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Clinical Article

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Determination of Aneurysmal Location with 3 Dimension-Computed Tomographic Angiography in the Microsurgery of Paraclinoid Aneurysms

Objective : Determining the location of paraclinoid aneurysms for microsurgery is important for selecting treatment options, especially when deciding on the release of the dural ring in direct clipping. We examined the reliability of using the optic strut as an anatomical landmark for evaluating the location of paraclinoid aneurysms.
Methods : Cadaveric dissection was performed to establish the relationship of the optic strut to the dural ring. Results from these anatomic studies were compared with the three-demensional computed tomographic angiographic (3D-CTA) findings of nine patients with ten paraclinoid aneurysms between May 2004 and October 2005. These, 3D-CTA results were then compared with intraoperative findings.
Results : The inferior boundary of the optic strut accurately localized the point at the proximal dural ring in cadaveric study. The optic strut and its relationship to the aneurysms was well observed on the multiplanar reformats of 3D-CTA. During microsurgery, nine of ten aneurysms were verified to arise from distal to the upper surface of the optic strut. Two aneurysms that had arisen between the inferior and superior boundary of the optic strut were observed to lie within the carotid cave. One aneurysm which had arisen at the inferior boundary of the optic strut and directed inferiorly was observed to lie within the cavernous sinus just after the release of the proximal ring.
Conclusion : The optic strut, as identified with multiplanar reformats of 3D-CTA, provided a reliable anatomic landmark for the proximal rings and an important information about the location of aneurysms around the anterior clinoid process (ACP). Therefore, 3D-CTA and the optic strut could become an invaluable tool and a landmark in the assessment of the location of paraclinoid aneurysms for microsurgery.

KEY WORDS : Optic strut · Dural ring · Three-dimensional computed tomographic angiography · Paraclinoid aneurysms.

INTRODUCTION

Paraclinoid internal carotid artery (ICA) aneurysms, of which the earliest report on carotidophthalmic aneurysms as a distinct entity was described in 1968 by Drake et al.[3], arise in the cavernous, clinoid, and ophthalmic segments of the ICA and were defined by Bouthillier et al.[2] as the C4, C5, and C6 segments, respectively. The complex anatomy of the paraclinoid internal carotid artery makes the microsurgical treatment of aneurysms arising from this segment difficult[17].

Determining the location of paraclinoid aneurysms for microsurgery is important for selecting treatment options. In direct clipping of paraclinoid aneurysms, it is important to clarify the relationship between the dural ring and aneurysm when deciding about the release of the dural ring. However, the exact topographic anatomy around aneurysm can be difficult to define using traditional landmarks such as conventional angiography or magnetic resonance angiography[7,11].

With digital subtraction angiogram (DSA), which is still considered the gold standard for evaluating intracranial aneurysms, the landmarks traditionally used to evaluate proximal intracranial ICA aneurysms are the origin of the ophthalmic artery and the anterior clinoid process (ACP)[14]. However, the origin of the ophthalmic artery varies considerably[4]. The ACP has been proposed as a landmark for extradural aneurysms located inferior to this bony process[12,14]. However, it can provide only estimates of the locations of these aneurysms because of the variability in the size and shape of the ACP. On the basis of our experience, we think

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Table 1. Summary of clinical findings of nine patients with paraclinoid aneurysms*

No.	Age(yr)/sex	Symptoms	3D-CTA	DSA	No. of An	Intraoperative findings
1	63/M	SAH	Distal to optic strut	Ophthalmic segment An	1	Ophthalmic segment An was clipped
2	49/F	Headache	Distal to optic strut	Ophthalmic segment An	1	Ophthalmic segment An was clipped
3	61/F	Headache	Distal to optic strut	Ophthalmic segment An	1	Ophthalmic segment An was clipped
4	40/F	Headache	Distal to optic strut	Ophthalmic segment An	1	Ophthalmic segment An was clipped
5	61/F	SAH	Distal to optic strut	Rt. SCA and both ophthalmic segment Ans	3	Rt. SCA and both ophthalmic segment An were clipped
6	48/F	SAH	Inferior and superior boundary of optic strut and directs medially	Lt. MCA bifurand carotid cave An	2	Lt. MCA bifur and carotid cave An were clipped
7	58/F	SAH	Most proximal to optic strut; uppermost at inferior boundary of optic strut	Lt. MCA bifurand cavernous sinus An	2	Lt. MCA bifur and cavernous sinus An were clipped after release of proximal ring
8	50/F	SAH	Distal to optic strut	Ophthalmic segment An	1	Ophthalmic segment An was clipped
9	69/F	Chr SDH	Between inferior and superior boundary of optic strut and directs medially	Carotid cave An	1	Carotid cave An was clipped

