

A Single-Center Experience with the Olympus ORBEYE 4K-3D Exoscope for Microsurgery of Complex Cranial Cases: Technical Nuances and Learning Curve

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Abstract

Background The introduction of exoscopes in neurosurgery has been welcomed due to their maneuverability, ergonomics, and low-profile frame. 3D devices have further enabled a better stereoscopic visualization. Reports on their application, albeit more and more frequent, are still at their beginning stages. We present our experience with the Olympus ORBEYE 4K-3D exoscope for major cranial procedures. The strengths and weaknesses of the exoscope are presented, and the nuances associated with the learning curve are illustrated.

Methods Over 2 weeks, patients undergoing surgery for major cranial pathologies were offered to participate in this evaluation of the Olympus ORBEYE 4K-3D exoscope. Information on the use of the exoscope was collected to assess the features and struggles in the learning curve. A comparison with the operating microscope was made.

Results Fourteen patients with different intracranial pathologies were operated on with the exoscope. No surgery-related complications occurred. The microsurgical part was performed with the exoscope in six cases. The exoscope was used for 72.9% ($\pm 37.5\%$) of the whole microsurgical time vs. 27.1% ($\pm 37.5\%$) microscope time ($p = 0.02$).

Conclusion The Olympus ORBEYE 4K-3D exoscope represents a useful evolution of the operating microscope. It requires time to overcome potential difficulties, mostly related to previous motor schemes acquired with operating microscopes. Its features could represent the basis for a paradigm shift in microsurgery.

Keywords

- exoscope
- stereoscopic view
- 4K-3D
- microsurgery
- neurosurgery

Introduction

The evolution of neurosurgery to its current standards is bound to the development of microsurgical techniques, following the introduction of the operating microscope and Yaşargil's contributions.^{1–3} Operating microscopes

have undergone significant modifications throughout the decades to enable better visualization, more fluid and precise surgical acts, and they improved operating team involvement during surgeries and trainees' education.^{4,5} To further enhance these features and reduce potential limitations of modern microscopes (short focal length, small depth of

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fields, bulky, space-occupying microscope body, poor ergonomics, suboptimal operative angles, and high costs).^{5,6} extracorporeal telescopes, or exoscopes, were conceived. They consist of tubular telescopes connected to a camera and a high-definition monitor.⁷ The advantages of exoscopes in comparison to microscopes include a longer focal distance and an ampler field of view, along with a smaller frame, providing the surgeon with a larger working space.

Initial experiences identified a significant limitation of the first exoscopes in the lack of stereoscopic view.^{6,8} The introduction of 3D systems was regarded as an improvement; good results were reported for both cranial and spinal cases,^{4,5,9–13} putting 3D exoscopes ahead for further clinical testing.

The use of the exoscope for major intracranial lesions has been tested, and previous works^{4,5} showed satisfactory results. Specifically, a 4K-3D microvideoscope (ORBEYE 4K-3D Orbital Camera System, Olympus Corporation, Tokyo, Japan) was tested on 41 patients, of which 24 were regarded complex or deep-seated cranial cases.

We aim at presenting our experience with the Olympus ORBEYE exoscope, describing possible features associated with the learning curve, and evaluating drawbacks and strengths of this tool in a routine setting.

Methods

All patients admitted to our department to undergo microsurgical removal of diverse intracranial pathologies during a 2-week period, in which the Olympus ORBEYE 4K-3D exoscope was on trial in our facility, were proposed to participate to this evaluation study and signed informed consent was obtained.

The Olympus ORBEYE exoscope consists of a 20 × 6 cm cylinder-shaped camera mounted on a flexible semi-robotic arm, equipped with a light-emitting diode (LED) light source and connected to an image processor. The camera enables a 12x optical zoom with an additional 1.5 to 2x digital zoom for a total of 24x magnification that can be adjusted manually or through a motorized pedal and has a working distance from the focal plane of at least 22 to 55 cm. The system connects to

a 55-inch 4K monitor with a 3,840 × 2,160 pixel resolution. Infrared and blue light filters are incorporated in the camera for use with indocyanine green (ICG) and 5-aminolevulinic acid (5-ALA) fluorescence. The 3D experience is possible through the use of specific glasses, as well as through two dedicated 4K sensors that acquire two images for the stereoscopic effect. The images can be recorded in 4K and stored in an internal hard disk drive.

