Three-Dimensional Imaging as a Teaching Method in Anterior Circulation Aneurysm Surgery

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■ OBJECTIVE: **Our objective is to present and asses the utility of three-dimensional (3D) intraoperative imaging as a teaching method for anterior circulation aneurysm surgery.**

■ METHODS: **The senior author's experience in anterior circulation aneurysm surgery during a 28-month period was documented and processed as 3D images and compared with two-dimensional (2D) images. Both 2D and 3D sets of images were created, and, along with a specially designed questionnaire, 30 physicians (15 experienced cerebrovascular surgeons and 15 neurosurgical trainees) were asked to answer the query and state the advantages and disadvantages of both methods.**

■ RESULTS: **All physicians interviewed agreed that 3D imaging was better than 2D imaging, and that depth perception improved understanding of surgical tactics and anatomical landmarks. The resident/young trainee group seemed to receive more benefit from this than the experienced group. A total of 40% of residents and 20% of the experienced surgeons acknowledged a change in clipping strategy when comparing both sets. 3D imaging improved understanding of the ophthalmic segment in 66.6% of residents and 33.3% of the experienced group.**

■ CONCLUSION: **Real 3D imaging in anterior circulation aneurysm surgery is an excellent tool to enhance vascular training. Inexperienced trainees seem to benefit greatly from it. This technique might be of use in the future development of new technologies.**

Key words
- 3D imaging
- Aneurysm
- Clipping
- Microsurgery
- Surgical anatomy
- Vascular anatomy

Abbreviations and Acronyms
2D: Two-dimensional
3D: Three-dimensional
MCA: Middle cerebral artery

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INTRODUCTION

Knowledge of microsurgical anatomy is an essential tool that neurosurgeons use to enhance results and facilitate procedures, making it safer to navigate the brain and its cisterns. There are numerous publications addressing this topic (3, 13, 14, 18). New techniques for didactic use have widened the transmission of such concepts, especially three-dimensional (3D) or stereoscopic imaging (1, 3, 8, 11, 12, 15-17).

A common disadvantage of previous publications is that laboratory anatomy is not the anatomy usually found during surgery in daily practice. It is missing major factors, such as brain turgescence, edema, bleeding, narrowed spaces limited by delicate tissue, and actual pathology (2, 18). It becomes difficult to extrapolate the so-called laboratory anatomy to the operating room, leaving an inexperienced surgeon with only a general anatomic idea of the surroundings of his or her target or the way of access to it, rather than giving the surgeon a full comprehension of the possible obstacles he or she will find. We have completed >2 years of laboratory work in an effort to improve the whole concept of anatomic training and apply 3D techniques to actual patients. In this article, we address the complex and specific microsurgical anatomy of anterior circulation aneurysm surgery.

The 3D viewing of aneurysm surgery adds a sense of depth and improves understanding of complex structural relations, becoming valuable, unpublished, and original didactic material. The aim of this study is to assess the actual benefit of real 3D imaging applied to real microsurgical anatomy as a superior and effective tool in training neurosurgeons. We compare 2D and 3D images and recognize differences and improvements from one method to another.

METHODS

In the past 66 months, one of the authors (P.A.R) has performed 128 anterior circulation aneurysm surgeries (in some patients with multiple aneurysms). In 65% of the cases, 3D images were obtained of the entire procedure—from patient positioning to wound closure. Macroscopic images were obtained by a Nikkon Reflex camera supplemented with a 2.8-mm, 105-mm microlens, with the aid of a Jaspers sliding bar (Jasper Engineering, Medina, Minneapolis, Minnesota, USA) attached to a Manfrotto tripod (Manfrotto, Cassola, Italy). Each shot consisted of a set of paired images with the same target at the

Table 1. Questionnaire Completed by Physicians

Were 3D images easily viewable?	Yes	No
Did it improve the sense of depth compared with the 2D images?	Yes	No
Did any structure appear different between 2D and 3D images?	Yes	No
Was any 2D structure misinterpreted after viewing it in 3D images?	Yes	No
Did clipping strategy change when comparing both methods?	Yes	No
Did the ICA and optic nerve appear in different depths in 3D images?	Yes	No
Were the ophthalmic segment and neighboring structures (optic nerve, anterior clinoid process) better understood in 3D images?	Yes	No
Did the dissection of the lateral aspect of the sylvian fissure become easier to understand compared with 2D images?	Yes	No
When the sylvian fissure was fully opened and dissected, could you recognize >3 depth levels in 3D images?	Yes	No
Did any vascular structure change its orientation compared with 3D images?	Yes	No
Was the orientation of the different segments of the MCA better understood in 3D images?	Yes	No
Was the orientation of the different segments of the ACA better understood in 3D images?	Yes	No

ICA, internal carotid artery; MCA, middle cerebral artery; ACA, anterior cerebral artery.

