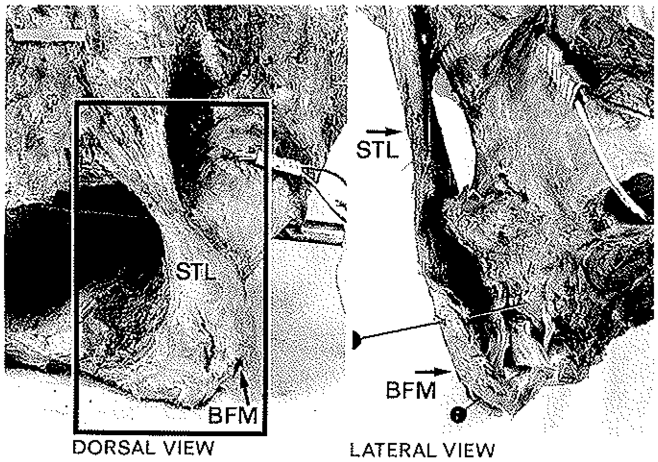

Fig. 4. Example of a partially fixed sacrotuberous ligament *(STL)* and its relation to the biceps femoris muscle tendon *(BFM)*

Table 1. Collected ligament data and applied force/measured force ratios for simulation of biceps femoris muscle force in erect stance and flexed stance[a]

Ligament	Side	Cadaver gender	Fixation	Upright stance	Flexed stance
1	Left	Female	Total	0.09	0.13
2	Right	Female	Total	0.08	0.13
3	Left	Female	Partial	0.20	0.43
4	Left	Female	Partial	0.54	0.33
5	Left	Male	Partial	0.08	0.42
6	Right	Male	Partial	0.16	0.52
7	Left	Male	Partial	0.69	0.19
8	Right	Male	Partial	0.19	0.31
9	Left	Female	Total	0.07	0.15
10	Right	Female	Total	0.07	0.17

[a] Ratios averaged over three repetitions. Correlation coefficient of all ratios > 0.98

Table 2. Statistical analysis of all ligaments

	Total fixation ($n = 4$)		Partial fixation ($n = 6$)
Simulated erect stance	0.08 ± 0.01	NS[b]	0.31 ± 0.24
	$P < 0.01$[a]		NS[a]
Simulated flexed stance	0.15 ± 0.02	$P < 0.01$[b]	0.36 ± 0.11

[a] Testing for the difference in mean ratio of force between simulation of erect and flexed stance for totally and partially fixed ligaments

[b] Testing for the difference in mean ratio of force between totally fixed and partially fixed ligaments for both force direction simulations

2. In comparing the simulated flexed stance with the simulated erect stance the following have to be noted: (a) for the totally fixed ligaments, force transfer in the simulated flexed stance is slightly but significantly higher than during simulated erect stance ($P < 0.01$, Table 2); (b) for the partially fixed ligaments, force transfer in the simulated flexed stance is not significantly different from that in the simulated erect stance. This is due to the aberrant data for ligaments 4 and 7 (Table 1).

Discussion

Insight into the spine-pelvis mechanism can only be obtained on the basis of a functional-anatomical approach [23]. Several anatomical studies [2, 3, 7, 8, 10, 11, 18, 23] have shown that the influence of soft tissues on lumbar and pelvic kinematics is considerably more complex than is presumed by standard anatomical references. The present study emphasizes this view. From a functional-anatomical viewpoint it can be assumed that massive ligaments like the sacrotuberous ligament conduct large forces. From the present study it can be concluded that part of these large forces have a dynamic character. However, the connections of fibres of the gluteus maximus muscle may also play an important role in the dynamic aspects of sacrotuberous ligament function. Connections of the sacrotuberous ligament with the fascia thoracolumbalis are being described (A. Vleeming et al., in preparation), but it is still unclear how far the sacrotuberous ligament has the capacity to influence lumbar spine function directly. To understand spine, pelvis and leg kinematics the function of these complex relations must be unravelled.

