

SPONDYLOLYSIS

The Role of the Posterior Elements in Resisting the Intervertebral Compressive Force

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Compressive tests were carried out on cadaveric lumbar intervertebral joints, before and after the neural arch was fractured. The results show that although the neural arch can play some part in resisting the intervertebral compressive force, there is no bony contact between the downward projecting tips of the inferior articular processes and the laminae of the vertebra below.

Key words: spondylolysis; neural arch; lumbar vertebrae; intervertebral joint

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The neural arch of a vertebra articulates with adjacent vertebrae through the apophyseal joints. The inferior articular processes hang down from the junction of the pedicles with the neural laminae and, through the articulation, resist forward shear forces acting on the intervertebral joint. The mechanics of this passive resistance is complicated by the muscles attached to the neural arch. These muscles have a net bracing effect by pulling down on the neural arch and countering any tendency to forward displacement of an upper vertebra on the one below (Cyron 1977, Hutton et al. 1977).

The neural arch is clearly subjected to mechanical stress during everyday activities and a fracture of the laminae across the partes interarticulares occurs in about 1 in 20 of the population (Newman 1963, Wiltse et al. 1975). This type of fracture, called spondylolysis, is often followed by spondylolisthesis, a forward slip of a vertebra on the one below. These conditions are most common at the lumbo-sacral level.

The mechanics of spondylolysis, as ex-

plained above, ascribes the stress on the neural arch as solely due to forces perpendicular to the inferior articular facets acting with muscle forces to produce a critical stress. This explanation does not allow the neural arch to take any part in resisting the compressive force acting on the intervertebral joint, in that the facets glide over each other and in no important way do the tips of the inferior articular processes come into contact with the neural laminae of the vertebra below. There is an alternative theory.

It is suggested that, due to lumbar lordosis, the neural arch of L5 lies in a pincer-like grip between the downward projecting tips of the inferior articular processes of L4 and the upward projecting tips of the superior articular processes of the sacrum. In this theory the compressive force transmitted by the intervertebral joints is resisted mainly by the neural arch of L5 (Nathan 1959).

This paper describes experimental work carried out to quantify the role of the neural arch in resisting intervertebral compressive forces.

MATERIALS AND METHOD

Cadaveric material

Fourteen lumbar spines from subjects aged between 18 and 73 years were removed during routine necropsies. The material was collected from cadavers in whom there was no evidence of bone disease. The spines were dissected into joints consisting of two vertebra and the intervening disc. Of the joints tested, five were L5-S1, six were L4-L5, four were L3-L4 and three were L2-L3. Table 1 gives details of the specimens tested.

Experimental method

Each joint was stripped of the excess fat and muscles, but the ligaments and muscles joining the vertebrae were not disturbed. The joint was then mounted in surgical cement (calstone) and wrapped in polythene to avoid dehydration. During mounting, care was taken to ensure that the plane midway through the intervertebral disc

was parallel to the end-plates of the containers holding the upper and lower vertebrae. This method of mounting helps to ensure that no shear components act on the disc, and so the neural arch is not subjected to backward bending when the subsequent compressive tests are carried out.

Calestone is a stiff material which deforms very little under the forces applied during these tests. When hardening, it is also exothermic and a stream of cold air was directed onto the specimen during this stage to avoid any damage from the heat generated.

In life the intervertebral joints are subjected to varying compressive and shear forces. In these experiments, however, only a pure compressive force was applied to the joint. This is not an unphysiological situation since mathematical analysis of forces acting on the lumbar vertebrae shows that the shear force can be easily counteracted by the muscle attachments to the spinous process (Hutton et al. 1977, Cyron 1977).