*DSA : digital subtraction angiography, 3D-CTA : three dimensional computed tomographic angiography, SAH : subarachnoid hemorrhage, MCA : middle cerebral artery, SCA : superior cerebellar artery, An : aneurysm, SDH : subdural hematoma, Lt : left, Rt : right

that the origin of the ophthalmic artery and the ACP should not be used to determinate the location of aneurysms in this region.

Three-dimensional computed tomographic angiography (3D-CTA) is a rapidly evolving, minimally invasive technique that accurately depicts the intracranial vasculature and fully demonstrates the relationship of the vessels to osseous structures[8]. Cadaveric dissections of the transition between the extradural ICA and the intradural ICA showed the relationship of the proximal dural ring, which defines the roof of the cavernous sinus, to the inferior margin of the optic strut[6]. Object of this study was to verify these findings in our cadaveric dissections and to examine the reliability of using the optic strut with high-resolution 3D-CTA as an anatomical landmark for evaluating the location of aneurysms in this critical region.

MATERIALS AND METHODS

Microsurgical specimen

Two adult cadaveric heads (4 sides) were dissected, and the arteries and veins were injected with colored silicone. The specimens were examined by microscope. Bony dissection was performed with a high-speed drill (Midas Rex Institute, Fort Worth, TX). After the proximal intracranial ICA had been exposed, the ACP was removed. The goal of the dissection was to examine the relationship between the ICA transition from extradural to intradural and the surrounding osseous structures. We dissected the paraclinoid region and looked for a pouch with its apex toward the cavernous sinus on the medial aspect of the ICA, so-called "carotid cave" [9], at the level of the distal ring.

Selective patients

Between May 2004 and October 2005, 9 patients with 10 aneurysms of the paraclinoid segment of the ICA were evaluated with 3D-CTA. All patients had at least one aneurysm thought to be intracranial (Table 1) and underwent high-resolution 3D-CTA of the paraclinoid aneurysm with a multi-detector helical scanner (Siemens Medical Systems). The 3D-CTA were obtained at a 2.5-mm slice thickness during a bolus injection of 90 ml of contrast material. Multiplanar reformats were created at 1 mm thickness in the axial, coronal, and sagittal planes. The best axial orientation was selected with an angle parallel to the limbus sphenoidale. The most inferior attachment of the inferior root of the optic strut to the lesser wing of the sphenoid bone was identified on the coronal multiplanar reformats at 3D-CTA. Two neuroradiologists experienced in interpreting 3D-CTA concurred regarding the attachment of the inferior root of the optic strut to the lesser wing of the sphenoid bone, and thus the position of the proximal dural ring attachment. This position was simultaneously cross-referenced in the sagittal and axial planes by using a digital cross-referencing tool (Fig. 1). Multiplanar reformats images that best profiled the optic strut and its relationship with the aneurysms were selected. The multiplanar reformats at 3D-CTA results were compared with the intraoperative findings of all patients.

RESULTS

Cadaveric dissection

The anterior insertion of the proximal dural ring or carotico-oculomotor membrane, which forms the roof of the cavernous sinus, was located at the inferior aspect of

