DISC SPACE NARROWING AND THE LUMBAR FACET JOINTS

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Cadaveric lumbar spine specimens of "motion segments", each including two vertebrae and the linking disc and facet joints, were compressed. The pressure across the facet joints was measured using interposed pressure-recording paper. This was repeated for 12 pairs of facet joints at four angles of posture and with three different disc heights. The results were that pressure between the facets increased significantly with narrowing of the disc space and with increasing angles of extension. Extra-articular impingement was found to be caused, or worsened, by disc space narrowing. Increased pressure or impingement may be a source of pain in patients with reduced disc spaces.

At each lumbar intersegmental level the intervertebral disc and the facet joints act together to resist the resultant force acting through the "motion segment". This force can be resolved into two components, one acting perpendicular to the plane of the disc to produce compression, and the other acting in the plane of the disc to produce shear.

The disc plays a relatively minor part in resisting shear, as the extensor muscles, pulling down on the neural arch, force the facet joint surfaces into close apposition. This "door knocker" effect results in a high inter-facet force and protects the disc from shear (Hutton, Stott and Cyron 1977). The compressive component of the resultant force is resisted primarily by the disc, while the small resistance provided by the facets is dependent on posture. In slight extension, as in standing erect, the facets resist about 16% of the compressive force between vertebrae; in slight flexion, as in sitting erect, they resist no part of the force (Adams and Hutton 1980).

This mechanical analysis applies to a normal spine and, clearly, any change in the properties of the disc must affect the facet joints. One of the most common changes seen in the disc is narrowing. Disc narrowing will probably increase facet loading, perhaps to such a level as to cause damage, and to produce pain. It was therefore decided to investigate the relationships between disc height, posture and facet load-bearing, using the pressure-sensitive paper technique described by Lorenz, Patwardhan and Vanderby (1983). This paper could be inserted between the surfaces of the facet joints to monitor the effect of posture and of disc narrowing on contact pressure.

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MATERIAL AND METHODS

Intervertebral motion segments. Lumbar spines were removed during routine necropsy from subjects aged between 31 and 70 years with no history or evidence of bone disease. The specimens were stored in sealed polythene bags at −20°C until required, and before dissection they were thawed slowly at 4°C for 12 hours. The specimens were then dissected into motion segments, each consisting of two vertebrae with the intervening disc and facet joints. Muscle tissue was removed as far as possible, but ligamentous structures were preserved. Any specimen with osteophytes causing abnormal articulation at the facet joints was rejected.

In each of 12 specimens the vertebrae of the motion segment were set in cups of mildly exothermic dental plaster with the ends of the cups parallel to the midplane of the disc. Fixation in the plaster was enhanced by screws placed into the neural arches and bodies of the vertebrae. During dissection and setting, the specimens were kept moist with Ringer's solution.

Test apparatus. This is shown in Figure 1. The combination of angle plate and rollers allowed the testing of an intervertebral joint while it was wedged at a predetermined angle of flexion or extension. The angles θ_1 and θ_2 were adjusted to produce an anterior shear force at physiological level directed parallel to the midplane of the disc. Compression was applied by a hydraulic servo-controlled testing machine; the force applied was plotted against vertical displacement by an X–Y recorder.

The pressure between facet joint surfaces was measured with pressure-sensitive paper—Fujifilm Prescale, medium grade. This paper has a nominal range of 70–250 kg/cm^2 and its calibration is in these units. The correct SI unit is N/m^2 and the conversion factor is 1 kg/cm^2 = 9.81×10^4 N/m^2. The paper has an "A-sheet" with a layer of micro-encapsulated colour-forming material, and a "C-sheet" with a layer of developing material. When the two sheets are pressed together some of the capsules on the A-sheet burst and are developed by the material on the C-sheet. The density of the red colour produced is a measure of the pressure applied. The sheets need only momentary pressure to produce a colour response. The paper was calibrated for the laboratory and the experiment using a dead-weight lever system to apply pressure. Colour density was measured with a double-beam recording microdensitometer (Joyce, Loebl & Co Ltd) used in the reflection mode. The same instrument was later used to quantify the colour density of the imprints obtained from the facet joints.

