Radiographic Imaging of the Distal Dural Ring for Determining the Intradural or Extradural Location of Aneurysms

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ABSTRACT

The effectiveness of several anatomical and radiological landmarks proposed to determine whether an aneurysm is located intradurally or extradurally is still debated. In anatomical and radiological studies, we examined the relationships of the distal dural ring (DDR) to the internal carotid artery (ICA) and surrounding bony structures to aid in the localization of aneurysms near the DDR. Anatomical relationships were examined by performing dissections on 10 specimens (5 formalin-fixed cadaveric heads). After the position of the DDR, optic nerve, and tuberculum sellae were marked with surgical steel wire, radiographs were taken in multiple projections. The only bony landmark consistently visible on radiographs was the planum sphenoidale. The superior border of the DDR is located at or below the level of the tuberculum sellae, which laterally becomes the superomedial aspect of the optic strut; thus, the optic strut marks the dorsal limit of the DDR. On 50 dry skulls, we measured the vertical distance between the planum sphenoidale and medial aspect of the optic strut (5.0 ± 0.4 mm), the interoptic strut distance (14.4 ± 1.4 mm), and the linear distance between the most posterior aspect of the planum sphenoidale (limbus sphenoidale) and the tuberculum sellae (6.0 ± 0.5 mm). Using these measurements and the planum sphenoidale, tuberculum sellae, and optic strut as reference landmarks, we determined the location of the aneurysm relative to the DDR on angiographic images. In this way, we were able to identify whether lesions were intra- or extradural.

KEYWORDS: Tuberculum sellae, planum sphenoidale, optic strut, distal dural ring, aneurysms

During the past three decades, internal carotid artery (ICA) aneurysms located near the distal dural ring (DDR) have been the subject of numerous reports for several reasons. The anatomy of this region is complex and varied. It contains a number of critical structures in an area of about 1 cm³ at the juncture of the cavernous (C4), clinoid (C5), and ophthalmic (C6) segments of the ICA. Aneurysms of this region are complex. They are often multiple (40%). More than 50% are large (have a diameter >1 cm) and 25% are giant. They also may occupy both the intra- and extradural compartments. Finally, treatment of these aneurysms remains a technical challenge for neurosurgeons.

Morbidity and mortality rates related to the treatment of these lesions have improved dramatically because knowledge of the surgical anatomy of this region has increased and because skull base techniques (e.g., anterior clinoidectomy) have been refined.¹ With the advent of endovascular techniques, a multidisciplinary neurovascular team approach is often desirable to develop the optimal treatment strategy. However, treatment of some of these lesions remains controversial. Intracavernous ICA aneurysms are notable for their benign natural history and low rates of subarachnoid hemorrhage. Therefore, small asymptomatic intracavernous ICA lesions found incidentally are associated with a good prognosis. Because of their extradural location, monitoring is justified. In contrast, an intradural aneurysm of similar proportions may rupture into the subarachnoid space and so is associated with a poor prognosis. Therefore, treatment depends on whether an aneurysm is located intradurally or extradurally.

The reliability of a number of landmarks (e.g., ophthalmic artery, anterior clinoid process [ACP]) proposed to distinguish whether aneurysms are intra- or extradural on imaging remains widely debated.²⁻⁴ The DDR is the anatomical reference point that marks the limit between the intra- and extradural compartments. Therefore, the relationship of any lesion to the DDR must be determined before a treatment plan can be developed. Identifi-

cation of the DDR is difficult if not impossible using current imaging techniques, including computed tomography (CT), three-dimensional CT angiography (3D-CTA), magnetic resonance imaging (MRI), magnetic resonance angiography (MRA), and angiography. New techniques, such as the three-dimensional contrast medium-enhanced CT (3D-CMECT) cisternography proposed as an adjunctive diagnostic procedure to locate intradural aneurysms selectively,⁵ may be time-consuming and are only applicable in select cases. Therefore, the best method for differentiating between intra- and extradural aneurysms remains undetermined.