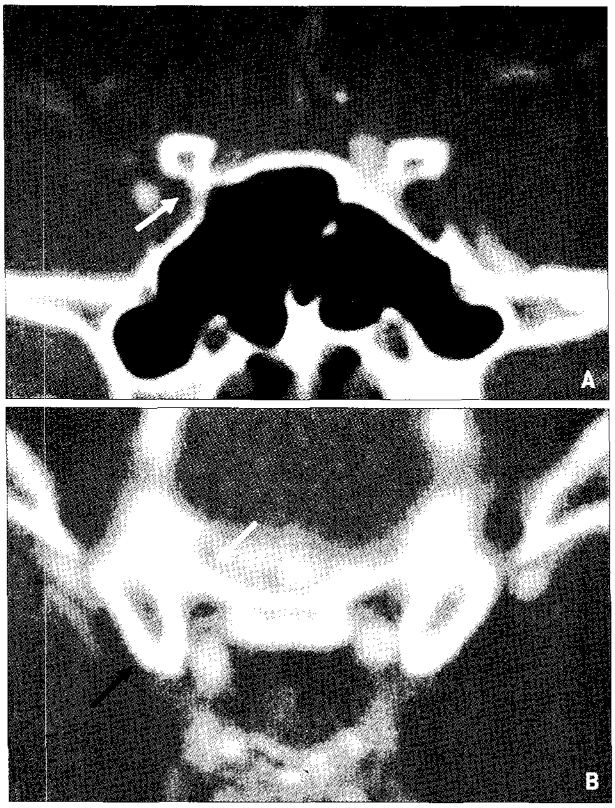


Fig. 1. A : Coronal reconstructed multiplanar reformats of 3 dimension-computed tomographic angiography, showing the optic strut (arrow) and its relationship to the internal carotid artery. B : Axial reconstructed multiplanar reformats of 3 dimension-computed tomographic angiography, showing the position of the ICA and the relationship of the optic strut (white arrow) and the anterior clinoid process (black arrow).

Fig. 2. Intraoperative view of the right pterional extradural transcavernous approach in a cadaveric head. The anterior clinoid process has been drilled, exposing the clinoid segment of the internal carotid artery between the proximal (double asterions) and distal rings (an asterion). It should be noted that the clinoid segment is located interdurally. The proximal ring, or carotico-oculomotor membrane, inserts at the inferior aspect of the optic strut (arrow). The cavernous segment is located proximal to the proximal dural ring. The distal dural ring, or diaphragma sella, marks the transition between the clinoid and ophthalmic segments of the internal carotid artery.

the optic strut (Fig. 2)[5]. The proximal and distal dural rings marks between the cavernous, clinoid and intradural segments of the ICA.

Clinical outcomes

During the study period, eight female and one male patients (age range 40-69 years) with ten paraclinoid aneurysms were treated. Pre- and postoperative imaging data were available for analysis in all patients. Preoperative 3D-CTA was performed in all patients.

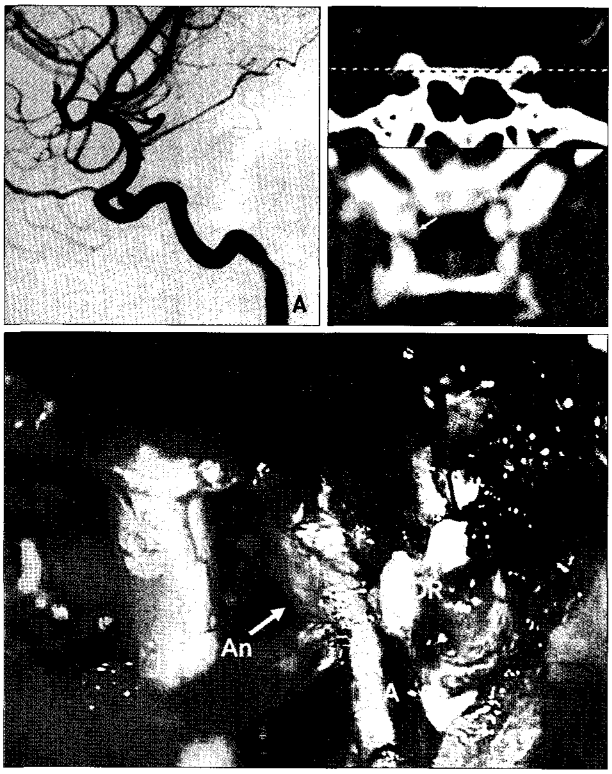
Three aneurysms were considered ophthalmic and four superior hypophyseal. They were observed to be distal to the optic strut on the multiplanar reformats of 3D-CTA and were observed in the ophthalmic segment of the ICA during microsurgery. They were clipped well after partial adequate manipulation of the distal ring. Preoperative 3D-CTA demonstrated two aneurysms between the inferior and superior boundary of the optic strut that were intraoperatively observed within the carotid cave, corresponding to "carotid cave aneurysm" by Kobayashi et al.[9], and could be clipped successfully after complete release of the distal ring and mobilization of the ICA. In one case, preoperative 3D-CTA demonstrated that most of the aneurysm was proximal to the optic strut; a uppermost neck portion of the lesion was at the inferior boundary of the optic strut. This lesion was not observed during surgery even after the ACP had been drilled and the distal ring opened. It was observed to be emerging from the cavernous sinus just after the release of proximal ring during microsurgery.

