THE STRUCTURE OF THE PARS INTERARTICULARIS OF THE LOWER LUMBAR VERTEBRAE AND ITS RELATION TO THE ETIOLOGY OF SPONDYLOYSIS

With a Report of a Healing Fracture in the Neural Arch of a Fourth Lumbar Vertebra

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Defects in the pars interarticularis are rarely present at birth, and seldom appear clinically before the age at which a child can stand upright. The incidence then increases up to the third or fourth decade (Rowe and Roche 1953, Stewart 1953). In radiological surveys of normal industrial and military populations, spondyloysis has been reported in up to 7.6 per cent (Friedman, Fischer and van Demark 1946; Moreton 1969; Hector 1972), though the incidence may be as much as 45 per cent in certain races and families (Hasebe 1913, Bakke 1931, Willis 1931, Friberg 1939, Roche and Rowe 1951, Stewart 1953, Baker and McHollick 1956, Nathan 1959, Wiltse 1962, Berquet 1965, Francillon and Schreiber 1966, Lester and Shapiro 1968, Kettelkamp and Wright 1971). There are therefore genetic factors which may predispose an individual to the defect. But spondyloysis is not a congenital lesion, nor are developmental errors considered relevant to the etiology (Batts 1939, Mutch and Walmsley 1956). The precipitating factor is now believed to be a mechanical one, fatigue or impact failure leading to fracture of the pars interarticularis on one or both sides (Roberts 1947, Unander-Scharin 1950, Anderson 1956, Nathan 1959, Newman 1959, de Palma and Marone 1959, Newman 1963, Murray and Colwill 1968, Arct 1971).

Despite the growing body of evidence in support of the theory that spondyloysis follows a fracture, there are notably few accounts of the normal anatomy of the region affected. The pathological anatomy of spondyloysis has been fully described (Willis 1931; Junghanns 1933; Raney 1945; Roche 1949; Gill, Manning and White 1955; Bosworth, Fielding, Demarest and Bonaquist 1955; Nathan 1959; Sullivan and Bickell 1960; Wiltse 1962). The pars at the site of the defect "may be of deep triangular shape or wide and flat" (Willis 1931); and Wiltse (1962) referred to cortical bone in the region of spondyloysis but did not define its extent. Gallois and Japiot (1925) radiographed sections of whole vertebrae and described the trabecular structure in each region of the spine, though in the lumbar neural arch they showed little of the pars, only reporting bony fasciculi at the superior margins of the laminae and between the transverse processes. Schlüter (1960) referred to cortical bone on the inferior and superior margins of the pedicles but did not describe its extent into the pars. Lethe (1962) also described cortical bone in the neural arch and demonstrated the direction of osteons histologically.

It was therefore decided to study the bony structure of the neural arch and to consider the forces it withstands in the course of daily activities and occasional exertions. Accordingly, specimens of the fourth and fifth lumbar vertebrae were obtained at necropsy from seven subjects aged seventeen to sixty-seven (see Table I) in order to study the normal structure.

METHOD

After removal, the specimens were cleaned of soft tissue superficially and immersed in 10 per cent formalin solution for eight to fourteen days. Serial slices two millimetres thick were cut in a milling machine in the following planes: 1) vertical slices parallel to the posterolateral margin of the spinal canal; 2) cross slices through the pars in the plane of the smallest
perimeter; and 3) *horizontal* slices parallel to the superior surface of the vertebral body. Details of the slices examined in each specimen are given in Table I.

The slices were set in serial order and radiographed in a Faxitron x-ray machine. They were then returned to formalin solution for twelve hours before being treated with acetone and sodium hypochlorite to remove bone marrow and periosteal tissue, and radiographed again.

