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Psoas muscle and lumbar spine stability: a concept uniting existing controversies

Critical review and hypothesis

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Abstract Psoas muscle (PM) function with regard to the lumbar spine (LS) is disputed. Electromyographic studies attribute to the PM a possible role as stabilizer. Anatomical textbooks describe the PM as an LS flexor, but not a stabilizer. According to more recent anatomical studies, the PM does not act on the LS, because it tends to pull the LS into more lordosis by simultaneously flexing the lower and extending the upper region, but due to the short moment arms of its fascicles, this would require maximal muscular effort and would expose the LS motion segments to dangerous compression and shear. The findings of the present study indicate that the described opposite action of the PM on upper and lower LS regions, performed passively and requiring minimal muscular effort, may serve to stabilize the LS in an upright stance. It was demonstrated that a vertically placed elastic metal strip, modelled into a lordotic configuration to imi-

tate the LS, will be brought into more lordosis, with maintenance of vertical position, if a string fastened at its upper end is pulled downward in a very specific direction. Conversely, any increase of lordosis of the strip brought about by vertical downward pushing of its top, will be stabilized by tightening the pulling string in the same specific direction. As this direction corresponded with the psoas orientation, the experiments show that the PM probably functions as a stabilizer of the lordotic LS in an upright stance by adapting the state of contraction of each of its fascicles to the momentary degree of lordosis imposed by factors outside the LS, such as general posture, general muscle activity and weight bearing. The presence of multiple PM fascicles, all of about equal length, and attaching to all LS levels, facilitates this function.

Key words Psoas muscle · Lumbar spine · Stability

Introduction

With the m. iliacus and m. psoas minor, the m. psoas major (PM) forms part of the m. iliopsoas. As the m. psoas minor is missing in 50% of individuals [9], it will not be dealt with further. Figure 1 presents an overview of the iliopsoas muscle. The PM arises from the lateral aspects of the lumbar vertebral bodies and discs, and with smaller fascicles from the transverse processes. With the iliacus

muscle, the PM converges towards the iliopubic eminence and, curving backwards along the inner side of the hip joint, inserts with a common tendon on the lesser trochanter of the femur.

According to anatomical textbooks [9, 18], the PM

1. Flexes the lumbar spine (LS) and bends it laterally
2. Powerfully flexes the femur and rotates it a little outwards, and
3. If the femora are fixed, flexes lumbar spine and pelvis.

Fig. 1 Anterior view of psoas major and iliacus muscles (drawing modified after Tittel [20]). The psoas major muscle arises bilaterally from the lateral aspects of vertebral bodies, intervertebral discs and transverse processes of lumbar spine (LS), the iliacus muscle from the iliac wings. The muscles converge towards the iliopubic eminence and, passing along inner side of hip joint, insert with a common tendon on the lesser trochanter of the femur

The textbooks do not describe the PM as having a stabilizing function with respect to the LS.

According to Nachemson [12] the osseoligamentous LS in the upright position must be stabilized by extrinsic factors, as the intrinsic ones are inadequate. He suggests that stabilization in the upright position is provided to some, probably a major, extent by the vertebral portions of the PMs.

According to Hadjipavlou et al. [7], the PM principally supports the trunk on the pelvis. The PM is uniquely positioned to prevent buckling of the spine and to control lordosis. By its attachment to the femur, it controls pelvic tilt. As the PM gives small anterior shear at the lower lumbar motion segments, it cannot be used to balance gravity.

Bogduk et al. [3] relate the function of the PM to the course of its separate fascicles with respect to their corresponding instantaneous flexion-extension centres (Fig. 2), and conclude that the lower PM fascicles tend to flex the lower LS and the upper fascicles to extend the upper LS. As the fascicles pass near the corresponding flexion-extension centres, their moment arms are small. As a result, at maximum PM contraction, severe compression forces

Fig. 2 Psoas fascicles and instantaneous flexion-extension centres (drawing modified after Bogduk et al. [3]) with psoas major muscle attachments (shaded). Black dots represent centroids of attachment, small circles centres of flexion-extension motion [15]. Arrows at "average attachments" (located one-third of the way along the line connecting centroids of smaller and larger attachments, nearer the larger attachment) indicate the direction of muscle force towards the iliopubic eminence (P). Arrows dorsal to the motion centres indicate extending force; arrows ventral to motion centres flexing force. Force moment arms are small

and large shear forces act on the lumbar motion segments, vertically crumbling the LS in a sigmoid fashion and forcing it into lordosis while severely shearing the L5/S1 segment. The PM, therefore, cannot be intended to act on the LS, they argue, but only on the femur. Overstressing the PMs in, for instance, 'sit-up' exercises, may dangerously overload the LS.