same distance with a 15-degree angle incidence. Microscopic images were obtained by applying 2 Nikon Reflex cameras (Nikon, Chiyoda, Tokyo, Japan) each attached to its own image divisor on both sides of the operating microscope. This way, paired images with a 15-degree difference of incidence were obtained. Images were processed with special software, Callipygian 3D (Callipygian freeware, created by Robert A. Swirsky). Data were processed by a 3D program. We created 2 different 3D presentations, one polarized and one using an anaglyphic system. Special 3D glasses are needed to fuse images and obtain the stereoscopic view. 3D images are paired with 2D images to compare both. Although the visual experience contains obvious interpersonal differences, 15 experienced neurosurgeons (with >10 years of experience) and 15 senior residents were given both sets of images and were asked to compare and note advantages and disadvantages. The participants (physicians and senior residents) were selected from 3 different institutions that are validated by the Argentinian Ministry of Health. Interviewed physicians also answered a simple questionnaire (Table 1) to quantify differences. All physicians had access to the entire set of images for each case. However, because of printing and editorial restrictions, only some of the pictures are shown in this article.

Illustrative Cases

The cases presented are illustrative, and it is not the aim of this study to analyze surgical techniques or results. Only 5 representative cases were selected for the participants. Cases are shown so that the reader can appreciate all different steps of aneurysm surgery in 3D images, making this technique a novel tool for learning and communicating with fellow neurosurgery trainees. 2D images are paired to compare both methods.

The senior author uses the pterional approach for most anterior circulation

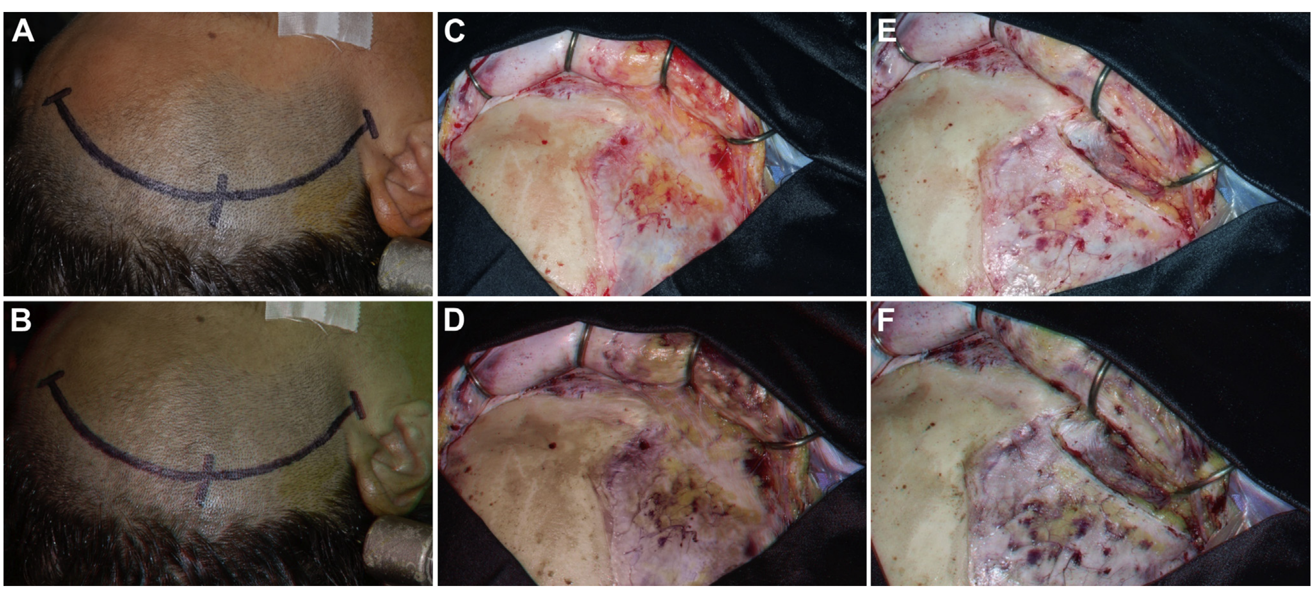

Figure 1. Right pterional approach for anterior communicating aneurysm. (**A**) The position and the incision for the pterional approach can be seen. (**B**) Same picture in 3D. (**C**) The flap includes the skin and the periosteal. The fat tissue between the layers of the temporal fascia can be observed. (**D**) Same picture in 3D. (**E**) Interfascial dissection. The deep layer of the temporal fascia can be seen. (**F**) Same picture in 3D.