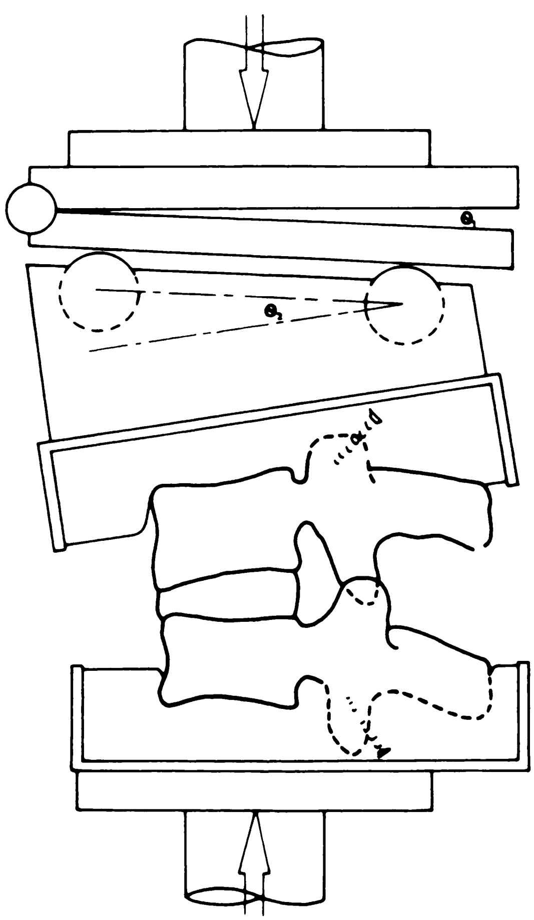

Fig. 1

The apparatus used to apply a combination of compression and shear forces to the specimens.

Experimental method. Each specimen was mounted on the testing machine and placed successively in one of four postures: 4° of flexion, neutral, 4° of extension and 6° of extension. In each posture, a compressive force of 1000 N was applied with a shear force of 200 N to 400 N; this was chosen as being similar to the physiological value for the selected posture.

For each posture the pressure between facet joint surfaces was measured, using pressure-sensitive paper encapsulated in Sellotape to prevent damage by moisture. The taped paper had a uniform thickness of 0.3 mm. Two pieces of paper were cut individually to fit each pair of facet joints and placed to cover the whole facet surface. Occasionally, small extra pieces were needed to cover the tips of the facets in order to avoid severe bending of the paper. When paper had been inserted in both facet joints, the motion segment specimen was placed in the apparatus at the chosen posture; force was applied at a rate of 300 N/s to a maximum of 1000 N, and then removed at once. The test was repeated at the next posture angle after a five-minute recovery period.

A full series of tests was carried out with each intervertebral disc at its original, unaltered height. The series of tests was then repeated after each of two reductions of disc height. First, 1 mm of reduction was obtained by compressive loading at 2000 N for about 2 hours. This was intended to simulate minor narrowing of the disc space. Secondly, 4 mm loss of height was achieved by the removal of disc material through a small anterior window in the annulus.

Pressure recordings for both facet joints were thus made for four postures at each of three disc heights for each specimen, using identical experimental methods. Each map on pressure-sensitive paper gave a peak which was taken as the maximum value recorded by the microdensitometer.

Peak pressure was felt to be the most important parameter measurable by this technique. An attempt was also made to estimate the total loading of the facet joints because the results of this would be comparable with those reported by other workers and would provide a check on the experimental method. For three pairs of facet joint recordings, the microdensitometer was used to establish pressure contours and in addition a planimeter was used to measure the area of each pressure band. The total load was then the sum of area times pressure for each band.

At the end of the experiment several facet joints were selected as having given high peak pressures during the first series of measurements when the disc was at its original unaltered height. These specimens were sent for histological examination in the hope of correlating areas of high pressure with localised degenerative change.

Thickness of paper. It seemed possible that the thickness of the pressure-sensitive paper produced artificially high pressures between the facet joint surfaces. Experiments were therefore carried out on four specimens, using pieces of taped paper of three different thicknesses. From the results a graph of recorded pressure against thickness of paper was obtained; the pressure for zero thickness was extrapolated from this graph. The average difference between the estimated pressure for zero thickness and for 0.3 mm thickness was applied as a correction factor to the results obtained in the main experiment. The results obtained using paper slides of 0.3 mm thickness were found to overestimate the pressure by about 30 kg/cm^2. It is recognised that this correction is by an inferred method and may itself be subject to some error.

