A percutaneous technique for producing intraspinal mass lesions in experimental animals

JOHN L. DOPPMAN, M.D., ROY RAMSEY, M.D., AND RAYMOND J. THIES, II, B.S.
Department of Radiology, University of California at San Diego, and University Hospital, San Diego, California

The authors describe a percutaneous technique for producing extra- and intramedullary mass lesions in the dog and monkey. Small balloon catheters introduced through needles into the spinal canal can be positioned under fluoroscopic control to simulate epidural masses or masses within the cord. Selective spinal cord arteriography and silicone perfusion studies demonstrate the effect of such masses on spinal cord blood flow.

KEY WORDS: spinal cord, experimental intramedullary and epidural lesions, percutaneous, balloon catheters

In the early 1950's, Tarlov described, in a classic series of experiments, the effect of extramedullary masses upon spinal cord function. He introduced balloon catheters into the epidural space of dogs and, with controlled inflation, differentiated the effects of slowly and rapidly expanding epidural masses. He attributed the functional disturbances to distortion and compression of neural elements rather than to ischemic factors. However, other authors have suggested that compression of major spinal arteries, particularly the anterior spinal artery, may be more important than direct cord compression in the spinal syndromes associated with severe cervical spondylosis, thoracic disc herniation, and some cases of trauma. The development of selective arteriographic techniques for visualizing spinal cord vessels in two laboratory animals (dogs and monkeys) offers the opportunity to evaluate the role of vascular compromise in various cord-compressing syndromes. Unfortunately, the laminectomy required to introduce cord-compression masses in experimental animals violates the closed-space concept of the spinal canal by partially decompressing the cord in the act of introducing the epidural balloon.

For that reason, we have developed a percutaneous technique for introducing space-occupying masses into the spinal canal. This paper will describe and illustrate the application of this technique in dogs and monkeys.

Technique

Epidural and intramedullary masses have been produced in eight mongrel dogs, 24 Mangaby monkeys, and two Rhesus monkeys. The technique is essentially the same in all animals except that larger needles and balloon catheters are used for the dog.
Percutaneous production of experimental mass lesions

Selective spinal cord arteriography is initially performed to determine the appropriate level for introduction. We use 3 cc of Renografin 76* (5 cc in dogs), preceded by 1 mg of diazepam† selectively injected into the appropriate lumbar artery. Thus far, we have been producing epidural and intramedullary masses only in the region of the lumbar intumescence, just below the entry of the artery of the lumbar enlargement (akin to the artery of Adamkiewicz in man). It is necessary to establish by arteriography both the level and side of entrance of this major spinal arterial feeder, since the balloon catheter should not be introduced through the same intervertebral foramen. The artery of the lumbar enlargement always arises from the 4th or 5th lumbar artery in the dog6 and from the 1st or 2nd lumbar artery in the Mangaby monkey.6 In the Rhesus monkey4 origin of the Adamkiewicz artery is more variable (T8-L3). Table 1 summarizes these data.

Once the vertebral level and the appropriate side have been determined, a No. 18 spinal needle (No. 16 in dogs) with a tapered catheter sleeve is passed under fluoroscopic control to the orifice of the intervertebral foramen. Initial needle positioning is most easily performed in the lateral projection but both anteroposterior (AP) and lateral fluoroscopy are required during the final stages of needle adjustment. When the balloon is to be placed in the anterior epidural space, the needle is angled slightly anteriorly so that it enters the intervertebral foramen passing forward toward the back of the vertebral body. A posterior angulation is used to place balloons in the posterior epidural space.

With the tip of the catheter sleeve just within the entrance of the intervertebral foramen, the needle is removed and a No. 3 French Fogarty arterial embolectomy catheter* (No. 4 French in dogs) is passed into the epidural space. Slight resistance may be encountered as the catheter enters the epidural space, but once introduced, the catheter can then be easily passed for great lengths up or down the spinal canal (Fig. 1). An anterior epidural balloon tends to ascend or descend in the anterolateral gutter opposite the side of introduction, and if a midline position is desired (to simulate a herniated disc or osteophytic spur), it must be withdrawn to the level of entrance at which it crosses the spinal canal. The balloon is inflated with a water-soluble contrast medium, and final positioning is accomplished under AP and lateral fluoroscopic control. It is important to deflate the balloon each time it is maneuvered to avoid

*Renografin manufactured by E. R. Squibb & Sons, 745 Fifth Avenue, New York, New York 10022.
†Valium manufactured by Hoffman-La Roche, Nutley, New Jersey.

---

**TABLE 1**

<table>
<thead>
<tr>
<th>Level</th>
<th>Dog (50)</th>
<th>Rhesus (37)</th>
<th>Mangaby (21)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T-8</td>
<td>0</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>T-9</td>
<td>0</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>T-10</td>
<td>1</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>T-11</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>T-12</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>L-1</td>
<td>7</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>L-2</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>L-3</td>
<td>2</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>L-4</td>
<td>2</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>L-5</td>
<td>15</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>L-6</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>L-7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>19</td>
<td>4</td>
<td>27</td>
</tr>
</tbody>
</table>

---

*Fogarty catheter manufactured by Edwards Laboratory, Santa Ana, California.
displacing the cord or tearing epidural veins. When the balloon has been positioned properly, the introducing catheter sheath is withdrawn.

