THE ANATOMY OF THE CAUDA EQUINA ON
CT SCANS AND MRI

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The nerve roots of the cauda equina may be visualised by contrast-enhanced CT scans and by surface-coil MRI. We have identified the pattern of anatomy from L2-L3 to L5-S1 in 10 human cadaver specimens and correlated this with anatomical dissections. Individual roots are slightly more distinct on contrast-enhanced CT than on surface-coil MRI. There is a crescentic oblique pattern of nerve roots at the lower lumbar levels which is still apparent in the more crowded proximal sections. In all cases, the axial images correlated precisely with the dissections. Current imaging modalities can help the clinical understanding and management of abnormalities in this region of the spine.

The nerve roots within the thecal sac of the cauda equina can be demonstrated on contrast-enhanced CT scans and by surface-coil MRI. The roots have been described as forming a crescentic pattern (Naidich et al 1980), which spreads diffusely and occupies the dorsal aspect of the dural sac at lower lumbar levels (Resjö et al 1979; Monajati et al 1987; Ross et al 1987). However, there have been no reports of the position of the individual spinal nerve roots on axial images, nor have the radiographic observations been correlated with anatomical findings.

We have recently identified an organised pattern of the intrathecal nerve roots in the cauda equina (Wall et al 1990), using fixation and dissection. This had the potential for artifact by displacement of the roots. Our new study was undertaken to validate this previous work and correlate it with contrast-enhanced CT scans and MRI studies.

MATERIALS AND METHODS

Ten fresh adult human cadavers without evidence of spinal surgery were studied, radiographs being taken of each specimen to exclude congenital abnormality or gross spinal pathology. The cauda equina was fixed in situ by injection of 2.5% glutaraldehyde in phosphate buffer into the thecal sac through a small laminotomy site; 3 ml of lohexol contrast agent (Winthrop, New York) was added. The entire cauda equina was then exposed by removal of the posterior spinal elements and embedded in situ with liquid nitrogen. A suture was used to mark each lumbosacral disc level and the fixed and embedded dural sac was lifted out of the vertebral canal for imaging.

The CT images were obtained on a GE 9800 unit, performing scans at 80 KVP, 40 mA, with 1.5 mm slices and a 2 s scan time. The MR images were obtained on a GE Signa 1.5-Tesla superconductive unit with a circular surface-coil. A multi-echo sequence with a repetition time (TR) of 2200 ms and echo times (TE) of 20 ms and 60 ms were used, with a 256 × 256 acquisition matrix and two excitations. Slices were 3 mm thick with a 1.5 cm interslice gap and a field of view of 12 cm.

Each specimen was subsequently sectioned at each disc level from L2-L3 to L5-S1 using a microtome knife (Cambridge Instruments, Edison, New Jersey). Sections were photographed, drawn and correlated with the corresponding CT and MR images. The specimens were then dissected under 3.5 × loupe magnification, tracing the individual spinal roots in their course through the thecal sac.

RESULTS

The nerve roots were well visualised on both contrast-enhanced CT and surface-coil MR images, although individual roots were slightly more distinct on CT than MR. In all cases, the nerve root patterns seen on the axial images correlated precisely with the individual nerve roots seen at dissection. We discuss the observed image pattern in relation to the identified nerve roots at each...
L5-S1 intervertebral level. A crescentic pattern of nerve roots is seen within the thecal sac, with the S1 root lying anterior and lateral.

L4-L5 intervertebral level. The L5 root is situated anterolaterally, displacing the S1 root, and the lower sacral roots are positioned dorsally. There is clear separation of the motor (anterior and medial) and sensory (posterior and lateral) roots.

L3-L4 intervertebral level. Although the anatomy is more crowded, the motor bundles of the L4, L5 and S1 nerve roots are visible anterior and medial to their corresponding multifascicular sensory bundles.

L2-L3 intervertebral level. The roots occupy most of the thecal sac at this level, with the motor bundle anterior to its sensory counterpart for each root.
disc level. The pattern is best appreciated by progression from caudal to cephalad (Figs 1 to 4).

**L5-S1** (Fig. 1). At the L5-S1 disc level, a crescent-shaped pattern of nerve roots is seen on both CT and MR images. The S1 root is seen as a projected large anterolateral density, with its motor bundle always anteromedial to the sensory component. The lower sacral roots are dorsally placed in the thecal sac.

**L4-L5** (Fig. 2). At the L4-L5 interspace, the L5 root assumes an anterolateral position, displacing the S1 root posteromedially. The lower sacral roots are grouped dorsally.

**L3-L4** (Fig. 3). At the L3-L4 disc level, the imaged nerve roots become more crowded, although a layered pattern is still discernible. The L4 root displaces the L5 and S1 roots dorsally and towards the mid-line. These three root bundles assume an oblique, layered configuration. Within each root layer, the motor bundle remains medial and anterior to its corresponding larger and multifascicular sensory bundle. The S2-S5 roots remain dorsal.

**L2-L3** (Fig. 4). The L3 root adds to the layered pattern at the L2-L3 intervertebral level. The nerve roots occupy the majority of the thecal sac at this level and are closely apposed. Although the individual roots are less distinct on both CT and MR images, the layered root pattern can still be appreciated on some specimens. Dissections revealed a tightly apposed oblique layering of individual nerve roots at this level. The motor bundles form the ventral surface of the layers.

**DISCUSSION**

Both contrast-enhanced CT (Resjø et al 1979; Naidich et al 1980; Haughton and Williams 1982; Dorwart and Genant 1983; Takata et al 1988) and surface-coil MRI (Reicher et al 1986; Monajati et al 1987; Ross et al 1987) allow the visualisation of cauda equina nerve roots within the thecal sac, and several authors have described a crescent-shaped pattern of nerve roots (Resjø et al 1979; Naidich et al 1980; Ross et al 1987). At more caudal lumbar levels the roots are said to separate into “delicate entities” (Ross et al 1987), becoming more diffuse (Monajati et al 1987), and more dorsal (Resjø et al 1979) within the thecal sac.

Our study has identified and described the individual nerve roots seen on both types of image at each disc level of the cauda equina, showing a crescentic pattern at the lower lumbar levels. More cephalad, the roots group together and become less distinct, but dissections have shown that the oblique layered pattern can be related to individual roots. The lower sacral roots (S2-S5) remain in the dorsal aspect of the thecal sac, while the lumbar and first sacral roots progressively separate before leaving the anterolateral part of the canal.

Naidich et al (1980) noted that the imaged roots were arranged in pairs. We have shown that within each root layer, the motor bundle is anterior and medial to its
larger sensory bundle. These separate components can be visualised on both CT and MR images for the lumbar and first sacral roots.

This nerve root arrangement is not an artefact of the technique: the imaging studies confirm that any dissection artefact is minimal. Contrast-enhanced CT images performed on living patients for the evaluation of sciatica have verified this nerve root arrangement (Fig. 5).

Using computer software and our CT images, it has been possible to construct three-dimensional models of the nerve roots in the cauda equina (Fig. 6). This enabled us to trace individual spinal roots through the thecal sac, and confirmed the nerve root anatomy between each axial section. It is possible to rotate these images and to study sections in any desired plane. As CT and MR imaging techniques improve, the identification and tracing of individual nerve roots will help the understanding and management of abnormalities of the lumbosacral spine.

The authors wish to express their appreciation to East County Radiology, La Mesa, California for the use of its CT facilities, and the University of California, San Diego, Magnetic Resonance Institute for the use of its scanner. We would also like to thank Dimensional Medicine Inc, Minnetonka, Minnesota for the use of its three-dimensional computerised software.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

REFERENCES