RESULTS

The pressure imprints from one facet with varied posture and disc height are shown in Figure 2. A similar set was obtained for 24 facet joints. The maximum pressure in each imprint was measured with the microdensitometer, corrected for paper thickness and recorded in Table I.

An analysis of variance was applied to the results. Individual results from the left or right side varied considerably but the average results from left and right-sided facets were not significantly different. There were no significant differences between the results from subjects under or over 60 years of age, or between the upper lumbar segments (L1–2, L2–3, L3–4) and the lower lumbar segments (L4–5, L5–S1). This lack of difference between various groups of facet joints allowed the results for all 24 joints to be grouped as averages in Table II. Analysis of variance showed that peak pressure increased significantly with loss of disc height, and with increasing extension. This is shown in Table II and in Figures 3 and 4.

Other information was obtained from the pressure maps. Substantial load may be transmitted from the tips of the facets directly to the lamina below, or to the pars interarticularis above. This effect was pronounced in five older specimens with very narrow and degenerate discs. Extra-articular impingement might be seen in the left or right facet, or both together; there was no set pattern. When these five degenerated specimens were tested at their full disc height, impingement was seen only in maximum extension; but when the disc had been made narrower it was found in all postures.

The pressure maps also showed that the position of maximum contact changed with posture. In 12 of the 24 sets of imprints, the contact area moved from the upper half of the facet in flexion, to the lower margin of the facet in full extension (Fig. 2). The other 12 sets showed no definite trend. This movement of the contact area would be expected from the orientation of the articular surfaces in different postures.