For the operations in which the Olympus ORBEYE exoscope was tested, the optic microscope was also draped to replace the exoscope in case of problems. Additionally, this was done to compare the two technologies and assess the main differences in visualization from both the surgeon's and the operating room (OR) staff's perspective. When feasible, the exoscope was used from the beginning throughout the microsurgical part.

Times of employment of the microscope and the exoscope were registered and are reported as a percentage with the standard deviation of the whole operative time and the microsurgical part of the operation. A paired *t*-test was performed to determine whether there was a significant difference in time between the use of the exoscope and the microscope. Calculations were performed with SPSS Statistics 23 (IBM Corp. Armonk, New York, United States), and graphics were made with Office Excel v. 15.30 (Microsoft Corp., Redmond, Washington, United States).

Results

During the trial period, 14 patients underwent microsurgical treatment of various complex intracranial cases with the Olympus ORBEYE exoscope: 1 choroid plexus papilloma of the fourth ventricle, 1 intracranial aneurysm, 1 colloid cyst of the third ventricle, 4 meningiomas, 2 cranial nerve tumors, 1 neurovascular conflict, 1 ethmoidal fistula, and 3 gliomas.

On average, the exoscope was used for 96.7 (±60.4) minutes, equal to 38.4% (±23.3%) of the operative time, whereas the microscope was used for 58 (±102) minutes, that is, 15.2% (±21%) of the whole surgical time. None of the cases showed intra- or postoperative surgery-related complications. However, some cases of

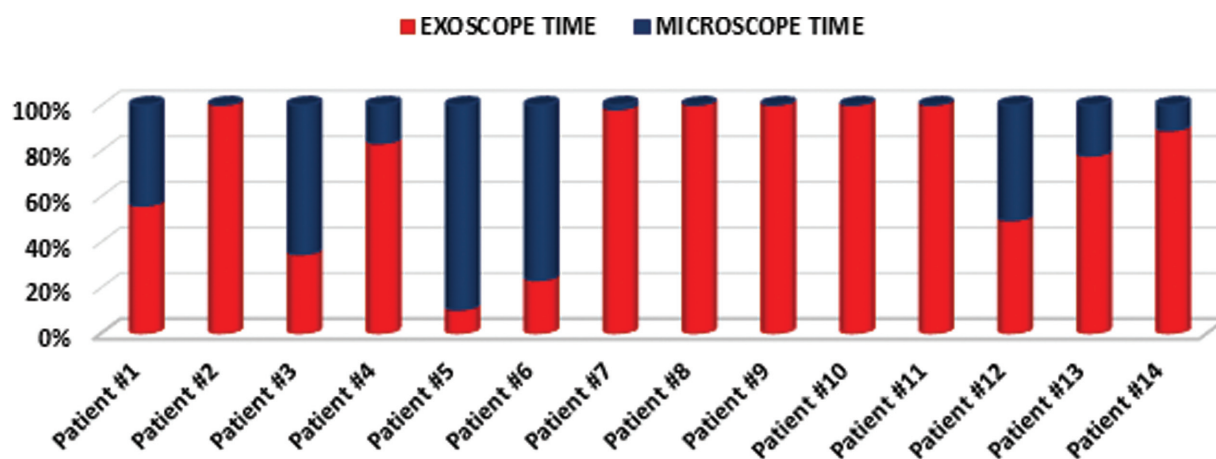


Fig. 1 Time of exoscope vs. microscope employment as a percentage of the whole microsurgical time.

