In-vitro mobility of the lumbar spine

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SUMMARY As part of a systematic study of the spine between D11 and S1 the response to stress has been assessed by measuring radiologically the total and segmental mobility of 103 specimens. The method was shown to be reproducible to within 10% of total mobility. No significant sex difference was seen. Total mobility varied widely, but mean total mobility fell with age. All lumbar segments became less mobile up to the fifth decade. Between the fifth and the eighth decade the mobility of the fifth lumbar segment continued to fall, whereas other lumbar segments became more mobile. The mobility of each segment also varied widely, but the mean segmental mobility fell progressively from L5 to D11. However, this smooth pattern of movement was seen in only 16 cases, mostly adolescents and young adults. Among the remainder, in which movement was irregularly distributed, there were 7 cases (4 aged less than 30 years) in which the mobility of at least 1 segment was more than 2 standard deviations above the mean. The cause of this hypermobility was not evident radiologically. It is suggested that segments with abnormally high mobility may be at risk.

Lumbar spinal mobility was first studied by Weber and Weber (1836) on 3 post-mortem specimens. Since then most investigators have measured mobility clinically, with or without the aid of radiographs (Elward, 1939; Gianturco, 1944; Tanz, 1953; Allbrook, 1957; Israel, 1959; Jonck and Van Niekerk, 1961; Clayson *et al.*, 1962; Lindahl, 1966; Loeb, 1967; Sturrock *et al.*, 1973; Sweetman *et al.*, 1974). Post-mortem studies of dorsolumbar mobility have been neglected despite the advantage that they facilitate analysis of mobility patterns and their relation to structural abnormalities.

The measurements of sagittal mobility described in this paper were obtained as part of a systemic study of the spine below D9.

Material and methods

The material consisted of 117 selected post-mortem specimens of the lower spine. Specimens were not removed from patients with known neoplasia or metabolic bone disease or if they had received long-term corticosteroids. Histological examination of an undecalcified bone block from the sacrum of each spine revealed 5 patients with unsuspected osteomalacia and 1 with mild secondary hyperparathyroidism. These patients were not included in the

study. Of the remaining 111, 52 were females and 59 were males. The age range was 13 to 96 years. Fifty-three patients were under 50 years and 58 were over 50 years of age. Most patients had died within 1 week of admission to hospital, and none had been confined to bed for more than 1 month.

MEASUREMENT OF SAGITTAL MOBILITY

The method used was an adaptation of that described by Ball and Meijers (1964) for mobility studies on the cervical spine. The lower spine, including the sacrum, was removed by dividing the ninth dorsal vertebra and the sacroiliac joints. Measurements were made at room temperature in a humid atmosphere. In most cases fresh specimens were used. The remainder were stored at 4°C, wrapped in several layers of gauze soaked in saline, and brought to room temperature before measuring mobility. It has been shown that this storing procedure does not affect the mechanical properties (Kazarian, 1972). A steel pin was inserted into the anterior aspect of each vertebral body from D11 to S1 inclusive. The sacrum was fixed in a clamp with the spine and pins lying in the horizontal plane about 5 cm above the surface of a table. A line attached to D9 was led anteriorly over a pulley to a cloth bag containing a 2 kg load. This load was selected because preliminary experiments had shown that with greater loads there was a risk of fracture, especially in older specimens. In a few younger

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cases 4 kg was also used, and it was found that this increased total mobility by up to 25%.

When maximum flexion had been achieved the specimen was maintained under load for approximately 10 minutes. This time lapse was selected because experiments on 2 spines had shown that the increase in total mobility due to creep was most marked in the first 10 minutes (8% and 6.4%) and that any subsequent increase was within experimental error (not more than 1%). Creep had no discernible effect on the pattern of mobility. A radiograph was then taken with the tube 110 cm above the table and centred over the mid point between D10 and S1. After the pulley and bar were transferred to the posterior side the procedure described above was repeated to obtain an x-ray in maximum extension.

