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THE POSSIBLE IMPORTANCE OF THE PSOAS MUSCLE FOR STABILIZATION OF THE LUMBAR SPINE

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Received 24.xii.66

By intravital discometry it is possible to calculate the load on a particular lumbar disc. This load is correlated to the weight of the subject and the position of the body (21, 24).

In the forward stooping and weight-lifting positions the results were lower than those theoretically calculated by earlier investigators, (19, 25, 30) but more in agreement with knowledge of the ultimate strength of the vertebral bodies (5, 10, 14, 16, 25, 28). (Table 1).

In the upright standing and sitting positions, however, the measurements showed that the discs have to carry relatively high loads (21, 24). It is the purpose of this paper to discuss these findings with special reference to the stabilizing function of the vertebral portion of the psoas muscle.

ELECTROMYOGRAPHIC INVESTIGATIONS

Many authors have demonstrated that in the upright positions the sacro-spinalis group of muscles are inactive (1, 6, 12, 15, 19, 20, 23, 27) but since the body in these positions sways somewhat, occasional bursts of activity were noted in long term studies by *Boman & Jalavisto* (3). On forward leaning these muscles increase their activity (12, 20, 23).

The abdominal muscles were investigated by *Floyd & Silver* (11) and it was found that they too were, for all practical purposes, inactive in these positions, with the exception of some slight activity in the internal oblique muscle.

The vertebral portion of the psoas muscle has received little interest, and hardly any reports on its function for the spine are found in the literature (18). *Close* (7) and *Basmaïjan* (2) investigated the muscle

Table 1. Approximate load in kg on the third lumbar disc in different positions in individuals of varying bodyweights.

Weight of subject (kg)	50	60	70	80	90	100
Position of body	load on the disc (kg)					
Upright sitting, un_supp.	110	126	142	158	174	190
Upright standing	75	87	99	111	123	135
Reclining (lateral decubitus)	55	63	71	79	87	95
Reclining (relaxed, supine)	15	15	20	20	25	25
Sitting + forward tilting of 20°	145	168	191	214	237	260
Sitting + forward tilting of 20° and 10 kg load in each hand	226	249	270	295	317	340
Standing + forward tilting of 20°	110	129	148	167	186	205
Standing + forward tilting of 20° and 10 kg load in each hand	177	195	215	234	262	287

with needle electrodes near the hip joint in order to elucidate its action on this joint. Recently an investigation was performed (23) by which it was demonstrated that the psoas muscle showed electromyographic activity in the upright sitting and upright standing positions (Figures 1 and 2). It was also noted that in the standing position the activity increased when leaning forward 20° (Figures 2C and D). In the sitting position there was no such increase while leaning forward but the activity while sitting upright was higher than that when standing upright (Figures 1C and D). This can be explained by the finding that in the upright sitting position the lumbar spine is somewhat flexed in comparison to the upright standing position (29, 31).

THE LINE OF GRAVITY

According to previous investigators (1, 4, 8, 9, 29, 31) the line of gravity falls in most subjects through the center of the third lumbar disc in the upright standing position and about 4 cm in front of the center of the disc in the upright sitting position. Thus muscular or ligamentous forces or both must be taken into consideration to explain the relatively high loads found in these positions by intravital discometry,

