MR Angiography of Normal Intralumbar Vessels of the Thoracolumbar Spine

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PURPOSE: To identify and describe the normal intralumbar vessels detected on MR angiograms of the thoracolumbar spine. METHODS: Six adult subjects who had clinical evidence of myelopathy, yet normal findings at spinal digital subtraction angiography (DSA), were also studied without and with contrast-enhanced MR imaging and three-dimensional time-of-flight, single-slab MR angiography. Sagittal and coronal subvolume (targeted) maximum intensity projection images were compared with arterial and venous phase DSA images. Angiographic images were then compared with postmortem, formalin-fixed cord specimens. RESULTS: Recognizable intralumbar vessels were detected only on contrast-enhanced MR angiograms. These vessels corresponded to the posterior and/or anterior median (midline) veins and the great medullary veins. The median veins had variable but mild tortuosity. The medullary veins, which extended from the median veins and coronal venous plexus on the cord surface to the epidural venous plexus, were relatively straight and usually located at T-12 or L-1. The anterior spinal artery could partially contribute to the anterior midline vascular signal. CONCLUSION: The intralumbar vessels identified on contrast-enhanced MR angiograms are primarily veins, and these are usually the largest vessels on or near the cord surface. The limited number and minimal tortuosity of these veins may serve as a baseline for the examination of patients with clinically suspected arteriovenous malformation or fistula.

Index terms: Magnetic resonance angiography; Meninges, magnetic resonance; Spinal cord, anatomy


The appearance of spinal vascular malformations on magnetic resonance (MR) angiograms, obtained with the use of either phase-contrast (1–3) or time-of-flight techniques (4), has recently been reported. The authors have suggested that MR angiography may be a useful adjunct to MR imaging in the examination of patients with suspected dural arteriovenous fistulas. In these reports, the vascular malformations were proved by catheter angiography, either conventional (cut-film) or digital subtraction angiography (DSA), and the results were compared with the MR angiographic findings.

These studies emphasized the detection of enlarged and tortuous intradural vessels at MR angiography (2–4). Previous investigations of the intradural vascular anatomy in the thoracolumbar region have emphasized the relatively large size of the anterior and posterior median veins on the cord surface, and of the few “great” anterior and/or posterior medullary veins that drain from the cord to the epidural plexus (5–16). The purpose of this article is to describe this appearance in the thoracolumbar region based on a comparison between MR angiograms and catheter angiograms in subjects with normal spinal DSA studies.

Materials and Methods

Six subjects (age range, 23 to 64 years; mean, 49 years) with various neurologic findings on clinical examination (Table) underwent MR imaging and three-dimensional time-of-flight angiography at 1.5 T, followed by spinal DSA. The length of time between the MR and DSA examinations ranged from 2 days to 6 months. The tech-
Angiographic findings in six subjects with various clinical neurologic findings

<table>
<thead>
<tr>
<th>Patient</th>
<th>Age, y/Sex</th>
<th>Clinical Findings</th>
<th>Diagnosis</th>
<th>MR Angiography</th>
<th>Digital Subtraction Angiography</th>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Median Veins*</td>
<td>Medullary Veins</td>
</tr>
<tr>
<td>1</td>
<td>23/M</td>
<td>Diminished sensation to pinprick in saddle area; urinary hesitancy, retention; duration: 1.5 y</td>
<td>Conus medullaris syndrome with myelopathy of unknown origin</td>
<td>T-9 to T-12 (P &gt; A)</td>
<td>R T-12(P) L L-1(P)</td>
</tr>
<tr>
<td>2</td>
<td>57/M</td>
<td>Adult onset diabetes; asymmetric quadriparaparesis and hyperflexia; duration: 2 y</td>
<td>Cervical spondylitic myelopathy</td>
<td>T-8 to L-1 (P &lt; A)†</td>
<td>R T-12(A) L T-11(P)</td>
</tr>
<tr>
<td>3</td>
<td>40/F</td>
<td>Minimal bilateral LE weakness; intermittent pain, paresthesias L LE; duration: 8 y</td>
<td>Myeloradiculopathy of unknown origin</td>
<td>T-11 to L-1 (P &gt; A)†</td>
<td>R T-10(A) L L-1(P)</td>
</tr>
<tr>
<td>4</td>
<td>64/M</td>
<td>Bilateral LE weakness, T-8 sensory level; urinary incontinence; duration: 6 m</td>
<td>HIV-related vacuolar myelopathy (cord biopsy)</td>
<td>T-9 to L-1 (P = A)</td>
<td>R L-1(P)</td>
</tr>
<tr>
<td>5</td>
<td>51/M</td>
<td>Bilateral LE weakness and recent numbness; urinary incontinence; duration: 2 m</td>
<td>Chronic inflammatory demyelinating polyneuropathy (conus/cauda equina biopsy)</td>
<td>T-10 to L-1 (P &lt; A)</td>
<td>R T-12(A) L T-12(P)</td>
</tr>
<tr>
<td>6</td>
<td>57/F</td>
<td>Lower back pain; R L-5 radiculopathy; R LE weakness; hyperreflexia UE &gt; LE; duration: 9 y</td>
<td>Myelopathy of unknown origin</td>
<td>T-12 to L-1 (P = A)</td>
<td>R L-12(P) L L-1(P)</td>
</tr>
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Note.—LE indicates lower extremity; UE, upper extremity; P, posterior; A, anterior; and HIV, human immunodeficiency virus.