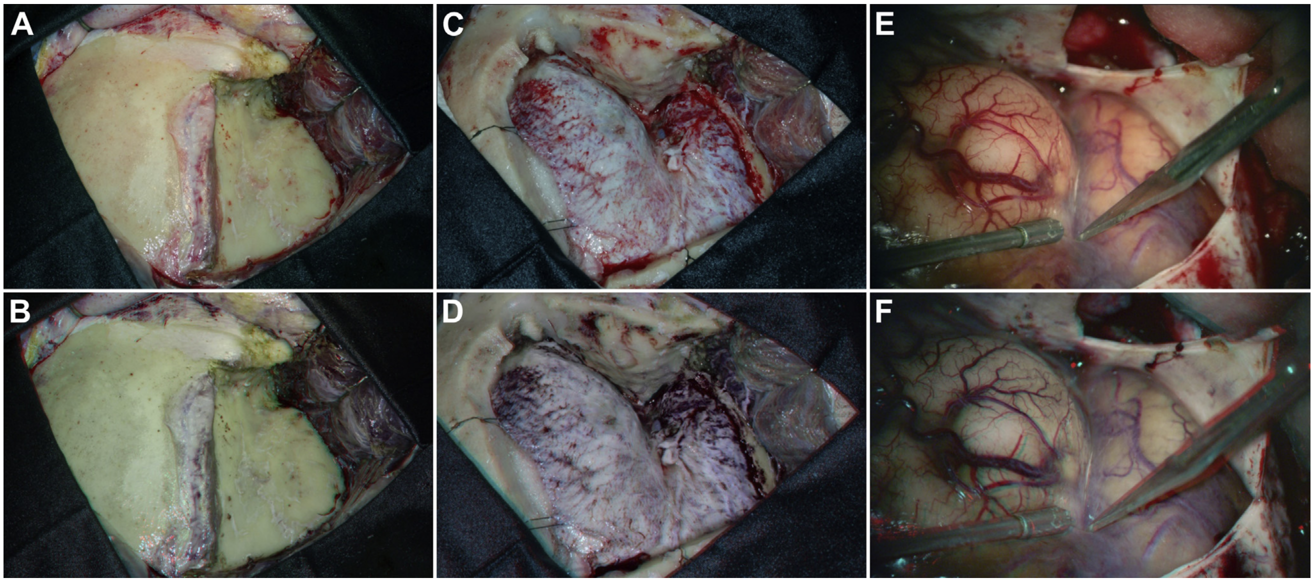

Figure 2. Continuation of the case in Figure 1. (**A**) The temporal muscle was retracted inferiorly; we preserved a cuff to suture the muscle at the end of the surgery. (**B**) Same picture in 3D. (**C**) After completing the craniotomy, we performed drilling of the orbital roof. (**D**) Same picture in 3D. (**E**) Intradural stage. We identified the pars triangularis of the inferior frontal gyrus, the most suitable place to start the dissection of the sylvian fissure. (**F**) Same picture in 3D.

aneurysms with a few exceptions, such as distal pericallosal aneurysms, for which a subfrontal or interhemispheric approach might be a more suitable choice (6, 7, 10). The cases presented illustrate diverse situations that might be found in anterior circulation aneurysms. The first case is an unruptured anterior communicating artery aneurysm with its corresponding approach (Figures 1–4). The second case is a ruptured posterior communicating artery aneurysm

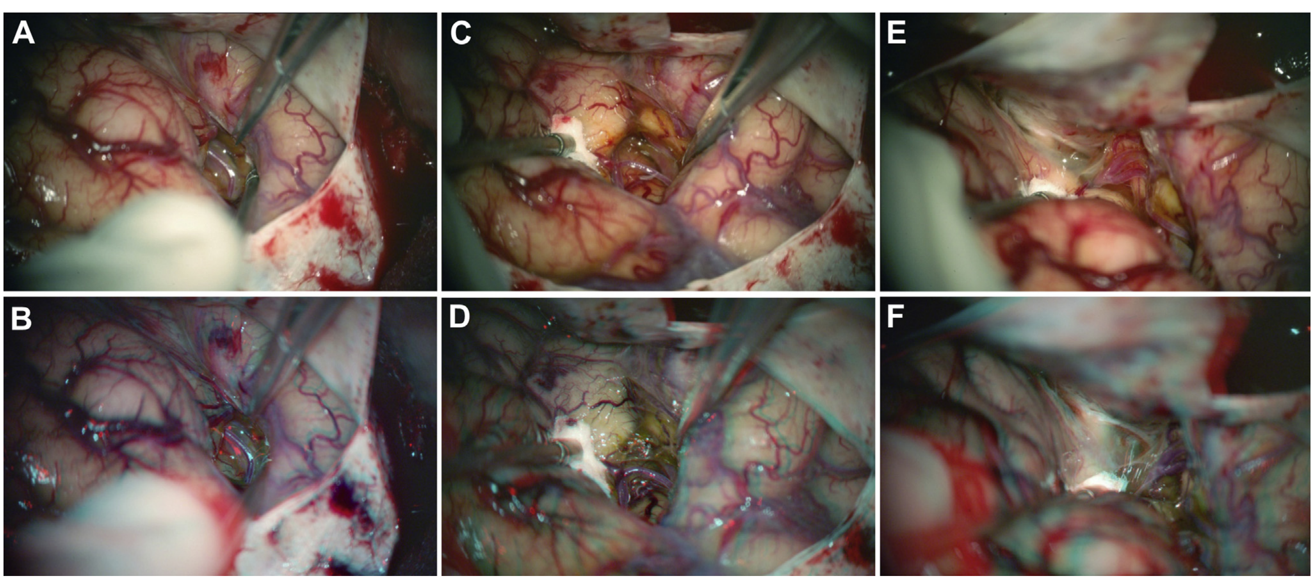

Figure 3. Continuation of the case in Figure 1. (**A**) The opening of the fissure has been completed from the frontal side. (**B**) Same picture in 3D. (**C**) The first collateral branches of the right middle cerebral artery can be seen. (**D**) Same picture in 3D. (**E**) The dissection reaches the limit between carotid and sylvian cisterns. Through the arachnoid membrane, the internal carotid artery and the optic nerve can be observed. (**F**) Same picture in 3D.