The compressive tests were carried out using a servo-controlled hydraulic testing machine. The upper cross-head of the machine incorporated a

Table 1. The details of the results obtained

Group 1

Specimen number	Age	Sex	Intervertebral level	Stiffness of the intact joint kN/cm	Stiffness after neural arch fracture kN/cm
24	18	F	L3-L4	56.7	56.7
24	18	F	L5-S1	27.5	27.5
27	26	M	L5-S1	23.6	23.6
38	38	M	L3-L4	30.7	30.7
38	38	M	L5-S1	21.4	21.4
53	44	M	L5-S1	18.8	18.8
A2	44	M	L4-L5	29.8	29.8
32	44	M	L3-L4	27.5	27.5
32	44	M	L5-S1	37.3	37.3
58	59	F	L3-L4	18.8	18.8

Group 2

Specimen number	Age	Sex	Intervertebral level	Stiffness of the intact joint kN/cm	Stiffness after neural arch fracture kN/cm
35	18	M	L2-L3	34.9	18.4
35	18	M	L4-L5	37.0	27.4
25	19	M	L4-L5	29.0	24.7
57	37	M	L4-L5	26.1	19.6
A1	44	M	L2-L3	32.7	27.5
34	44	M	L4-L5	30.7	21.9
31	46	F	L4-L5	26.0	19.6

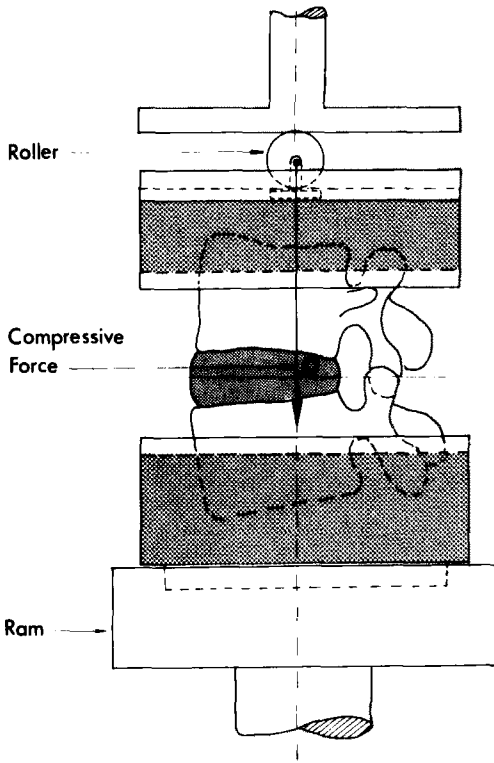


Figure 1. The arrangement of the apparatus for applying a pure compressive force (F_c) to a lumbar intervertebral joint.

load cell while the base unit held a hydraulic actuator and a displacement transducer.

The following two experiments were then performed:

Experiment 1

The force/deformation characteristics of the intervertebral joint when subjected to a force perpendicular to the plane midway through the disc were determined. This was achieved by applying forces of known magnitude and direction to the joint through a roller (Figure 1). The roller was free to rotate but its axis was fixed. It was placed at the top of the upper container with its centre lying on the line between the point of application of the force and the centre of rotation of the joint. The position of the roller was located by trial and error; a small compressive force (up to 50 N) was applied at each position until it did not cause any tilting of the upper vertebra. The outputs from the load cell and displacement transducer were fed to the X-Y plotter which

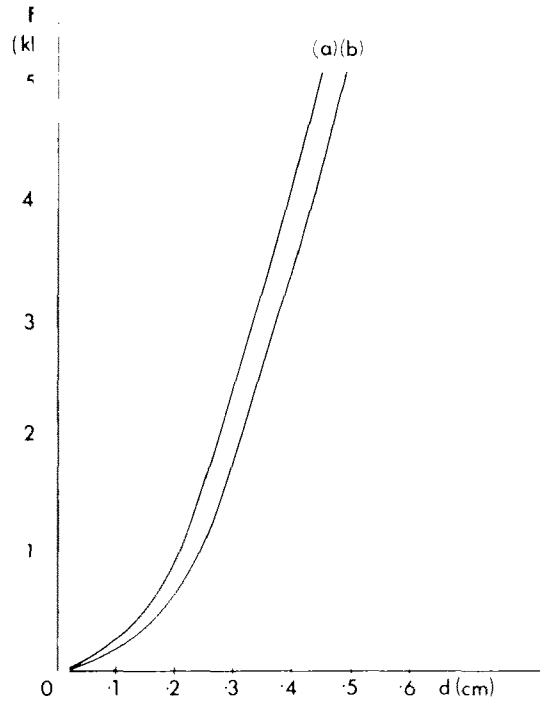


Figure 2. Typical result showing the force/deformation characteristics of a lumbar intervertebral joint in group 1. In this group the stiffness remained the same after the neural arch had been cut.

