Check for updates

Three-Dimensional, High-Definition Exoscopic Anterior Cervical Discectomy and Fusion: A Valid Alternative to Microscope-Assisted Surgery

Giuseppe M.V. Barbagallo and Francesco Certo

■ BACKGROUND: **Anterior cervical discectomy and fusion (ACDF) remains one of the most commonly taught procedures during residency and one of the most frequently performed by neurosurgeons. Neurosurgeons use microscopes to perform surgery and to train other surgeons. Although the microscope provides excellent illumination and magnification, its use will be limited to 2 people: the surgeon and the assistant. Consequently, the scrub nurse and residents watching 2-dimensional images on monitors will have a reduced perception of the surgical field depth and anatomical details. The exoscope has been introduced as an alternative to microscopes and endoscopes. We used a 3-dimensional (3D), high-definition exoscope (3D Vitom [Karl Storz, Tuttlingen, Germany]) in 2 patients undergoing 2-level ACDF for cervical myeloradiculopathy.**

■ METHODS: **The exoscope was used during soft tissue dissection, discectomy, osteophytectomy, and cage insertion. Microsurgical drilling of the posterior osteophytes, which will usually require adequate magnification and proper microscope angulation, was also performed using the exoscope.**

■ RESULTS: **The exoscope provided a 3D view of the surgical field similar to that provided by a microscope and allowed us to effectively and safely perform the required surgical steps. The main advantage of 3D exoscope-assisted surgery, compared with microscope-assisted surgery, is the possibility to generate videos with a similar view and image quality as perceived by the surgeon. Therefore, the didactic capabilities of exoscopic videos are greater than those provided by microscopic videos. Exoscopes are also smaller compared with microscopes, allowing for comfortable use from the early surgical steps to device implantation.**

■ CONCLUSION: **We believe that exoscope-assisted surgery could become a safe and effective alternative to microscope-assisted surgery in ACDF.**

INTRODUCTION

Anterior cervical discectomy and fusion (ACDF) is considered the reference standard to treat spondylotic myeloradiculopathy causing anterior neural compression. The anterior cervical approach was first described by Cloward[1] in 1957 and then modified by Smith and Robinson[2] in 1958. Subsequent technical variations were added; however, the basic principles of the ACDF surgical technique have remained unchanged over the years.[3-5]

The introduction of the operative microscope (OM) as a visualization tool for ACDF procedures represented a significant technical improvement.[6] The OM allowed for better illumination and direct visualization of posterior osteophytes and the posterior longitudinal ligament through the anatomical corridor created after removing the intervertebral disc. This also made direct neural decompression feasible and effective in multilevel cases.[2,7,8] The OM is an essential tool in neurosurgery. However, although its application in a large number of spinal neurosurgical procedures has become routine, some surgeons have still reported difficult maneuverability and encumbrance on the operative field as motivations for its limited use in spinal procedures,[9] especially when implants with dedicated surgical instruments (which can be

Key words
- 3D surgery
- ACDF
- Disc hernia
- Exoscope
- Spondylosis
- Vitom

Abbreviations and Acronyms
ACDF: Anterior cervical discectomy and fusion
CT: Computed tomography
OM: Operative microscope

Department of Neurological Surgery, Policlinico "G. Rodolico" University Hospital, Catania, Italy

To whom correspondence should be addressed: Francesco Certo, M.D.
[E-mail: francesco.certomd@gmail.com]

Citation: World Neurosurg. (2019) 130:e244-e250.
https://doi.org/10.1016/j.wneu.2019.06.049

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***

1878-8750/$ - see front matter © 2019 Elsevier Inc. All rights reserved.

