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The tensile strength of the capsular ligaments of the apophyseal joints*

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INTRODUCTION

Flexion of the lumbar intervertebral joint is resisted by the posterior ligaments and the intervertebral disc (Adams, Hutton & Stott, 1979) with the apophyseal joints gliding upon one another by as much as 5 to 7 mm (Lewin, Moffett & Viidik, 1962). Axial rotation, on the other hand, is resisted primarily by the apophyseal joints coming into firm apposition after about 1° of rotation per intervertebral joint (Adams & Hutton, unpublished observations); this compares with a normal range of movement of about 10° between two vertebrae in flexion. Thus flexion seems more liable to overstretch the posterior ligaments.

Previous work on the ultimate strength of the anterior and posterior ligaments (Nachemson & Evans, 1968, ligamentum flavum; Tkaczuk, 1968, longitudinal ligaments) never included the capsular ligaments of the apophyseal joints. It has already been noted that it is the apophyseal joints that play the major role in resisting full flexion (Adams, Hutton & Stott, 1979), however it is not yet clear just how far the capsular ligaments can be stretched before rupture.

The effective length of these ligaments, as measured round the rim of the joint, has been estimated to be about 1·2 cm (Farfan, 1973) although it is difficult to divorce them from the ligamentum flavum on the ventral aspect and the tendon of the multifidus attached to the dorsal side of the joint. Therefore any mechanical properties of these ligaments measured must include some parts of these other tissues. A further difficulty arises in that the centre of rotation in flexion is variable and the position of the centre may influence the relative stretching of each of the ligaments of the capsule. Since the centre of rotation lies within the intervertebral disc, then the most distal part of the ligament will be stretched more than the proximal part. Thus to overcome any artifact produced by choosing the wrong centre of rotation to simulate flexion, we have decided to test the strength of the capsular ligaments of the apophyseal joints under pure tension.

MATERIALS AND METHODS

Lumbar spines from subjects aged between 26 and 80 years were removed during routine necropsies. The material was collected from cadavers in whom there was no history or evidence of bone disease. In addition spines which showed some degree of scoliosis, had osteophytes around the peripheries of the vertebral bodies or a noticeably narrow and bulged-out intervertebral disc were also regarded as unsuitable for testing.

All specimens were stored in sealed polythene bags at a temperature of −20°

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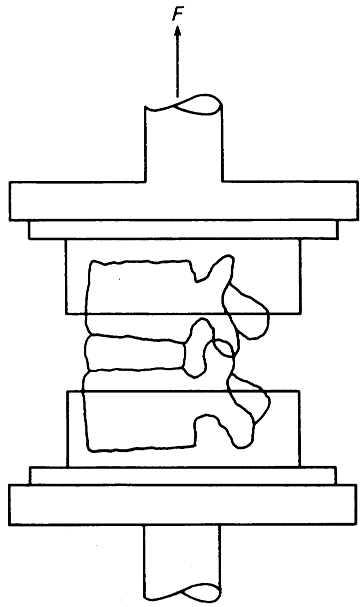

Fig. 1. The arrangement of the apparatus for applying a tensile force to the capsular ligaments.

until required for testing. Prior to dissection the specimens were placed in a refrigerator for 24 hours to allow for slow defreezing. The spines were then dissected into joints consisting of two vertebrae and the intervening disc.

Each joint was cleaned of the excess soft tissue. All the ligaments, with the exception of the intertransverse, were kept intact. It was decided that the intervertebral disc, the supra/interspinous ligaments and the ligamentum flavum should be cut after the specimen was mounted, since the intervertebral joint is more rigid when all its ligaments and the intervertebral disc are intact and so can be handled more easily.

Wood screws were fixed into the vertebral bodies to ensure a firm fixation in dental plaster (Calestone). Screws were also used to prevent any relative movement between the plaster and containers holding the top and bottom vertebrae. The intervertebral joints were mounted in the plaster (Fig. 1) with each vertebral body having about three quarters of its height embedded in such a way that the axes of the apophyseal joints were lying parallel to the axis of the applied force. This method of mounting allowed free sliding movements between the articular facets while the capsular ligaments were under tension.

The top and bottom containers holding the vertebrae were clamped onto the cross-head and the ram of a universal testing machine and the intervertebral disc, the supra/interspinous ligaments and the ligamentum flavum were cut with a scalpel.

A tensile force was applied to each specimen at a rate of displacement of $1{\cdot}0 \times 10^{-3}$ cm/s. The applied force and corresponding displacement were recorded by an X–Y plotter.

