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The internal vertebral venous plexus prevents compression of the dural sac during atlanto-axial rotation

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Abstract Deformation of the extradural space and the possibility of impression upon the dural sac during atlanto-axial rotation are investigated. Atlanto-axial rotation leads to a reduction in the cross-sectional area of the bony spinal canal of approximately 40 %. Atlanto-axial rotation was recorded by endocanalar views from a video camera fixed inside the skull of six unembalmed cadavers. Axial thin-section T1-weighted MRI slice sets were acquired from three volunteers (mid-position and maximal left and right rotation of the head and cervical spine). The axial cross-sectional areas of the bony spinal canal, dural sac and spinal cord were measured. In two other persons post-gadolinium contrast-enhanced T1-weighted MRI volume scans with fat-suppression prepulse were acquired (mid-position and rotation) to determine venous contents of the extradural space. The 50:50 ratio between left and right extradural halves in mid-position changed to an ipsilateral:contralateral ratio of 20:80 in maximum rotation at the level just above the lateral C1-C2 joints. Directly below these joints the opposite occurred. The post-contrast studies showed an enhancing internal vertebral venous plexus (IVVP), which almost completely occupied the extradural space at the atlanto-axial level. This could not be shown in the cadaver experiments, because of absence of blood and cerebrospinal fluid (CSF) pressure. During atlanto-axial rotation blood displacement in the IVVP allows major deformations of the extradural space. This prevents dural sac impression.

Keywords Atlanto-axial rotation · Internal vertebral venous plexus · Dural sac compression · Epidural space · Arachnoidal space

Introduction

Rotation in the atlanto-axial segment (C1-C2) occurs on a vertical axis through the centre of the odontoid process (Lai et al. [9], Penning and Wilmink [11], Sutherland et al. [14], Werne [16]) (Fig. 1). This means that the axis of rotation is located eccentrically with regard to the cross-section of the spinal canal. With the head turned to the left, the right articular mass of the atlas moves anteriorly and medially, whereas the left lateral mass is rotated posteromedially (Dumas et al. [4]). An in vitro study on matching atlas and axis bones has shown that at the extreme of physiological atlanto-axial rotation (47°) the bony spinal canal is reduced to 61 % of its cross-sectional area compared with the mid-position (Tucker and Taylor [15]). CT studies in vivo (Penning and Wilmink [11]) also indicate that the cross-sectional area of the bony spinal canal at the level of the lateral atlanto-axial joints is smaller in maximum rotation than in mid-position. At the level of the axis, however, the spinal cord occupies only 27 % of the cross-sectional area of the bony spinal canal in the mid-position, and at the level of the atlas

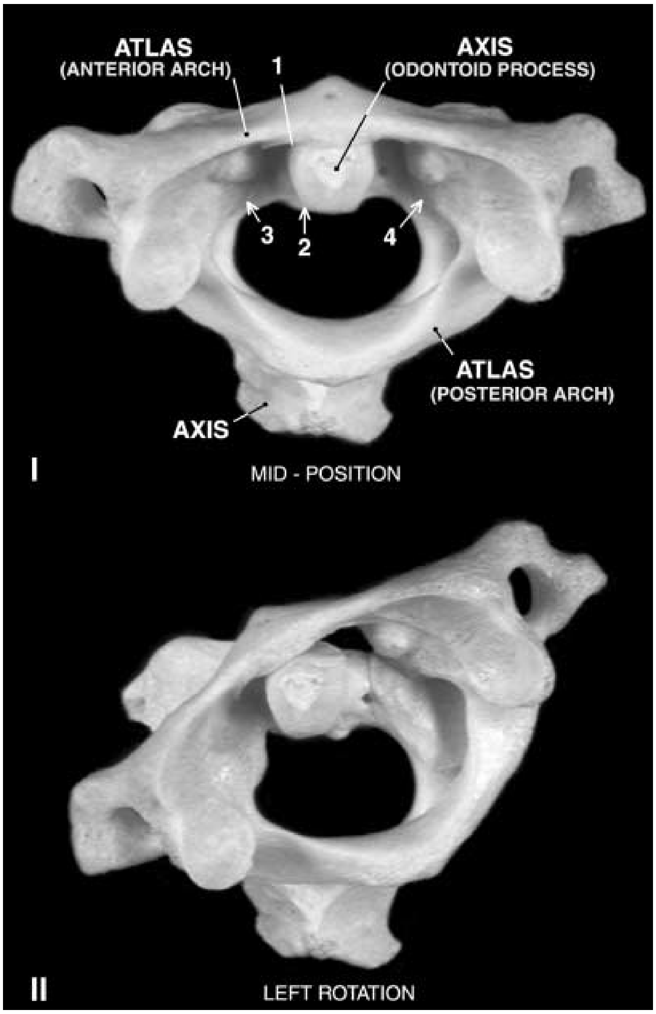

Fig. 1 Atlas mounted on axis in mid-position (*I*) and at maximum left rotation (*II*). Four articulations guide motion around a vertical axis of rotation between atlas and axis; one ventral (*1*) and one dorsal (*2*) to the odontoid process and the left (*3*) and right (*4*) lateral atlanto-axial joints. The bony spinal canal in maximum rotation is narrowed at the level of the lateral atlanto-axial joints, because of a scissors movement between atlas and axis