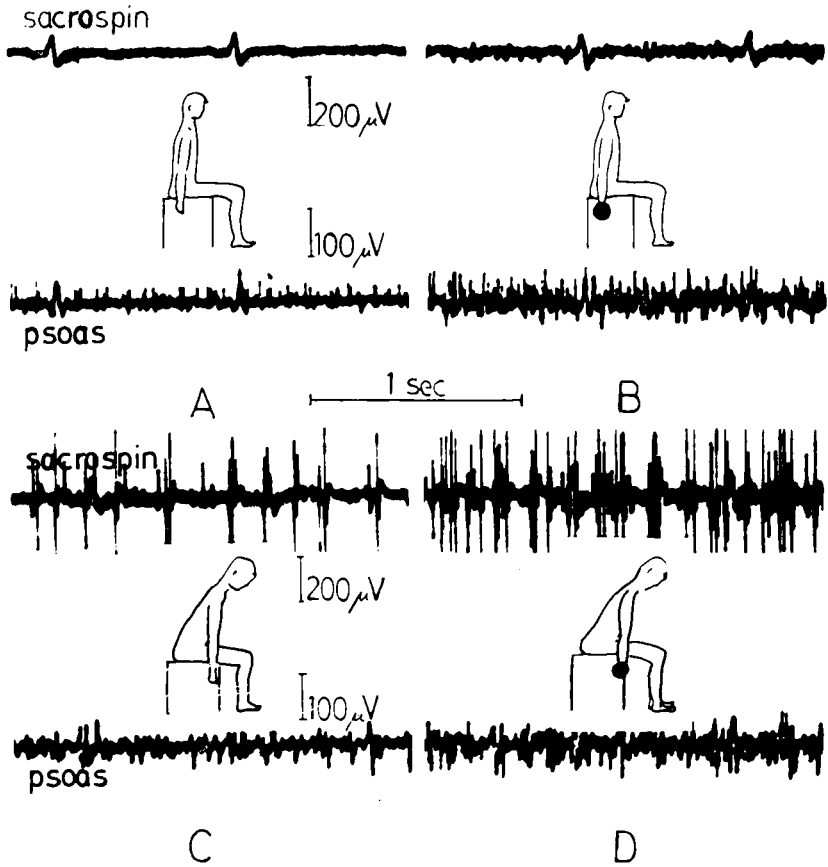


Figure 1. The electromyographic activity of the vertebral portion of the psoas major muscle, right side, in a male, age 24 years. A) upright unsupported sitting. B) upright unsupported sitting, 10 kg in each hand. C) sitting and forward leaning twenty degrees by flexion in the hip joints. D) sitting and forward leaning twenty degrees by flexion in the hip joints and holding 10 kg in each hand. The electromyographic activity of the sacro-spinalis muscles is also shown, in the different positions.

since gravity alone would give less load. In a man who weighs 70 kg, about 40 kg is the weight of the part of the body above his third lumbar disc, according to *Ruff* (28). (Table 2).

THE STABILITY OF THE SPINE

The spinal column, which serves as a sustaining rod for the maintenance of the upright position of the body, was considered by *Lucas*