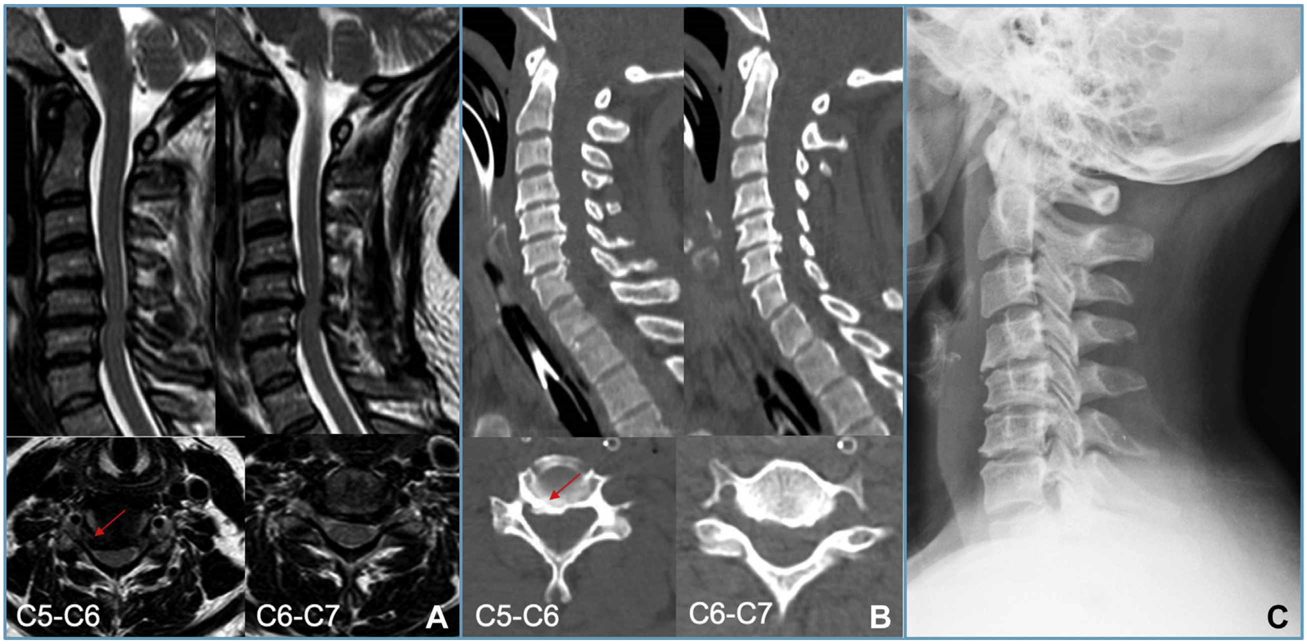

Figure 1. Preoperative (**A**) sagittal T2-weighted sequences of cervical magnetic resonance and (**B**) multiplanar reconstructed computed tomography scans depicting spinal cord and nerve root compression at C5-C6 and C6-C7 and obvious foraminal stenosis at C5-C6 on the right side. (**C**) Lateral cervical spine radiograph showing loss of physiological lordosis.

too long to be used under the microscope) are required. In addition, some investigators have reported that a clear advantage in clinical outcomes has not been found for patients undergoing ACDF with or without use of the OM.[9]

Recently, the exoscope, a new visualization tool with applications in several surgical disciplines, has been introduced to the neurosurgeon's armamentarium.[10,11] Integration of a 3-dimensional (3D) camera in the exoscope and the availability of dedicated 3D glasses and high-definition (HD or 4K) 3D screens in theaters, has widened the application of this new tool to spine surgery, as an alternative to the microscope and/or endoscope.

We report our experience with a 3D, HD exoscope system (Vitom 3D [Karl Storz, Tuttlingen, Germany]) used as a visualization tool in 2 cases of ACDF. The technical advantages and limitations, with a focus on the comparison with microscope-assisted ACDF, have been discussed. The setup of the operating room and exoscope integration into the surgical environment have been highlighted.