The critical factor for successful placement of balloon catheters in the epidural space is proper needle positioning. The tip of the needle should be advanced only to the intravertebral foramen, and puncture of the dura should be avoided. The balloon catheter will then remain extradurally. Bleeding from the introducing catheter is common when the needle is first withdrawn and probably originates from the paravertebral venous plexuses. Although hemorrhagic staining of epidural tissue is usually observed at autopsy, significant epidural hematomas were rarely encountered.

Attempts to introduce the balloon catheter through the same intervertebral foramen as the artery of the lumbar enlargement may injure this vessel and compromise arterial flow to the entire lumbar cord. This foramen is best not used. The intervertebral foramen at the same level on the opposite side may be used, but since right and left lumbar arteries at any level usually arise from a single aortic orifice in the monkey, leakage of contrast from the paravertebral veins (Fig. 2) will obscure subsequent selective spinal arteriograms, especially in the lateral projection. For these reasons, an adjacent (cranial or caudal) intervertebral foramen should generally be used for balloon placement.

Spinal cord arteriography is then performed to verify the position of the epidural balloon with respect to the cord and to determine the balloon diameter necessary to achieve the desired displacement of the cord.
Percutaneous production of experimental mass lesions

Fig. 2. Early (left, 2 sec) and late (right, 4 sec) spinal arteriograms in a monkey following placement of balloon catheter through the foramen contralateral to the artery of the lumbar enlargement. Note on the late film (right) the active bleeding from the paravertebral venous plexus along the tract of the introducing trocar. Lateral arteriograms to evaluate posterior displacement of the anterior spinal artery would be obscured by this extravasation. Black arrowhead = artery of lumbar enlargement; clear arrowhead = anterior spinal artery; black arrow = stem of balloon catheter. Note delayed filling (left) and prolonged opacification (right) of the anterior spinal artery below the balloon.

(Fig. 3). Inflation of anterior epidural balloons may be graduated to produce increasing posterior displacement of the cord and progressive interference with anterior spinal artery blood flow (Figs. 4 and 5).

When the object is to produce a mass lesion within the cord, the needle and catheter sheath are passed through the intervertebral foramen, the dura is penetrated, and the needle tip is positioned in the center of the spinal canal. Arteriography verifies the position of the needle tip within the substance of the cord. A Fogarty balloon catheter is introduced through the sheath and the balloon is inflated to the desired size with a contrast medium (Fig. 6).

Once satisfactory balloon placement is achieved, a permanent epidural or intramedullary mass may be produced by inflating the balloon to the appropriate volume with opaque silicone rubber. The balloon of the No. 4 French embolectomy catheter can be inflated up to a diameter of 9 mm and the No. 3 French to 5 mm. These balloon "diameters" fill over 50% of the lumbar spinal canal in the dog and monkey and therefore constitute significant masses. The technique of injecting silicone rubber through small catheters as polymerization is taking place has been described by the authors. Once the balloon is permanently inflated, the catheter may be transected at skin level and allowed to retract into the subcutaneous tissue as a permanent implant. Paraplegic animals with this kind of simulated spinal mass have survived for 4 days until sacrificed for microangiographic perfusion studies.

In vivo spinal artery perfusion studies are always performed before sacrificing the animal to evaluate the effects of the mass on...
Fig. 3. Anterior (left) and posterior (right) epidural balloons indenting the spinal cord (monkeys). Cord is outlined by anterior and posterior spinal veins.

Fig. 4. Control arteriogram (left). Moderate inflation (center) and maximal inflation (right) of epidural balloon producing nonobstructive displacement (center), and complete occlusion (right) of the anterior spinal artery in dog. Very dilute contrast agent in balloon permits optimal visualization of the anterior spinal artery (arrowheads) in this dog.
spinal cord blood flow. The appropriate lumbar artery is percutaneously catheterized and perfused with opaque silicone rubber. The animal is sacrificed and the thoracolumbar spinal column removed and fixed in formalin in the upright position to avoid artifactual indentation on the cord due to gravity. The spinal cord is then removed through an extensive posterior laminectomy. Microradiography of the specimen permits correlation of the epidural or intramedullary mass with changes in arterial perfusion along the surface or within the substance of the cord (Fig. 7).

Results

Selective spinal cord arteriography was performed in 10 dogs and two monkeys but no attempt was made at balloon placement. No animals were paraplegic. Both monkeys showed a disinclination to use the leg on the side of catheter introduction but this disability cleared within a few days. We attribute it to the femoral artery ligation. Three additional monkeys underwent selective spinal cord arteriography and introduction of an epidural balloon catheter but, for various reasons, permanent inflation of the balloon in the desired location was not achieved. (Rupture of the balloon during inflation (1), displacement into the anterolateral gutter (1), and leakage of inflating material back along the catheter (1), accounted for these failures.) None of these animals was paraplegic. Thus, although no formal control series was planned, there is evidence that neither the arteriography nor the catheter introduction without balloon...
Fig. 6. Anteroposterior (left) and lateral (right) arteriogram with an intramedullary balloon. Note absence of narrowing or displacement of the anterior spinal artery. Some air remains trapped in Silastic-filled balloon (right).

inflation seriously compromised cord function in either animal.