Table 1 Axial cross-sectional area values from three volunteers (nos. 1, 2 and 3) of right and left extradural halves (in mm^2 and percentage of total cross-sectional area of the corresponding level), above and below the lateral atlanto-axial joints (*LAAJ*); mid-position, left and right rotation of the head and cervical spine (● ipsilateral, ○ contralateral)

A

		Above the LAAJ			Below the LAAJ		
		mid-position	rotation right	rotation left	mid-position	rotation right	rotation left
1	right half	120.4	74.9 ●	266.5 ○	97.4	176.0 ●	20.9 ○
		52.5%	25.4%	85.2%	47.1%	83.7%	9.1%
	left half	109.1	220.2 ○	46.5 ●	109.2	34.2 ○	208.8 ●
		47.5%	74.6%	14.8%	52.9%	16.3%	90.9%
2	right half	107.9	43.9 ●	231.4 ○	93.7	148.5 ●	36.8 ○
		51.8%	16.9%	89.1%	51.8%	77.1%	22.6%
	left half	100.4	216.0 ○	28.2 ●	87.3	44.0 ○	125.7 ●
		48.2%	83.1%	10.9%	48.2%	22.9%	77.4%
3	right half	121.9	58.4 ●	241.8 ○	86.3	132.4 ●	40.9 ○
		52.3%	24.2%	79.3%	48.9%	76.0%	25.2%
	left half	111.1	182.7 ○	63.2 ●	90.3	41.9 ○	121.2 ●
		47.7%	75.8%	20.7%	51.1%	24.0%	74.8%

B

	Above: ipsilateral ●	Above: contralateral ○	Below: ipsilateral ●	Below: contralateral ○
MEAN OF 6	18.8%	81.2%	80.0%	20.0%

22 %. Thus the spinal cord is safe from compromise during rotation (Tucker and Taylor [15]). It has not been clarified which structures inside the bony spinal canal are deformed at the level of the constriction. This deformation can be studied in vitro during head-turning in unembalmed specimens with or without intact extradural space and dural sac, and in vivo by MRI. The present study aims to make clear whether the cerebrospinal fluid (CSF)-filled dural sac is impressed or the extradural (epidural) space is deformed. We suppose that a substantial extradural space is present at the atlanto-axial level and that the contents allow a major deformation, for instance by displacement of fatty tissue and/or emptying and filling of vascular (venous) structures.

Method

Six unembalmed cadavers (aged 48–82 years) were studied. The skullcap, the brain and proximal part of the spinal cord were removed. A small video camera (3.5 × 3.5 × 2.0 cm) was mounted inside the posterior cranial fossa and focused on the foramen magnum (endocanalar view) to record motion of atlas and axis during head turning. Movements were carried out with the cervical spine in the mid-position concerning flexion/extension and lateroflexion. They were registered with the dural sac intact and after removal of the dural sac (Fig. 2).

Subsequently three asymptomatic volunteers (two men and one woman aged between 22 and 27 years) were examined by MR imaging. Using a 3-D volume scanning technique we acquired a thin-section T1-weighted slice set containing 60 overlapping 2-mm axial slices covering the region from the caudal endplate of the axis to the foramen magnum. Three slice sets per volunteer

Table 2 Means of all ipsilateral and all contralateral area percentages above and below the lateral atlanto-axial joints, respectively

	Ipsilateral	Contra-lateral	Ipsilateral	Contra-lateral
Mean of six measurements	18.8	81.2	80.0	20.0

were acquired: in mid-position and at maximum left and right rotation of the head (Fig. 3).

The cross-sectional area of the bony spinal canal, extradural space, dural sac and spinal cord were measured by drawing the outlines of the bony spinal canal, dural sac and spinal cord of all images on tracing paper. Per image these were divided into a left and right half by a line drawn through the centre of the odontoid process (or body of the axis) and the centre of the spinal cord (Fig. 4). The axial cross-sectional areas of these halves were calculated with the aid of an X–Y tablet (Summagraphics ID). The values determined from the images with the cervical spine in the mid-position and at maximum rotation, were compared (Fig. 5).