To address this problem, we proposed to first identify the DDR radiographically and then to develop a simple reproducible means to determine its position in angiographic studies relative to aneurysms in this region. In this article, we describe the cadaveric, bony, and radiological anatomy of this region; the bony landmarks that were identified radiographically; and the cadaveric measurements that served to establish the radiographic features of the DDR. Finally, we propose a method for predicting the position of the DDR on angiograms, thus allowing the aneurysm location to be identified as intra- or extradural.

ANATOMY IN THE REGION OF THE DDR

The anatomy of the region around the DDR is complex, containing a number of bony, connective tissues and vascular structures that interrelate within a confining space.⁶⁻⁸ The DDR is juxtaposed to the cavernous (C4), clinoid (C5), and ophthalmic (C6) segments of the ICA.⁹ The cavernous (C4) segment extends from the petrolingual ligament proximally to the proximal dural ring distally. The proximal dural ring is part of the connective fold that extends from the inner layer of the lateral wall of the cavernous sinus to the inferior aspect of the ACP and optic strut, and to the anterior loop of the ICA. The ACP, which is the posterior projection of the

lesser wing of the sphenoid bone, is attached to the sphenoid body by the superior and inferior roots. The superior root forms the roof of the optic canal; the inferior root (also known as the optic strut) forms the inferolateral aspect of the optic canal and the superomedial border of the superior orbital fissure. The optic strut is a cylindrical-like structure of variable length and inclination, with a superior and inferior surface.

The clinoid (C5) segment of the ICA extends from the proximal dural ring to the DDR and lies immediately below the ACP; removal of the ACP exposes the clinoid space, an extradural space that contains the clinoid ICA. Delimiting the border between the intra- and extradural compartment, the DDR is part of the fold that extends from the outer layer of the lateral wall of the cavernous sinus to the superior aspect of the ACP, planum sphenoidale, and ICA. Unlike the proximal dural ring, the DDR forms a complete ring around and fuses with the adventitia of the ICA. The DDR is firmly adherent to the dorsolateral aspect of this vessel.

On the ventromedial side of the ICA, facing the carotid groove, the DDR may be redundant and form a pouch known as the carotid cave.¹⁰ Anatomical studies have demonstrated that this space is present in 68 to 90% of cases^{4,6,11} and is part of the subarachnoid space. According to Kobayashi et al,¹⁰ most carotid cave aneurysms lie below the level of the ACP. In their microanatomical study of the carotid cave, Hitotsumatsu and colleagues demonstrated that the neck of the carotid cave aneurysm on lateral angiographic views could be seen just below or proximal to the level of the tuberculum sellae, which they believed corresponded laterally to the middle clinoid process. It is often difficult to determine the intra- or extradural location of carotid cave aneurysms, an atypical group of ICA aneurysms.

Finally, the ophthalmic (C6) segment of the ICA extends from the DDR to the origin of the posterior communicating artery. This segment is the most proximal segment of the intradural ICA. The ophthalmic artery and the superior hypophyseal artery complex usually originate from this seg-

ment. In about 10% of cases, the ophthalmic artery arises proximal to the DDR from either the clinoid (C5) (8%) or cavernous (C4) (2%) segment.⁶ Origin of the ophthalmic artery proximal to the DDR may be associated with a separate ophthalmic canal through the optic strut⁸ or with the entry of the ophthalmic artery into the orbit via the superior orbital fissure.

MATERIALS AND METHODS

Measurements in Cadaveric Specimens

Ten specimens obtained from five formalin-fixed human cadaveric heads were dissected to investigate the region surrounding the DDR. In each specimen, the arterial and venous systems were injected under pressure with colored silicone rubber (Dow Corning, Midland, MI) through the ICA, vertebral arteries, and internal jugular veins.¹² A bifrontal craniotomy and bifrontal lobectomy were performed to expose the optic nerve and chiasm, ophthalmic (C6) segment of the ICA, and ACP. Microanatomic dissections were performed with magnification ($\times 3$ to $\times 40$) using a Contraves Zeiss microscope (Carl Zeiss, Oberkochen, Germany).

