Normal Intraoperative Spinal Sonography

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The normal intraoperative sonographic features of the spinal canal, spinal cord, conus medullaris, and cauda equina are described and illustrated. Important observations concerning the normal spinal cord include its highly reflective dorsal and ventral surfaces, its uniform hypoechogenicity, and the presence of a central echo. Other easily identified structures within the spinal canal include the dura-arachnoid layer, subarachnoid space, denticulate ligament, dorsal arachnoid septations, and the roots of the cauda equina. In addition the sonographic appearance of commonly encountered iatrogenically introduced material including Gelfoam, Pantopaque, cottonoid pledgets, suture material, Harrington rods, and freeze-dried dura is also demonstrated. These normal images can serve as a baseline for the interpretation of various pathologic conditions of the spinal canal and its contents as seen with intraoperative spinal sonography.

With the widespread use of computed tomography and water-soluble myelographic contrast agents, the ability to more precisely assess the spine and its contents has improved significantly over the past few years. Magnetic resonance imaging of the spine offers an even more promising method of spine evaluation without subjecting the patient to the risk and discomfort of myelography. Sonography has also been reported as a pre- and postoperative method of imaging the spine in postlaminectomy patients [1] and in screening infants with spinal dysraphism [2–5].

Despite these advances in preoperative diagnoses, until recently [6, 7] there has not been a satisfactory method of imaging the spine and its contents during surgery. Such a method would enable structures beyond the immediate operative field to be visualized, and abnormalities within the dura or spinal cord could be identified and localized before being subjected to operative intervention. The recent development of a high-resolution, portable, real-time sonographic scanner that can be used in the operating room allows not only the visualization of intraspinal abnormalities but permits the surgeon and radiologist to assess the progress and final result of surgery before the operation is completed. We have termed this procedure *intraoperative spinal sonography* (IOSS).

A basic understanding of the normal sonographic anatomy of the spine is essential before full advantage of this technique can be taken. It is our object to describe and illustrate the normal intraoperative sonographic anatomy of the spinal canal, spinal cord, and cauda equina, so that this information can serve as a foundation for analyzing various pathologic states of the spinal canal and its contents. The sonographic characteristics of a number of iatrogenically introduced materials will also be described and shown.

Materials and Methods

During an 18 month period, 130 patients were examined with IOSS. A variety of pathologic disorders, including soft-tissue tumors of the spinal canal and spinal cord, trauma to the spine

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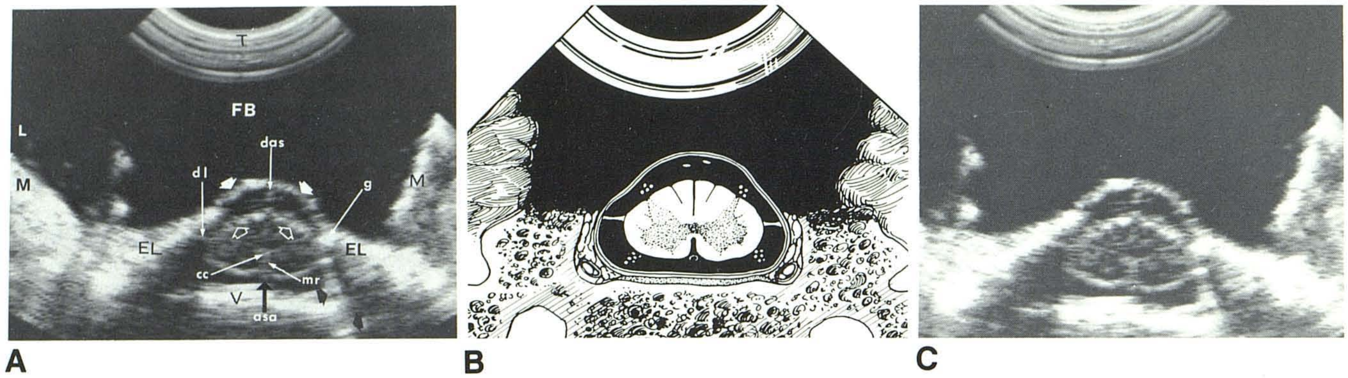