The leg-back system

The aim of this study is to specify the role of the sacrotuberous ligament and the biceps femoris muscle in the kinematic chain of spine-pelvis-leg. Like the gluteus maximus muscle, the hamstrings are able to tilt the pelvis backwards, thus flattening the lumbar spine. In addition to this gross pelvic positioning system we want to distinguish a second, more refined leg-back system. Because of the distinct tendon form of the biceps femoris muscle while approaching and crossing the ischial tuberosity, the muscle is able to conduct its force upwards to the sacrotuberous ligament. As shown in this study, fibres of the biceps femoris muscle tendon are able to alter sacrotuberous ligament tension in all cases. The transfer of force in the fixed ligaments can be explained in two ways: firstly superficial fibres that connect ligament and muscle in all preparations can transduce some force. Secondly, since we noticed a high tension in the sacrotuberous ligament, distortion of the ischial tuberosity (bone elasticity) could easily lead to altered ligament tension.

Increased sacrotuberous ligament tension diminishes sacrum nutation and may consolidate self-bracing of the sacrum [18, 19]. Consequently, diminished sacrotuberous ligament tension may increase SI joint mobility. This mechanism may even be more subtle: in eight of all ten ligaments tested a relatively higher percentage of force was transferred from the biceps femoris muscle to the sacrotuberous ligament during the flexed situation than during the erect situation. From a biomechanical point of view this could be expected, since the flexion torque on the lumbar spine increases with the change from erect stance to flexed stance [9, 22]. Therefore, in the flexed position larger contranutating forces are needed to prevent the sacrum from tilting forward. As emphasized by the present findings in most individuals, part of this force can be derived from the biceps femoris muscle.

The specific role of the described coiled structure of the sacrotuberous ligament is still unclear, but some speculations can be made. As a result of the coiled structure of this ligament, the lateral part of the biceps femoris tendon creates a force which is directed to the sacrum horizontally. This force has the same direction as the resultant of ligament forces (F_1), which compress the SI joint and are essential for the self-bracing mechanism as described by Vleeming [21]. It can be noted that the coiled structure of the sacrotuberous ligament resembles the structure of the cruciate ligaments [4, 16]. This could imply that different parts of the sacrotuberous ligament, like the cruciate ligaments, are loaded during different stages of motion of the SI joint.

SI joint stabilization during walking

Stabilization of the SI joints during daily activities like walking must be considered a dynamic process. During walking the leg as well as the homolateral SI joint become weight-bearing at heel-strike. At this very moment or better, just before, its self-bracing system must be activated to stabilize the SI joint. Gait analysis shows the hamstrings to become active just before heel-strike [26]. This action increases sacrotuberous ligament tension and presumably self-bracing of the SI joint in addition to limiting knee extension. On heel-strike the homolateral SI joint and the spine will benefit from an optimal stabilization induced by muscular activity of the lower extremity. However, small physical changes, such as functionally short hamstrings, can disturb this leg-spine mechanism.

'Short hamstrings' phenomenon

The phenomenon of 'tight' or 'short' hamstrings is often considered as a secondary effect or residual sign of low back trouble [5, 6, 12, 13, 15]. According to the data presented here, shortened hamstrings can affect the self-bracing mechanism of the pelvis. An altered self-bracing mechanism might change the pattern of forces in spine and pelvis. Consequently, short hamstrings may prolong or even initiate low back problems. Whether stretching the hamstrings influences 'low back' pain is unclear, since scientific data are lacking [12]. However, it might well be that stretching the hamstrings restores pelvic and lumbar kinematics and breaks the vicious circle of 'low back' pain and shortened hamstrings.

Pelvic instability and leg muscle training

Exercise of muscles which influence the pelvis directly or indirectly via the sacrotuberous ligament can be of special importance for women suffering from hypermobility of the pelvis [25]. Pelvic instability is often regarded as exclusively a failure of the pelvic ligaments, the passive structures stabilizing the pelvis. As emphasized here, leg and pelvic muscles can actively influence the mobility of the SI joint and thus influence pelvic stability. By leg muscle training the self-bracing mechanism can be influenced. Specific muscle training is therefore recommended for women with complaints of pelvic hypermobility [25].

Conclusion

Sacrotuberous ligament tension can be influenced by biceps femoris muscle force. Consequently, a leg muscle like the biceps femoris can affect the SI joint and hence pelvic and lumbar stability. In solving complex low back problems, it is essential to see the spine, pelvis and lower extremities as integrated and mutually influencing entities.

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