The DDR, optic nerve at the level of the optic foramen, and tuberculum sellae were marked for radiographic identification using 22-gauge surgical steel wire (Fig. 1). Plain digital radiographs, including a true planum view (Fig. 2A) and a true lateral view (2B), were obtained using a biplanar angiographic C-arm; the latter was obtained by observing the anteroposterior (AP) fluoroscopic image as the tube rotated through the craniocaudal angulations. The angle at which the planum sphenoidale was most tangential, as manifested by maximal radiodensity, was chosen as the best planum view. We determined the interrelationships of the tuberculum sellae, DDR, and optic nerve, as well as the inclination of the DDR against the horizontal plane of the planum sphenoidale on AP views.

Figure 1 Photograph of cadaveric specimen shows the superior aspect of the parasellar region. The proximal aspects of both intracranial internal carotid arteries (ICA) are marked with 22-gauge surgical steel wires. The ophthalmic artery (OA) arises immediately distal to the distal dural ring. The tuberculum sellae (TS) is marked by a 10-mm straight segment of surgical wire. (Printed with permission from the Mayfield Clinic.)

Measurements in Dry Skulls

Bony relationships in 50 dry skulls were measured to determine (a) the vertical distance between the plane of the planum sphenoidale and the superomedial aspect of the optic strut; (b) the distance between the superomedial aspects of the right and

left optic struts, which we termed the interoptic strut (IOS) distance; and (c) the linear distance from the posterior limit of the chiasmatic sulcus or tuberculum sellae to the posterior boundary of the planum sphenoidale (i.e., limbus sphenoidale) (Fig. 3). The angle of inclination of the DDR (marked by steel wires on the cadaveric heads) was measured on AP angiographic images against the horizontal plane of the planum sphenoidale.

RESULTS: ANATOMIC AND RADIOGRAPHIC CONSIDERATIONS ON THE DDR

The only bony landmark consistently visible on both the AP and lateral radiographs was the planum sphenoidale. Looking at the cadaveric dissections and skulls, the inferior root of the ACP (i.e., optic strut) clearly separates the DDR and optic nerve. Thus, the superior or dorsolateral boundary of the DDR corresponds to the superomedial aspect of the optic strut. Following the tuberculum sellae laterally, the superomedial aspect of the optic strut is reached, that is, the floor of the optic canal. In contrast, the plane of the planum sphenoidale corresponds laterally to the roof of the optic canal.

Figure 2 Radiographic images of a cadaveric head. (A) Planum anteroposterior view shows the planum sphenoidale (PS) and tuberculum sellae (TS). The optic foramen (OF) is outlined, and a metal marker (semicircle) identifies the distal dural ring (DDR). The region between the optic foramen and the DDR is the optic strut (OS). (B) Lateral view shows the PS and optic canal (OC). The small line above the metal marker on the DDR identifies the TS. (Printed with permission from the Mayfield Clinic.)

Figure 3 Photograph of the sellar region with schematic illustration of measurements made on dry skulls shows the vertical distance (a) between the planum sphenoidale and medial aspect of the optic strut (OS); the interstrut distance (b); the linear distance (c) between the limbus sphenoidale (LS) and tuberculum sellae (TS). ACP, anterior clinoid process; DS, dorsum sellae. (Printed with permission from the Mayfield Clinic.)

Therefore, a horizontal line drawn from the tuberculum sellae laterally reaches the superolateral border of the DDR (Fig. 4).

The radiographs show that the DDR was inclined along the lateromedial plane on AP view and along an anteroposterior plane on lateral views. The DDR did not extend above the tuberculum sellae in any specimen but lay in the same plane or just below it (Figs. 2A, B).