The same authors [3] noted remarkable similarity in length of the fleshy (nontendinous) fibres of the PM fascicles. Within a given specimen, the different fascicles measured within a centimetre in length of one another, and differences between specimens were not large. This, they argued, indicated that the PM was not designed to execute or control flexion of the LS, because the expected far greater arcuate flexion excursions of the upper lumbar vertebrae would require longer fascicles attaching to this

region. As the fascicles were uniform in length, the PM must solely be designed to act from the LS on the femur, and not in a reverse way.

Purpose of the study

The conflicting views regarding PM function stimulated us to perform experiments in order to try to find a way of uniting these apparently contradictory views in a concept whereby the opposite action of the PM on upper and lower parts of the LS serves to stabilize the LS.

Fig.3 Computed tomographic (CT) sections of PM with flexion-extension axes (CT sections of LS redrawn from atlas of Gamberelli et al. [5] and instantaneous axes of motion as determined by Pearcy and Bogduk [15]). Three upper muscle centroids (*black dots*) are posterior to the flexion-extension axes; at L4/5 they coincide with the axis, and at L5/S1 they are far anterior to the corresponding axis

Fig.4 PM course in the sagittal plane (reconstruction of the course of PM fascicles from Fig.3). At the upper four levels, the fascicles remain lateral to the vertebral bodies and pedicles; below L4, the fascicles take a more forward/downward course in the direction of the iliopubic eminence (P)

Fig. 5a-c Experiments with an elastic metal strip. Lateral view of the S-shaped metal strip, pulled down in **a** a specific direction by string fastened to the upper cross-strip, **b** a more anterior direction, causing flexion (in the direction of the arrow at the top, flexion position *not drawn*) and **c** a more posterior direction, causing extension (in direction of the arrow at top, extension position *not drawn*), which could both be corrected by additional pull at other sites (*small arrows*; length of arrows not related to magnitude of force) (*E* extension, *F* flexion)

Materials and methods

Firstly, additional anatomical proof was sought to support the thesis of opposite action of the PM on upper and lower regions of the LS. Figure 3 presents a drawing of transverse CT sections of the LS, as presented by Gambarelli et al. [5], and comparable to those of Möller and Reif [10], with superimposed instantaneous axes of flexion-extension motion, as determined by Percy and Bogduk [15]. Figure 4 is a reconstruction of the projection of the PM in the sagittal plane from the transverse plane images of Fig. 3.

Secondly, the effect of PM action on the LS was studied with the help of a metal strip from Meccano, 316 mm long, 12.5 mm wide and 1 mm thick, with 25 round perforations. One end of the strip was fastened vertically over 10 mm in a vice, angulated over 35° at the entrance into the vice, and supported in this position, as shown in Fig. 5. Next the strip was manually modelled into an S-shape, imitating lumbar lordosis at L2/S1, and gradually changing into thoracic kyphosis above L2, with the top of the strip vertically above its entrance into the vice. Hooked cross-strips, indicating vertebral levels L1-L5, and allowing attachment of strings and measurement of degree of bending, were rigidly fastened to the main strip.

To keep the model relatively simple, the sacroiliac joints were not taken into consideration, the vice representing sacrum and

pelvis as an immobile unity. This was considered acceptable, as the flexion mobility of the sacroiliac joints is small, averaging 1.7° [8]. Due to its elasticity (elasticity modulus was not measured), the strip deformed upon loading and returned to its original position after unloading. However, after more than two or three deformations, the original configuration tended to be slightly lost and the strip had to be remodelled. In the experiments recorded, the top of the strip always returned to within 1 mm of its original position.

In the experiment depicted in Fig. 5 a-c, a string was fastened to the upper cross-strip at a site corresponding with the average PM attachment to L1, as shown in Fig. 2, and the effect of manually pulling down the string in a variety of directions in the plane of the model was studied (pulling force not measured). Special attention was paid to the direction of pull, which caused vertical downward motion of the top of the strip ("specific direction"), without bending of the strip to the left ("flexion") or to the right ("extension"). In Fig. 5b and c, the effect of additional pull by one or more strings fastened at other positions was studied.