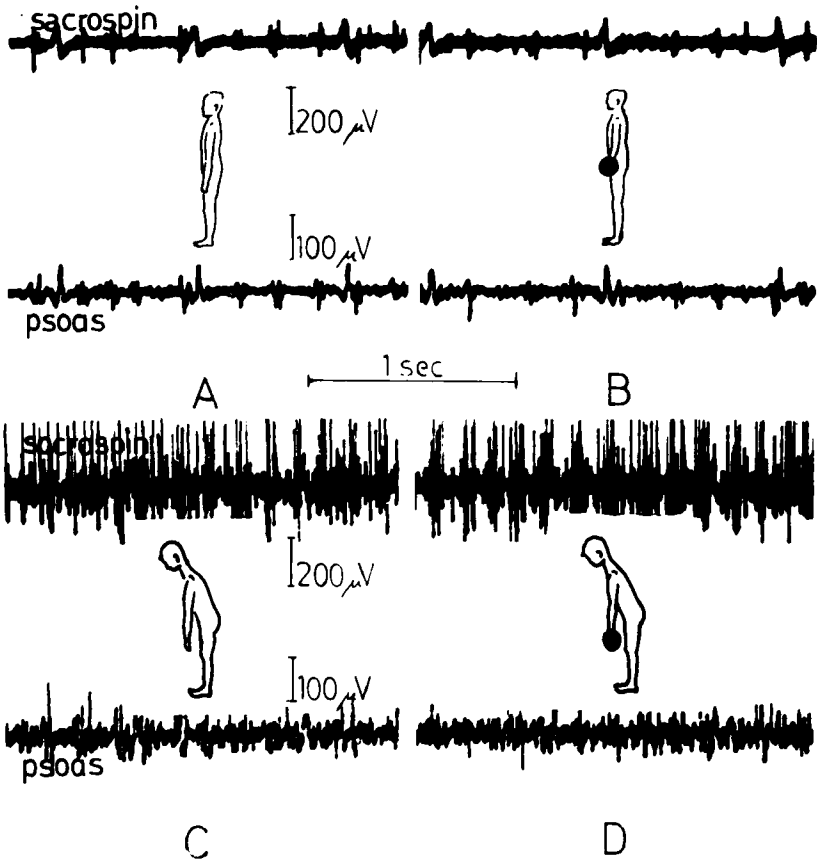


Figure 2. The electromyographic activity of the vertebral portion of the psoas major muscle, right side, in a male age 24 years. A) upright standing at ease. B) upright standing, 10 kg in each hand. C) standing and forward leaning twenty degrees by flexion in the hip joints. D) standing and forward leaning twenty degrees, by flexion in the hip joints and holding 10 kg in each hand. The electromyographic activity of the sacro-spinalis muscles is also shown, in the different positions.

& Bresler (17) to have both an intrinsic and an extrinsic stability. Intrinsic stability is provided by ligaments and discs which bind together the alternating vertebral bodies, while extrinsic stability is provided by the paraspinal and trunk muscles.

Considered alone, the spinal column and its ligaments behave like a modified elastic rod. When it is fixed at the base its critical load—*i.e.* the greatest load it can sustain without buckling, is only 2 kg (17). Therefore the stability of the spine in the living human being is de-

Table 2. Approximate formulas for load (P) on lumbar discs in different positions.

<i>Position</i>		
Upright sitting with arms and back unsupported	$P_{\text{sitt.}} = P_0 + 2.8 W;$	$P_0 \approx 30 \text{ kg}$
Upright standing	$P_{\text{stand.}} = P_0 + 2.1 W;$	$P_0 \approx 15 \text{ kg}$
Reclining (tilted on side, lateral decubitus)	$P_{\text{recl.}} = \frac{P_0 + 2.8 W}{2};$	$P_0 \approx 30 \text{ kg}$
Reclining, (relaxed supine)	$P_{\text{recl.}} = P_0$	$P_0 \approx 15 \text{ kg}$
Sitting + forward leaning α degrees	$P_{\text{sitt.}} = P_0 + 2.8 W + 3.6 W \sin \alpha;$	$P_0 \approx 30 \text{ kg}, \alpha = 10-20^\circ$
Standing + forward leaning α degrees	$P_{\text{stand.}} = P_0 + 2.1 W + 3.6 W \sin \alpha;$	$P_0 \approx 15 \text{ kg}, \alpha = 10-20^\circ$

P_0 = intrinsic pressure. W = weight above the level measured. (59 per cent of bodyweight above L:IV, 57 per cent above L:III and 55 per cent above L:II).

pendent on the extrinsic support provided by the trunk muscles. The lack of inherent intrinsic stability of the vertebral column and the importance of the trunk muscles are clearly demonstrated if one tries to hold an unconscious person upright.

DISCUSSION

Intravital discometry has demonstrated that the load on the middle lumbar discs varies with the position of the subject and weight of the body (21, 24). The results of these measurements are summarized in Tables 1 and 2.

It is unlikely that gravitation forces are sufficient to explain the relatively high loads in both upright standing and sitting positions found from these measurements.

Previous electromyographic investigations on the activity of the sacro-spinalis and anterior abdominal muscle groups demonstrated that all these are, with few occasional exceptions, inactive in these positions (1, 3, 6, 11, 12, 15, 19, 20, 23, 27, 29).

On the other hand it was recently demonstrated that activity existed in the upright positions in the vertebral portion of the psoas muscle

(23). This muscle should then be considered in providing some of the stability of the lumbar spine. By its activity it also increases the load on the discs in these positions.

Lucas & Bresler (17) demonstrated that ligamentous forces are too small to provide the necessary stabilization and discometry in anaesthetized individuals resulted in pressure values corresponding to a load of about 30 kg. This is the magnitude of force that could result from tension in the ligaments. This verified *Petter's* (26) and *Nachemson's* (22) findings on autopsy material.

With our present knowledge it is possible to approximate the amount of force which the vertebral portion of the psoas muscle compresses the lumbar spine in some positions.