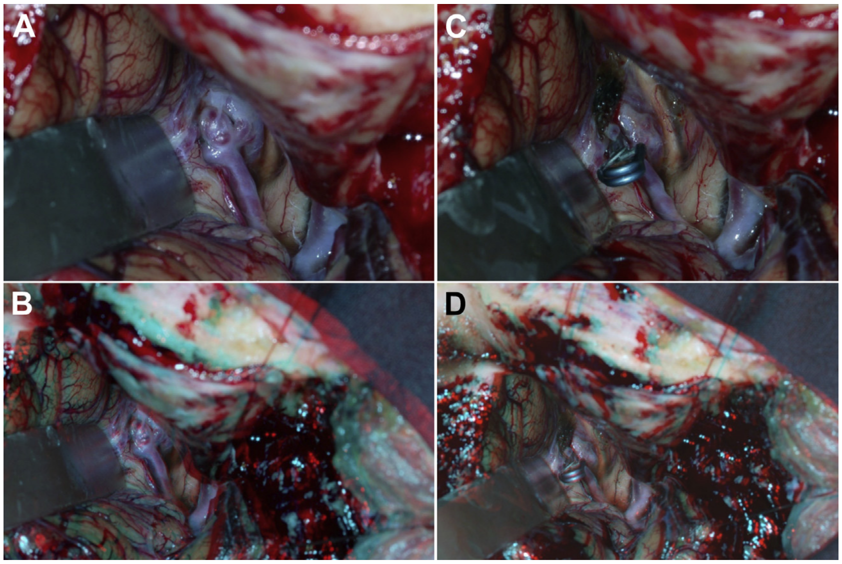

Figure 4. Continuation of the case in Figure 1. (**A**) As can be seen, we have changed the orientation of the microscope. We can now identify the internal carotid artery, the carotid bifurcation, the initial segments of the middle cerebral artery, and the anterior cerebral artery; we also can see the contralateral anterior cerebral artery and an anterior communicating aneurysm. (**B**) Same picture in 3D. (**C**) After dissection of the aneurysm and the neighborhood branches, the aneurysm could be clipped. (**D**) Same picture in 3D.

(Figure 5). The third case is a ruptured anterior choroidal artery aneurysm in a patient with multiple aneurysms (Figure 6). The fourth case is a large aneurysm of the middle cerebral artery (MCA) manifesting with subarachnoid hemorrhage (Figure 7). Finally, the fifth case comprises 2 aneurysms in a patient operated on using a single approach; one aneurysm is located in the contralateral carotid bifurcation and one is a right paraclinoid aneurysm (Figures 8–10).

RESULTS

When consulted, all 30 of the interviewed neurosurgeons agreed that 3D imaging was superior to 2D imaging. Regarding aneurysm surgery, they stated the following advantages: better visualization of internal carotid artery, MCA, and anterior cerebral artery, with a better understanding of the differences in depth of frontal and temporal cortex with vascular walls. Better identification of the limits of the MCA with surrounding insular cortex and the sylvian cistern was also mentioned. The actual orientation of the aneurysm fundus was fully understood only through 3D imaging. Viewers had a better interpretation of neck dissection and could visualize the correct clip positioning beforehand. Perforating vessels were also best visualized in 3D images, with the correct direction and depth of these structures being in contrast with the aneurysm sac, an understanding that is fundamental for

