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Short Report

The role of the vertebral laminae in the stability of the cervical spine

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ABSTRACT

The aim of this study was to determine the contribution of the vertebral laminae to the stability of the cervical spine since laminectomy may result in deformity of the neck. In 40 dry adult male cervical columns the weight-bearing areas of the inferior surfaces of the bodies and articular facets from C2 to C7 were measured and the means and S.D.s calculated. In all columns the lamina index (height × thickness) of right and left halves of each lamina was calculated and summed at each cervical level. Means and S.D.s were calculated for the series. The trabecular patterns in the laminae were studied in 6 of the columns. Results show that the laminae of C2 and C7 are heavily loaded, whilst the intervening ones are not. Thus laminectomy at C2 and C7 would tend to lead to instability, but between C3 and C6 this would be less likely. Significant segmental variation in weight transmission was not found for the facet joints.

Key words: Cervical vertebrae; laminectomy.

INTRODUCTION

There are numerous reports of spinal instability after cervical laminectomy (Haft et al. 1959; Bailey & Badgley, 1960; Tachdjian & Matson, 1965; Cattell & Clark, 1967; Boersma, 1969; Fairbank, 1971; Sim et al. 1974; Lonstein et al. 1976; Callahan et al. 1977; Yasouka et al. 1981, 1982; Raynor et al. 1985; Herkowitz, 1988; Miyazaki et al. 1989; Zdeblick & Bohlman, 1989; Butler & Whitecloud, 1992). Resultant deformities include kyphosis, anterior subluxation, 'swan neck', hyperlordosis, scoliosis and gibbus formation. The incidence of deformity following laminectomy is higher in children than in adults although reports have varied from 100% (Lonstein et al. 1976) to 19% (Haft et al. 1959). Butler & Whitecloud (1992) attributed the high incidence in children to the effects of growth and relative laxity of ligaments, whilst Yasouka et al. (1981, 1982) considered that the primary cause of deformity was altered static and dynamic stability, influenced secondarily by growth of the spine.

Findings in adults vary. Sim et al. (1974) reported the development of swan neck after extensive laminectomy. Callahan et al. (1977) found that removal of laminae did not cause immediate instability but progressive deformity developed in certain individuals. They suggested that the weight of the head and muscular pull overstretched the remaining ligaments. Whilst Raynor et al. (1985) and Zdeblick & Bohlman (1989) recorded instability after laminectomy in adults, according to D. D. Aronson et al. (unpublished observations, 1989) laminectomy alone is not usually associated with a significant postoperative incidence of kyphosis.

None of these authors correlated the incidence of deformity with the levels of laminectomy or considered the possible role of the neural arch in maintaining stability. Pal & Routal (1986, 1987), Pal (1988) and Pal et al. (1988) provided evidence indicating that the neural arch shared in the transmission of the axial load borne by the cervical, thoracic, lumbar and sacral vertebrae. In the cervical spine from C3 downwards, compressive forces are

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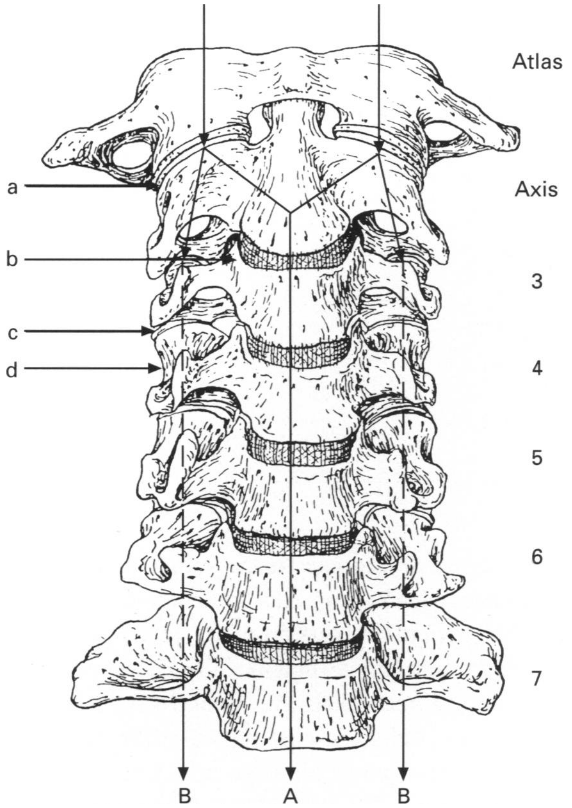