Postoperative angiography demonstrated complete obliteration of the aneurysms in all patients. There was transient oculomotor nerve palsy only in three patients and no postoperative serious complications or death.

Illustrative cases

Case 1

A 40-year-old woman presented with a serious headache. DSA demonstrated an unruptured right paraclinoid aneurysm (Fig. 3A). Because she was relatively young and wanted an microsurgical treatment, we decided on the microsurgical option. A right pterional craniotomy with extradural untethering was performed. The distal dural ring was opened partially and a part of the medial aspect of the ICA was explored. An inferiomedial directed aneurysm was observed to be arising at the level of the distal ring, so a right-angled fenestrating clip was placed successfully in the distal-to-proximal direction without complete release of the distal ring. Preoperative multiplanar reformats of 3D-CTA demonstrated that most of the aneurysm was observed to be distal to the optic strut and in the ophthalmic segment of the ICA : the lower margin of the aneurysm arose at the superior aspect



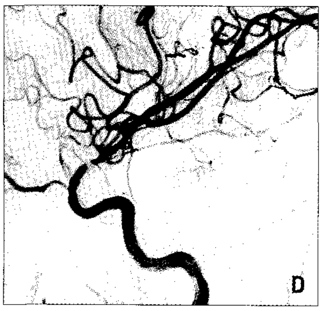
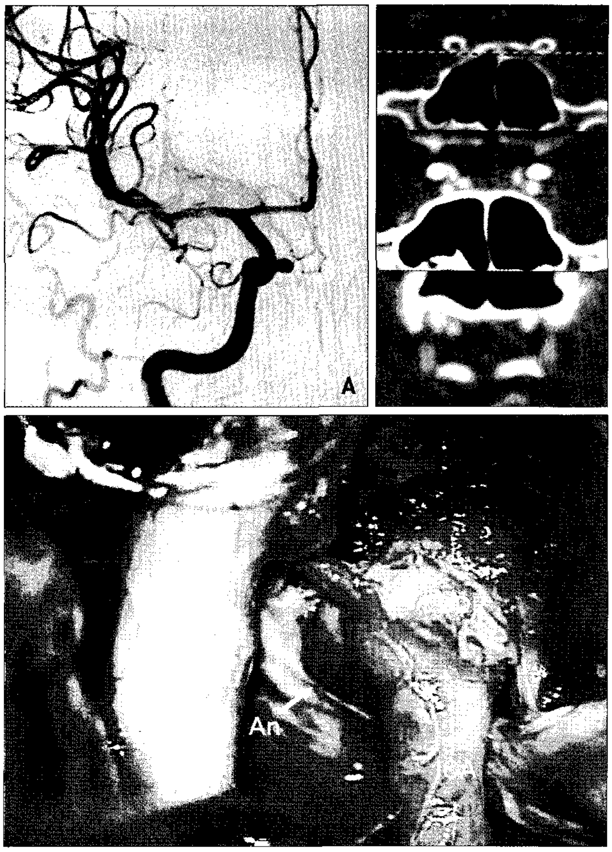


Fig. 3. A : Right lateral digital subtraction angiogram scan, showing an ophthalmic segment aneurysm. B : Multiplanar reformats at 3 dimension-computed tomographic angiographic reconstructions in axial planes, are simultaneously cross-referenced in the coronal planes by a digital cross-referencing tool. The cross-referenced coronal plane is at level of the superior aspect of the optic strut. The lower margin of the ophthalmic segment aneurysm (arrow) can be observed. C : Intraoperative findings of the right pterional extradural transcavernous approach. The distal dural ring (DDR) has been opened partially and a part of the medial aspect of the internal carotid artery (ICA) has been explored. Then, an inferiomedial directed aneurysm (An) is observed to be arising at the level of the distal ring. A right-angled fenestrating clip is placed in the distal-to-proximal direction successfully with a partial release of the distal ring. D : Postoperative lateral digital subtraction angiogram scan confirming complete obliteration of the ophthalmic segment aneurysm.

of the optic strut. On the basis of the preoperative imaging studies and the intraoperative evaluation, it was thought to be in the ophthalmic segment of the ICA. Postoperative DSA confirmed complete occlusion of the aneurysm (Fig. 3B, C, D).