Figure 6a and b shows a comparison of the effect of pull at strips with different degrees of curvature (degrees of "lordosis"). In Fig. 6c the pulling string was guided through an opening in the strip between levels L4 and L5.

All experiments depicted in Fig. 5 and Fig. 6 were also performed in a reverse way, by first pushing the top of the strip verti-

Fig. 6a-c Experiments with an elastic metal strip. Direction of specific pull was nearly identical in **a** slight and **b** marked lordosis. In **c**, string guided through the vicinity of a specific point (small circle) had wider range of specific pull direction (between arrows)

cally down and then determining which direction of adequate pull was required to stabilize the strip in this position.

Finally, a line drawing of vertebral body contours (as shown on a lateral LS radiograph) with superimposition of instantaneous axes of motion was used to study LS movements during increase of lordosis kinematically (Fig. 7). In Fig. 8, the lordotic and increased lordotic LS positions of Fig. 7 served to measure the distances of the five average PM fascicle attachments, as shown in Fig. 2, from the iliopubic eminence *P*.

Results

Figure 3 supports the theoretical concept of Bogduk et al. [3] of opposite action of individual PM fascicles on upper and lower LS. At L1/2 and L2/3, the bilateral fascicles have a locally extending effect, as their centroids are posterior to the flexion-extension axes. At L3/4 and L4/5 the main local effect is pull in a downward direction, as the fascicle centroids are about aligned with the corresponding axes. At L5/S1 the fascicles have a locally flexing effect as their centroids now are positioned anterior to the corresponding axis.

Figure 4 demonstrates that the PM fascicles, from L1 down to L4 inclusive, remain lateral to the lumbar vertebral bodies and pedicles, at L1 only posteriorly, at L4 also anteriorly. Below L4 the fascicles take a more antero-caudal course, in the direction of the iliopubic eminence (*P*) of the pelvis. This grants the PM in lateral view a slight S-shape, which is also found in the sagittal anatomical cross-sections of Möller and Reif [10].

Fig. 5a shows the direction of pull that caused vertical downward motion of the top of the strip. The range of this "specific direction" proved to be very narrow: less than 2°. The string crosses the strip at a "specific" point between cross-strips L4 and L5. In the new strip position (interrupted line; solid line indicates original position), the curvature ("lordosis") of the strip has increased, with accompanying extension of cross-strips L1 and L2, and flexion of cross-strips L3, L4 and L5. It is of interest to note that these opposite strip movements were effected by pulling at the top of the strip only.

Pull slightly to the left of the narrow range of specific direction (Fig. 5b) resulted in additional flexion (extent

Fig. 7 Increase in lumbar lordosis by opposite lumbar spine motions. *Left*: LS image with line of arbitrarily increased lordosis; L5 has been flexed (arrow) around the corresponding centre of motion until the anterior contour reached this line. *Right*: by movement around their corresponding centres of motion, the anterior contours of the other vertebral bodies have been brought against the line of increased lordosis (solid lines; original LS position is shown by interrupted lines). Ranges of vertebral body motion are shown on the right, and ranges of intersegmental motion on the left (E extension, F flexion)

indicated by arrow at top; new strip position not drawn). Annulment of this additional flexion could be obtained by additional pull, parallel to the direction of the main pull, on a string fastened at one of the other sites, indicated by small arrows. Annulment of additional flexion by pull at the L4 cross-strip required more force than annulment by pull at the L1 cross-strip, with gradual transitions in-between. Pull at other sites (small open circles without arrows) did not annul flexion.

Pull slightly to the right of the narrow range of specific direction (Fig. 5c) resulted in additional extension. Annulment of this additional extension could be achieved by additional pull, parallel to the direction of the main pull, on a string fastened at one of the other sites, indicated by small arrows. The required pulling force was larger at the

Fig. 8 Changes in psoas fascicle length. Same configuration as in Fig. 7, right. Centroids of average psoas major muscle attachments of Fig. 2 are indicated on vertebral bodies in both positions, and their distances to iliopubic eminence P measured

L5 cross-strip than at the L2 cross-strip. Pull at other sites (small open circles) did not annul extension.

Degree of curvature (degree of lordosis) hardly affected the specific direction of pull (Fig. 6a, b), the string always crossing the strip in the direct vicinity of the 'specific point' of Fig. 5a, between levels L4 and L5. Guiding the string through an opening in the direct vicinity of the specific point (Fig. 6c) markedly widened the range of specific pull direction (between arrows).