Per volunteer, the mean values of the axial cross-sectional areas of the extradural space (right and left halves, respectively) on the fourth, fifth and sixth slices above the slice through the centre of the lateral atlanto-axial joints, were calculated. This procedure was also carried out on the fourth, fifth and sixth slices below the centre of the lateral atlanto-axial joints. Left and right mean area values are given in Table 1. These values are also expressed as a percentage of the total extradural cross-sectional area on these images. Partial volume effects and the fact that the axis, atlas and head are tilted somewhat obliquely to the axial cross-sectional plane in left and right rotation, cause differences between the total cross-sectional area of the structures selected in the mid-position and the areas in the rotated positions (Table 1). Therefore, only the percentages given in Table 1 were used to present mean percentages of the ipsilateral and contralateral halves (Table 2).

Contrast-enhanced and fat-suppressed T1-weighted MR images showed the composition of the extradural tissue (Caruso et al. [3]). Two patients aged 45 and 57 years, undergoing cranial gadolinium contrast MR studies for suspected acoustic neuroma, but with normal findings, consented to undergo two additional MR imaging sequences, one with the head in mid-position and one with the head at maximum rotation. The same T1-weighted volume acquisition was performed as described in the first three volunteers. A fat-suppression prepulse was applied to allow better visualisation of enhancing venous structures (Fig. 6).

Results

The endocanalar video recordings of the six unembalmed cadavers show that the axial cross-sectional area of the intradural space as well as the extradural space are decreased in maximum head turning (maximal atlanto-axial rotation) compared with the same area with the cervical spine and head in the mid-position (Fig. 2).

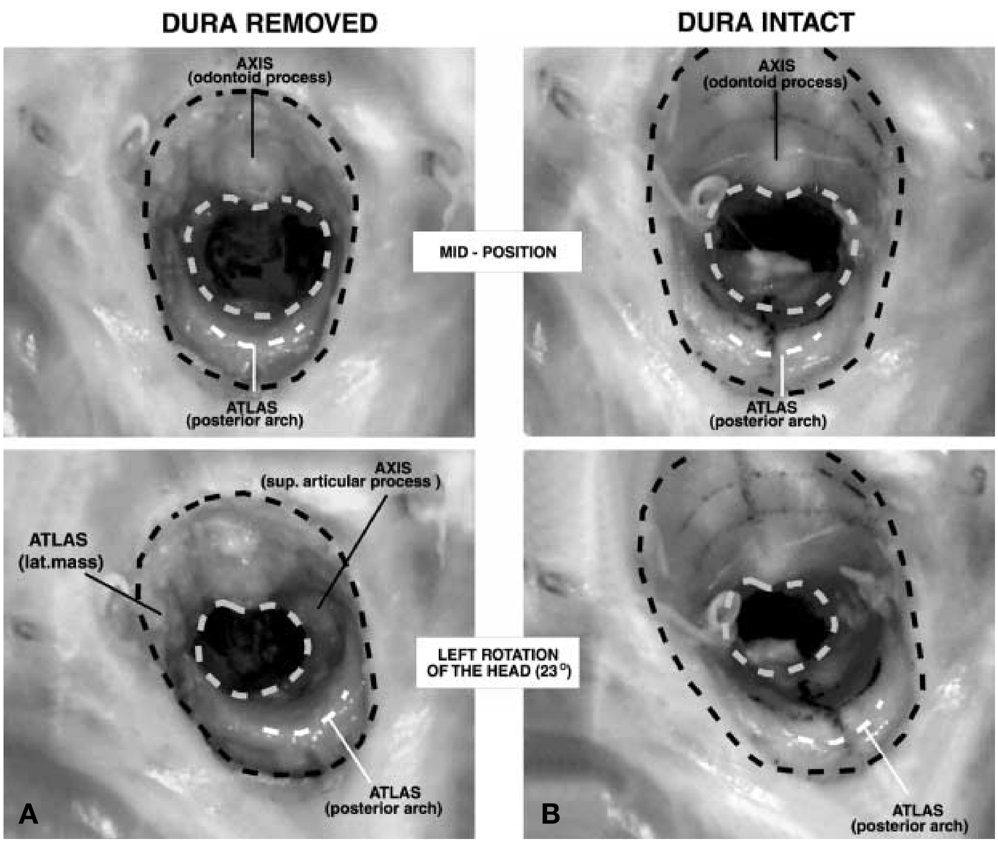

Fig. 2 A, B Endocanalar views of the cervical spinal canal of a cadaver in which the skullcap and brain were removed. In **A** the spinal cord and vertebral arteries have also been removed. The extradural space as well as the intradural space are apparently narrowed in the rotated position