The two radiographs were used to measure angular movement about each of the 8 discs between D10 and S1. With the pin in S1 being taken for reference, the difference between the angle subtended by the pin in L5 in flexion and extension gave the angular movement of L5 on S1. The angular movement of L4 with reference to S1 was then calculated, and the difference between this angle and that calculated for L5 gave the movement of L4 on L5. This procedure was repeated for each disc level.

The reproducibility of the method was tested by repeated measurements on 3 specimens and found to be within 10% of total mobility, with no change in the segmental distribution (Table 1).

Results

Among the 111 cases 5 unsuspected cases of primary instability and 3 unsuspected cases of spondylolisthesis were found. These were excluded, thus leaving 103 cases for analysis. There were 25 males

Table 1 Triplicate measurements of mobility

	Specimen 1 (F37)			Specimen 2 (M53)		
L5	7	7	7.5	18	18	18.5
L4	14.5	14	14	9	9.5	9
L3	9.5	10	10	6.5	6.5	7
L2	7	8.5	8	6.5	7	6.5
L1	10	9.5	10	4	4.5	4.5
D12	4	3.5	4.5	2.5	2.5	2
D11	3.5	3.5	3	1	1	1.5
D10	2	1.5	2.5	0.5	0.5	0.5
Total	57.5	57.5	59.5	48	49.5	49.5

and 23 females aged under 50 years of age and 29 males and 26 females aged 50 years and over.

CHANGES IN MOBILITY WITH AGE

At all ages there is a marked variation in total mobility, though the mean falls with age by about 25% between those aged up to 30 and those aged over 70 years (Fig. 1). No sex difference in these variables was seen.

The mean mobility of each lumbar segment is shown for males in Fig. 2. Segmental mobility falls with age up to the fifth decade. Thereafter the mobility of the fifth lumbar segment continues to fall to the eighth decade whereas that of L4, L3, L2, and L1 tends to increase. The results in females were similar, though the fall in mobility at L5 was less uniform. The fall in mobility at L5 in the elderly is shown most strikingly when the mean mobility at each disc level in the age groups less than 50 and 50+ years are compared (Fig. 3). It can be seen that in the older age group reduced mobility is virtually confined to the L5 segment. A study of the grades of disc narrowing and osteophyte formation at each disc level (to be reported elsewhere) showed that this fall in mobility at L5 in males and females could not be attributed to either of these factors. More disc narrowing occurred at L5 than at other segments,

Fig. 1 Individual and mean total mobility in age groups.

Fig. 2 Mean mobility by age and disc level.

but even when cases with disc narrowing at L5 are excluded, the fall in mobility at L5 is still present (Fig. 3).

MOBILITY PATTERNS

In both sexes there is a considerable scatter of

Fig. 3 Mean mobility by disc level in age groups ≤ 49 and 50+ years.

mobility values at each disc level, but the mean mobility falls progressively from L5 (Fig. 4). However, this smooth fall in mean mobility is misleading since in the majority of individuals mobility is to varying extent irregularly distributed. Indeed, only 9 females and 7 males conform to this mean mobility pattern. Of these 16, 13 are aged less than 50 years. It can be seen (Figs. 5a and 5b) that the irregularity in mobility patterns occurs irrespective of age and sex and can be due to either an abnormal reduction or an increase in mobility at any disc level or a combination of these (Fig. 6).

In both sexes approximately 25% of mobility values at each segment are greater than plus or minus one standard deviation from the mean and greater than 2 standard deviations between 1 and 10% (Fig. 4). In discs with mobility greater than 2 standard deviations below the mean only 45% showed radiological evidence of disc degeneration. In none of the examples shown in Fig. 5a was there disc degeneration. In the 7 cases with isolated segmental mobility greater than 2 standard deviations above the mean (Fig. 5b) 4 were aged less than 30 years and were radiologically normal. The other 3 showed only minimal radiological evidence of disc degeneration of the affected discs. It can be seen (Fig. 5b) that the abnormal segmental mobility in all 7 is not due to reduced mobility at other levels.