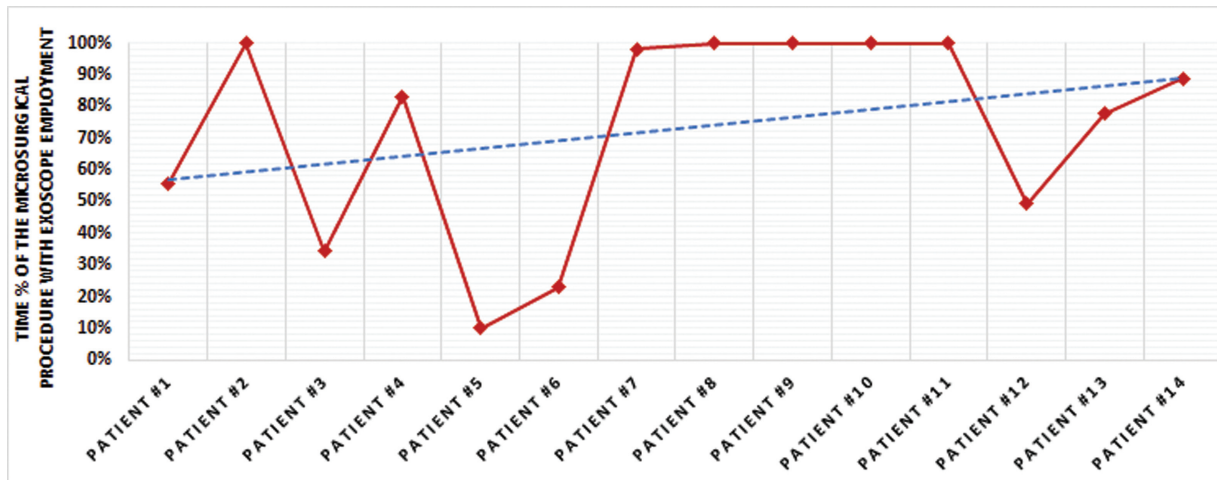


Fig. 2 Trend in the employment of the exoscope expressed as a percentage of the microsurgical time.

complexity and challenging anatomy required replacing the exoscope with the operating microscope for a longer time: a colloid cyst of the third ventricle, a cranial nerve XII schwannoma, a malignant peripheral nerve sheath tumor, and an anterior communicating artery (AcoA) aneurysm. Considering only the microsurgical part, we used the exoscope as a stand-alone tool in six patients (patient no. 2 and patient nos. 7–11; see ►Fig. 1), and in four cases, the microscope was used for a more prolonged time, due to problems encountered with the exoscope use. These were the third (a colloid

cyst of the third ventricle), fifth (a cranial nerve XII schwannoma), sixth (a malignant peripheral nerve sheath tumors of cranial nerve VIII), and twelfth (an AcoA aneurysm; ►Fig. 1) patients of our series. In the microsurgical part of the operations, the time in which the exoscope was used accounted for 72.9% ($\pm 37.5\%$) of the whole microsurgical time vs. 27.1% ($\pm 37.5\%$) microscope time (mean difference: 45.8% [$\pm 64.3\%$], $p=0.02$) and a trend toward increasing employment of the exoscope with the time that was documented (►Fig. 2). Overall, the use of the exoscope did not