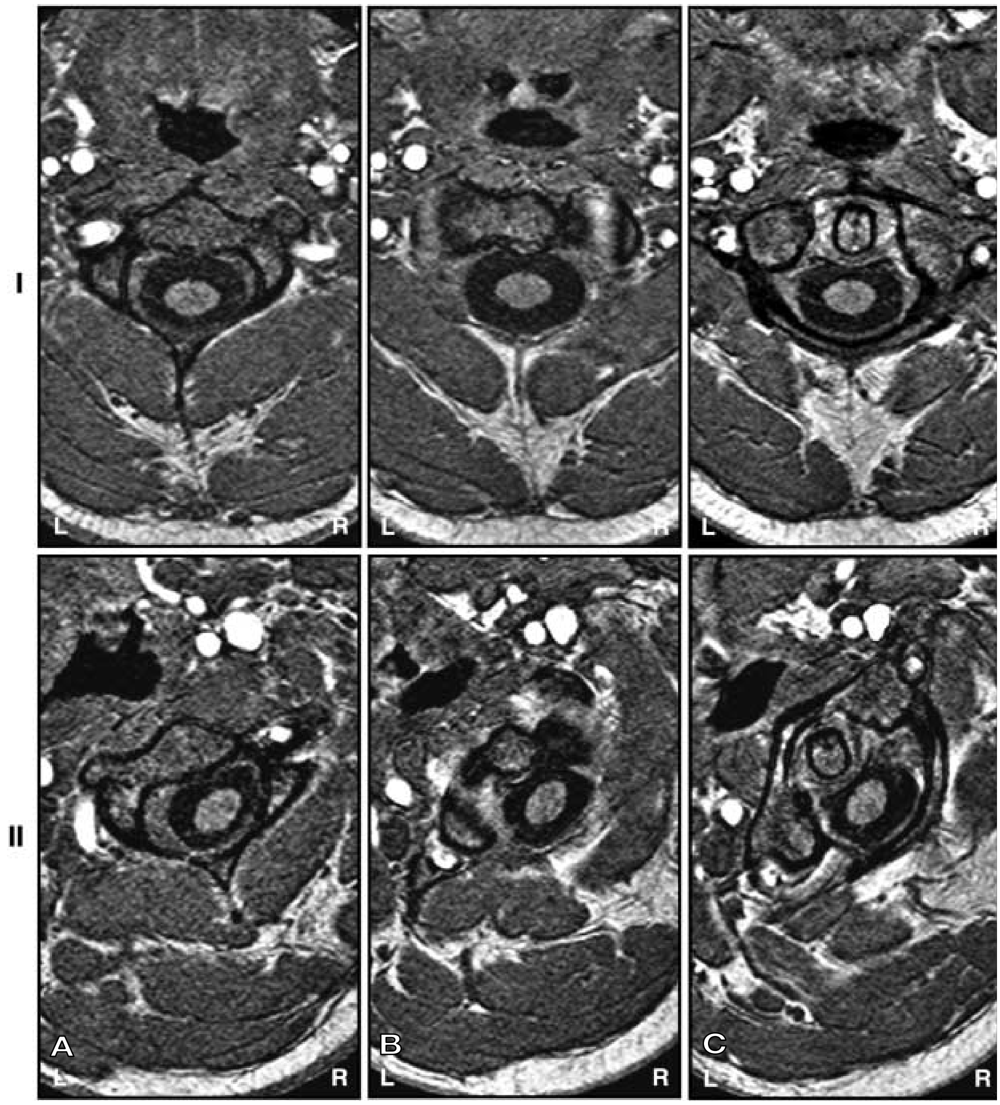

Fig. 3 A–C Axial T1-weighted MR images (volunteer no. 3) at the level of **A** the body of the axis, **B** the lateral atlanto-axial joints and **C** the central part of the lateral mass of the atlas with the head in mid-position (*I*) and at maximum left rotation (*II*). In rotation the extradural space cross-sectional area differs per level compared with the mid-position; at the level seen in **A** there is an increase at the left (ipsilateral) side and a decrease contralaterally, the reverse occurs at the level seen in **C**, and at the level in **B** both sides are decreased

Comparison of the MRI investigations of the mid-position and the maximally rotated positions shows that at maximum rotation the lateral mass of the atlas causes only a small impression on the dural sac at the ipsilateral side. The extradural space shows major deformations (Fig. 3).

At the level above the lateral atlanto-axial joints the axial cross-sectional area is decreased on the ipsilateral side and increased contralaterally. At the level below these joints the axial cross-sectional area of the extradural space is increased at the ipsilateral side and decreased contralaterally.