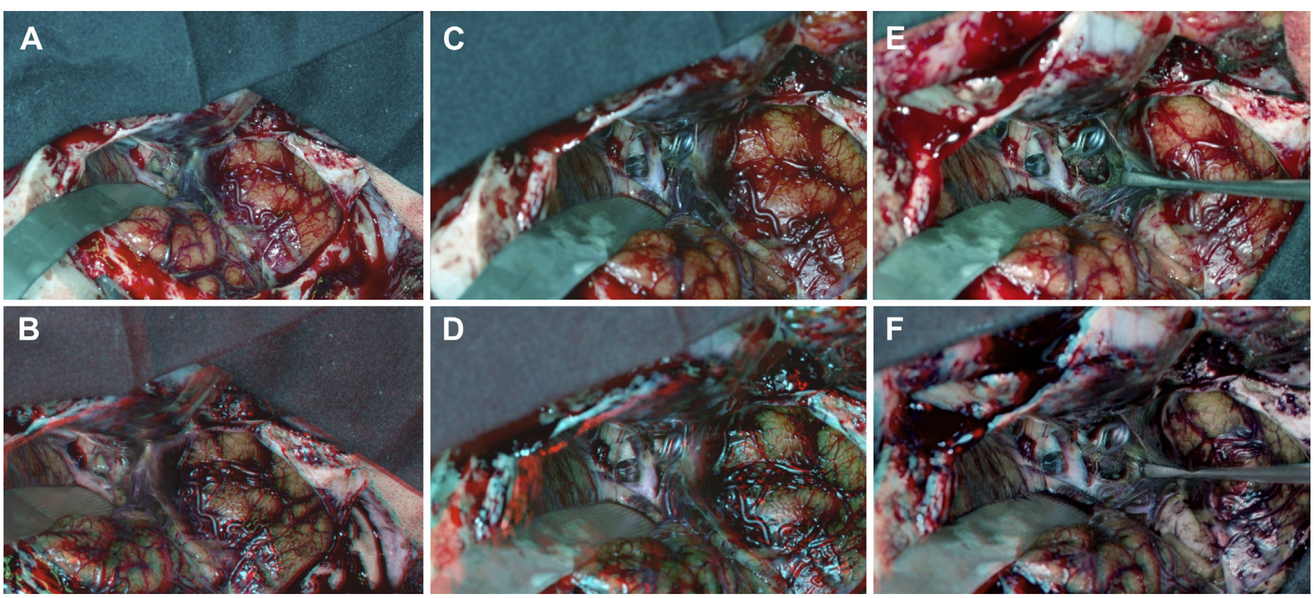

Figure 5. Ruptured posterior communicating aneurysm. (**A**) The internal carotid artery, the optic nerve, the collateral branches, and a posterior communicating aneurysm can be identified. (**B**) Same picture in 3D. (**C**) We clipped the aneurysm, and through the arachnoids perforating branches from the posterior communicating artery can be seen. (**D**) Same picture in 3D. (**E**) After clipping, we dissect the aneurysm to free the perforating branches and the oculomotor nerve. (**F**) Same picture in 3D.

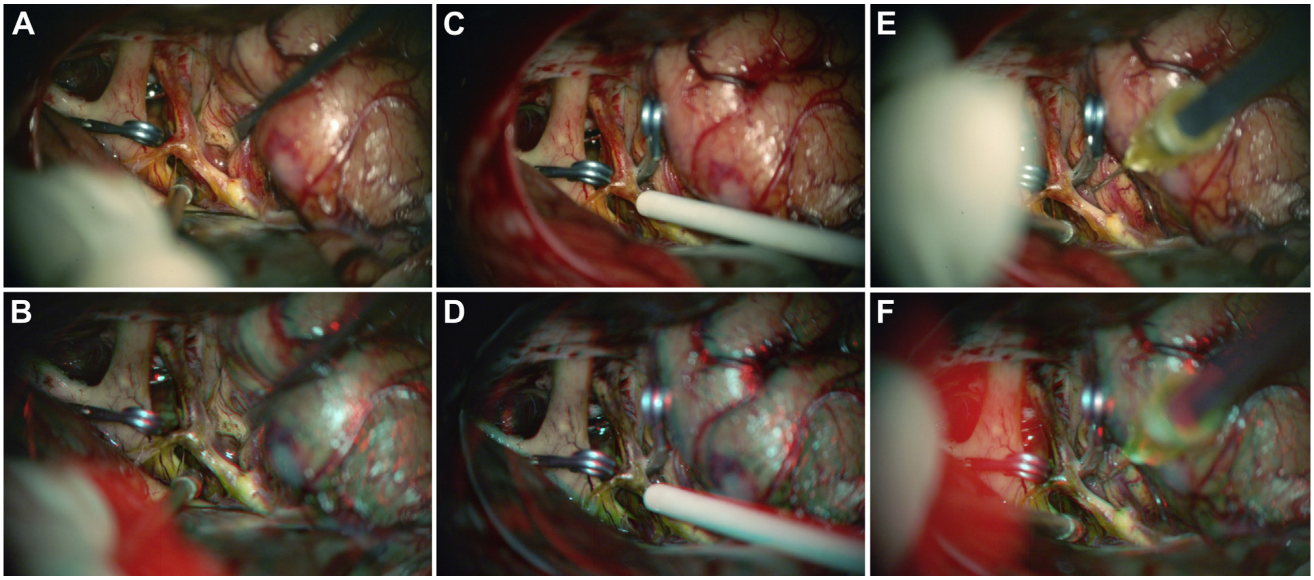

Figure 6. Anterior choroidal artery aneurysm. The patient had 2 more aneurysms. (**A**) After opening the basal cisterns, the aneurysm was dissected as well as the carotid bifurcation and the perforating branches. (**B**) Same picture in 3D. (**C**) We placed a curved clip and then checked the artery and the aneurysm with the Doppler probe. (**D**) Same picture in 3D. (**E**) We also punctured the aneurysm sac to check a correct clipping. (**F**) Same picture in 3D.

clipping at each site; in addition, protection of these structures is one of the main goals of surgery.