All experiments depicted in Fig. 5 and Fig. 6, carried out in a reverse way by first pushing the top of the strip vertically down and then stabilizing the increased curvature by tightening the string(s), yielded the same results as the primary experiments: specific direction(s) remained unchanged.

Table 1 Real distances (millimetres) between five centroids of psoas muscle attachment to the lumbar spine L1-L5, in lordosis and increased lordosis, and the iliopubic eminence *P* (depicted in Fig. 8). The real values were obtained by taking 35 mm as the mean anteroposterior diameter of the end-plates of a lumbar vertebral body. Differences represent real shortening of distances by increased lordosis. Decrease of disc height due to compression by loading could not be accounted for

Distance	Lordosis	Increased lordosis	Shortening
L1- <i>P</i>	237	226	11
L2- <i>P</i>	203	192	11
L3- <i>P</i>	167	157	10
L4- <i>P</i>	134	126	8
L5- <i>P</i>	118	112	6

Figure 7 demonstrates that increased lordosis, with preservation of the upright position, can be produced by simultaneous extension of the upper lumbar region and flexion of the lower lumbar region. The required movements of the motion segments are indicated on the left. On the right side the extent of vertebral body movements is recorded (from position in *broken line* to position in *solid line*); these movements correlate with those of the cross-strip movements in Fig. 5a.

The results of the measurements in Fig. 8 are presented in Table 1. The distances were converted to real values, taking 35 mm as the mean anteroposterior diameter of the end-plates of a lumbar vertebral body. Increasing lordosis proves to be attended by shortening of distances, absolute shortening being about equal for levels L1-L3, slightly less for L4 and markedly less for L5. Figure 5a shows a comparable shortening, as evidenced by downward motion of the cross-strips.

Discussion

The metal strip experiments demonstrate that lordosis of a vertical elastic structure can be increased, without loss of vertical position, by pull at the upper part of the structure, provided pull takes place in a specific direction within narrow limits; pull in other directions annuls vertical position. Increase of lordosis is attended by opposite motions of the upper and lower parts of the strip (Figure 5a). Any given degree of lordosis of the elastic strip can be stabilized by tightening the pulling string in the specific direction (Fig. 6).

Although caution must be exercised in comparing the elasticity of the ligamentous LS to that of an elastic metal strip, there are nevertheless some interesting similarities. Like the string fastened to the top of the strip, the PM is able to increase lordosis of the LS, without affecting vertical position, by moving upper and lower regions in opposite directions (Fig. 7). Furthermore, the course of the PM with respect to the LS corresponds strikingly well

Fig. 9 Comparison of experimental specific pull and psoas orientation. *Left*: image of Fig. 5a; *right*: slightly changed image of Fig. 4 (*small circles* indicate centres of motion). Both images show the same degree of lordosis. The general direction of the psoas major muscle corresponds fairly well with the experimental direction of specific pull

with the specific direction of string pull in the metal strip experiment (Fig. 9).

These similarities suggest that the PM may have an effect on the LS that is comparable to the effect achieved by the specifically directed string on the metal strip. According to the metal strip experiments, the PM may theoretically act in two different ways: by actively pulling the upright LS into more lordosis, or by passively stabilizing any given upright LS lordotic position by tightening its individual fascicles.

Bogduk et al. [3] pointed out that pulling the LS into more lordosis would require maximum PM effort, as its fascicles have short moment arms (pass at short distances from the motion centres) and hence will tend to exert severe compression forces on the lumbar motion segments. Consequently, this does not seem a purposeful function.

The passive PM function of stabilizing any given degree of LS lordosis, therefore, seems more natural, notably because degree of LS lordosis in upright stance,

apart from intrinsic osseo-ligamentous factors, is dependent on factors outside the LS, including general body posture, general muscle activity and weight bearing.

Electromyography provides evidence that, during relaxed upright stance, activity of back muscles is restricted to continuous minimal activity of the PMs and sporadic bursts, either from the rectus abdominis or erector spinae muscles [1, 7, 11]. LS stabilization in relaxed upright stance thus requires minimal muscular energy. Its explanation is that in relaxed upright stance the body segments are so aligned around the line of gravity that torques and stresses generated by gravity are minimized [2, 4, 16].

As changes in degree of lumbar lordosis are attended by about equal changes in required fascicle length at L1-L4 (Table 1), equal length of the different PM fascicles, as demonstrated by Bogduk et al. [3], is optimally suited to adapt to changes in degree of lordosis.