Fig. 1. Anterior view of the articulated cervical spine. a, R atlantoaxial articulation; b, uncinate process; c, R zygapophyseal joint between C3 and C4; d, articular pillar (see also Fig. 6 in which the R pillar is seen in an oblique anterolateral view). A, line of weight transmission through vertebral bodies and intervertebral discs; B, lines of weight transmission through the 2 posterolateral columns formed by the articular pillars. The drawing by Mrs Audrey Besterman appeared in *Cervical Spondylosis* edited by Lord Brain and Marcia Wilkinson, Heinemann Medical Publications, 1967. It has been modified, by permission of the publishers, to show lines of weight transmission in the anatomical position.

transmitted through 3 parallel columns (Pal & Routal, 1986). A single, anterocentral one is formed by vertebral bodies and intervertebral discs, and 2 rod like posterolateral ones consist of the articular processes and facet joints (Fig. 1).

The present morphometric and morphological investigation analyses the mechanism of weight transmission in the cervical spine and the relative magnitude of forces acting at each lamina. Variations in the latter might explain the apparent discrepancies in the reported incidence of postlaminectomy deformity.

Evidence suggests that the area of the articular surfaces of vertebral bodies and facets represents the relative magnitude of axial forces transmitted at that level, and also that the mass of bone is correlated with the stresses imposed upon it (Pal & Routal, 1991). In addition, it is known that the trabecular pattern indicates the direction of transmitted stresses.

MATERIALS AND METHODS

Forty adult male skeletons prepared by maceration for the collection of the M. P. Shah Medical College, Jamnagar, India, were selected for this study. The cervical vertebrae were free from osteophytes and other abnormalities. The trabecular patterns of cervical laminae were investigated in 6 vertebral columns. The following measurements and observations were made on vertebrae from C2 to C7 inclusive.

The areas of the inferior articular surface of the vertebral body and the inferior articular facets

Thin tracing paper was applied to the inferior articular surface of the vertebral body, including the uncovertebral joints. The outline was drawn and the area was determined by planimetry. The means and standard deviations (S.D.S) at each level of the 40 columns were calculated. The same technique was used at each level to measure the areas of the 2 inferior facets which were summed and the mean values and S.D.S were calculated.

The lamina index

The lamina index was obtained by measuring the height and thickness of the left and right halves of each lamina. Measurements were taken at the midpoint between the medial margin of the inferior articular facet and the median plane. The indices of the 2 halves were added together and the mean was taken. The mean values and S.D.S at each vertebral level were calculated for the 40 columns. If the area of the 2 articular facets is proportional to the total load passing through the neural arch, the lamina index reflects the magnitude of the load diffused through the lamina during transmission of the load from the upper to the lower facets.

The trabecular pattern in the laminae of cervical vertebrae C2–C7

In 6 columns the trabecular architecture of the lamina was exposed by carefully removing bone cortex with a small bone nibbler.

RESULTS

The mean values for the areas of the articular surfaces of the bodies and inferior facets are given in Table 1 and illustrated graphically in Figure 2. As might be

Table 1. *Areas of inferior articular surfaces of cervical vertebrae C2–C7**

Vertebral level	Mean body area	Mean articular facet area
C2	1.99±0.45	1.18±0.31
C3	2.18±0.49	1.25±0.44
C4	2.38±0.49	1.31±0.33
C5	2.58±0.61	1.42±0.37
C6	2.73±0.51	1.49±0.36
C7	2.96±0.58	1.61±0.48

* Means±S.D. (cm^2); number of specimens = 40.

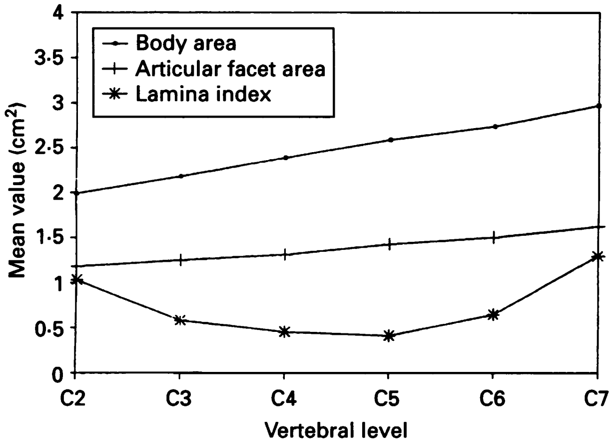

Fig. 2. Graph showing the mean body surface area, mean articular facet area and mean lamina index at different vertebral levels.