If we first consider the load on the lumbar disc in the upright standing position, it can be expressed by the following equation (Table 2):

$$\text{eq. (1)} \quad P_{\text{standing}} = 15 + 2,1W$$

where W is the bodyweight above the lumbar disc measured and 15 corresponds to the "intrinsic" load, that force resulting from the ligaments. When the body is in equilibrium in the upright standing position, there is only occasional activity in the sacro-spinalis muscles (15, 27), while the activity of the psoas muscle seems less variable (23).

When standing the line of gravity falls through the center of the third lumbar disc (4, 9) and the force by which the psoas muscles (P_{psoas}) compress this disc, in a man of 70 kg, thus can be calculated, using the above-mentioned equation (1). In this case $W = 40$ kg, $P_{\text{standing}} = 99$ kg, and thus

$$\text{eq. (2)} \quad P_{\text{psoas}} = P_{\text{standing}} - W - 15 = 99 - 40 - 15 = 44 \text{ kg}$$

The bodyweight is calculated according to *Ruff* (28) who stated that 59 per cent of the bodyweight is above L: 4 and 57 per cent above L: 3.

Activity in the sacro-spinalis group of muscles, which probably occurs when the center of gravity moves forward due to swaying (3), will lessen the force by which the psoas muscles compress the disc.

In the upright unsupported sitting position, the load on the third lumbar disc in a 70 kg man is 142 kg according to Tables 1 and 2. In this position some light activity was found in the sacro-spinalis group of muscles in most cases by *Schoberth* (29), but only in exceptional cases by *Nachemson* (23) and *Åkerblom* (31). The distance from the midpoint of the nucleus pulposus to the midpoint of the attachment of the back muscles is approximately 5 cm, according to *Waris* (30)

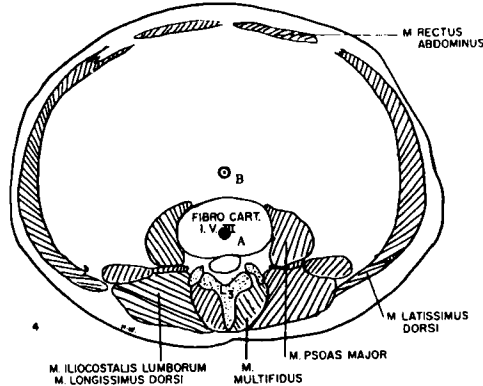


Figure 3. Schematic drawing of the vertebral portion of the psoas major muscle and its relation to the third lumbar disc. The line of gravity in the standing position probably falls through the center of the disc (A). In the upright unsupported sitting position this line falls in front of the center of the disc, (B).

and Pery (25). The line of gravity falls about 4 cm in front of the nucleus of the disc (4, 8, 31). If we assume that the midpoint of the psoas attachment is 1.5 cm behind the center of the disc (Figure 3), the force derived from the activity of the psoas muscle (P_{psoas}) and of the sacro-spinalis muscles (P_{sacro}) can be calculated from the following equations:

$$\text{eq. (3)} \quad P_{\text{psoas}} + P_{\text{sacro}} + W = P_{\text{sitting}} - P_0$$

$$\text{eq. (4)} \quad P_{\text{psoas}} \cdot a_1 + P_{\text{sacro}} \cdot a_2 = W \cdot a_3$$

if $a_1 = 1.5$ cm, $a_2 = 5$ cm, $a_3 = 4$ cm (Figure 4), $W = 40$ kg and $P_0 = 30$ kg then

$$P_{\text{psoas}} + P_{\text{sacro}} = 142 - 40 - 30 = 72$$

$$1.5 P_{\text{psoas}} + 5 P_{\text{sacro}} = 160$$

$$P_{\text{psoas}} \approx 58 \text{ kg}; P_{\text{sacro}} \approx 15 \text{ kg}.$$

In some subjects no activity was found in the sacro-spinalis group of muscles (23, 29). According to the eq. (3), the compressive force exerted by the psoas muscles then amounts to 72 kg. In these cases the line of gravity will tend to move closer towards the center of the disc and according to eq. (4) this line will now fall only 2.7 cm in front of the center of the disc, instead of 4 cm, as in the example given above. From these examples it should be clear that if the line of gravity is located 2 cm or 4 cm in front of the center of the disc, the compressive

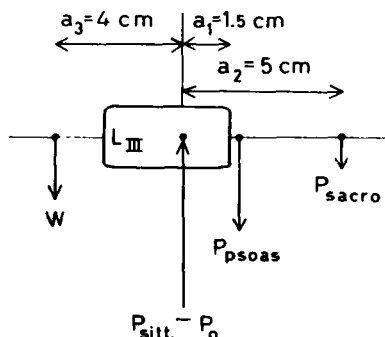


Figure 4. Schematic drawing of the forces and lever arms around the center of the third lumbar disc in the upright sitting position.