* Levels over which veins were detected are listed. Visibility of posterior (P) median vein was better than (>), equal to (=), or poorer than (<) that of anterior (A) median vein.
† An anastomosis between anterior and posterior median veins was demonstrated.
was not injured. The time from death to autopsy was less than 24 hours in each case.

Results

As illustrated in Figures 1 and 2, DSA showed opacification of the artery of Adamkiewicz, with a characteristic hairpin turn, and the anterior spinal artery within a few seconds after contrast injection. On sequential images, there was a normal temporal sequence of opacification of the anterior spinal artery, posterolateral spinal arteries, and, subsequently, intradural veins. Vascular detail on the early (arterial) images was generally better than on the later (venous) images, in part because of patient motion and in part because of dilution of the iodinated contrast material.

The intradural vessels seen on the postcontrast MR angiograms corresponded to the anterior and posterior median veins on the cord surface and to the draining medullary veins seen on the DSA images (compare Figs 1 and 3, and Figs 2 and 4). No vessels corresponding to the posterior medullary arteries or the posterolateral spinal arteries were seen, and, except for possibly a short vascular segment...
shown in Figure 3B, neither the artery of Adamkiewicz nor the anterior spinal artery was clearly identifiable on the source or MIP images. Precontrast MR angiograms failed to show any of the intradural vessels (Fig 3C). Precontrast MR images in all subjects showed no evidence of cord enlargement. There was no abnormal signal intensity or postcontrast enhancement within the cord except in subject 4, who had diffuse hyperintensity on T2-weighted images between T-9 and T-12, with associated mild enhancement.

Posterior medullary draining veins, delineated on coronal reprojec- tion MR angiograms (Figs 3A and 4A), were identified in all subjects, with the most commonly observed levels being T-12 and L-1. The anterior and posterior medullary veins were not tortuous (Figs 1–4). Sagittal subvolume MIP images (Figs 3D and 4B), produced from source images near the midline, were useful to show the median or paramedian veins that could be correlated with findings on postcontrast T1-weighted spin-echo images (Figs 3E and 4C and D). In four subjects, the posterior median vein was larger than or equal to the anterior median vein (Table 1). The midline vessels were identified over an average distance of four vertebral levels on MR angiograms (3-D acquisition slab length was six to seven levels). The posterior median veins had variable, usually mild, tortuosity, whereas the anterior median vein was relatively straight.

Similar features were noted on the postmortem cord specimens (Fig 5). The anterior median vein was located immediately adjacent and deep to the anterior spinal artery and both had a relatively straight course (Fig 5A). The cephalad and caudad contributions from the median vein to the draining medullary vein were unequal in size, with the caudad segment being larger and of similar size to the medullary vein. These size relationships mimicked those seen for the anterior medullary arteries and their branches to the anterior spinal artery. On both the angiographic studies (Figs 1B and 2C and D) and the postmortem cord specimens, the junction of a medullary vein with a median vein usually had less acute angulation (coathook configuration) than did the junction of a medul-
lary artery with an anterior or posterolateral spinal artery (hairpin configuration).

Discussion

Vascular Anatomy

The terminology that we use to describe the spinal vascular anatomy delineated by DSA and MR angiography in this study is based primarily on the published works of Gillilan (7, 10), Thron (14), Lasjaunias and Berenstein (15), and Moes and Maillot (11), all of whom expanded upon the pioneering work of Adamkiewicz (17) and Kadyi (18). This terminology is discussed in the following sections.