Case 2

A 48-year-old woman presented with a SAH. Preoperative DSA demonstrated a ruptured left MCA bifurcation aneurysm and an unruptured right paraclinoid aneurysm (Fig. 4A). The endovascular interventionist hesitated to coil because of the broad-neck hence, an unruptured right paraclinoid aneurysm operation was planned. A right transcavernous approach was



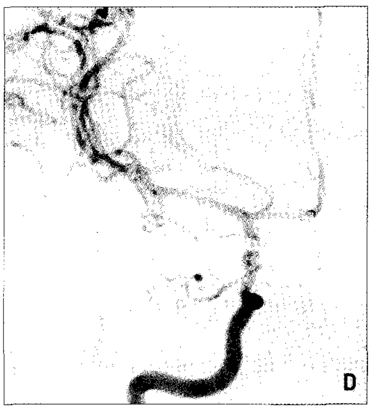


Fig. 4. A : Right anterior-posterior, right lateral digital subtraction angiogram scan, showing an ophthalmic segment aneurysm. B : Multiplanar reformats at 3 dimension-computed tomographic angiographic reconstructions in axial and coronal planes, There are simultaneously cross-referenced in the coronal planes by a digital cross-referencing tool. The cross-referenced coronal planes are between the inferior and superior boundary of the optic strut. The medial-directed ophthalmic segment, or carotid cave aneurysm can be observed. C : Intraoperative findings of the right pterional extradural transcavernous approach. The distal dural ring (DDR) has been opened completely and the internal carotid artery (ICA) has been mobilized freely. Then, the inferior and medial-directed aneurysm (An) is observed to be in the carotid cave. A right-angled fenestrating clip is applied parallel to the internal carotid artery and placed in the distal-to-proximal direction. D : Postoperative right anteriorposterior digital subtraction angiogram scan confirming complete obliteration of the carotid cave aneurysm.

performed, and the ACP was removed with a high speed drill extradurally. The distal dural ring was opened completely and the ICA was mobilized freely. The medial aspect of the ICA was explored and the inferior and medial-directed aneurysm was observed to be in the small "pouch" of subarachnoid space, termed the "carotid cave" by Kobayashi et al.[9]. A

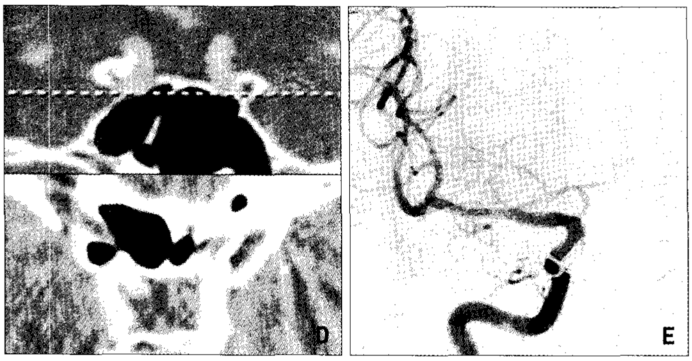


Fig. 5. A : Right anteriorposterior digital subtraction angiogram scan showing cavernous sinus aneurysm. B : Intraoperative findings of the right pterional extradural transcavernous approach. After the proximal and distal dural ring has been opened completely, the aneurysm (An) is observed to be arising at the level of the ring and lying within the cavernous sinus. C : A right-angled fenestrating clip us applied parallel to the internal carotid artery and placed in the proximal-to-distal direction because of the sphenoid bone interfering with the distal-to-proximal advancement of the clip. D : Multiplanar reformats at 3 dimension-computed tomographic angiographic reconstructions in axial planes. There are simultaneously cross-referenced in the coronal planes by a digital cross-referencing tool. The cross-referenced coronal plane is at the inferior boundary of the optic strut. The uppermost portion of the cavernous sinus aneurysm can be observed. Most of the aneurysm is proximal to the optic strut. E : Postoperative right anteriorposterior digital subtraction angiogram scan confirming complete obliteration of the cavernous sinus aneurysm.

right-angled fenestrating clip was applied parallel to the ICA and placed in the distal-to-proximal direction. Preoperative multiplanar reformats of 3D-CTA demonstrated that the origin of aneurysm seemed to arise between the inferior and superior boundary of the optic strut and directed medially. On the basis of the preoperative imaging studies and the intraoperative evaluation, it was thought to be a "carotid cave aneurysm". Postoperative DSA confirmed complete occlusion of the aneurysm (Fig. 4B, C, D).