TECHNICAL REPORT

Patient 1

A 41-year-old woman had presented with neck and right arm pain associated with right C6 and C7 sensory and motor radiculopathy. Preoperative cervical magnetic resonance imaging and computed tomography (CT) scans demonstrated the presence of diffuse spondylotic alterations at C4-C5, C5-C6, and C6-C7, with spinal cord and nerve root compression more evident at C5-C6 and C6-C7 and obvious foraminal stenosis present at C5-C6 on the right side (Figure 1A,B). A lateral cervical spine radiograph showed loss of physiological lordosis, without signs of overt instability (Figure 1C).

After provision of written informed consent for surgery, the patient underwent 3D-Vitom exoscope-guided C5-C6 and C6-C7 ACDF. Anterior foraminotomy and osteophyte removal was achieved using a high-speed drill, with, first, a 4-mm ball-tip cutting burr, followed by a diamond burr, similar in size, when most of the spondylotic bone had been removed and the soft tissue was reached. The role of the 3D exoscope, as a visualization tool, in helping us to perform standard ACDF microsurgical techniques has been detailed in the section 3D Exoscopic System. Zero-profile lordotic cages (Zero-P VA [Depuy-Synthes, West Chester, Pennsylvania, USA) were used for interbody fixation and fusion. The postoperative course was uneventful, and the patient was discharged 48 hours after surgery. The postoperative cervical CT scan documented adequate neural decompression and correct positioning of cages and screws (Figure 2A). Cervical radiographs showed restoration of cervical lordosis compared with the preoperative condition (Figure 2B).

Patient 2

A 54-year-old woman with a complaint of neck pain associated with burning and tingling sensory changes in both upper limbs and signs of impaired corticospinal tract function was admitted to our department. Cervical magnetic resonance imaging and CT scans documented central spinal cord compression at C4-C5 and C5-C6 secondary to both spondylosis and disc hernia (Figure 3A).

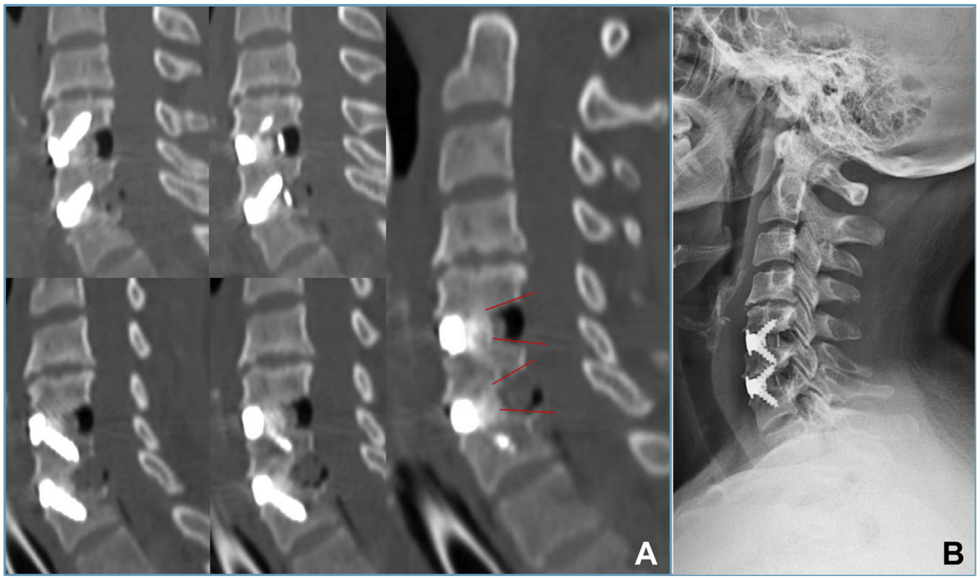

Figure 2. (**A**) Postoperative multiplanar reconstructed computed tomography scan, demonstrating satisfactory osteophytectomy and good positioning of the zero-profile cage plates. (**B**) Lateral radiographs documenting restoration of cervical lordosis.