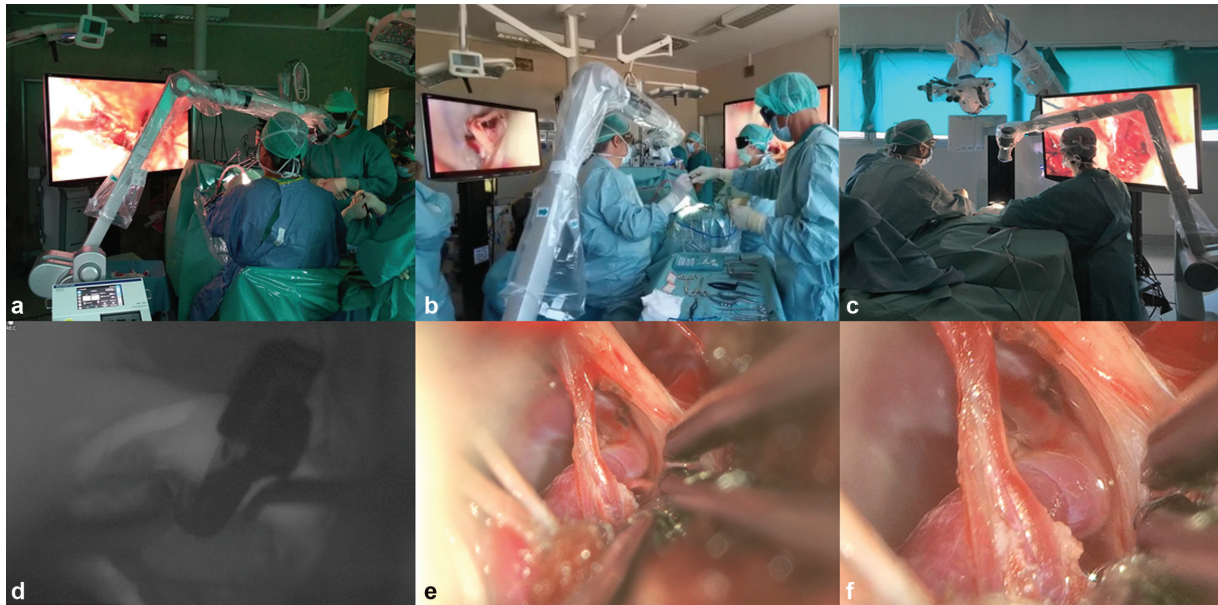


Fig. 3 Intraoperative pictures of microsurgery with the exoscope in an operative room setting. (a–c) The surgeon and the operating team visualize the operative field on a 55-inch 3D screen with the aid of 3D glasses. This setting allows the surgeon to disengage from the oculars attached to the body of the microscope, leaving the camera free to move in an ampler range of motion. The small frame of the exoscope permits movement of surgical tools on both sides of the surgeon according to the lesion's localization with relatively small changes in the room's settings. Occasionally, a second screen (b) can be used for better visualization for the scrub nurse and the assistant. (c) The frame of the exoscope is smaller than the frame of most operating microscopes and allows surgeons to operate via various approaches with minimal variations in the overall operating room setting. (d) Use of indocyanine green during aneurysm surgery. With the default settings, a brighter image carries the disadvantages of a less contrasting depiction of the vessels under infrared light. (e,f) Features of the digital zoom. Microvascular decompression of a left neurovascular conflict (anterior inferior cerebellar artery [AICA]–cranial nerve VII) is depicted at the highest magnification (12x), with a high-quality visualization of the details. The incorporation of digital zoom (2x) can further allow for higher magnification of anatomical details (24x).

extend surgical times. 5-ALA was used in 1 glioblastoma and ICG was used in 2 meningiomas, 1 temporal-insular glioblastoma to evaluate arterial and venous relationships around and within the lesions, and 1 aneurysm to assess aneurysm morphology and postclipping exclusion from the circulation (►Fig. 3).

Discussion

We present our experience with the Olympus ORBEYE 4K-3D exoscope for microsurgical treatment of major cranial pathologies and provide the literature with 14 additional cases. In our series, particularly in those in which both the microscope and the exoscope were employed, we were able to appreciate the strengths of this new device and recognize its limitations as compared with the operating microscope.

In our experience, the use of the Olympus ORBEYE 4K-3D exoscope was not associated with prolonged surgical times or higher complication rates than expected. Previous reports described the use of 4K-3D exoscopes for nonmicrosurgical procedures, such as the evacuation of subdural hematomas⁵ or peripheral nerve neurolysis.⁴ Potential problems at the beginning of the learning curve are associated with the inherent features of stereoscopic view in deep surgical fields. However, these problems can be predicted, and routine use of exoscopic systems allows surgeons to overcome them with practice. In our series, the experience gained in a short time led us to prefer the exoscope to the operating microscope for microsurgical procedures.