To prevent additional LS flexion or extension, which would nullify the stabilizing effect, the range of specific PM pull should be wide enough. As the experimental range of specific pull direction with one string is very narrow (Fig. 5a), the use of multiple strings is required to counteract additional flexion or extension (Fig. 5b,c). The PM fulfils this requirement, as it is composed of multiple fascicles, attaching to different sites of vertebrae and discs, at all LS segmental levels.

The range of specific pull direction is further widened by tunnelling the pulling strings through the region between the L4 and L5 levels (Fig. 6c), where the specific point of Fig. 5a is located. Accordingly, the PM is seen to follow the lateral aspect of the LS from L1 downward, to depart from the LS at the L4/5 level (Fig. 4). The enveloping fascia psoica is supposed to help in guiding the PM along this specific path.

In the experiments, flexion was counteracted by strings fastened relatively far posterior to the centres of motion (Fig. 5b). This suggests that the PM fascicles attaching to the transverse processes (Fig. 2) serve to counteract flexion. In contrast, extension is counteracted by fascicles attaching right in front of the instantaneous centres of motion (Fig. 5c).

As the individual PM fascicles bridge more than one motion segment, their action is not limited to the region of attachment, but also affects the more caudal segments. For instance, the string in Fig. 5a extends not only cross-strip L1, but also L2, and flexes L3, L4 and L5. The experiments depicted in Fig. 5b and c reveal that different strings require different pulling force, indicating that effective PM action necessitates individual tuning of separate fascicles to the general effect. It is assumed, therefore, that each of the PM fascicles is able to function relatively independently of the other fascicles.

The joint action of the individual PM fascicles has to be guided by a neural control system. In general, such a system registers the momentary strains and stresses evoked in the individual elastic ligaments, processes this informa-

tion and feeds the results back to the individual muscle fibres [13].

In the stabilizing PM function, additional factors play a role. As the PM contracts, its muscle mass impinging against the lateral aspects of the vertebral bodies and the anterior aspects of the transverse processes becomes shorter and fatter, and provides an anterolateral buttress on each side of the spine, helping to control lordosis and provide stability [7]. This additional stabilizing function can be exerted because the PM moves the LS in opposite directions without changing vertical position. If the PM were to flex the LS, as contended by the anatomical textbooks [9, 18], the bulk of the PM mass would not be expected to counteract this movement.

The upright spine is able to absorb vertical loads by elastic increase in its alternating lordotic and kyphotic curvatures [9, 18, 19, 20]. Loading of the LS is met by increasing resistance to motion, providing more stability [14]. Experimental compression of lumbar discs has proved to result in increased stiffness [17]. Intravital discometry has shown that, due to spinal muscular activity, intradiscal pressure of the (middle) lumbar discs in standing upright position is higher than body weight above these discs can account for [12]. Finite element studies have confirmed that spinal muscular activity increases stiffness of the lumbar motion segments, and thus enhances stability [6].

This study exclusively deals with PM action in upright stance, with fixed femora. PM action during walking and upright sitting position conditions requires additional investigation. It may be deduced from Fig. 4 that in sitting upright position, due to 90° hip joint flexion, the lesser trochanter is nearer to the LS, requiring shortening of the PM to be effective in fastening the lumbar spine. Electromyographic studies show that PM activity in sitting upright position is greater than in standing upright position [12].

Because PM action was studied in the sagittal plane, the conclusions of this investigation are valid only as long as bilateral PM action is symmetric, keeping the LS in the sagittal plane. If this is the case, stability in the frontal plane will also be ensured, as symmetric PM action opposes lateral bending.

Conclusion

Bogduk et al. [3] established that the PM theoretically is able to move upper and lower LS in opposite directions, but did not consider this function purposeful, as they argued that, in practice, it would damage the LS by forcing it into more lordosis, severely shearing the L5/S1 segment. Their finding of a roughly equal length of all PM fascicles pleaded against a PM function as flexor of the LS. The PM, they argued, could therefore only be intended to act on the femur, and not on the LS.

Our experiments indicate that opposite PM action on upper and lower LS, if passively performed by adapting individual fascicle length to the instantaneous degree of LS lordosis, serves to stabilize the LS in the upright stance. This stabilizing function is facilitated by the presence of multiple PM fascicles, all of about equal length, and attaching to all LS levels. This concept is supported

by electromyographic evidence that activity of back muscles in relaxed upright stance is restricted to continuous minimal activity of the PM [1, 7, 11].

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