Table 2 quantifies these changes. At the level above the lateral atlanto-axial joints, the ipsilateral half of the cross-sectional area of the extradural space comprises 18.8 % and the contralateral half 81.2 % of the total cross-sectional area of the extradural space in maximum rotation. The reverse occurs directly below the lateral atlanto-axial joints: the extradural ipsilateral half comprises 80.0 % and the contralateral half 20.0 %. Figure 5 shows that such major left–right differences in the extradural space between mid-position and a maximally rotated head occur only directly above and below the lateral atlanto-axial joints.

The post-contrast MRI studies show that the extradural space at this level consists almost exclusively of an enhancing venous plexus, which is emptied or filled in accordance with the rotations described above (Fig. 6).

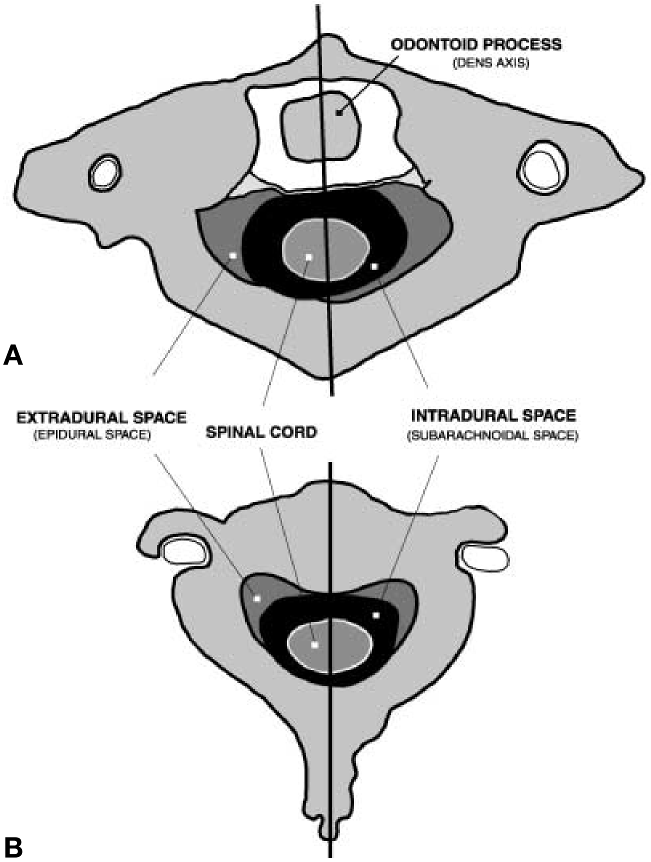

Fig. 4 A, B Schemes of the anatomical dimensions in the mid-position **A** directly above the lateral atlanto-axial joints and **B** directly below these joints. The axial cross-sectional areas of the extra- and intradural space and the spinal cord are divided into a right and a left half. Values of these six axial cross-sectional areas are used in graphs as given in Fig. 5 and in Table 1

Discussion

The MRI investigations show that the dural sac, which is a fluid-filled tube, is not compressed during head rotation. The bony spinal canal is narrowed at the level of the lateral atlanto-axial joints during rotation, due to a scissors movement between atlas and axis. Atlas and axis rotate in opposite directions around a minimally deformed dural sac. This results in a marked asymmetry between the left and right halves of the extradural space. The asymmetry directly above the lateral atlanto-axial joints is opposite to the asymmetry directly below these joints.

In vitro studies cannot demonstrate this phenomenon. The study by Tucker and Taylor [15] shows the marked reduction of the cross-sectional area of the bony spinal canal. Our video recordings also suggest that the cross-sectional area of the dural sac is reduced. These endocanalar views are misleading because the dural sac has been opened, CSF and venous blood are absent and thus the extradural volume adaptations, which we have found to take place in vivo, do not occur. In the cadavers the epidural veins have been drained of blood and thus their buffer function has been abolished. The resistance to deformation of the dural sac as a fluid-filled tube has also disappeared with the CSF pressure.

Extradural volume adaptations during rapid turning of the head must be executed instantaneously to prevent dural sac compression. The internal vertebral venous plexus (IVVP) is the only structure in the extradural space that allows for such rapid major volume adaptations. Large IVVP sinuses cover the lateral atlanto-axial joints. Breschet described them in 1828 as the extradural anterior sinuses that are paired and become a network