Case 3

A 58-year-old woman presented with a SAH. Preoperative DSA demonstrated a ruptured left MCA bifurcation aneurysm and an unruptured right paraclinoid aneurysm (Fig. 5A). For the unruptured right paraclinoid aneurysm, we planned to operate because the location of aneurysm would not be within the cavernous sinus but in the subarachnoid space. A right transcavernous approach was performed. The distal dural ring was opened completely, and the medial aspect of the ICA was explored. However, the aneurysm could not be observed and was thought to arise below the level of the proximal dural ring. Just after complete release of the proximal ring, it was observed to be originated at the level of the proximal ring and lying within the cavernous sinus. A right-angled fenestrating clip was applied parallel to the ICA and placed in the proximal-to-distal direction because the sphenoid bone interfered with the distal-to-proximal advancement of the clip (Fig. 5B, C). Postoperative DSA confirmed complete occlusion of the aneurysm (Fig. 5D, E). However, retrospective review on, preoperative multiplanar reformats of 3D-CTA demonstrated that most of the aneurysm was proximal to the optic strut : a uppermost portion of the lesion was at the inferior boundary of the optic strut and it was thought to be within the cavernous sinus. Therefore, it was considered to be a cavernous sinus aneurysm and not an indication for surgery.

DISCUSSION

The key features of the successful microsurgical treatment of paraclinoid ICA aneurysms include establishing control of the proximal artery, adequate exposure of the aneurysm neck, aneurysm decompression in large aneurysms and successful obliteration of the aneurysm with minimal manipulation of the optic nerve[1]. Determining the aneurysmal location in the microsurgery of paraclinoid aneurysms is critical when considering microsurgical treatment options, especially deciding on the release of the dural ring in direct clipping. However, a precise evaluation of the paraclinoid aneurysmal location relative to the dural ring can be difficult because assessment is complicated by the lack of reliable imaging landmarks.

Conventional imaging landmarks used to evaluate paraclinoid aneurysms include the origin of the ophthalmic artery[16] and the ACP[17]. However, the origin of the ophthalmic artery is quite variable as Rhoton et al.[4] reported that the origin of the ophthalmic artery was within the cavernous sinus in 8%

of their specimens, was intradural in 89%, and was absent in 3%. The ophthalmic artery typically originates from the dorsal surface of the ICA, immediately adjacent to the distal dural ring. When the ophthalmic artery arises more distally or more proximally than usual, use of its origin as a marker for a distal dural ring could lead to the false conclusion of the relationship between the aneurysm and distal ring. The ACP has been used as an osseous landmark to distinguish between paraclinoid aneurysms and those of the cavernous sinus[17]. However, the ACP is a relatively large structure that cannot be clearly observed with conventional imaging such as DSA. Projection artifacts and the variability of the orientation add to the difficulty of determining locations of aneurysms on the basis of this structure. Moreover, carotid cave aneurysms are located around the distal rings intradurally (subarachnoid) but project at or inferior to the ACP on lateral angiographic projections. In an attempt to clarify this issue, Oikawa et al.[13] studied the relationships between the distal dural ring and adjacent bony structures in cadavers. They observed that the distal ring was located at the same level as the tuberculum sellae, and they emphasized that carotid cave aneurysms were inferior to this plane. They did not differentiate between carotid cave and cavernous aneurysms when the ACP was used as an osseous landmark, because both are located inferior to the tuberculum sella. Consequently, this landmark is unreliable for these lesions.