Fig. 1.—Normal cervical spinal cord. Transverse IOSS. Dura and arachnoid layers (*solid white arrows*) are seen as single reflective surface between fluid bath (FB) and subarachnoid space. In cervical and thoracic areas, ventral dura cannot be separated from back of vertebral bodies. Subarachnoid space surrounds spinal cord, and left denticulate ligament (dl) and dorsal arachnoid septations (das) can be seen within subarachnoid space. Right denticulate ligament and parts of subarachnoid space to right of cord are not seen because of Gelfoam powder (g) in surgical bed. Acoustical shadowing (*black arrows*) from Gelfoam powder is seen in right ventrolateral part of subarachnoid space extending through vertebral body (V). Dorsal and ventral roots usually are not identified clearly with IOSS. Spinal cord surface (*open arrows*) is highly reflective, while cord substance is composed of relatively uniform low-level echoes. Central echo (cc) is constant sonographic feature of normal cord. Median raphe (mr) is seen frequently ventral to central echo. On anterior cord surface adjacent to median raphe is anterior spinal artery (asa). T = transducer; M = paraspinal muscles; EL = edge of laminectomy; L = left.

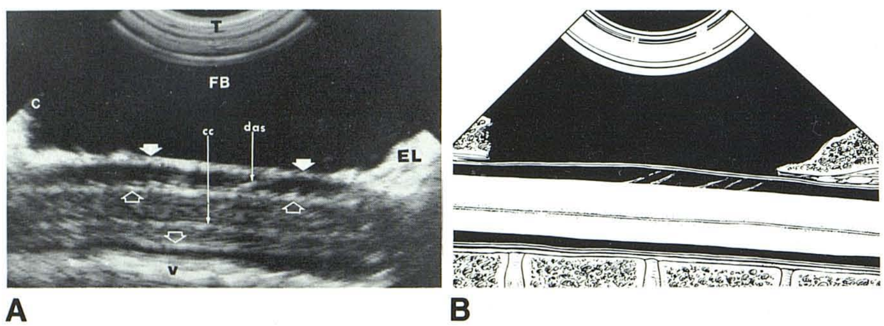


Fig. 2.—Normal cervical cord. Longitudinal IOSS (same patient as in fig. 1). Midline longitudinal IOSS shows highly reflective dorsal and ventral surfaces of cord (*open arrows*) and central echo (cc). Dorsal arachnoid septations (das) are seen traversing subarachnoid space between cord surface and dura-arachnoid layer (*closed arrows*). T = transducer; FB = fluid bath; C = cephalad; V = vertebral body; EL = edge of laminectomy.

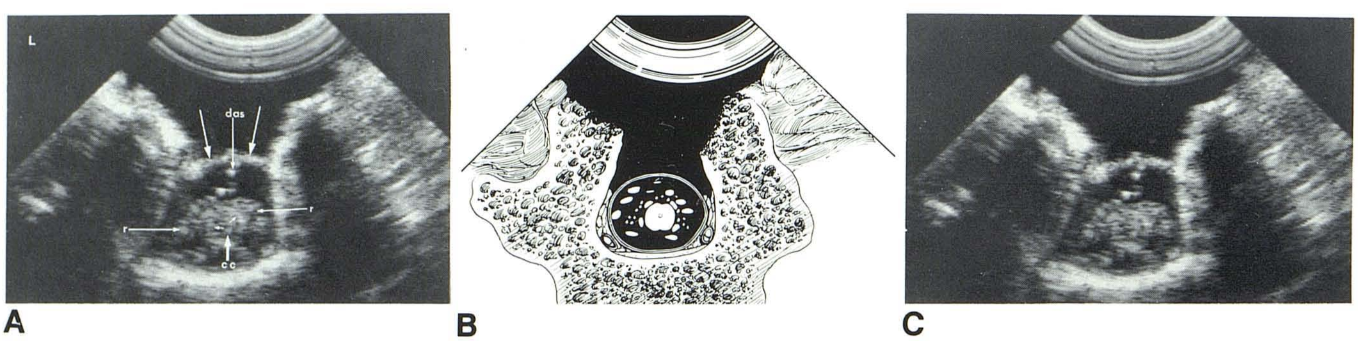


Fig. 3.—Normal conus medullaris. Transverse IOSS. Dura-arachnoid layer (*long arrows*), dorsal arachnoid septations (das), multiple roots (r) surrounding conus medullaris, highly reflective surfaces of normal conus (*short arrows*), and central echo (cc) are well seen. L = left.