Table 2. *Percentage inferior articular areas of bodies and facet joints of C2–C7**

Vertebral level	Total area (body+facets)		Body area		Area of 2 articular facets	
	(cm^2)	(%)	(cm^2)	(%)	(cm^2)	(%)
C2	3.17	(100)	1.99	(62.77)	1.18	(37.23)
C3	3.43	(100)	2.18	(63.55)	1.25	(36.44)
C4	3.70	(100)	2.38	(64.46)	1.31	(35.54)
C5	4.00	(100)	2.58	(64.50)	1.42	(35.50)
C6	4.22	(100)	2.73	(64.69)	1.49	(35.30)
C7	4.57	(100)	2.96	(64.77)	1.61	(35.22)

* Number of specimens = 40.

Table 3. *Percentage area of inferior articular facets and percentage lamina indices of cervical vertebrae C2–C7**

Vertebral level	Articular facets (R+L) area		Lamina index	
	(cm^2)	(%)	(cm^2)	(%)
C2	1.18	(100)	1.03	(87.28)
C3	1.25	(100)	0.58	(46.40)
C4	1.31	(100)	0.45	(39.82)
C5	1.42	(100)	0.40	(28.16)
C6	1.49	(100)	0.63	(42.28)
C7	1.61	(100)	1.28	(80.00)

* Number of specimens = 40.

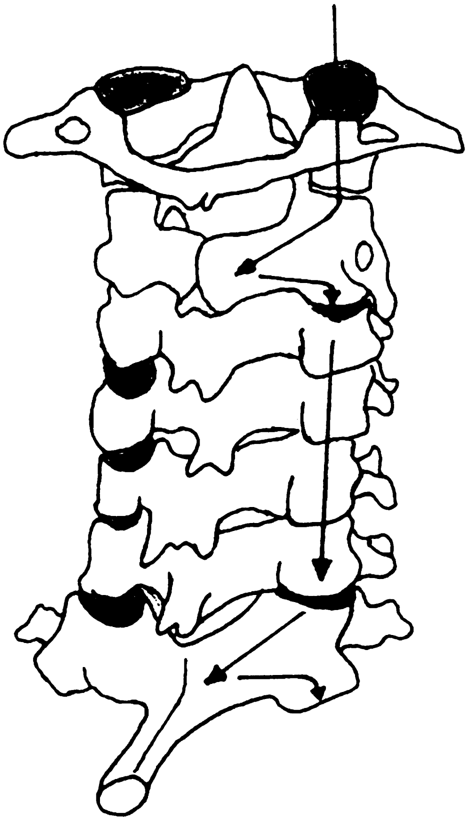

Fig. 3. Diagram indicating route of the axial load transmitted through the neural arches (arrows). The load becomes diffused into the laminae of C2 and C7 while it remains mostly confined to the articular pillars between C3 and C6 levels.

expected, both values increase from above downwards, but this was relatively slower for the facets. Means and S.D.s were calculated for the total articular area at each level. Taking the combined figures as 100%, the percentage area represented by surfaces of the bodies and facets respectively was calculated (Table 2). The percentage area for inferior surfaces of the bodies ranged from 62.77% at C2 to 64.77% at C7, with a steady rise in values. For articular facets the highest percentages were at C2 and C3, being 37.23 and 36.44% respectively. From C4 down to C7 the percentage areas decreased gradually from 35.54 to 35.22%.

The lamina indices are given in Table 3. The highest values were 1.28 at C7 and 1.03 at C2. However, taking the lamina index as a percentage of the total area of the facets at a given level, the highest values of 87.28 and 80.00% were at C2 and C7 respectively. The percentages at intervening levels ranged from 28.16 to 46.40, the lowest being at C5.

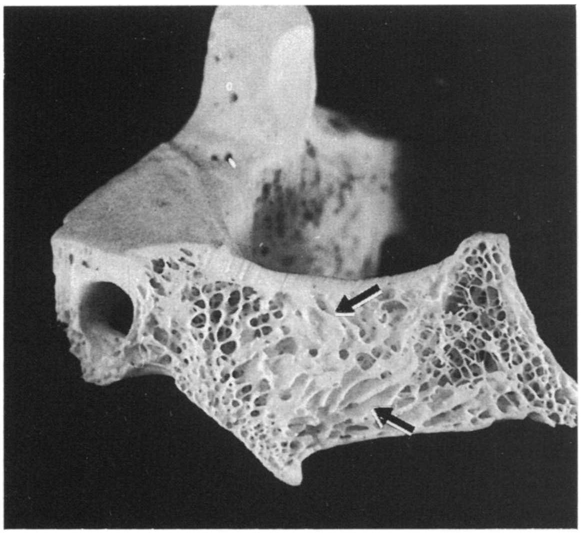

Fig. 4. Trabeculae in the lamina of the axis exposed after removal of the compact bone from the lateral surface. A set of bony plates is seen to run downwards and backwards from the thick compact bone at the superior border (upper arrow). Another set of parallel plates runs obliquely from the upper set towards the inferior articular facet (lower arrow).