Occasionally, after the ACP has been drilled and the distal ring opened completely, the microsurgical procedure may become disoriented, because no aneurysm can be identified (illustrative case 3). This situation can be avoided with adequate preoperative imaging techniques that can establish the locations of certain aneurysms. Anatomically, the transition of the ICA from the extradural cavernous segment to the intradural clinoid segment is demarcated by the proximal dural ring, which surrounds the ICA as it exits the cavernous sinus. This dural ring is not visible with conventional imaging techniques, including CT scanning, magnetic resonance imaging, and angiography. It has been proposed that, on surface-shaded, reconstructed, 3D-CTA images, the distal dural ring can be identified as an indentation on the ICA wall[10]. However, indentations on the ICA wall can be related to atheromas or calcifications on the wall, that may interfere with an interpretation[6]. The proximal dural ring is continuous with the oculomotor membrane which forms the roof of the cavernous sinus. We confirmed in the laboratory that the oculomotor membrane arises from the inferior surface of the optic strut and is thus a reliable landmark for identification of the level of the proximal dural ring. The optic strut can be readily identified on CT scans, while 3D-CTA demonstrates both the aneurysm and the optic strut. Because the optic strut is small (35 mm) and obliquely oriented, multiplanar reformats may be helpful for observation. Window level magnification and cross-referencing tools are invaluable. The window and level of the CT images should be modified to maximize the ability to distinguish bone from intravascular contrast material and images should be magnified to facilitate identification of the optic strut. Anatomic concepts used in previous studies were evaluated in this comparison. In 1998, Seoane et al.[15], reported that the proximal dural ring or the roof of the cavernous sinus, arises from the inferior surface of the optic strut. In 2003 Gonzalez and Walker[6], described that if an ICA aneurysm arises proximal to the optic strut, then it is located in the cavernous sinus and if an ICA aneurysm originates distal to the optic strut, then it is located in the subarachnoidspace or within the clinoid segment.

However, determination of the precise location of aneurysms in the paraclinoid region remains unresolved[12]. In our study, we compared the multiplanar reformats of 3D-CTA results with intraoperative findings and presumed the precise location of aneurysms in the paraclinoid region.

If the paraclinoid aneurysm arises proximal to the inferior boundary of the optic strut on 3D-CTA, then can be considered to be located in the cavernous sinus. If the aneurysm is at such a level, the distal dural ring must be opened completely and, in addition, just after the complete release of the proximal ring, it can be observed to lie within the cavernous sinus. If the paraclinoid aneurysm originates distal to the upper surface of the optic strut, then it can be presumed to be located in the ophthlamic segment. In such lesion, the distal dural ring might be opened partially or completely and successful clipping is possible even if the medial aspect of the ICA is explored partially. Moreover, if the paraclinoid aneurysm arises between the inferior and superior boundary of the optic strut and directs medially, the inferior and medial-directed aneurysm is considered to be within the carotid cave. The distal dural ring must be opened completely and the ICA mobilized freely in such a lesion. Carotid cave aneurysms constitute a small but critical group of intradural aneurysms, with a potential for subarachnoid hemorrhage, that are problematic because they project at or inferior to the ACP and can be mischaracterized as extradural cavernous sinus lesions with DSA. Some of these were considered unclippable or were associated with disastrous surgical results[10].

Our early experience with the use of the optic strut as a landmark is shown to be encouraging. However, it has some limitations. Most of all, a precise anatomical landmark for the distal dural ring still remains obscured, although the location in outline can be presumed. Because the dura that extends medially off of the upper surface of the clinoid to line the upper surface of the optic strut and form the distal dural ring which slopes downward, the medial part of the distal dural ring may actually lie at the level of the lower rather than the upper surface of the clinoid[15]. In some situations, the landmark may not be applicable or may be problematic. For example, giant aneurysms can distort the anatomic structures by eroding normal bones. These aneurysms can grow superiorly and violate traditional anatomic boundaries. Pneumatization of the optic strut, which is unusual, also complicates the precise assessment.

CONCLUSION

The precise identification of the aneurysmal location for the microsurgery of paraclinoid aneurysms is critical when considering such treatment option. Conventional imaging landmarks used to evaluate paraclinoid aneurysms include the origin of the ophthalmic artery and the ACP, but they are unreliable. 3D-CTA provides a minimally invasive technique that can accurately demonstrate the relationship of the arterial vasculature to the osseous cranial base. Our anatomic dissections confirmed that the proximal dural ring, which delimits the roof of the cavernous sinus, inserts onto the inferior margin of the optic strut. The optic strut, as identified with multiplanar reformats of 3D-CTA, provides a reliable anatomic landmark for proximal rings and important information about the location of aneurysms around the ACP. Therefore, the optic strut with multiplanar reformats of 3D-CTA could become invaluable tools in the assessment of the location of paraclinoid aneurysms in microsurgery. A prospective analysis is further needed to assess the clinical usefulness of this landmark.

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