Arteries.—Each thoracolumbar vertebral segment is largely supplied by dorsal rami, dorsospinal arteries (15), originating from paired segmental arteries (ie, posterior intercostal or lumbar arteries). The intraspinal, or spinal, branch of the dorsal ramus enters the neural foramen, gives off small epidural arteries, and becomes the meningeoradicular artery (15), or the radicular-medullary-dural artery (19) (Fig 6). The dural branches originate proximally, and the remaining radicular-medullary artery (19) is often simply referred to as the spinal “radicular artery” (5, 13, 14, 15). The designation radicular-medullary artery is preferable because it implies that both radicular and medul-
Fig 3. MR angiography and MR imaging in subject 3. Parts A, B, and D are produced from the same 3-D acquisition slab (sagittal orientation).

A and B, Postcontrast, coronal subvolume angiograms. The MIP image in A encompasses approximately the posterior half of the spinal canal and shows the posterior median vein (open arrows), the left L-1 great posterior medullary vein (large solid arrow), the T-10 posterior draining veins (small solid arrows), and the anastomotic loop at T-11 (arrowhead). The MIP image in B encompasses approximately the anterior 10% to 20% of the canal, and shows a midline vessel with features of the anterior median vein. Note the kinked segment (curved arrow) at T-12, corresponding to the contour seen in Figure 1D. The right T-10 anterior medullary vein (straight arrow) and the anastomosis (arrowhead) on the right side of the cord at T-11 are shown. The vessel (open arrow) projecting to the left of the midline and inferior to the T-11 foramen corresponds to the level of the hairpin turn of the artery of Adamkiewicz in Figure 1A. The T-10 and T-11 neural foramina are numbered.

C and D, Precontrast (C) and postcontrast (D) sagittal subvolume angiograms. The MIP images encompass the midline vessels and are approximately 3 mm thick. The vessels are shown well in D but not in C, and primarily correspond to the anterior and posterior median veins described above. The posterior median vein in D has a discontinuity at T-10, corresponding to the findings in Figures 1D and 3A.

E, Postcontrast T1-weighted right parasagittal and midsagittal images. The anastomosis (arrow) between the anterior and posterior median veins at T-11 is seen on the right parasagittal image. There is no enlargement or abnormal enhancement of the cord.
Fig 4. MR angiography and MR imaging in subject 6. Parts A and B are produced from the same 3-D acquisition slab (sagittal orientation).

A and B, Postcontrast coronal (A) and sagittal (B) subvolume angiograms. In A, the subvolume encompasses only the posterior half of the canal, and thus demonstrates the right L-1 (short arrows) and left T-12 (longer arrows) posterior medullary veins, as well as the posterior median vein (arrowhead) seen in Figure 2B and D. The prominent venous segment at T-11 between the origins of these veins is evident (curved arrow). In B, the subvolume MIP image (from eight source images) encompasses the midline and left paramedian portion of the cord.

C and D, Postcontrast sagittal (C) and axial (D) T1-weighted images at level of T-11 foramina show portions of the anterior median vein (open arrow), left T-12 posterior medullary vein (solid straight arrow), and prominent venous segment (curved arrow) seen in A and B. Cord size and intrinsic signal characteristics are normal.
lary arteries (7) may originate from the parent artery. The radicular artery, with anterior and posterior branches, supplies the corresponding nerve roots at each spinal segment (7). Radicular arteries are very small (less than 0.25 mm in diameter [5]) and are seldom shown by catheter angiography (15). These arteries are the radicular subtype of spinal “radicular” arteries in the nomenclature of Lasjaunias and Berenstein (15). The medullary artery, which supplies the cord, is not present at all segmental levels. It may exist as only a single anterior branch, measuring approximately 0.5 to 1.0 mm in diameter, or as a smaller posterior branch, at a given level (Fig 6). The medullary arteries have been termed radiculomedullary arteries by Doppman and colleagues (12). Lasjaunias and Berenstein (15) refer to the anterior medullary artery as a radiculomedullary artery and to the posterior medullary artery as a radiculopial artery, each being a subtype (total of three subtypes) of spinal “radicular” artery. There are approximately 6 to 10 (5, 7, 15), and up to 14 (14), anterior medullary arteries that contribute to the anterior spinal artery. In the thoracolumbar region, there is always a dominant, great anterior medullary artery, or artery of the lumbar enlargement, called the artery of Adamkiewicz (Figs 1A, 2A, and 5A). It originates between T-9 and T-12 in 62% (8) to 75% (15) of cases, although a frequent origin at L-1 or L-2 was noted by Gillilan (7).