- W = Body weight above the disc.
 P_o = The "intrinsic" load on the disc.
 P_{sacro} = Force derived from activity of the sacro-spinalis muscles.
 P_{psoas} = Force derived from activity of the psoas muscles.
 P_{sitt} = Total load on the disc in the sitting position.
 a_1 = distance from center of psoas muscles to center of disc.
 a_2 = distance from sacro-spinalis muscles to center of disc.
 a_3 = distance from line of gravity to center of disc.

force of the sacro-spinalis muscles (P_{sacro}) is small in comparison to that of the psoas muscle (P_{psoas}).

At the third lumbar level the cross-sectional surface area of the psoas muscle is nearly 25 cm², (Figure 3). According to Michele (18) it is a unipennate muscle, which is able to develop a force of between 6 and 10 kg/cm² (Hettinger (13)).

With this knowledge in mind, the above-mentioned figures for the compressive force exerted by psoas muscles in the upright standing and sitting positions fall within reasonable limits.

It should be remembered, however, that these compressive forces vary somewhat since occasional activity in both the sacro-spinalis and anterior abdominal muscles are registered.

SUMMARY

In the upright sitting and standing positions the lumbar spine must be stabilized by extrinsic forces, since it has been demonstrated that the intrinsic ones are inadequate.

It is possible that this stabilization in the upright positions is provided to some, probably a major extent by the vertebral portions of

the psoas muscles. It can be calculated that in upright standing this force is about 40 kg and in upright sitting about 60 to 70 kg. In both examples possible activity in the sacro-spinalis group of muscles will tend to diminish the forces exerted by the psoas muscles.

RESUME

Dans les positions assise redressée et debout, la colonne lombaire doit être stabilisée par des forces extrinsèques puisqu'il a été démontré que les forces intrinsèques sont inadéquates.

Il est possible que la stabilisation dans les positions redressées est assurée par une extension probablement majeure des portions vertébrales des muscles psoas.

On a calculé qu'en position redressée, il faut une force d'environ 40 kg et en position debout entre 60 et 70 kg. Dans les deux exemples une activité éventuelle du groupe des muscles sacro-spinalis tend à diminuer les forces exercées par les muscles psoas.

ZUSAMMENFASSUNG

In der aufrechten sitzenden und stehenden Haltung muss die Lendenwirbelsäule von äusseren Kräften stabilisiert werden, da es sich erwiesen hat, dass die inneren Kräfte nicht hinreichend sind.

Es ist möglich, dass diese Stabilisierung in aufrechter Haltung zu einigem, wahrscheinlich grösserem Ausmasse von dem vertebralen Anteil des m. psoas besorgt wird. Man kann berechnen, dass diese Kraft bei aufrechtem Stehen ungefähr 40 kg und beim aufrechten Sitzen ungefähr 60 bis 70 kg beträgt. Bei beiden Stellungen wird eine mögliche Aktivität der sacro-spinalen Muskelgruppe die Neigung haben die von den Psoasmuskeln ausgeübten Kräfte zu vermindern.

REFERENCES

1. Asmussen, E. & Klausen, K. (1962) Form and function of the erect human. *Clin. orthop.* **25**, 55-63.
2. Basmajian, J. V. (1958) Electromyography of iliopsoas. *Anat. Rec.* **132**, 127-132.
3. Boman, K. & Jalavisto, E. (1953) Standing steadiness in old and young persons. *Ann. Med. exp. biolog. Fenn.* **31**, 447-455.
4. Braune, W. & Fischer, O. (1889) Über die Lage des schwerpunktes des menschlichen Körpers. Vol. XV: *Abh. Math. Phys.* Klasse d. Kgl. Sachsen, *Ges. d. Wiss Leipzig*, S. Hirzel.