### TABLE I

**The Ages, Sex and Cause of Death of the Subjects, together with the Details of Slices Examined in Specimens of L.4 and L.5 Taken at Autopsy**

<table>
<thead>
<tr>
<th>Case number</th>
<th>Age</th>
<th>Sex</th>
<th>Cause of death</th>
<th>Slices examined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Vertical</td>
</tr>
<tr>
<td>1</td>
<td>17</td>
<td>Male</td>
<td>Peritonitis</td>
<td>L.4 right</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L.5 left</td>
</tr>
<tr>
<td>2*</td>
<td>22</td>
<td>Male</td>
<td>Lysol poisoning</td>
<td>L.4 left</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>Female</td>
<td>Diabetes</td>
<td>L.4 right</td>
</tr>
<tr>
<td>4</td>
<td>51</td>
<td>Male</td>
<td>Coronary infarction</td>
<td>—</td>
</tr>
<tr>
<td>5</td>
<td>58</td>
<td>Male</td>
<td>Coronary infarction</td>
<td>L.4 left</td>
</tr>
<tr>
<td>6</td>
<td>66</td>
<td>Male</td>
<td>Coronary infarction</td>
<td>L.5 left</td>
</tr>
<tr>
<td>7</td>
<td>67</td>
<td>Female</td>
<td>Cerebral aneurysm</td>
<td>L.5 left</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>L.5 right</td>
</tr>
</tbody>
</table>

* L.5 in this subject was sacralised.

### RESULTS

**NORMAL ANATOMY**

**Vertical slices** (Figs. 1 and 2)—Two dense layers of cortical bone were visible in all specimens antero-laterally and postero-medially, the former being the thicker. The antero-lateral layer extended from the inferior border of the pedicle to the subchonchal region of the inferior articular process. The postero-medial layer arose from the subchondral region of the superior facet and curved postero-medially into the lamina, but partly extended into the inferior articular process. Both layers were thickest in the narrowest region of the pars. Between the two layers the trabecular structure was markedly more sturdy than elsewhere in the neural arch.

**Cross slices** (Fig. 3)—The narrowest region of the pars presented a curved antero-lateral surface but postero-medially it tended to be biconcave, divided by a ridge of bone extending from the superior to the inferior articular process. In the slices from younger specimens the antero-lateral and postero-medial layers of cortical bone seen in the vertical slices were joined to form a ring with a central trabecular region. In older specimens the trabecular region effectively separated the two layers so that they were more or less parallel. The trabeculations were arranged at about 90 degrees to the layers, being directed infero-lateral-anteriorly: this arrangement was less obvious in the younger subjects.

**Horizontal slices** (Fig. 4)—The two layers of cortical bone were visible in the slices from the specimens examined. They also showed parallel trabeculation directed from the postero-medial cortical zone at the base of the superior facet towards the medial margin of the pedicle into which the antero-lateral layer of cortical bone extended.
FIG. 1
Two vertical slices through the neural arch of the fifth lumbar vertebra of a 66-year-old male, cut parallel to the postero-lateral margin of the spinal canal (Case 6).

FIG. 2
Serial vertical slices through the neural arch of the fifth lumbar vertebra of a 17-year-old male. From left to right the slices are arranged from antero-medial to postero-lateral (Case 1).

REPORT OF A UNILATERAL HEALING FRACTURE

A defect in the antero-lateral region of the right pars interarticularis of the fourth lumbar vertebra from Case 1 is shown in serial radiographs of vertical slices of the neural arch (Figs. 5 and 6). The defect extends vertically from the antero-lateral border of the narrowest region of the pars through the cortical layer into cancellous bone. Callus formation is visible in the radiograph. Histological sections showed a track between bony tissue at the site of the defect. In Figure 7 remodelling can be seen with new bone becoming incorporated with the original lamellar structure of the antero-lateral layer of cortical bone in the pars. The appearances are typical of healing in a recent fracture.
DISCUSSION

The antero-lateral and postero-medial layers of cortical bone in the pars and the consistently greater thickness of the former, which were revealed in all seven subjects, appear to represent the normal anatomical structure. The few trabeculae between these layers appeared to be of greater strength than those elsewhere in the neural arch. This suggests that the pars is capable of withstanding considerable stress. However, it is notable that where the cortical bone is thickest it is not only the narrowest part, but also the site of the defect in spondylolysis.