plotted the magnitude of the applied compressive force F and the corresponding vertical displacement d (Figures 2 and 3, graphs (a)).

Experiment 2

The neural arch on the upper vertebra was cut with a chisel through the partes interarticulares and Experiment 1 was repeated, giving force/deformation characteristics of the intervertebral joint without any contribution from the neural arch (Figures 2 and 3, graphs (b)). It should be noted that the joint was loaded slowly and allowed to recover before the second experiment. By doing so the amount of residual deformation, after the first experiment, was kept to a minimum.

After the tests the discs were examined macroscopically for the degree of degeneration. Only results for normal discs and those in which the lack of a clear boundary between the annulus fibrosus and the nucleus pulposus was the only evidence of degeneration were collected.

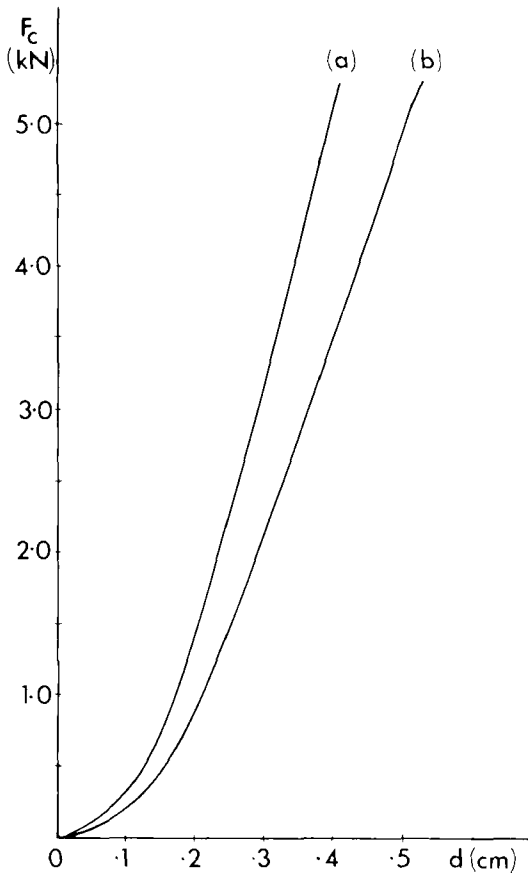


Figure 3. Typical result showing the force/deformation characteristics of a lumbar intervertebral joint in group 2. In this group the stiffness decreased after the neural arch had been cut.

RESULTS

The experimental results are summarized in Table 1.

The joints were tested to a maximum compressive load of about 5 kN. After about 1.5 kN the graphs became relatively linear up to the maximum load, and the slope of this portion of the graph was measured. The slope in each case represents the compressive stiffness of the joint (or to be more precise the compressive stiffness of the intervertebral joint plus two vertebrae embedded in caestone).

The results fall into two groups as illustrated by Figures 2 and 3. In the first group, consisting of eleven joints, the results show some residual deformation between graphs (a) and (b) (Figure 2), although the slope of the main portion of the graphs is the same. In the second group, consisting of seven joints, there is a combination of residual deformation and a change in stiffness. Graph (b) in Figure 3 illustrates a result for a joint which is less stiff after the neural arch has been cut.