The interviewed neurosurgeons did not have any difficulty in viewing large sets of 3D images. None of the participants referred to any visual disturbance with prolonged use of 3D glasses. All participants (100%) agreed that depth perception improved when switching to 3D images. The main alteration was the recognition of slight MCA curves in 1 dimension. Among the residents, 40% acknowledged a change in clipping strategy when comparing 2D with 3D images. Only 3

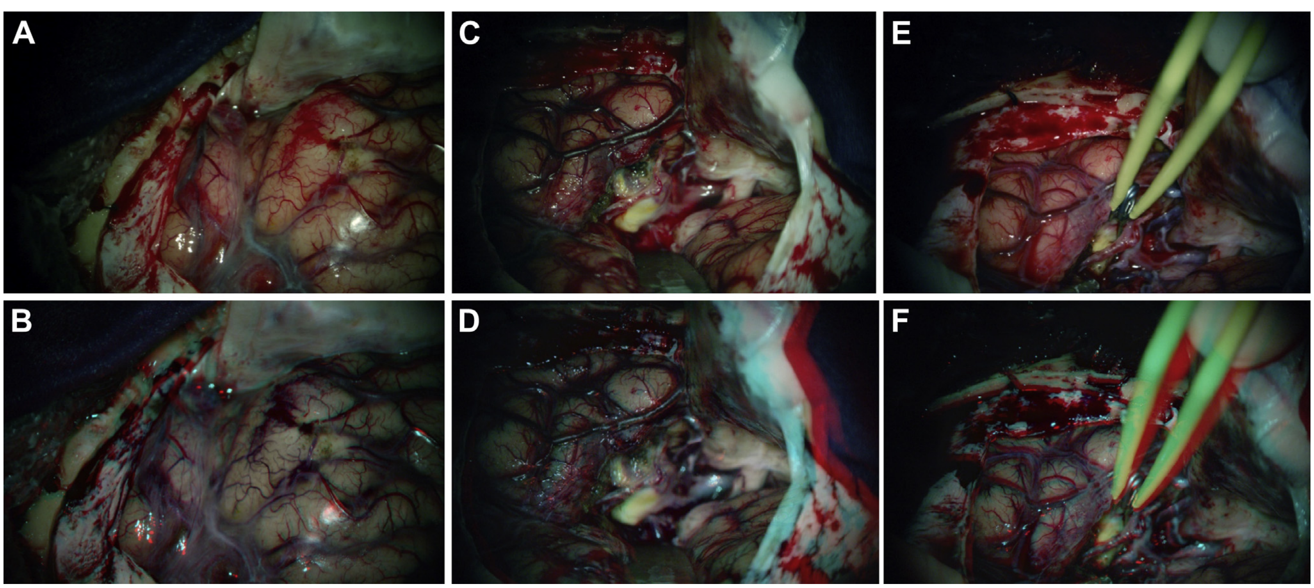

Figure 7. Left middle cerebral aneurysm with acute bleeding. (**A**) After performing the pterional approach, the sylvian fissure is exposed. (**B**) Same picture in 3D. (**C**) After exposing the sylvian fissure, we can see a large middle cerebral aneurysm, which involved both branches of the sylvian artery bifurcation. These branches were dissected. (**D**) Same picture in 3D. (**E**) After completing the dissection, we clipped the aneurysm preserving the branches. (**F**) Same picture in 3D.

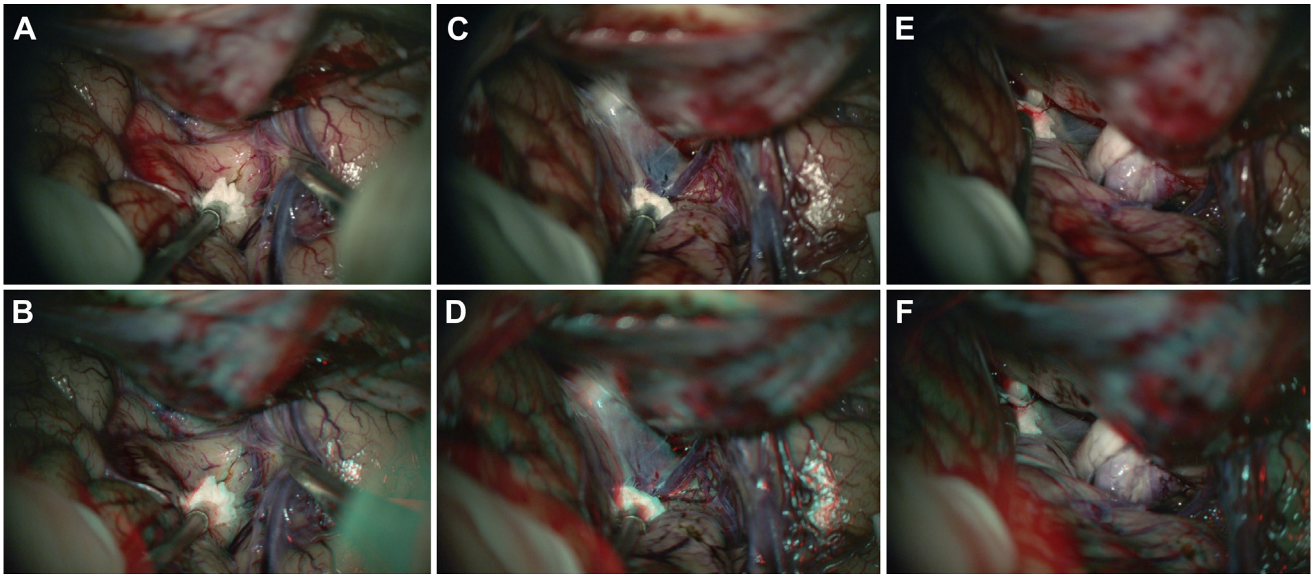

Figure 8. Left contralateral carotid bifurcation artery aneurysm. The patient also had a right paraclinoid aneurysm. (**A**) The opening is started at the pars triangularis of the sylvian fissure. (**B**) Same picture in 3D. (**C**) We found the limit between sylvian and carotid cisterns. (**D**) Same picture in 3D. (**E**) Dissection progresses to the lamina terminalis cistern. (**F**) Same picture in 3D.