with resultant bone, disk and/or bullet fragments within the canal, posttraumatic intramedullary or subarachnoid cysts, spondylosis, and herniated disks, had been analyzed sonographically. Our ability to distinguish normal from abnormal findings in the canal and spinal cord on IOSS comes from this clinical experience and the correlation we have made with the findings during surgery. Normal IOSS images are shown in figures 1–7, and accompanying drawings highlight the important features. The sonographic images are appropriately labeled, but the matched drawings are self-explanatory and are free of any overlying labels. Also, in figures 1 and 3, where many labels were used, a duplicate sonographic image is shown for clarity.

The images shown here were obtained with the ATL NeuroSectOR portable real-time unit (Advanced Technology Laboratories, Bellevue, WA) using a 7.5 MHz in-line transducer. This transducer has an optimal focal zone of 3–4 cm, which is the usual depth of the fluid bath (Ringer solution or sterile saline) in which the transducer is placed. The transducer never is allowed to touch the dura, cord surface, or nerve roots. The NeuroSectOR unit has an automatic time-gain control setting for the 7.5 MHz transducer that we have found to be adequate for our spinal sonographic procedures. The transducer element diameter is 6.4 mm and is small enough to be used for all sonograms after laminectomies and for most sonograms

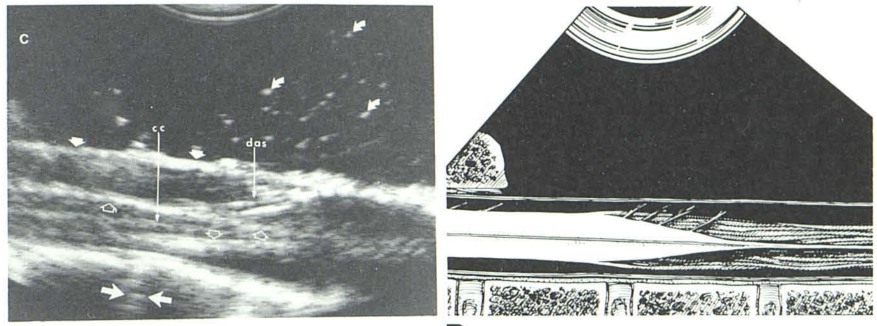


Fig. 4.—Normal conus medullaris. Longitudinal IOSS (same patient as in fig. 3). Midline longitudinal sonogram shows typical tapering of conus medullaris and highly reflective nature of cord surface (*open arrows*). Central echo (cc) is seen extending to tip of conus. Dorsal arachnoid septations (das) extend from surface of conus to dura-arachnoid layer (*short solid arrows*). Roots distal to tip of conus are poorly seen because they are at periphery of sound beam. Echogenic band (*long straight arrows*) perpendicular to vertebral body edge is intervertebral disk material. Multiple scattered air bubbles (*curved arrows*) can be seen within fluid bath. C = cephalad.

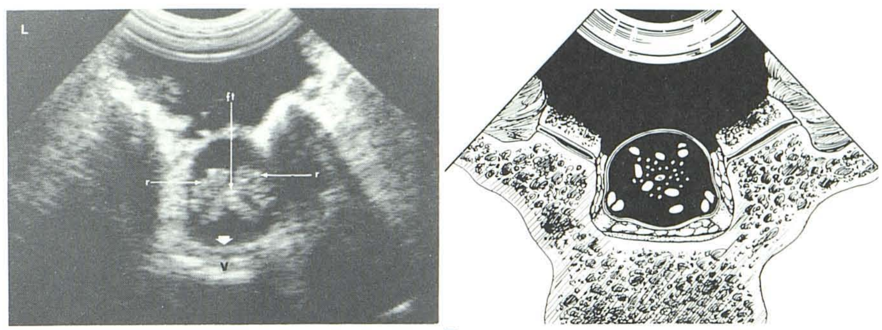


Fig. 5.—Normal proximal cauda equina. Transverse IOSS. Individual roots (r) of proximal cauda equina can be seen forming nearly an x-shaped pattern, a configuration noted often by us on transverse IOSS in this area. Single midline structure may represent filum terminale (ft). Slight separation can be seen between ventral dura-arachnoid layers (*arrow*) and back of vertebral body (v). Probably this is lumbar epidural space, which may become even more prominent in distal lumbar canal. L = left.