Visualization and Image Quality

High image quality is one of the striking features of the exoscope. A digital zoom enables a more in-depth depiction of anatomical details (►Fig. 3), a valuable tool when working between deep-located structures of small size. The 3D vision, on the other hand, enhances the in-depth stereoscopy, which could be difficult for surgeons with a long experience with the operating microscope. The depth perception was significantly increased with the exoscope, representing an improvement in comparison to the operating microscope; however, this improvement required extra effort during dissection due to long-standing motor schemes that surgeons had acquired and refined with the operating microscope. That improved depth perception was perceived as an additional strain during long operations in delicate fields, such as the petroclival junction or the cerebellopontine angle, and led to switching to the operating microscope to complete lesion removal more safely and straightforwardly (►Fig. 1). These cases, however, were encountered during the early stages of our experience with the exoscope. The next cases showed, that some time is required to become familiar with this enhanced depth depiction. In our opinion, this should be taken into account during the first stages of the learning curve.

The LED light source of the exoscope, which is cold and does not cause heating of the anatomical structure, represents an advantage if compared with the operating

microscopes. A third advantage of the exoscope could be seen when using ICG: The surgeon can watch live under infrared light without needing to wait for the end of the registration of the frame in which the ICG passes through the vessels. However, despite the high quality of the image (►Fig. 3), we found the image brighter and less contrasted under the exoscope, representing a potential disadvantage for some surgeons.

Ergonomics

The dissociation between the line of sight and that of work is another striking aspect in the use of the exoscope. This feature, as already illustrated,^{4,5} allows for a more comfortable and less physically demanding surgery since the surgeon is not forced to follow the body of the operating microscope to look into the oculars (►Fig. 3). Some authors¹⁴ have stated that this dissociation could be considered a drawback, but we feel this to be of relevance only for the first steps in the learning curve, and the attainment of the appropriate motor schemes would compensate for this initial obstacle.

In our opinion, this dissociation between the line of sight and that of work is positive, especially for lesions of the posterior fossa or the cerebellopontine angle. However, the more significant the difference the harder would be the coordination for the surgeon with ample experience using an operating microscope and consolidated motor schemes.

However, the dissociation between the line of sight and the surgeon's hands allows for a broader range of motion with the possibility to angle the camera more steeply and tangentially to the operating field, therefore widening the field of view through the "keyhole" of the craniotomy (►Fig. 4). Even though the operating microscope can theoretically accomplish the same, the surgeon is obliged to look into the ocular, thereby limiting the tool's range of motion. Moreover, the body of the microscope itself also poses a physical limit to the range of motion compared with the exoscope, due to its large structure. When the operating microscope is used, different lesion localizations, the chosen surgical approach, and patients' positioning require the surgeon to plan in detail the operating room setting, which, due to the size of the body of the microscope, will provide little room for relevant changes. On the other hand, we did not need that planning of the operating room setting when using the exoscope, with the sole exception of adding a second screen to allow proper visualization to the scrub nurse/assistant (►Figs. 3 and 4).

Additionally, the use of the exoscope can be considered for nonmicrosurgical parts of the surgeries: its small frame allows for a natural shift between direct visualization and use of the exoscope, which is hardly possible with the modern operating microscope. This can represent an advantage during particular steps, such as checking the correct position with frameless neuronavigation systems, or for recording nonmicrosurgical steps for didactic purposes. Besides these points, however, we did not feel that the use of the exoscope could add anything essential to naked eye visualization.