The mean vertical distance between the planum sphenoidale and superomedial aspect of the optic strut (a) was 5.0 mm (SD, 0.4 mm). The mean interoptic strut distance (b) was 14.4 mm (SD, 1.4 mm). The linear distance between the posterior aspect of the planum sphenoidale (limbus sphenoidale) and the tuberculum sellae (c) was

Figure 4 Oblique view of a skull that has been cut sagittally. The bottom line was drawn from the tuberculum sellae laterally to the superomedial aspect of the optic strut where the superolateral border of the distal dural ring is attached. The top line was drawn from the planum sphenoidale laterally to the roof of the optic canal. The distance between these lines indicates the linear distance between the limbus sphenoidale and the tuberculum sellae. (Printed with permission from the Mayfield Clinic.)

6.0 mm (SD, 0.5 mm). The mean angle of the DDR relative to the planum sphenoidale was 30 degrees (range, 10 to 45 degrees).

DISCUSSION

The superomedial aspect of the optic strut forms the superior or dorsal and lateral border of the DDR and can be measured. On this basis, we predicted the superior extent of the DDR on planum angiographic images, with the planum sphenoidale the first visible landmark on imaging without subtraction. The DDR never extended above the tuberculum sellae, but lay on the same plane or just below it (Figs. 2A, B). Furthermore, knowledge of the interoptic distance enabled determination of the lateral extent of the DDR. For example, a mean interoptic strut distance of 10 mm would indicate that the lateral and superior (dorsal) extent of the DDR lay 5 mm lateral to the midline (along the horizontal line drawn after determining (a). The mean inclination (30 degrees) of the DDR on

Figure 5 Angiographic application of this method in a clinical case. Two horizontal lines represent the plane of the planum sphenoidale above (solid line) and the superomedial aspect of the optic strut/tuberculum sellae below (dashed line). The vertical line represents the midline. Once the interoptic strut distance, the mean inclination of the ring, and the diameter of the internal carotid artery are known, the shape of the distal dural ring (DDR) can be drawn. This aneurysm is located immediately below the tuberculum sellae, medial to the DDR. Therefore, by this analysis, it is a carotid cave aneurysm located intradurally. (Printed with permission from the Mayfield Clinic.)

AP angiographic images (from lateral to medial) allows its position to be estimated down to its medial and inferior border. Thus, the theoretical shape of the DDR can be drawn on AP views using these parameters and the specific diameter of the ICA, which corresponds to one of the DDRs (Fig. 5). Finally, the distance between the limbus sphenoidale and tuberculum sellae (c, Fig. 3) allows determination of the location of the tuberculum sellae from the most posterior aspect of the planum sphenoidale on a true lateral view. Therefore, a more accurate location of the superior border of the DDR can be obtained.

Using this method, we estimated the position of the DDR on angiography and in most cases determined whether the aneurysm was located in-

tradurally or extradurally. Lesions located at the level or above the horizontal line corresponding to the tuberculum sellae are intradural. Lesions below the tuberculum sellae and lateral to the DDR along the ICA are extradural. Carotid cave aneurysms, which are either intradural or intra- and extradural, can be differentiated because they are located immediately below the tuberculum sellae and are medial to the DDR along the ICA (Fig. 5).

This method allowed determination of the position of the DDR and its relationship to the C5 and C6 segments of the ICA. Specific anatomical landmarks on cadaveric specimens and radiographic studies were identified for locating the DDR. The DDR was always below the plane of the tuberculum sellae, which allowed the intra- or extradural location of the aneurysms to be identified. Carotid cave aneurysms could also be defined with this method on AP angiographic views when at the level of the DDR, medial to it, and immediately below the horizontal plane of the tuberculum sellae.

This method has two limitations. First, the steps performed to define the DDR on AP angiographic views were based on average values applied to a specific case; therefore, such averages may not reflect the actual distances in a particular patient. Second, some aneurysms in this region (particularly carotid cave aneurysms) arose intradurally or extradurally but expanded into the adjacent region, ultimately occupying both spaces. Furthermore, complex or giant aneurysms can distort the anatomical features by eroding normal osseous structures and violating traditional anatomical boundaries.