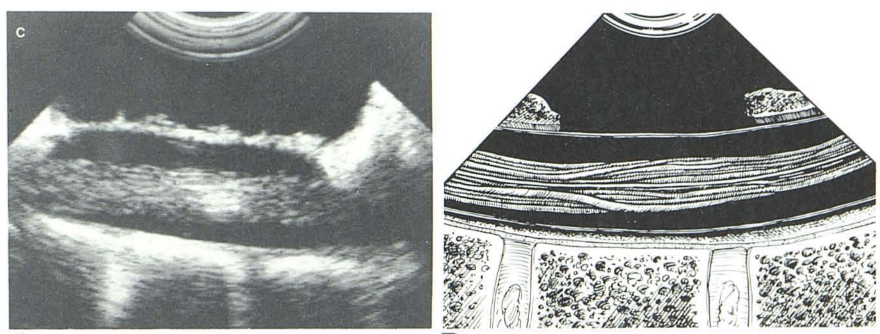


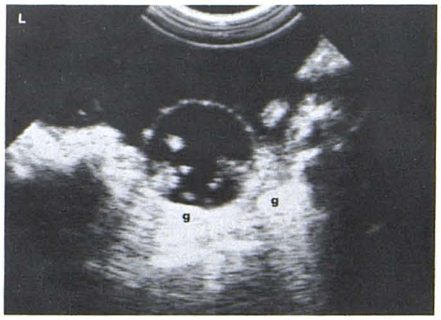
Fig. 6.—Normal proximal cauda equina. Longitudinal IOSS (same patient as in fig. 5). Along central acoustical axis, higher level echoes are seen when compared with more peripheral parts of sonogram. Roots of cauda equina are identified clearly. C = cephalad.

after a corpectomy (i.e., partial or total removal of a vertebral body). The transducer is placed in a sterile latex sheath and is coupled to it via a sterile gel. Any air bubbles trapped within the latex sheath are smoothed out, and rubber bands are placed over the latex sheath to secure it firmly to the transducer.

IOSS is performed in both longitudinal and transverse planes. Multiple images are obtained in each plane by gradually moving the transducer across the operative field. The entire procedure is recorded on videotape, and in addition filmed static images are obtained throughout the study. On the longitudinal sonograms our convention is to have the most cephalad area to the viewer's left. The transverse sonograms are labeled just as the surgeon sees the operative field, namely, after a laminectomy, the patient's left will be to the viewer's left. Conversely, following a corpectomy the patient's left will be to the viewer's right.

Observations

The edges of laminectomy are usually well seen on transverse sonograms but may also be seen on longitudinal sonograms when only a one or two level laminectomy is performed. These bone edges and the posterior edges of the vertebral bodies are highly reflective and allow little or no through-transmission of the sound waves. Along the central acoustical axis, structures tend to be perpendicular to the



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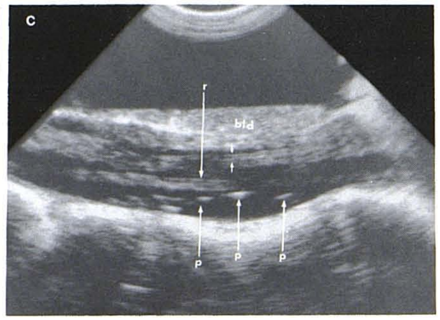

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Fig. 7.—Normal distal cauda equina. Transverse IOSS. Distal roots of cauda equina are no longer seen to be arranged in x-shaped pattern as was seen in proximal cauda equina (see fig. 5) but instead are more widely spread throughout subarachnoid space. Thick, highly echogenic areas surrounding thecal sac ventrally and laterally represent Gelfoam (g). Gelfoam blends with and acoustically shadows ventral epidural space and adjacent vertebral body. L = left.