Fig. 5. Trabeculae in the lamina of the 7th cervical vertebrae. Trabeculae are in the form of hollow tubules. The upper set of trabeculae runs from the superior articular facet to the lamina and the inferior set from the lamina to the inferior articular facet.

A well-defined trabecular pattern was found in the laminae of the axis and C7. In the axis (Fig. 4) bony parallel plates ran downwards and posteriorly from the superior facets of the axis and a second set ran obliquely from this set towards the lower facet. In C7 trabeculae appeared tube-like (Fig. 5). An upper set ran from the superior facet to the lamina and an inferior set ran from the lamina towards the inferior facets. From C3 to C6 the laminae consisted of thin plates of compact bone and there was no trabecular pattern.

DISCUSSION

As the material of this study consisted of dry skeletal material, weight transmission through the cervical spine could only be calculated for bony elements considered in the anatomical position. In these circumstances the transmission of compressive forces would be shared mainly by the vertebral bodies, discs and the articular facets. During movement, ligaments, muscles and tendons are also involved and the magnitudes of compressive forces borne by the bodies and facets would change. For example, during flexion the load on the body would increase, and in extension it would rise on the articular facets.

If the articular surface area is an indicator of the magnitude of the force resisted by a bone and its mass is correlated with the magnitude of the stress to which it is subjected (Pal & Routal, 1991), the present findings show that the compressive forces acting in the cervical spine are transmitted mainly through the bodies and intervertebral discs and that a little over a third is borne between the two rod-like columns formed by articular processes and the facet joints. Since the facets and the articular processes are parts of the neural arch, the role of the laminae in diffusion of the forces between the upper and lower facets is of interest. The laminar indices indicate that the neural arches of the axis and C7 have a significant load-bearing function in the cervical spine (Fig. 3). As shown in Table 3, the sequence from maximum to minimum load bearing by the laminae is C2, C7, C3, C6, C4 to C5. The implications of these findings are supported by the arrangements of the intralaminar trabeculae.

The diffusion of load is low in the laminae between C3 to C6 and minimal at C5. This is because, at these levels, the articular processes are in the form of a bar-like structure and form rod-like columns (Fig. 6).

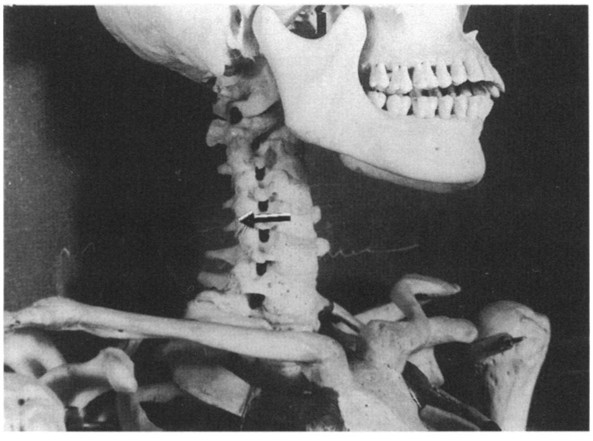

Fig. 6. Lateral view of cervical vertebral column; arrow indicates the pillar formed by the articular processes.

Secondly, the superior and inferior articular facets lie in the same vertical line. Because of this, loads passing from superior to inferior articular facets are not dispersed much onto the laminae and remain confined to the rod-like column. However, at C2 and C7 levels, articular processes are not in the form of a bar-like structure and superior and inferior articular facets do not lie in the same vertical line. Because of this, loads diffuse into the laminae at C2 and C7 levels while they are being transmitted from the superior to the inferior articular facets (Fig. 3).

The diffusion of loads in the laminae varies. However, the level of laminectomy is unfortunately dictated by the site of the lesion. The proportion of load bearing at facet joints is remarkably uniform and the two rod-like columns take just over a third of the load between them. Therefore to minimise post-operative deformities interference with facets and articular processes is to be avoided as far as possible. Risks of deformity might be diminished by careful replacement of muscle and tendon and possibly by some form of reinforcement if the more vulnerable laminae at C2 and C7 have to be removed. A critical analysis of levels of laminectomies, with and without facetectomies, and the incidence of postoperative deformity would be of interest and value.

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