The stiffness of the intact joints varied between 18.8 kN/cm (L5-S1, specimen 53) and 71.1 kN/cm (L2-L3, specimen 22). The stiffness will depend, *inter alia*, on the thickness of the intervertebral disc (L2-L3 is usually thinner than L5-S1). However, even the highest value of stiffness does not represent the value which would be obtained at very high loads (7–9 kN in flexed posture) when the disc is highly compressed and the end plates of the vertebral bodies are brought closer to each other. In other words, the stiffness of the joint varies with the compressive load, although in the range of loads in these experiments there is a long linear portion.

As to intervertebral level, all of the L5-S1 joints tested fall into group 1 and five out of six L4-L5 joints fall into group 2. There is no clear variation with age or sex.

For four subjects it was possible to test joints at two levels (Table 1), and in every case both joints for each subject fell into the same group (three in group 1 and one in group 2).

DISCUSSION

The maximum value of stiffness recorded in these tests was 71.1 kN/cm. Let us compare this value with the calculated value for the compressive stiffness of the neural arch, when subjected to a force along the line of the neural lamina.

Although the neural lamina is an irregularly shaped structure, to provide an approxima-

tion of its stiffness we can assume it to be a tube of cross-sectional area twice that of each pars interarticularis. (A force acting along the neural laminae would also produce shear across the partes interarticulares although we will neglect this for a first approximation.)

The cross-sectional area at the partes interarticulares is about 1.5 cm^2 , considering both partes (Cyron & Hutton submitted for publication). The length from the tip of the inferior process to the base of the pedicle is about 2 cm, and the modulus of elasticity of cortical bone, when subjected to compression, has not been found to be less than 300 kN/cm^2 (Evans 1973); therefore the stiffness of the neural laminae is at least 225 kN/cm [$(300 \times 1.5/2)$]. Now the greatest change in stiffness of a joint after cutting the neural arch is 16.5 kN/cm ($34.9 - 18.4$, specimen 35) and this value is over ten times lower than the lowest approximation for the stiffness of the neural laminae. The suggestion that the compressive force on the L5-S1 joint is transmitted for the most part through the neural arch is not supported by our results.

It could still be argued that the pincer-like process may be due to rubbing on the upper and lower surfaces of the L5 neural laminae. This would require the neural laminae to be in close proximity to the tips of the inferior and superior processes of adjacent vertebrae. Under the maximum load in these experiments it would be expected that contact would be made and the graphs would change in slope when the stiff neural arch came to bear. This did not occur in any of our joints, although our sample may have been too small.

However, it is possible that under long periods of sustained activity the intervertebral disc may creep and thus narrow, bringing adjacent neural arches closer together. This would suggest that a narrowing of the disc, as may occur in disc prolapse, would correlate with an increase in spondylolysis. There is no evidence to date of this.

In hyperextension the centre of rotation of the intervertebral joint lies in the anterior half of the disc and it is possible that contact

between the tips of the inferior articular process of L4 and the neural laminae of L5 could be made before the spinous process came to bear. If heavy weights were then carried while in this posture the intervertebral disc may narrow and allow the compressive force to be transmitted through the neural arches. This, however, is not likely to be a common cause for spondylolysis when we consider the high incidence of pars interarticularis defects in soldiers walking in the partially flexed posture with a pack on their back (Newman 1963). In addition, the neural arch has been shown to be vulnerable to a cyclic force applied to the inferior articular facets (Cyron & Hutton 1978) and mechanical fatigue seems the most common mode of failure.

The question remains, why do some of the joints decrease in stiffness after the neural arch has been cut? Consider the magnitude of the change in stiffness for group 2; the values recorded are compatible with the stiffness of soft tissue; the capsular ligaments offer resistance to tension and the inter-spinous ligament resistance to compression. This may be an individual variation; specimen 35 shows the same characteristics at two levels.

Conclusion

The results of these experiments suggest that, although the posterior elements can transmit compressive force across the intervertebral joint, there is no bony contact between the downward projecting tips of the inferior articular processes and the laminae of the vertebrae below. This mechanism is therefore not the usual factor in the aetiology of spondylolysis.

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