Table 1. *Experimental results*

Specimen No.	Age	Sex	Intervertebral level	Initial displacement d_1 mm	Displacement to first peak d_2 mm	Force first N	Displacement to second peak d_3 mm	Force second peak N
1	26	F	L1–L2	0·5	7·9	1266	9·1	1160
1	26	F	L3–L4	0·7	5·1	1122	6·6	1140
2	29	F	L2–L3	0·1	3·7	1050	4·9	2660
2	29	F	L4–L5	0·5	6·7	1140	10·6	1060
3	37	M	L1–L2	0·3	5·1	518	7·9	950
3	37	M	L3–L4	0·6	4·5	244	8·7	635
4	52	F	L2–L3	1·1	5·7	730	12·0	340
4	52	F	L4–L5	1·1	5·2	513	7·6	649
5	52	F	L2–L3	0·9	4·7	425	7·7	403
5	52	F	L4–L5	1·7	5·3	295	8·0	365
6	56	M	L4–L5	1·6	4·5	600	8·0	620
7	59	M	L2–L3	1·0	4·1	370	8·6	360
8	60	M	L3–L4	1·0	4·0	437	4·8	479
9	63	F	L2–L3	1·2	3·6	153	6·4	475
9	63	F	L4–L5	0·9	4·1	303	6·1	357
10	73	M	L2–L3	1·0	2·5	275	4·1	160
10	73	M	L4–L5	0·5	1·5	230	3·1	252
11	74	M	L2–L3	0·6	1·5	210	2·0	220
11	74	M	L4–L5	0·7	2·6	467	—	—
12	80	F	L2–L3	0·5	1·7	267	2·8	285
12	80	F	L4–L5	0·2	2·4	510	—	—

RESULTS

In all, 21 intervertebral joints were tested and the results are summarised in Table 1. Because of difficulties in mounting, the lumbosacral joints were not tested. Figure 2 shows a typical graph obtained for each specimen tested except for specimens number 11 (L4–L5) and 12 (L4–L5) where a different type of graph was obtained and its features will be described later.

In Figure 2 the zero position of the X axis refers to an unloaded position for the intact joint, in that any excursion in the negative X direction would have placed a compressive force on the intervertebral disc.

We can interpret the graph as follows: d_1, the slack in ligaments is taken up and the fibres align along the axis of the applied force; d_2, the ligaments show an increase in resistance with the applied force and at the limit, the first peak, the shorter fibres rupture; d_3, the shorter fibres having ruptured the force falls off and then builds up again as the longer fibres are stretched and the second peak represents the tensile strength of these fibres. The value of applied force for the first peak and for the second peak both decrease with age ($r = -0{\cdot}76$ $P < 0{\cdot}005\,\%$ for the first peak and $r = -0{\cdot}74$ $P < 0{\cdot}02\,\%$ for the second peak). There is no similar trend for the displacement to rupture of the short fibres (d_2) or of the long fibres (d_3).

For the two specimens mentioned above a typical graph obtained is shown in Figure 3. This graph has one peak only. After the test the apophyseal joints of these specimens were examined macroscopically and it was observed that there was evidence of secondary bone formation at the superior and inferior margins of the joints, fusing the facets together.

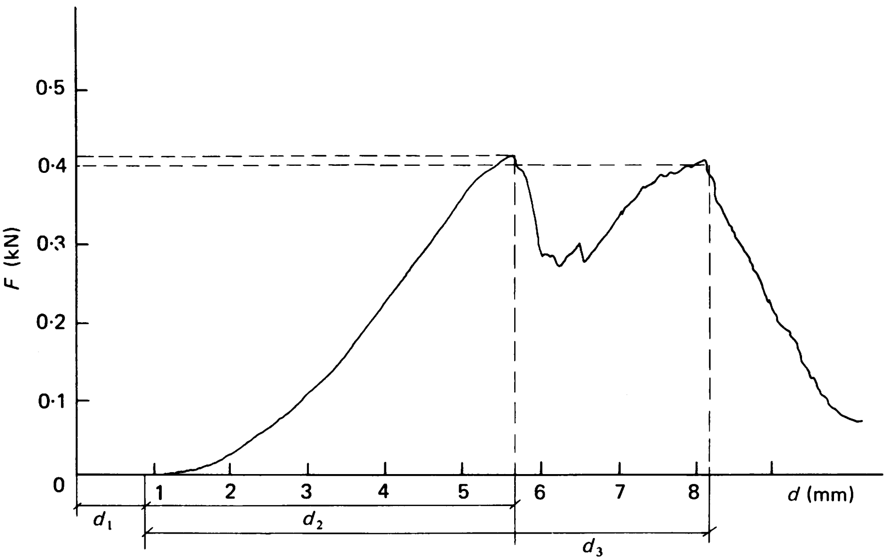

Fig. 2. A typical graph of applied tensile force against displacement for capsular ligaments tested to destruction. The displacements d_1, d_2 and d_3 are explained in the text.