Determining whether the location of the aneurysm is proximal or distal to the DDR (extradural or intradural, respectively) before surgery is critical to develop a successful treatment strategy and to obtain a good patient outcome. The presence and importance of the DDR and its relationship to the C4, C5, and C6 segments of the ICA have captured the interest of clinicians for centuries, including Thomas Willis¹³ in 1681 (Fig. 6). Although ICA aneurysms near the DDR are often detected much earlier since the advent of angiography, CT, and MRI, their location relative to the DDR cannot

Figure 6 Willis (1681) writes, "The Artery being slid out of the bony chanel, lays aside also its ascititious or additional Coat; and now being well enough defended within the Skull, goes forward clothed only with its proper Coat, and creeps under the Dura Mater, and being as it were depressed in the midst of its passage into a valley, being immediately carried out again, it goes on till it comes to the head of the Turkey Chair; where again being bent in and intorted, with a certain compass, it ascends straight, and boring through the Dura Mater, is carried towards the Brain." We interpret "boring through the dura mater" as the ICA passing from the extradural to the intradural space at the level of the DDR. Willis adds, "Shows the ascent of the Carotidick Artery, and in its situation with an humane Skull, before it is carried toward the Brain. (A) The trunk of the Artery ascending toward the Skull. (B) The same, while it is included in the bony Chanel, being clothed with an additional Coat. (C) The incurvature or bending of the Artery, reaching within the bosom of the Skull representing the bending of the double S. (D) The trunk of the same being carried toward the Brain." (Reprinted from *The Anatomy of the Brain* by Thomas Willis, 1681 edition. Reprinted with original illustrations by Sir Christopher Wren.¹³)

always be predicted and whether they are intradural, extradural, or both cannot always be determined.

A number of anatomical-radiological landmarks have been proposed to distinguish whether an aneurysm is intra- or extradural. Punt² proposed that the level of origin of the ophthalmic artery serves as a practical landmark to identify where the ICA becomes intradural and the position of the DDR on angiograms. Although reporting that the origin of this artery was extradural in 11% of the cases, he stated that aneurysms originating more than 1 mm proximal to the origin of the ophthalmic artery could be considered extradural. As Linskey et al¹⁴ stated in their analysis of aneurysms of the cavernous ICA, the variable origin of the ophthalmic artery, which may arise proximal to the DDR, precludes the reliability of this rule. In fact, when the origin of the ophthalmic artery is more distal than its common location, Punt's criterion can lead to the false conclusion that the lesion is extradural. In contrast, if this vessel originates more proximally than its typical location, an extradural lesion can be erroneously interpreted as intradural.

Taptas³ proposed that the base of the ACP on lateral angiographs was a reliable marker to

determine whether the ICA was located intradurally or extradurally. However, the size and shape of the ACP can vary conspicuously. Consequently, this rule occasionally fails because carotid cave aneurysms, which are commonly intradural, can be observed below the level of the ACP.

More recently, Oikawa and associates⁴ observed that the orientation of the DDR inclines toward the posteromedial direction so that the most distal (superior) point of the ring corresponds to its anterolateral side. Its boundary is considered to be the superior border of the ACP and the most proximal (inferior) point of the DDR is its posteromedial edge, which corresponds to the tuberculum sellae on lateral angiographs. Concurring with the microanatomical study of the carotid cave reported by Hitotsumatsu and colleagues,¹¹ Oikawa and group concluded that the DDR is always at or above the level of the tuberculum sellae and that a carotid cave aneurysm (although intradural) may originate below the level of the tuberculum sellae. Therefore, an aneurysm originating below this plane can cause subarachnoid hemorrhage. For this reason, this landmark cannot reliably be used to differentiate carotid cave aneurysms from extradural intracavernous aneurysms.

To solve this dilemma, Gonzales and associates¹⁵ emphasized that the proximal dural ring, which defines the roof of the cavernous sinus and the distal extension of the cavernous ICA, arises from the inferior surface of the optic strut. This bony structure is a reliable landmark for identification of the level of the proximal dural ring. It can be readily identified on CT angiography, which demonstrates both the aneurysm and the optic strut. The inferior aspect of the optic strut allows aneurysms proximal to the proximal dural ring (i.e., intracavernous) to be differentiated from lesions distal to the proximal dural ring and optic strut (i.e., either clinoid or intradural). Carotid cave aneurysms, which are distal and medial to the optic strut, can be more easily characterized by this landmark. Based on all these criteria, the aneurysm can only be determined to be intracavernous or extracavernous; whether it is intra- or extradural cannot be determined.