The stresses to which this part of the lumbar neural arch is subject are complex. They arise primarily from shearing forces between the articular processes (Troup 1970). But the effects of these forces vary with posture, for Reichmann (1971) has shown that the angles between articular facets change with movement. He found the angulation most marked on lateral flexion, and greater in extension than flexion.

When the trunk is horizontal in stooping, gravity tends to displace each vertebra anteriorly on the one below. Thus, the superior articular facets resist a downward vertical force and the inferior facets an upward force. Mainly this induces a shearing stress between the articular
processes in any one vertebra, the apposing articular facets being more or less parallel and the surfaces in contact being reduced by separation of the adjacent neural arches on flexion.

When erect, the lumbar spine is extended but on the sloping surface of the first sacral body so there is still a force causing a shearing strain on the neural arch. Now, however, the stresses between the apposed articular processes are in a part of the articular facet different from that in the flexed position. They are applied to the inferior margin of the superior facet by the tip of the inferior facet, the two facets now being at an angle. This implies that the pars must withstand a compressive force concentrated at the inferior margin of the superior facet, and a bending force producing mainly tensile stresses in the antero-lateral zone. These forces will be magnified on the side to which there is lateral flexion in the extended posture.

The amount of cortical bone in the pars is clearly related to the theoretical shear stresses to which the neural arch is subjected, but there is a difference between the thickness in the two cortical layers. The inferior articular processes are longer than the superior, thus the tensile stresses induced in the antero-lateral layer are probably greater than those in the postero-medial. This consideration applies to flexion when adjacent neural arches are separated and the apposed areas of the articular facets thereby reduced; and it applies in extension and lateral flexion when forces are transmitted between the lower margin of the inferior process and the base of the superior facet. These factors may partly account for the greater thickness of the antero-lateral layer. Furthermore, the concentration of pressure at the base of the superior articular process in extension may explain the large size and direction of the trabeculae between the two layers in the pars.

Stewart (1953) suggested that spondyloysis in Eskimos arose from stresses arising from work in stooping postures. But Lane (1884, 1885), Nathan (1959), Newman (1959) and Moreton (1969) believed that the stresses on the neural arch were greater in extension.
study of the structure reveals that the normal neural arch is capable of withstanding major stresses in both positions. Without case histories to analyse, no kind of statement can be made about the postural or dynamic conditions likely to favour an impact failure. However, it seems reasonable to suppose that the circumstances giving rise to fatigue failure are more likely to obtain in activities such as running and jumping or marching across country in which repetitive lateral flexion movements are imposed on the extended spine.

The defect reported in the neural arch of the seventeen-year-old male (Case 1) has all the appearances of a healing fracture. It is consistent with fatigue or impact failure in the antero-lateral region of the pars in response to bending stresses applied to the inferior articular process. In this specimen, the fracture line extended vertically rather than in the plane of the typical spondylolytic defect; no other such case appears to have been reported. However, nothing is known of the factors which determine the direction of propagation of cracks in this region.

No radiographs were taken of the intact vertebra, though it is most unlikely that the fracture would have been visible, particularly as it did not involve the full thickness. Some increased opacity due to callus formation could perhaps have been seen, comparable to the cases of healing spondylolysis described by Roberts (1947), Roche (1948), Wilte (1962) and Murray and Colwill (1968). As Roberts (1947) suggested, fractures in the pars may be relatively common. Recent reports of the incidence of spondylolysis in young males point to a marked increase associated with certain athletic activities (Hector 1972, Ichikawa 1972), and it may be a more frequent injury than radiological surveys have indicated.

**SUMMARY**

1. An anatomical study of the bony structure of the pars interarticularis of the fourth and fifth lumbar vertebrae has been made in specimens from seven cadavers aged seventeen to sixty-seven.
2. Layers of cortical bone have been described antero-laterally and postero-medially which are thickest in the narrowest region of the pars.
3. In one specimen from a seventeen-year-old male, a healing fracture was found in the antero-lateral layer of cortical bone in the right neural arch of the fourth lumbar vertebra.
4. The stresses to which the pars is subject consist primarily of shear forces applied to the articular processes. The significance of these stresses to the etiology of spondylolysis is discussed.

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