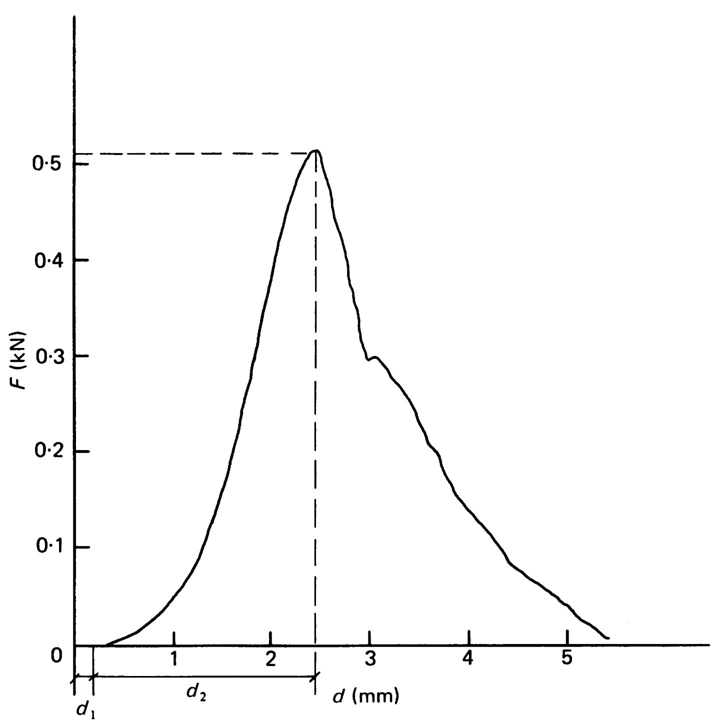

Fig. 3. A typical graph of applied tensile force against displacement for a specimen with degenerated capsular ligaments. Compared to Fig. 2 the characteristic displacement d_3 is missing.

DISCUSSION

In 19 out of the 21 intervertebral joints tested, the results showed two peaks of loading. This is consistent with the idea of fibres of different lengths. If the centre of rotation in flexion is situated near the middle of the intervertebral disc, then the fibres on the ventral aspect of the apophyseal joints would be stretched by a lesser amount than the fibres on the dorsal aspect, so it is likely that the long and short ligaments are at the dorsal and ventral margins respectively. Thus, in our tests, when we stretched the ligaments in pure tension, if our hypothesis is correct, then the ventral fibres ruptured first. What we are saying, in fact, is that the ligaments are arranged so as to provide maximum resistance to flexion and the two separate peaks in our tests are produced by the method of loading. (Our attempts to test our hypothesis by microscopic analysis were unsuccessful because of the difficulty in excising the complete capsule.) The results show that the separate ligaments are strong, with the capsular ligaments of the younger joints able to support about twice body weight. That their strength decreases with age is not unexpected since this has been shown to occur in other tissue (Nachemson & Evans, 1967; Yamada, 1970).

However, the question remains, how much do the ligaments have in reserve at the limit of flexion? A previous study (Adams, Hutton & Stott, 1979) showed that at the limit of flexion, when the supra/interspinous ligaments sprain, the tensile force in the capsular ligaments (acting together) averaged 585 N, with a range of 141 to 2016 N. This suggests that the capsular ligaments have some strength in reserve at the limit of flexion, but the great range of values recorded does not permit any more definite conclusion.

The initial slack (d_1) shown by our method of testing is to be expected when we consider how short the ligaments have been estimated to be (1·2 cm *vide supra*). As we have said before, the apophyseal joints glide over one another by up to 7 mm, and, without slack, this could mean an extension of about 60 % for some fibres. This value is rather high when we consider that the average strain measured for ligamentum flavum in simulated flexion experiments was estimated to be 31 % (Adams, Hutton & Stott, 1979). A better explanation is that the fibres around the joint capsule are rather slack until this has been taken up by bending forward; this implies that the distance round the rim of joint (1·2 cm) gives an under-estimate of the true length of the ligaments.

The results for the two joints with osteophytes show unusually high forces and displacements at rupture. It may be that the process of degeneration calcifies the whole ligament and any analogy to short and long fibres would then be redundant.

CONCLUSION

The capsular ligaments of the apophyseal joints are arranged to provide maximum resistance to flexion. They can support about twice body weight in the young although their strength decreases with age.

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