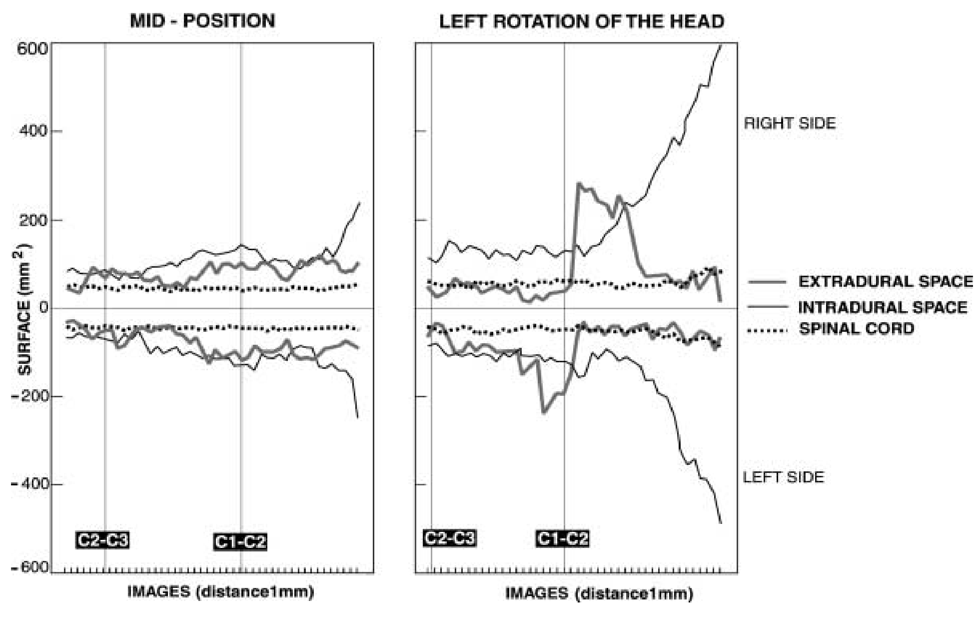

Fig. 5 Axial cross-sectional area values of the left and right halves of the spinal cord, intradural and extradural space determined on all images (volunteer no.1). *The vertical lines* indicate the level of the intervertebral disc C2-C3 and the lateral atlanto-axial joints (C1-C2), respectively. Major left–right differences of the extradural space are only found directly above and below the lateral atlanto-axial joints