The anterior spinal artery varies in size from approximately 0.2 to 0.5 mm in the cervical and thoracic regions to 0.5 to 0.8 mm in the thoracolumbar region (postmortem injected specimens [14]). The greatest diameter is at and immediately caudad to the entrance of the artery of Adamkiewicz, which usually measures from 0.5 to 0.8 mm, but may be as large as 1.0 (14) to 1.2 mm (15) in diameter. In the thoracolumbar region, the course of the anterior spinal artery varies from straight to slightly serpiginous. Caudally, it forms anastomoses with the terminal branches of the posterolateral spinal arteries. The paired posterolateral arteries, which are usually less than 0.4 mm in diameter, are dominant yet variable longitudinal channels within the pial plexus on the posterior surface of the cord (Figs 2 and 6). Posterior (paramedian) arteries may also be present, especially in the thoracic spine (14). The posterior medullary arteries, which supply the posterolateral or posterior spinal arteries, measure approximately 0.2 to 0.5 mm in the thoracolumbar region (14) and are usually difficult to see on angiograms (15), except in the vicinity of the lumbar enlargement (Fig 2C) (7). There is no longitudinal arterial trunk in the midline posteriorly (Figs 1, 2, and 5B).

Veins.—The venous drainage of the spinal cord proceeds by way of intrinsic and extrinsic veins (Fig 6). The extrinsic veins constitute the coro-

![Vein Diagram](image-url)
dent of the arteries, except for the anterior median (spinal) vein, which often parallels the anterior spinal artery (14). In the thoracolumbar spine, the anterior median vein is usually a single, midline trunk, ranging in size from 0.5 to 1.5 mm (11). The posterior median vein is distinctive, since there is no posterior midline artery (Fig 5B). The size of the posterior median vein on postmortem specimens is reported by some anatomists to be about the same (11, 14) or smaller (10) than the anterior median vein. Other investigators report that the posterior median vein is always larger (5), measuring up to 2 mm in the thoracolumbar region. Fried et al (16) found that the posterior median vein was the largest vessel on the cord surface on selective spinal angiograms, measuring 1 to 2 mm in diameter. The posterior median vein terminates in a perimedullary plexus, which communicates with the anterior median vein, and in posterior medullary vein(s), which drain to the epidural venous plexus. The posterior median vein and other posterior coronal veins tend to be more tortuous than the veins on the anterior and lateral cord surfaces, and their tortuosity increases with age (10).

The medullary veins that drain blood from the coronal plexus on the cord surface are not present at every segmental level and are not concomitant with the medullary arteries (10, 19, 20). Doppman et al and Fried et al (12, 16) refer to these veins as radiculomedullary veins. Much smaller veins, called radicular veins by Gillilan, drain the nerve roots at every segment (10). French anatomists Moes and Maillot (11) also distinguish between veins that drain the cord and those that drain the nerve roots, calling the former (ie, the medullary veins) “les veines radiculaires,” and the latter (ie, the radicular veins) “les veines radicellaires.” Other investigators (5, 14, 15) refer to all veins accompanying nerve roots as radicular veins.

The number of anterior medullary veins ranges from 8 to 14 (10) to approximately 20 (15), with a similar (15) or larger (10) number of posterior medullary veins. They are generally larger than the medullary arteries (14). The largest (1.5 to 2.0 mm) are in the thoracolumbar region, identified as the great anterior and/or great posterior medullary vein(s) (Fig 5). They usually accompany the corresponding anterior or posterior root between T-11 and L-3 (10, 15, 16). As indicated in the Table, medullary veins, usually the posterior ones, are routinely seen on postcontrast MR angiograms. They may be identified on postcontrast T1-weighted spin-echo images (Fig 4D) and should not be mistaken for enhancing nerve roots (21).

The configuration of a medullary vein where it joins either the anterior or posterior median vein has been described as a coathook (16). The medullary vein penetrates the dura with the nerve root (22) or through a separate foramen (23) a few millimeters cephalad or caudad to the exit of the nerve root.

**Technical Considerations**

As has been shown for intracranial vessels (24–26), intravascular contrast material often improves the visibility of small vessels and is essential to the detection of spinal intradural vessels by means of the technique described.
here (Fig 3C and D). A contrast bolus technique, such as the one we have used, provides small-vessel detail equivalent to that achieved by constant infusion during scanning (26). There are drawbacks to postcontrast MR angiography (24). One of these is the inability of flow presaturation pulses to suppress signal adequately from the contrast-containing flowing blood. In theory, this could limit the opportunity to display arteries versus veins selectively using presaturation bands; however, selective presaturation to distinguish spinal arteries from veins on time-of-flight acquisitions without contrast material is likely to be difficult at best, given the size, course, direction of flow, and hemodynamics of these vessels. For example, portions of the anterior spinal artery have bidirectional flow, and the same is likely true for the median veins, at least in the thoracic region (15). A second drawback is that contrast enhancement of a mass or of the cord itself in pathologic conditions may obscure or mimic the enhancement within spinal vessels; however, this was not a problem in the study by Bowen et al (4). Because flow enhancement at MR angiography, without or with contrast material, may be mimicked by subacute thrombus, it is prudent to obtain T1-weighted and T2-weighted spin-echo MR images, as well as MR angiographic source images before contrast material is administered. Careful evaluation of all images for thrombus should avoid this pitfall. Another potential pitfall is confusion between a normal medullary vein and nerve root enhancement (21). The medullary vein and root may be distinguished, though, if there is continuity of the vein with a vessel on the cord surface, such as the anterior or posterior median vein.