Fig. 8.—Pantopaque in subarachnoid space. Longitudinal IOSS. Roots (r) of cauda equina are well seen within subarachnoid space. When perpendicular to sound beam, each root is seen as parallel echogenic lines (*arrows*) with central hypoechogenic region. In addition isolated, highly reflective echogenic structures (p) represent Pantopaque droplets within cerebrospinal fluid. Blood (bld) is seen layering along dorsal dural surface. C = cephalad.

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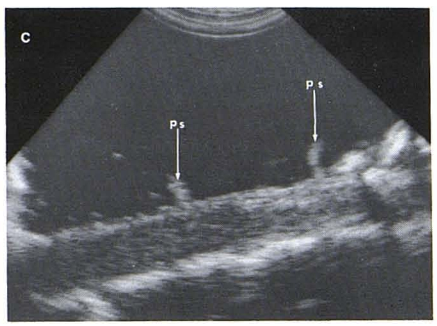

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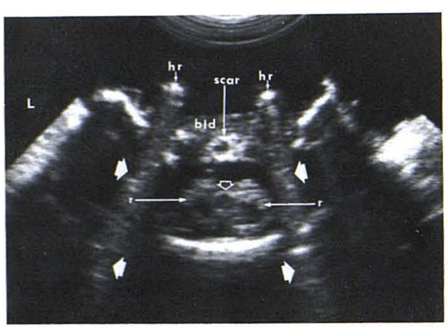
Fig. 9.—Cottonoid pledgets in laminectomy defect. Transverse IOSS. After posterior decompression for cervical stenosis and cervical spondylosis, cottonoid pledgets (*arrows*) were placed in surgical site. These pledglets are less echogenic than Gelfoam powder and are not associated with significant acoustical shadowing (cf. figs. 1 and 7). As in fig. 1, dura-arachnoid layer, ventral and dorsal subarachnoid space, dorsal arachnoid septations, and highly reflective surface of cervical cord are seen well. L = left.

Fig. 10.—Suture material used to sew dura together. Longitudinal IOSS. After opening of dura, needle biopsy of thoracic intramedullary mass was performed. Subarachnoid space has collapsed after dura and arachnoid were entered. Prolene sutures (ps), used to sew dura back together, are seen along dorsal dural surface projecting into fluid bath. Sutures are creating no shadowing artifacts. Central echo is not visualized, which we attribute to infiltrating spinal cord glioma. C = cephalad.



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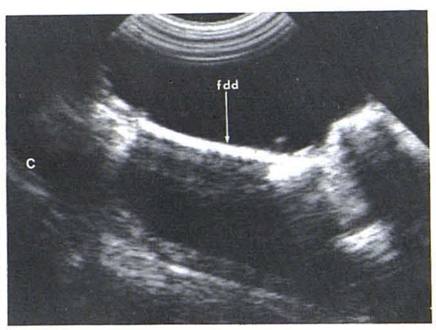

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Fig. 11.—Harrington rods. Transverse IOSS. Passage of sound waves through Harrington rods (hr) results in typical sonographic reverberations (*closed arrows*) that obscure all anatomic details in its path. Layering of blood (bld) and densely echogenic scar (scar) are seen along dorsal dural surface. Echogenic surface of conus (*open arrow*) and roots of cauda equina surrounding conus (r). L = left.

Fig. 12.—Dural graft. Longitudinal IOSS. After posterior C1–C2 decompression and excision of dura for treatment of Chiari I malformation, freeze-dried dura (fdd) was used as dural graft. This echogenic material transmits sound waves poorly, and as a result no significant sonographic information behind this material can be obtained. Note the lack of visualization of spinal cord. C = cephalad.

sound beam, and as a result the reflectivity pattern in the center of the image is the strongest (e.g., fig. 6). Consequently, structures of the spinal canal are seen most clearly when they are in line with the central acoustical axis. Therefore, before an area of the spinal cord is called abnormal, the examiner must be assured that the area under question is centered to the transducer. Bleeding can be observed on real-time sonography as finely echogenic uniform material of relatively high intensity that swirls and mixes with the fluid bath. This fresh blood usually then layers along the dorsal surface of the dura and forms a fluid layer (fig. 8), but occasionally it can appear as clumps of finely echogenic material dorsal to the dura. Constant features outside of the spinal canal seen with IOSS at all levels examined are labeled only in figures 1 and 2; these include the transducer, the fluid bath in which the transducer sits, dorsal paraspinal muscles, edge of the laminectomy, and the vertebral body. Normal IOSS of the spinal cord is shown and described later (figs. 1–7). Iatrogenically introduced substances commonly seen with IOSS include Gelfoam, Pantopaque, cottonoid pledgets, sutures, Harrington rods, and freeze-dried dura. These are shown in figures 7–12.