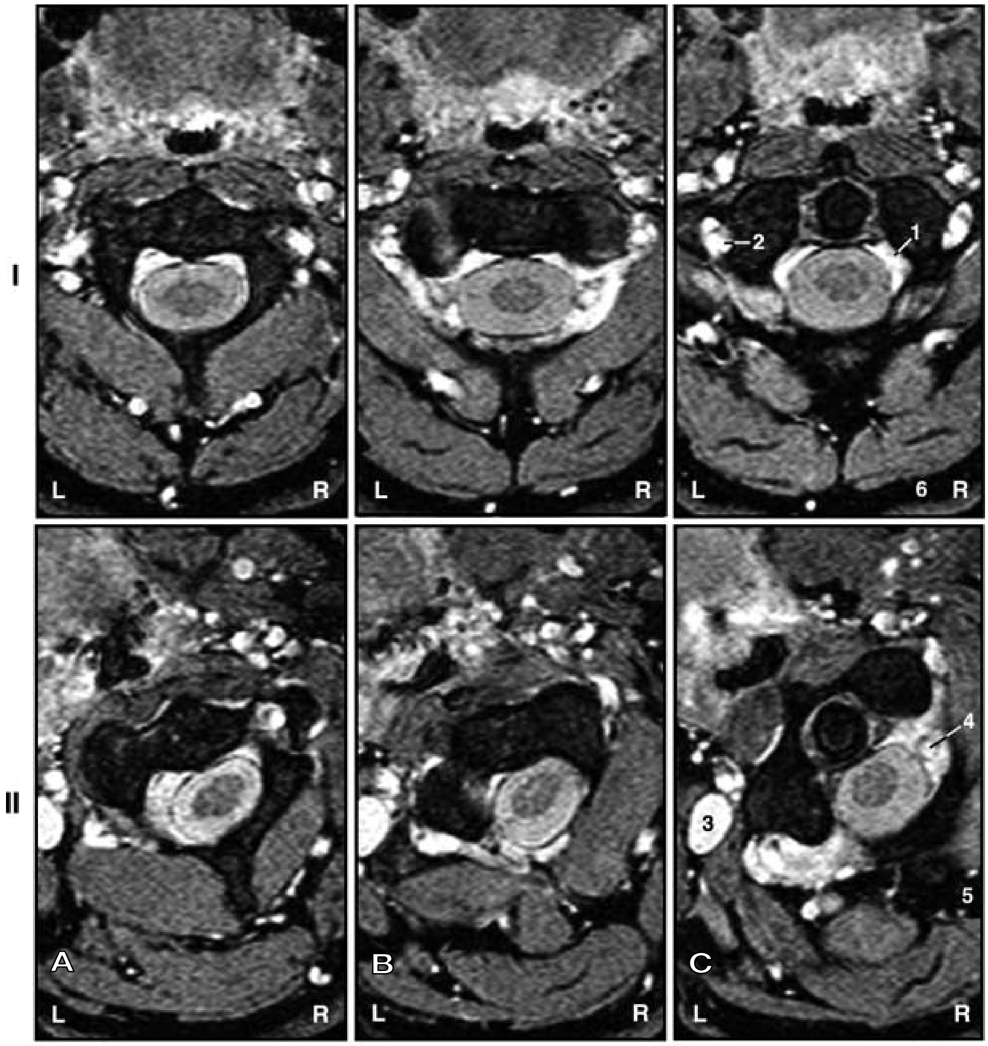

Fig. 6 A–C Axial T1-weighted MR images after intravenous contrast injection (Magnevist, 1 mmol/kg body weight) with fat-suppression technique (patient no. 1), at the level of **A** the body of the axis, **B** the lateral atlanto-axial joints and **C** the central part of the lateral mass of the atlas with the head in mid-position (*I*) and at maximum left rotation (*II*). The contrast medium is located in arteries as well as in veins. Indicated on *CI* and *CII* are: the right half of the internal vertebral venous plexus (*IVVP*) (*1*), left vertebral artery (*2*), left jugular vein (*3*) and emerging nerve root of C2 at the right side (*4*). The bright IVVP completely fills the cranio-cervical extradural space, which does not contain fat in that region. Fat, between the short and long neck muscles (*5*) and subcutaneous fat (*6*), is dark due to the fat-suppression technique. The dural sac, which contains the cerebrospinal fluid (*grey*) and spinal cord (*dark grey*), is not significantly deformed during rotation. Left and right extradural cross-sectional area differences are comparable with those shown in Fig. 3

near the skull (Batson [1]). Groen et al. [7] concluded that the anterior part of the IVVP is fairly constant. Flannigan et al. [5] found that this plexus is particularly prominent at the level of C2. The epidural venous system consists of medial and lateral longitudinal channels located in the anterolateral portion of the epidural space. This agrees with the venous plexus configurations in the cranio-cervical junction in mid-sagittally sawn specimens ($n = 5$) at our anatomy department (Fig. 7).

Post-contrast MRI investigation with fat suppression demonstrates that the extradural space at the atlanto-axial level only contains an enhancing IVVP. This corresponds with the results of Ramsey [12], who described the fact that the extradural space does not contain epidural fat in the upper part of the cervical spine. Limited amounts of epidural fat are only described as being below the level of the C8 roots.

The IVVP sinuses are considered to function as a ‘hydraulic shock absorbing sheath’ that helps buffer the spinal cord during movements of the vertebral column; they are largest in the suboccipital and upper cervical region (Rothman and Simeone [13]). Our data indicate that in the cranial cervical region they can absorb large volume changes of the bony canal. Blood can be displaced in and out of the IVVP sinuses, because this system does not contain structural valves (Groen et al. [7]) or functional valves as is suggested for the radicular veins of the IVVP in other parts of the vertebral column (Kuip et al. [8]). A free communication exists between the IVVP and the extravertebral veins (Groen and Ponssen [6]).

Penning and Wilmink [10] have noted for the lumbar region that emptying and filling of anterior epidural veins prevent excessive CSF pressure changes during flexion/extension movements. These veins are easily compressed, draining readily to valveless intravertebral and paravertebral collaterals. They probably function as ’pressure stabilizers’ allowing changes in