New techniques have been proposed to identify the location of the DDR and aneurysm. Murayama et al¹⁶ examined the paraclinoid segment of the ICA by shaded-surface reconstruction on targeted 3D-CT angiography. A concavity on the ICA between the levels of the tuberculum sellae and the ACP coincided with the level of attachment of the DDR. According to these authors, the concavity may be the effect of either the DDR squeezing the ICA or the altered pulsation of the ICA near the DDR. However, concavities on the wall of the ICA also can be caused by calcifications, atherosclerotic plaques, movement artifacts, insufficient density of the contrast medium, and influence of the venous sinus.

White and associates¹⁷ observed the angiographic appearance of a waist or indentation on the aneurysm dome when the lesion protruded into the subarachnoid space through the dural margin from the extradural compartment. This observation may help distinguish pure intracavernous lesions from lesions that are both intra- and extradural.

In 1997, Nagasawa et al¹⁸ proposed the use of the source axial MR angiographic images as an adjunct to locate the aneurysm. More recently, the

3D-CMECT cisternography has been used for the preoperative evaluation of paraclinoid ICA aneurysms. By selective enhancement of intradural lesions, it enables confirmation of their intra- or extradural location.⁵ However, this technique can be time-consuming and can only be performed in select cases (i.e., patients with unruptured cerebral aneurysms when a lumbar puncture is contraindicated). Therefore, neither the proposed radiological landmarks nor the most advanced imaging techniques seem to offer a reliable and reproducible landmark to distinguish between intra- and extradural aneurysms.^{19,20}

CONCLUSIONS

We present the clinical application of a simple, reproducible method to estimate the position of the DDR on angiographic images and its relationship to aneurysms of this region. The DDR is always below the plane of the tuberculum sellae, which corresponds to the superomedial margin of the optic strut. Aneurysms above or below this plane are considered intra- or extradural, respectively. Carotid cave lesions are usually located immediately below the plane of the tuberculum sellae but can still be intradural. Their location medial to the DDR allows aneurysms below the tuberculum sellae and lateral to the DDR to be differentiated from aneurysms that are extradural. As the anatomical features of the DDR are better understood, carotid cave aneurysms,^{4,10,21,22} ventral paraclinoid aneurysms,^{23,24} and transitional aneurysms^{25,26} must be reanalyzed. It must be considered that some lesions in this region are complex and arise intradurally or extradurally but ultimately occupy both compartments. Consequently, it is difficult to evaluate their origin and location preoperatively. As Alleyne et al²⁷ stated: "it may be impossible to predict the exact site of the origin of some aneurysms arising in this region because of their size and complexity of the dural, bony and arterial relationships of the region."

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Commentary

The study of the proximal distal dural ring has been of interest to skull base surgeons for many years. Numerous reports attempt to characterize these structures and to relate them to the surrounding anatomy. The evolution of skull base surgery, which includes less invasive techniques to treat aneurysms or radiosurgery for skull base tumors, applies even greater pressure for skull base surgeons to minimize the complications associated with surgery. This outstanding anatomical study by Beretta and coworkers helps skull base surgeons to fulfill this challenging obligation.

We use computed tomographic (CT) angiography to identify whether an aneurysm is located

intradurally or extradurally. Of course, the traditional method for discriminating between an intra- or extradural aneurysm is to use the ophthalmic artery and anterior clinoid process as landmarks. However, the origin of the ophthalmic artery varies considerably so this vessel is an unreliable indicator. In our experience, the anterior clinoid process should not be used to define the location of aneur-

ysms in this region either. Based on anatomic dissections and correlations with CT angiography, we have found that the optic strut, as identified on CT, is a reliable landmark for accurately distinguishing intra- and extradural aneurysms.

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