Spinal Cord

In figures 1 and 2 intraopoerative sonography of a normal cervical cord after a midcervical laminectomy is shown in the transverse (fig. 1) and longitudinal (fig. 2) planes. The only sonographic difference we have noticed between the cervical and thoracic levels is that the thoracic cord has a rounder shape and the anterior spinal artery is less clearly defined in the thoracic area. The important structures are clearly labeled and illustrated; however, a few features deserve special comment. The dorsal and ventral surfaces of the spinal cord are seen as highly reflective structures because the change in physical density from cerebrospinal fluid to spinal cord tissue creates an acoustical interface. The spinal cord itself is composed of relatively uniform, low-level echoes, and this hypoechogenicity is best appreciated when the spinal cord is compared with the echogenic properties of the surrounding paraspinal muscles. The linear highly reflective structure in the mid to ventral part of the spinal cord is the central echo. These three features—the highly reflective cord surfaces, the uniform hypoechogenicity of the cord, and the central echo—should be looked for carefully, because in our experience [6] their absence indicates the presence of a pathologic process affecting the spinal cord. The dorsal and ventral rootlets surrounding the cervical and thoracic cord are usually not clearly delineated; however, the dorsal arachnoid septations and the denticulate ligaments are commonly seen within the subarachnoid space. It is important not to mistake these normal structures for either aberrantly coursing nerve roots or fibrotic bands or scars. Constant pulsations of the cord that reflect the normal heartbeat can be observed with real-time IOSS. Occasionally, pulsations of the anterior spinal artery itself can be seen.

Conus Medullaris

The characteristic tapering of the conus medullaris is well seen on longitudinal IOSS (fig. 4), and on midline sections the central echo can be followed to its tip. On transverse IOSS (fig. 3) the highly reflective surface of the conus is more difficult to identify than is the cord surface in the thoracic or cervical area because the conus is surrounded by nerve roots that tend to blend in with the surface of the conus. However, careful observation will show the individual roots to be separable from the conus itself.

Cauda Equina

Individual roots of the cauda equina area seen both in the upper (figs. 5 and 6) and lower (fig. 7) lumbar canal. Fewer roots are seen in the distal sac since the upper lumbar roots have already exited. We have noted that in the upper cauda equina the roots assume nearly an X pattern when viewed transversely (fig. 5). In the lumbar sac there is often a widening of the ventral epidural space because of the presence of fat and connective tissue. This may be seen sonographically as a space between the dura-arachnoid layer and the edge of the adjacent vertebral body (fig. 5). This space is not seen as well in the cervical and thoracic spine since the ventral epidural space is normally very small in those areas.

Iatrogenically Introduced Substances

During an operative procedure, materials may be used that may cause a confusing sonographic image and/or may obscure many of the anatomic details within the spinal canal. A number of these substances are shown in figs. 7–12. Gelfoam powder used in the surgical wound to diminish bleeding is highly echogenic (fig. 7) and will obscure many of the details within the spinal canal. Pantopaque droplets (fig. 8) within the subarachoid space are seen as highly reflective structures, without shadowing, not in continuity with the surrounding nerve roots. Cottonoid pledgets (fig. 9) have a typical "squared-off" appearance with echogenic properties quite different from those of Gelfoam powder. The pledgets are less echogenic and do not have the acoustical shadowing we have noted with Gelfoam powder. Suture material commonly used to sew the dura (prolene sutures in fig. 10) causes no shadowing artifacts in the sonographic field. Harrington rods (fig. 11) are clearly identified with IOSS and, like other metallic foreign bodies, give off a characteristic reflective shadow in response to the effect of the sound waves striking the metallic rods. Freeze-dried dura (fig. 12) acts as an effective acoustical barrier, and as a result no useful sonographic information is obtained distal to this material after it has been sewed in place.

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