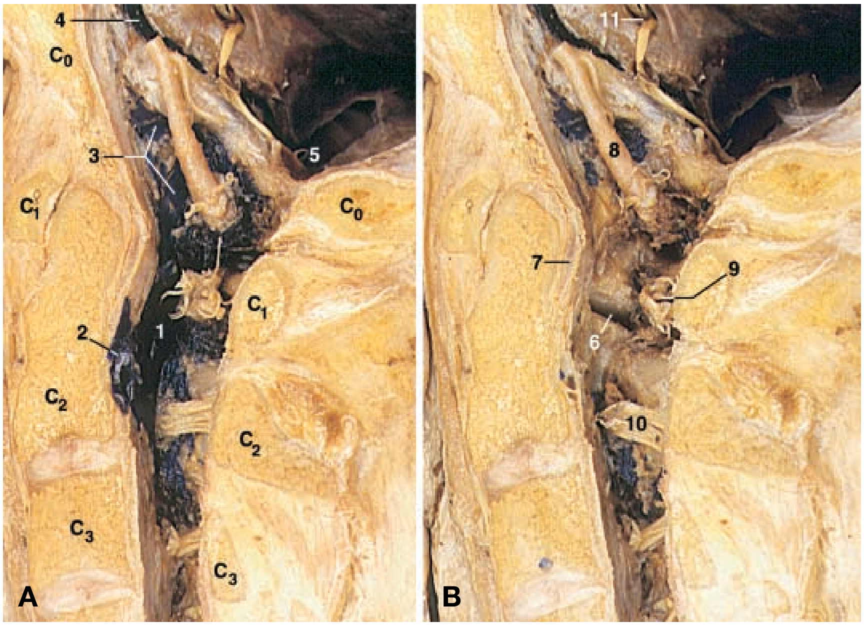

Fig. 7 A mid-sagittally-sawn specimen of the head and cervical spine within in **A** a plastic cast of the internal vertebral venous plexus (IVVP). The spinal cord and brain were removed. Blood remnants in the IVVP sinuses were drained by extensive flushing with warm water and massage of the dura mater at the level of the right lateral atlanto-axial joint (*LAAJ*) prior to injection of a mixture of Technovit 7001 and 0.1 g Macrolex blue via the deep cervical vein. **B** The plastic cast (IVVP) covering the LAAJ, has been removed. A large anterior sinusoid left–right connection is present at the level of the lateral atlanto-axial joint. **A** IVVP sinus covering the right LAAJ (*1*), cross-sectioned left–right anastomosis of IVVP (*2*), marginal sinus and basilar plexus (*3*), inferior petrosal sinus (*4*), superior bulb of internal jugular vein (*5*). **B** Right LAAJ (*6*), transverse ligament of atlas (*7*), vertebral artery (*8*), spinal nerve roots C2 (*9*), spinal nerve roots C3 (*10*), internal acoustic meatus (*11*)

the epidural volume without excessive pressure changes.

The CSF pressure is higher than the venous pressure in the IVVP (Beatty and Winston [2]). The CSF-filled dural sac compresses and empties the IVVP during atlanto-axial rotation. At opposite sides IVVP sinuses fill to allow expansion of the extradural space. We conclude that the blood flow in the IVVP in the cervical region prevents dural sac compression and resulting increase in CSF pressure during atlanto-axial rotation.

References

1. Batson OV (1957) The vertebral vein system. AJR 78: 195–212
2. Beatty RM, Winston KR (1984) Spontaneous cervical epidural hematoma, a consideration of etiology. J Neurosurg 61: 143–148
3. Caruso RD, Rosenbaum AE, Kwei Chang J, Joy SE (1999) Craniocervical junction venous anatomy on enhanced MR images: the suboccipital cavernous sinus. ANJR 20: 1127–1131
4. Dumas JL, Thoreux P, Attali P, Goldlust D, Chevrel JP (1994) Three-dimensional CT analysis of atlantoaxial rotation: results in the normal subject. Surg Radiol Anat 16: 199–204
5. Flannigan BD, Lufkin RB, McGlade C, Winter J, Batzdorf U, Wilson G, Rauschning W, Bradley WG Jr (1987) MR imaging of the cervical spine: neurovascular anatomy. AJR 148: 785–790
6. Groen RJM, Ponssen H (1991) Vascular anatomy of the spinal epidural space: considerations on the etiology of the spontaneous spinal epidural hematoma. Clin Anat 4: 413–420
7. Groen RJM, Groenewegen HJ, Alphen van HAM, Hoogland PVJM (1997) Morphology of the human internal vertebral venous plexus: a cadaver study after intravenous araldite CY 221 injection. Anat Rec 249: 285–294
8. Kuip van der M, Hoogland PVJM, Groen RJM (1999) Human radicular veins: regulation of venous reflux in the absence of valves. Anat Rec 254: 173–180
9. Lai H, Goto S, Yamagata M, Tamaki T, Moriya H, Takahashi K, Mimura M (1994) Three-dimensional motion of the upper cervical spine in rheumatoid arthritis. Spine 19: 272–276
10. Penning L, Wilmink JT (1981) Biomechanics of lumbosacral dural sac. A study of flexion-extension myelography. Spine 6: 398–408
11. Penning L, Wilmink JT (1987) Rotation of the cervical spine, a CT study in normal subjects. Spine 12: 732–738

12. Ramsey L (1953) Comparative morphology of fat in the epidural space. Am J Anat 105: 219–232
13. Rothman RH, Simeone FA (1982) The spine. Saunders, Philadelphia, p 47
14. Sutherland JP, Yaszemski MJ, White AA (1995) Radiographic appearance of the odontoid lateral mass interspace in the occipitoatlantoaxial complex. Spine 20: 2221–2225
15. Tucker SK, Taylor BA (1998) Spinal canal capacity in simulated displacements of the atlantoaxial segment, a skeletal study. J Bone Joint Surg 6: 1073–1078
16. Werne S (1957) Studies in spontaneous atlas dislocation. Acta Orthop Scand [Suppl 23]