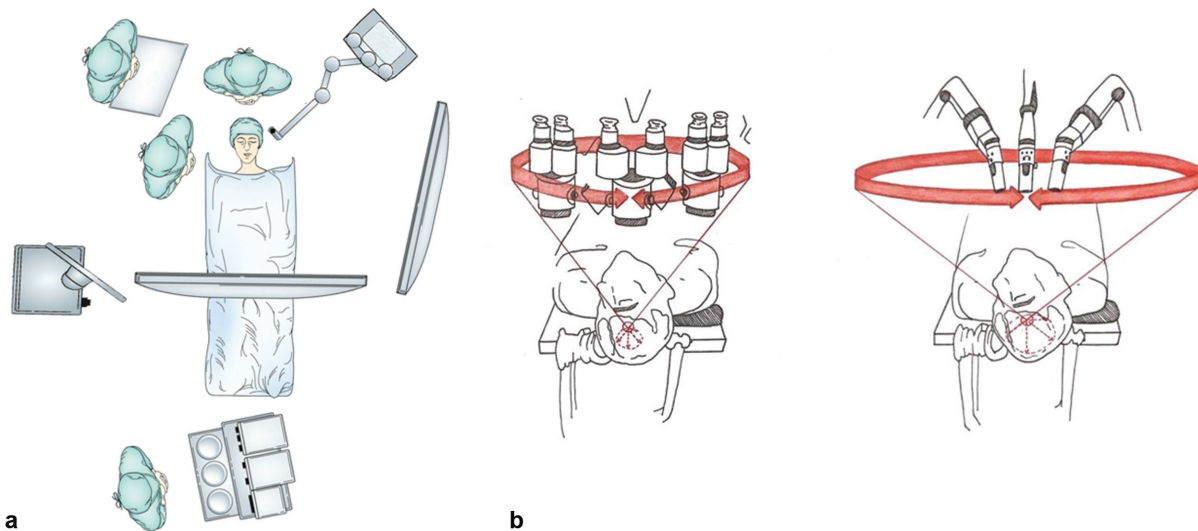


Fig. 4 Graphic illustration of the features of the exoscope compared to the operating microscope regarding the operating room setting and the different views obtained. (a) The operating room setting is depicted, with the scrub nurse is on the right of the surgeon. Due to the small frame of the exoscope, the surgeon's assistant and the exoscope can be placed on either side of the surgeon, according to the different lesion locations and the chosen approach with minimal changes in the overall room setting. An additional screen is placed as needed for better visualization for the scrub nurse and the assistant, while the anesthesiologist is placed at the patient's feet. (b) The broader range of motion of the exoscope (on the right) compared with the microscope (on the left), due to its low-profile frame, mobility, and the fact that the surgeon is not obliged to follow the instrument to look into the oculars, allows the surgeon to angle the camera more steeply and tangentially to the operating field, thereby permitting a more extended view through the craniotomy.

Operative Team Involvement

Operative team involvement and the interaction between the team and the surgeon are enhanced when operating with the exoscope. The presence of two large screens allows, in our opinion, better communication between the surgeon and the team. On the other hand, the surgical assistant/resident can visualize the same image as the first surgeon despite being positioned at a different angle to the operating field, which could be challenging in some cases. This limitation may be overcome by adding a screen for the assistant with different image orientation. An essential benefit of the exoscope for the surgeon is, in our opinion, not only the more extensively visualized operating field if compared with the microscope, but also the more harmonic inclusion in the surrounding environment of the operating room, allowing the surgeon having a better perception of what is happening around him. Thereby, the surgeon is not disturbed by the sudden appearance of the assistant's instruments in the operating field or by movements from the team.

Conclusion

In our experience, the main strengths of Olympus ORBEYE exoscope are a wider surgical field and a better depiction of anatomical details, as well as the possibility to visualize a more extended area through the craniotomy due to the broader range of motion of the camera compared with the optic microscope. To exploit the features of the learning curve, we would advise avoiding cases of deeply located lesions, in which two specific aspects of exoscopes are accentuated, which are a more accentuated stereoscopic

view compared with the operating microscope and the higher eyes–hands dissociation. A better perception of the operating room environment and involvement of the surgical team could also put the basis for a future shift from microscopic to exoscopic microneurosurgery.

Conflict of Interest

None declared.

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