experienced surgeons (20%) recognized this element when asked in the questionnaire. Among both groups, >80% of the interviewed physicians acknowledged >3 levels of depth when asked to compare 3D images of fully dissected sylvian fissures with the same images in 2D format.

The ophthalmic segment area was better understood by 66.6% of the resident group. Only 5 (33.3%) experienced neurosurgeons admitted a better understanding of this complex anatomic structure by acquiring 3D images. No structure was misinterpreted by participants in either of the two groups.

DISCUSSION

When specialists are asked to validate the utility of this work, 2 main questions arise: the relevance of 3D imaging in anatomic studies, and the context in which they are obtained—that is, in the operating room, with a real case with unique anatomy and

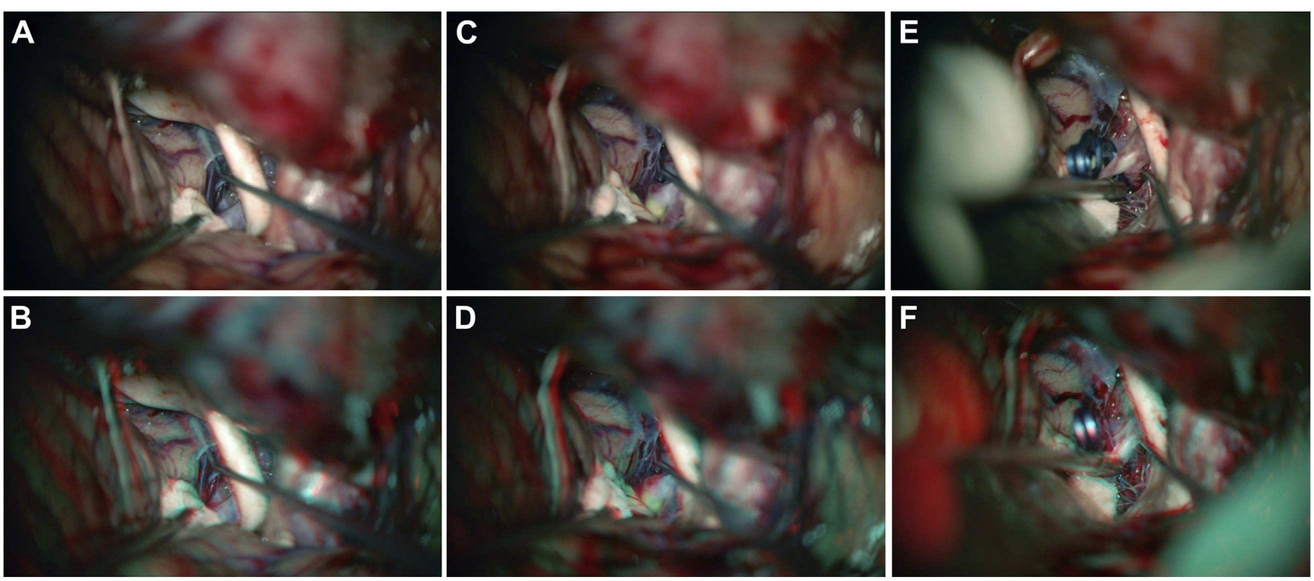

Figure 9. Continuation of the case in Figure 8. (**A**) We reached the contralateral junction between the carotid and sylvian fissure. (**B**) Same picture in 3D. (**C**) We dissected the contralateral aneurysm. (**D**) Same picture in 3D. (**E**) We clipped the aneurysm with a lateral curved clip and checked the perforating branches of this area. (**F**) Same picture in 3D.