The 3-D time-of-flight technique used here does not allow de novo differentiation of the anterior median vein and anterior spinal artery. However, on the basis of having identified some contour differences between the anterior median vein and the anterior spinal artery, as well as having detected associated anterior medullary and anastomotic veins on MIP images and DSA images (Figs 1 and 3), we conclude that the anterior median vein is the anterior midline vessel primarily seen on postcontrast time-of-flight MR angiograms. Our findings do not exclude the possibility that some parts of the midline vessel on MIP images represent the anterior spinal artery alone or an unresolved combination of the anterior median vein and anterior spinal artery (Fig 3B). Why might the anterior median vein be detected instead of the anterior spinal artery? The most likely reason is that the anterior median vein is usually larger than the anterior spinal artery. Other possible explanations are (a) the greater pulsatility within the anterior spinal artery and (b) the higher velocities, which produce greater acceleration around the hairpin turns at the junctions of the anterior medullary arteries and the anterior spinal artery. Both these phenomena would contribute to phase dispersion when compared with the slower, less pulsatile flow in the medullary veins and anterior median vein. Differentiating normal intradural arteries from veins on the basis of velocities may be possible by using phase-contrast MR angiographic techniques with phase-difference data processing (27).

Normal versus Abnormal Vessels

The subjects included in this study were symptomatic and had objective evidence of myelopathy. However, each had normal findings on spinal DSA images and, except subject 4, on routine MR images of the cord. All potential segmental arterial contributions to the anterior spinal artery were investigated by means of DSA, and images were obtained into the venous phase. In the thoracolumbar region, an orderly progression of vascular opacification occurred when the catheter was not wedged. Normal intradural veins were usually seen within 15 seconds of injection, and no later than 22 seconds. In subjects 4 and 5, open biopsy was performed, and no abnormal intradural vessels were identified at the time of surgery (Table).

A relatively large, posterior paramedian venous segment was identified in subject 6 (Figs 2 and 4). This was opacified in the normal temporal sequence on DSA and drained to two sequential great posterior medullary veins. Although the paramedian segment may seem atypical, the presence of a few short, enlarged venous segments (varices) on the surface of normal cord specimens has been a common finding (11, 14). In subject 3 (Figs 1 and 3), the posterior median vein was discontinuous at T-10, draining to both neural foramina at this level via veins that followed an ascending, rather than the typical descending, course. Although an ascending course may be atypical, it has been observed elsewhere (see Fig 4 in Gilli-
and in our study that these veins were opacified in the normal temporal sequence. Could subjects 3 and/or 6 have had thrombosed segments of the posterior median vein, accounting for these findings? This seems unlikely, since no abnormal signal corresponding to either acute, subacute, or chronic thrombus was identified on the precontrast spin-echo or gradient-echo (MR angiography) acquisitions.

In summary, postcontrast 3-D time-of-flight MR angiography of the thoracolumbar spine in patients with normal vessels by DSA detects primarily or exclusively the largest veins on the cord surface and those extending from the cord to the epidural venous system. Anteriorly, these intradural veins are the anterior median vein and the draining anterior medullary veins. Posteriorly, these veins are the posterior median vein and the draining posterior medullary veins, especially the great posterior medullary vein. Some portions of the anterior median vessel could represent parts of the anterior spinal artery in addition to or in place of the anterior median vein, since the artery and vein are located adjacent to each other in the midline. For the posterior median vein, there is no corresponding midline artery. Thus, a dominant midline vessel on the posterior aspect of the cord on MR angiograms almost certainly represents the posterior median vein, and vessels extending from it to the dural surface represent posterior medullary veins. These medullary veins are straight, whereas the posterior median vein may have mild tortuosity over a length of several spinal segments. In view of these normal findings, excessive tortuosity, size, and number of vessels on the posterior surface of the cord, extending over several segments and in association with a tortuous medullary vein, should suggest the possibility of enlarged intradural veins, which in the proper clinical setting may be associated with an arteriovenous malformation or dural fistula (4).

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References