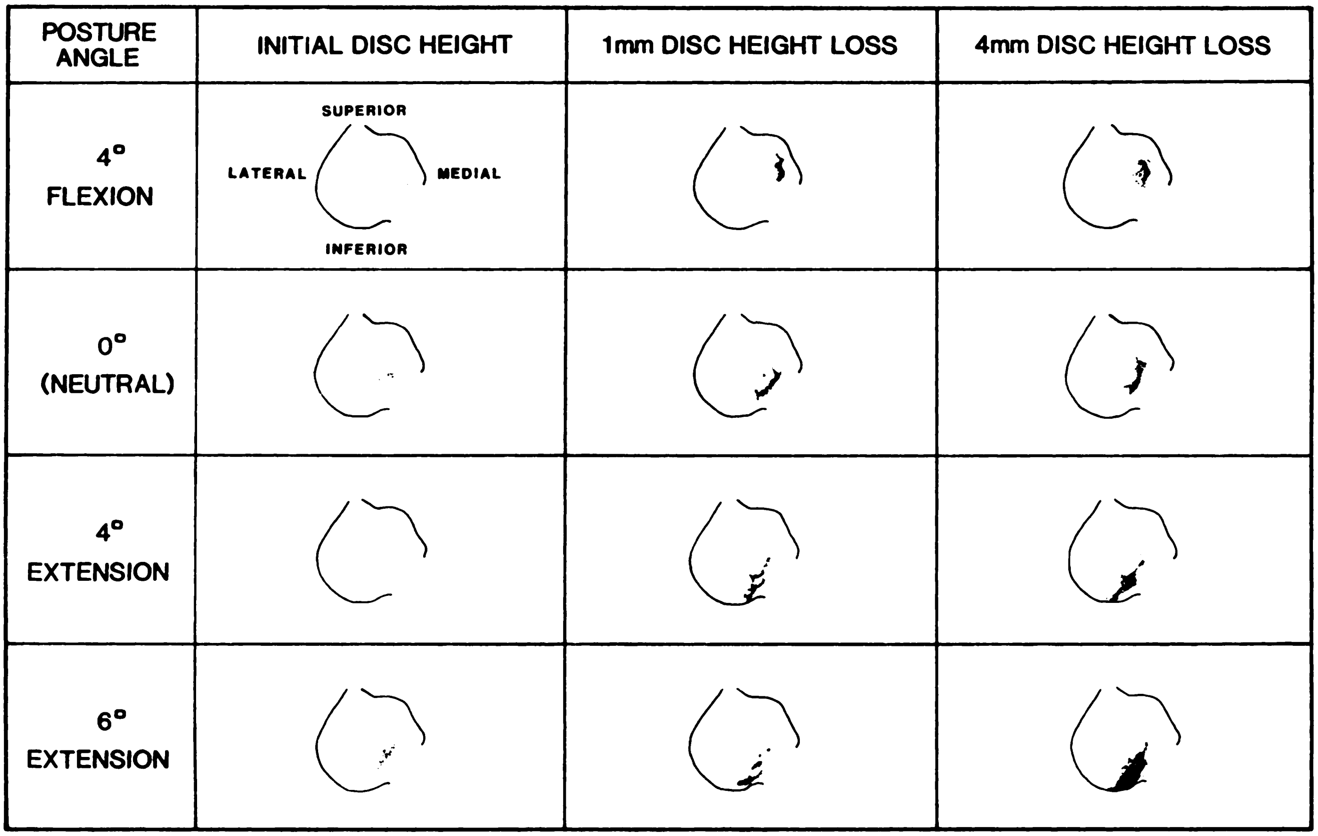

Fig. 2

A set of imprints obtained for a complete test series on one facet joint. The original imprint was in red. The outline of the facet was drawn with a steel pencil at the start of the test, and the pressure imprint is seen within this area. The density of the imprint increases with extension of the motion segment and with loss of disc height.

The results of histological examination were inconclusive. Although regions of peak pressure often coincided with macroscopic alteration of the cartilage surface, these areas did not reveal the histological features of osteoarthritis.

Estimates of total load on the three pairs of facet joints measured for that purpose showed that they carried between 10% and 40% of the applied compressive force when in 4° of extension, with disc narrowing of 1 mm. The method used was inaccurate but the results were in broad agreement with those obtained by other methods (Adams and Hutton 1980).

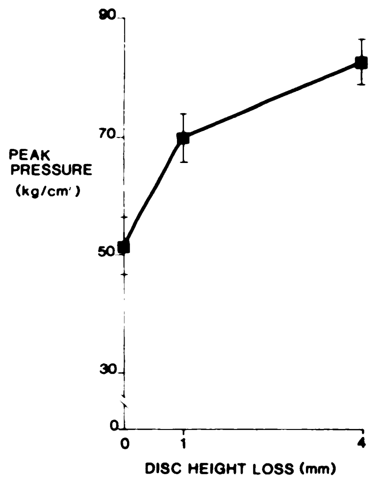

Fig. 3

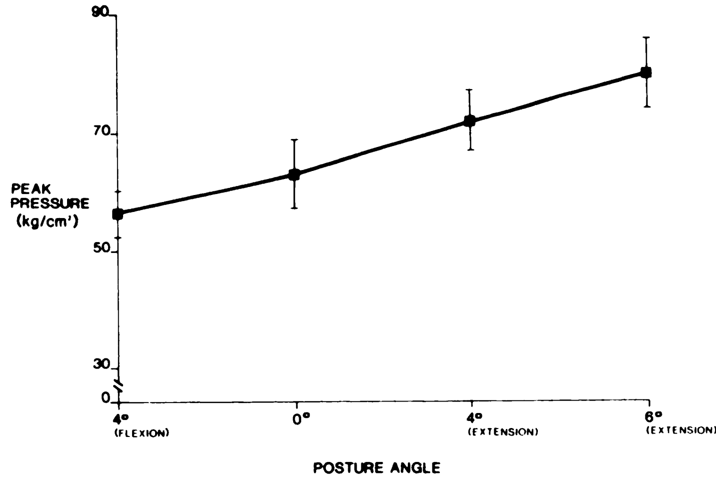

Fig. 4

The average values of peak pressure plotted against loss of disc height (Fig. 3), and against posture angle (Fig. 4). The 95% confidence limit of the mean is shown for each point.