5. Brown, T., Hansen, R. J. & Yorra, A. J. (1957) Some mechanical tests on the lumbosacral spine with particular references to the intervertebral discs. *J. Bone Jt Surg.* **39A**, 1135-1164.
6. Carlsöö, S. (1961) The static muscle load in different work positions: An electromyographic study. *Ergonomics* **4**, 194-211.
7. Close, J. R. (1964) Motor function in the lower extremity. Charles C. Thomas, Springfield, Illinois.
8. Dempster, W. T. (1958) Analysis of two-handed pull using free body diagram. *J. appl. Physiol.* **13**, 469-480.
9. Dempster, W. T. (1955) Space requirements of the seated operator. *WADC Technical Report*, **55**, 159.
10. Evans, F. G. & Lissner, H. R. (1959) Biomechanical studies on the lumbar spine and pelvis. *J. Bone Jt Surg.* **41A**, 278-290.
11. Floyd, W. F. & Silver, P. H. S. (1950) Electromyographic study of patterns of activity of the anterior abdominal wall muscles in man. *J. Anat.* **84**, 132-145.
12. Floyd, W. F. & Silver, P. H. S. (1955) The function of the erectores spinae muscles in certain movements and postures in man. *J. Physiol.* **129**, 184-203.
13. Hettinger, T. (1964) *Isometrisches Muskeltraining*. Georg Thieme Verlag, Stuttgart.
14. Hirsch, C. & Nachemson, A. (1961) Clinical observations on the spine in ejected pilots. *Acta orthop. scand.* **31**, 135-145.
15. Joseph, J. (1960) *Man's posture: Electromyographic studies*. Charles C. Thomas Publisher, Springfield, Illinois.
16. Laurrell, L. & Nachemson, A. (1963) Some factors influencing spine injuries in seat ejected pilots. *Aerospace Med.*, **34**, 726-729.
17. Lucas, D. B. & Bresler, B.: Stability of the ligamentous spine. Biomechanics Laboratory, Technical Report No 40, Dec. 1960. University of California, San Francisco, U.S.A.
18. Michele, A. A. (1962) *Iliopsoas*. Charles C. Thomas Publisher, Springfield, Illinois.
19. Morris, J. M., Lucas, D. B. & Bresler, B. (1961) Role of the trunk in stability of the spine. *J. Bone Jt Surg.* **43A**, 327-351.
20. Morris, J. M., Benner, G. & Lucas, D. B. (1962) An electromyographic study of the intrinsic muscles of the back in man. *J. Anat.*, **96**, 509-520.
21. Nachemson, A. & Morris, J. M. (1964) In vivo measurements of intradiscal pressure. *J. Bone Jt Surg.* **46A**, 1077-1092.
22. Nachemson, A. (1963) The influence of spinal movements on the lumbar intradiscal pressure and on the tensile stresses in the annulus fibrosus. *Acta orthop. scand.* **33**, 183-207.
23. Nachemson, A. (1966) Electromyographic studies on the vertebral portion of the psoas muscle. *Acta orthop. scand.* **37**, 177-190.
24. Nachemson, A. (1966) The load on lumbar discs in different positions of the body. *Clin. orthop.* **45**, 107-122.
25. Perey, O. (1957) Fracture of the vertebral end-plates in the lumbar spine. An experimental biomechanics investigation. *Acta orthop. scand.* Suppl. 25.

26. Petter, C. K. (1933) Methods of measuring the pressure of the intervertebral disc. *J. Bone Jt Surg.* **15**, 365-368.
27. Portnoy, H. & Morin, F. (1956) Electromyographic study of postural muscles in various positions and movements. *Amer. J. of Physiol.* **186**, 122-126.
28. Ruff, S. (1950) Brief acceleration: Less than one second. In German Aviation Medicine, World War II. Washington, D.C., U.S. Government Printing Office, **1**, 584-597.
29. Schoberth, H. (1962) Sitzhaltung, Sitzschaden, Sitzmöbel. Springer Verlag, Berlin.
30. Waris, W. (1948) Lumbar disc herniation. Clinical studies and late results of 374 cases of sciatica. *Acta chir. scand.* Suppl. 140.
31. Akerblom, B. (1949) Standing and sitting position. AB Nordiska Bokhandeln, Stockholm.