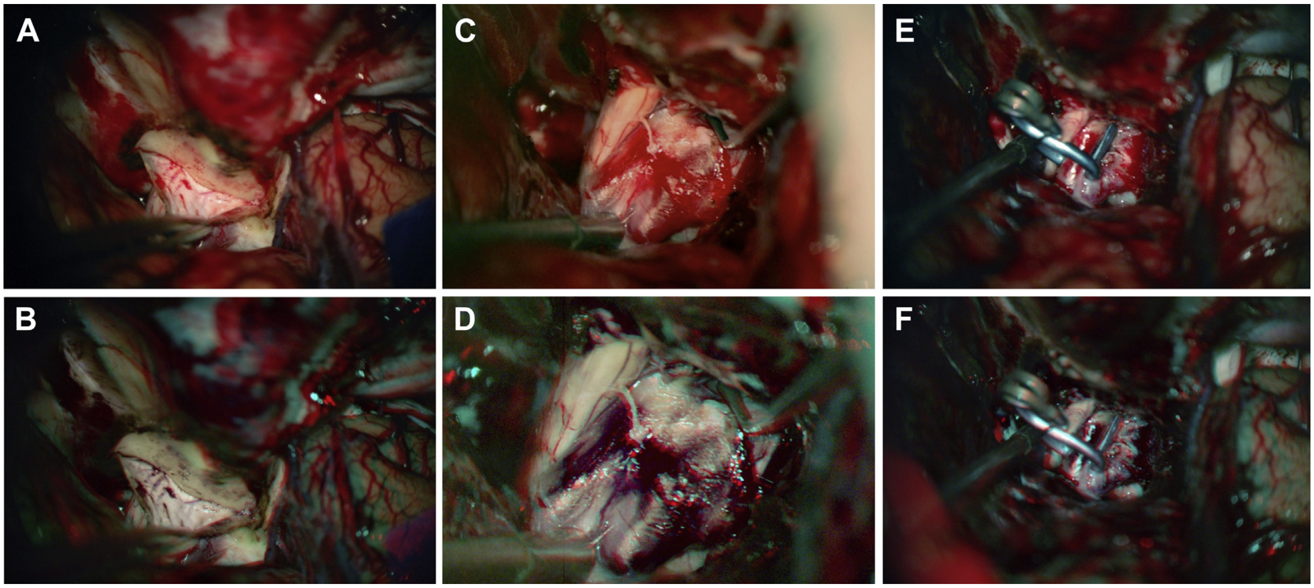

Figure 10. Continuation of the case in Figure 8. (**A**) We moved to the right paraclinoid aneurysm, so we removed the dura mater to start the clinoidectomy. (**B**) Same picture in 3D. (**C**) After completing the clinoidectomy, we could expose the large aneurysm. (**D**) Same picture in 3D. (**E**) We clipped the aneurysm with a fenestrated clip. (**F**) Same picture in 3D.

lesion. The main advantage is the perception of depth in the image, preserving the main factor in surgical anatomy study: the relationships within the different stages. For instance, in a normal average brain, there is a medium distance of 38 mm between the temporal bone and the anterior clinoid process. Many structures arise in this path, either in the sylvian fissure dissection or progressing through the subfrontal, pretemporal, or subtemporal corridors (19, 20). The correct comprehension of the distance between these elements helps to direct the surgeon to the target. If a trainee refers to a surgical atlas, he or she has to make the active effort of understanding that the optic chiasm is just a few millimeters after the olfactory bulb, but when seen on a 3D image, this process is directly visual, with no conscious effort from the surgeon.

Regarding the pterional approach, for many authors one of the most traditional and versatile accesses to the anterior and middle cranial fossa (5, 9), the notion of depth allows one to comprehend fully the importance of certain technical aspects, such as adequate and exhaustive drilling of the lesser sphenoid wing or the importance of correct positioning of the head to facilitate gravitational retraction of frontal and temporal lobes, reducing the use of a brain spatula and the risk of ischemia on the underlying parenchyma.

Some aneurysmal sites of the anterior circulation have the extra challenge of being extremely close to highly delicate or complex structures. Such is the case for ophthalmic or paraclinoid aneurysms (4). All participants acknowledged a better interpretation of the anterior clinoid process, the distal dural ring, and superior hypophyseal arteries.

The other concept refers to obtaining this image contrast and information in the surgical environment in vivo with all its associations: systolic-diastolic movements of the parenchyma, turgescence, color, blood, and adequate perception of volume; changes in shape of the brain while the arachnoids are being dissected and after a spatula is repositioned; changes in vascular and cisternal configuration induced by the presence of a structural abnormality (i.e., the lesion itself). In these cases, aneurysms represent the structural abnormality.

We believe that 3D imaging does not replace the traditional training elements such as laboratory anatomy, surgical atlas, and 2D imaging; however, it does seem to be a logical progression in didactic comprehension of neurosurgery. Real imaging allows one to take all of what was learned up to that point and adds possible scenarios of situations that arise during surgery: the brain is very turgid because of edema, cisterns cannot open widely enough, aneurysmal sacs are "buried" in brain parenchyma, or dense arachnoidal adhesions "hide" aneurysmal necks.

This tool is not limited to this specific pathology or restricted to the anatomic area of the anterior and middle cranial base. It should be extended to other areas in the wide neurosurgical spectrum. Also, the technologic advance of 3D imaging in film and photography is likely soon to become part of numerous technical devices, such as neuroendoscopy. 3D imaging could soon be a teaching approach to these devices.

CONCLUSIONS

The use of 3D imaging in real anterior circulation aneurysm surgery is an excellent tool to enhance knowledge transmission. It adds contrast (depth) to neighboring structures making them more readily differentiated, correlating the distances in depth between one and another, and improving understanding of complex vascular and nervous structures of anterior and middle cranial fossa. It seems to be particularly beneficial for younger neurosurgeons. 3D imaging is likely to extend to other anatomic sites and pathologies and could be a new platform in the introduction of new technologies.

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