Table I. Peak pressure recordings (kg/cm^2) for 12 pairs of joints. Values have been corrected for thickness of paper (see text). The values marked with an asterisk are the lowest recordable by the technique, and are generally overestimated

Specimen				**Left**				**Right**			
Sex	**Age *(years)***	**Level**	**Loss of disc height *(mm)***	**Flexion 4°**	**Neutral**	**Extension 4°**	**Extension 6°**	**Flexion 4°**	**Neutral**	**Extension 4°**	**Extension 6°**
M	43	L3–4	0	39	59	62	75	38	43	60	66
			1	76	81	85	88	58	68	81	74
			4	81	84	91	95	85	88	75	59
M	53	L2–3	0	57	49	43	30	56	64	84	84
			1	59	57	39	61	80	75	82	92
			4	62	43	74	83	89	84	101	101
F	67	L3–4	0	26*	43	75	92	26*	30	26*	57
			1	52	89	93	103	75	101	75	81
			4	96	92	102	111	110	91	73	113
F	60	L2–3	0	26*	26*	50	26*	26*	26*	52	73
			1	43	79	82	85	38	77	81	87
			4	51	60	80	96	75	70	70	92
F	67	L5–S1	0	39	30	30	43	26*	54	66	68
			1	26	71	80	89	64	71	43	74
			4	85	89	70	95	75	73	85	92
F	60	L4–5	0	34	34	26*	41	34	26*	59	69
			1	57	75	78	88	39	72	68	73
			4	79	93	93	96	78	75	87	75
F	67	L1–2	0	68	73	79	81	26*	26*	59	69
			1	90	88	92	93	49	78	88	83
			4	93	95	87	92	83	88	96	98
M	70	L5–S1	0	62	74	79	78	26*	73	65	35
			1	71	75	75	80	39	60	43	77
			4	81	75	73	80	70	70	75	77
F	31	L4–5	0	38	46	55	49	26*	39	38	34
			1	38	43	81	83	50	53	64	61
			4	65	40	88	90	80	85	85	81
M	44	L2–3	0	39	45	64	84	34	55	73	81
			1	43	47	78	91	26*	49	67	96
			4	49	50	100	100	88	49	98	105
F	31	L2–3	0	26*	55	77	79	26*	49	54	59
			1	61	78	83	87	52	85	83	91
			4	87	70	96	100	91	95	100	92
M	53	L4–5	0	54	63	66	63	50	26*	66	51
			1	50	60	53	80	71	45	53	82
			4	44	68	85	104	86	85	96	92

DISCUSSION

The important conclusion from these experiments is that disc space narrowing causes a marked increase in peak pressure across the facet joints. Patients who undergo disc excision or chemonucleolysis must face the possible consequences of this increase in stress.

Table II. Averge peak pressures (kg/cm^2) of 24 joints

Posture		**Disc height**	
4° flexion	56.8	Unaltered	51.6
Neutral	63.9	Loss of 1 mm	70.1
4° extension	72.8	Loss of 4 mm	83.3
6° extension	79.9		

Average values for peak pressure are given in Table II; they range from 51.6 to 83.3 kg/cm^2. Some single joint values in Table I are over 100 kg/cm^2. The only comparable values we could find reported refer to the hip joint. Rushfeld, Mann and Harris (1979), using an instrumented prosthetic femoral head, measured the contact pressure as 69.3 kg/cm^2 (quoted as 6.8 MN/m^2). Afoke, Byers and Hutton (1982), using a finite element method, calculated the maximum contact pressure as 61 kg/cm^2 (quoted as 6.0 MN/m^2). Our results from intact specimens in flexion are very similar. However, once the disc spaces are narrowed and extension takes place we found markedly higher peak pressures.

The higher contact pressures with disc narrowing and in extension could possibly damage the facet joints. Lewin (1964), in a comprehensive review, found a link between osteoarthritis of the facet joints and osteophytic lipping of the vertebral bodies. In our experience, lipping of the vertebral body is usually accompanied by disc narrowing. Can it follow then, that disc narrowing produces high contact pressures in the facet joints and is a cause of osteoarthritis?

Another consequence of high pressure and of extra-articular impingement may be pain, not from articular cartilage, but from subchondral bone or from soft tissue nipped between the facets. This could explain why many patients with disc space narrowing have either reduced extension or pain on extension, or both.

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