Anterior and lateral epidural masses have been produced in eight dogs (15 to 25 kg), 20 Mangaby monkeys (4 to 7 kg) and two Rhesus monkeys (3 to 5 kg). Posterior epidural and intramedullary masses have been produced in five monkeys. The results of these studies will be presented in detail elsewhere. Briefly, the location of a mass within the spinal canal seems to influence its effect upon anterior spinal artery blood flow profoundly (Fig. 7). Midline anterior masses displace the anterior spinal artery posteriorly, and at an early stage obstruct the subjacent central perforating arteries. Filling of the anterior spinal and central perforating arteries caudal to the balloon remains unaffected. Complete obstruction of the anterior spinal artery can be achieved but requires large anterior masses, at least one-half the diameter of the spinal canal. Central perforator occlusion, on the other hand, occurs much earlier with masses of smaller “clinically relevant” diameters. Lateral epidural masses rotate and displace the cord without compromising anterior spinal and central perforator filling. Intramedullary masses similarly have little vascular occlusive effects when compared to anterior masses of comparable size. This tendency of masses in front of the cord to obstruct central perforating arteries may result from compression of these thin-walled vessels
Percutaneous production of experimental mass lesions

**Fig. 7.** Left: Maximally inflated intramedullary balloon does not prevent good filling of the anterior spinal and central perforating arteries. Center: A posterior epidural balloon indents the spinal cord but causes no displacement of the anterior spinal artery. Central perforators are splayed but filled. Right: Indentation of the cord by the anterior epidural balloon does displace the anterior spinal artery posteriorly and occludes the subjacent central perforating arteries. The anterior spinal artery and central perforators below the balloon fill normally from this selective perfusion of the artery of Adamkiewicz.

against the lips of the anterior median fissure. “Stump filling” beneath the balloon suggests some such mechanism. We are currently investigating the efficacy of laminectomy in restoring perforator perfusion in the presence of anterior epidural masses of the spinal canal.

**Discussion**

The percutaneous technique offers several advantages over the previous method of blindly passing balloon catheters into the epidural space through a laminectomy incision. Balloon position and diameter can
be precisely controlled. The relationship of the mass to the anterior spinal artery and its effect on flow through this vessel can be studied in vivo. Control of balloon position by the old technique was not precise; the catheter passed preferentially up the anterolateral gutter, and inflation of the balloon tended to displace and rotate the cord rather than compress it posteriorly. This may account for the fact that Tarlov, producing mainly anterolateral epidural masses, was not impressed with the ischemic component associated with such lesions. Because the myelopathy of cervical spondylosis or midline herniated discs (cervical and thoracic) is initiated by masses in front of the cord, any technique to study the pathophysiology of these lesions must allow accurate balloon positioning. Kamiya has devised an ingenious operative technique for placing anterior epidural masses in the cervical spinal canal of dogs through a drill hole in the intervertebral disc. However, the surgery is major, and final positioning is performed blindly.

The use of an in vivo perfusion with opaque silicone rubber selectively introduced into the artery of the lumbar enlargement offers advantages over the more usual postmortem regional barium perfusions. The perfusate is introduced under physiological conditions (normal blood pressure and body temperature) selectively into the artery of Adamkiewicz, and its distribution reflects blood flow through the lumbar segment of the anterior spinal artery at that moment. The significance of a posteriorly displaced but unoccluded anterior spinal artery can be evaluated in terms of functional patency and blood flow distal to the occlusion. Regional barium perfusions, often performed at nonphysiological pressures (200 mm Hg), fill all patent vessels, and although anatomical detail is superb, few deductions can be drawn concerning in vivo flow dynamics.

The development of these techniques for use in monkeys provides, for the first time, an experimental model with spinal vascular anatomy similar to man's. Studies of cord hemodynamics in dogs (the laboratory animal used in most previous investigations) have little clinical relevance since the canine spinal cord has medullary arteries at almost every level and is particularly resistant to ischemia. Monkeys, on the other hand, have few spinal arterial feeders at widely separated levels and, like man, are much more dependent upon flow along the anterior spinal artery. Cord ischemia, due to masses in the epidural and intramedullary space, can only be evaluated in primates.

References

10. Mair WGP, Druckman R: The pathology of spinal cord lesions and their relations to the clinical features in protrusion of cervical intervertebral discs: a report of four cases. Brain 76:70-91, 1953
Percutaneous production of experimental mass lesions


This work was supported by Research Grant USPHS-1 R01-HE13945-01 and Training Grant USPHS-5 T01-GM02023-02.

Address reprint requests to: John L. Doppman, M.D., Department of Diagnostic Radiology, Bldg. 10, Room 6S 211, The Clinical Center, National Institutes of Health, Bethesda, Maryland 20014.