Discussion

Clinical assessments of total sagittal mobility in healthy individuals have yielded variable results (Israel, 1959; Lindahl, 1966; Loeb, 1967; Sturrock *et al.*, 1973; Sweetman *et al.*, 1974) partly because of

Fig. 4 Mean mobility and discs with mobility $\pm 1SD$ and $\pm 2SD$ at each disc level.

Fig. 5 Irregular spinal mobility patterns: (a) due to segmental reduction in mobility; (b) due to segmental increase in mobility.

Fig. 6 Irregular mobility patterns due to combined reduction and increased mobility.

differences in the consistency and accuracy of the methods used (Reynolds, 1975). Movement between individual discs can be measured only by radiographs (Elward, 1939; Gianturco, 1944; Tanz, 1953; Allbrook, 1957; Jonck and Van Niekerk, 1961; Clayson *et al.*, 1962), but such studies have been infrequent.

In clinical studies total mobility and its distribution may of course be influenced by the presence or absence of pain and the effectiveness of muscular activity. Pathological studies are not subject to these constraints and hence may provide a more accurate estimate of the underlying mechanical stability as determined by ligamentous and bony structures.

The simple method adopted in the present study was shown to yield reproducible results for sagittal mobility of the whole specimen (D11–S1) and its constituent segments. No attempt was made to preload the spine (equivalent to the erect posture), and the findings might be criticised on this account. According to Panjabi *et al.* (1977) preloading would tend to increase sagittal mobility, but there were no grounds for assuming that the segmental distribution of mobility would be altered, though this cannot be excluded. In fact the overall spinal mobility between D11 and L5 observed in the present *in vitro* studies was found to be of a similar order to that reported for this region in healthy recumbent subjects by Tanz (1953) using radiological methods, but some 30% less than that reported by Loeb (1967) for each decade using a goniometer and measuring flexion in the sitting position and extension with the patient prone. The higher mobility reported by Loeb (1967) could have been achieved in the present experiment by doubling the load, but for practical reasons (see above) this degree of loading could not be used. At all ages in both sexes there is a wide range of total mobility. Mean total mobility in adult life is similar in males and females,

and in both sexes falls by about 25% between those aged up to 30 and those aged over 70 years.

Surprisingly, almost all the loss of mobility in the elderly occurs at L5 in both sexes and is accompanied by an apparent compensatory increase in mobility above L4. This compensating increase in mobility which has not previously been reported, could mean that the dorsolumbar junction becomes less resistant to stress in the middle aged and elderly. A disproportionate loss of mobility at L5 was also reported in the clinical studies of Tanz (1950, 1953), who like ourselves could not explain this on the basis of disc degeneration.

Mean segmental mobility falls progressively from L5. However, there is a wide scatter of mobility at each disc level. This finding is not accounted for by high and low mobility spines but reflects irregularities in the distribution of mobility in individual spines. Thus, spines conforming to the regular pattern of mobility described by the mean values are rarely found in adults. The irregular distribution of mobility is due to either decreased or increased mobility in 1 or more segments or a combination of these abnormalities. The irregularities are often unpredictable from straight x-rays and do not necessarily reflect gross pathology, since they can occur in relatively healthy young specimens. In about 7% of our specimens one or more segments had a sagittal mobility greater than two standard deviations above the mean. This type of abnormal movement was not explicable on the basis of reduced mobility at other levels. It was found at all levels except L4 and L5. In 4 of the 7 cases it occurred in healthy spines aged less than 30 years. The nature of the 'hypermobility' is obscure, but it cannot be attributed to primary instability in the sense of Morgan and King (1957), since such cases have been excluded radiologically, and, unlike primary instability, there was no predilection to affect the L4–L5 disc. However, it seems reasonable to assume that such hypermobile segments may be at risk to mechanical stress. Clinical methods designed to detect such segments may be of some value in the study of low back pain.

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