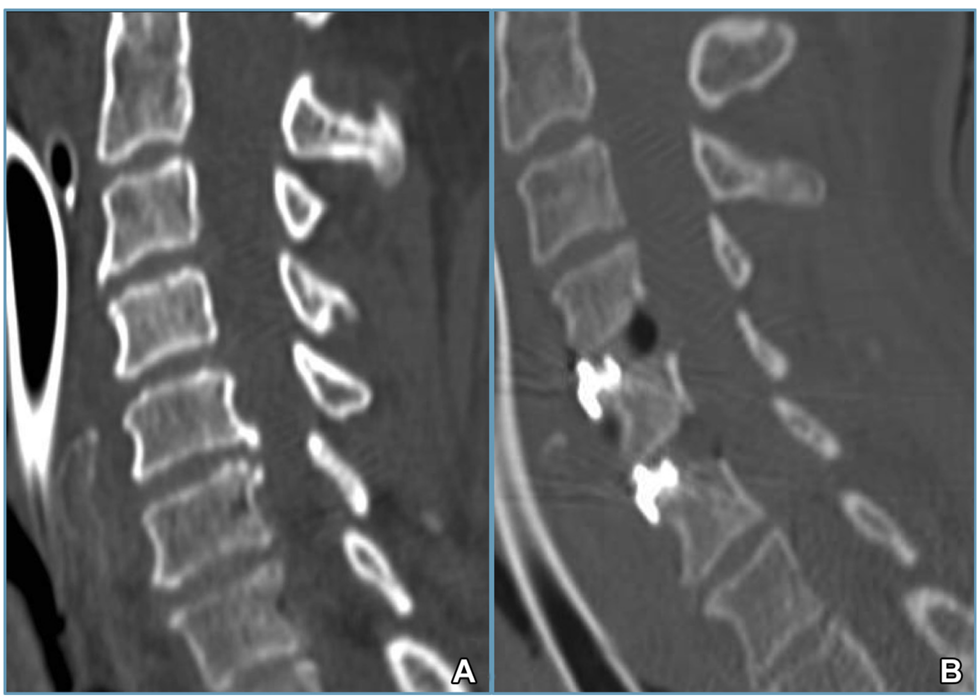

Figure 3. Comparison between (**A**) preoperative and (**B**) postoperative sagittal reconstructed cervical computed tomography scans documenting complete resection of osteophytes at the C4-C5 and C5-C6 level with the V-shape bony removal obtained by exoscopic-assisted microdrilling.

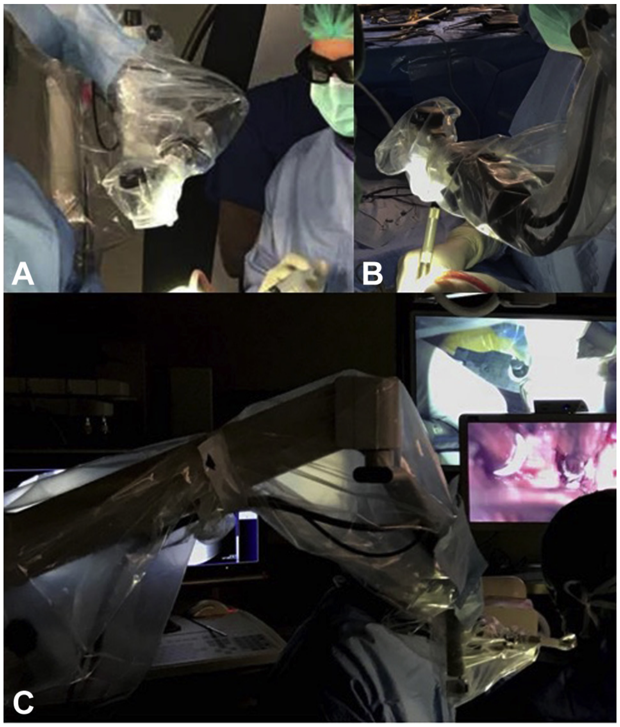

Figure 4. Different components of Vitom 3-dimensional exoscopic system with (**A**) mobile stand (Versacrane); (**B**) controller (image 1 pilot), and (**C**) 3-dimensional camera.

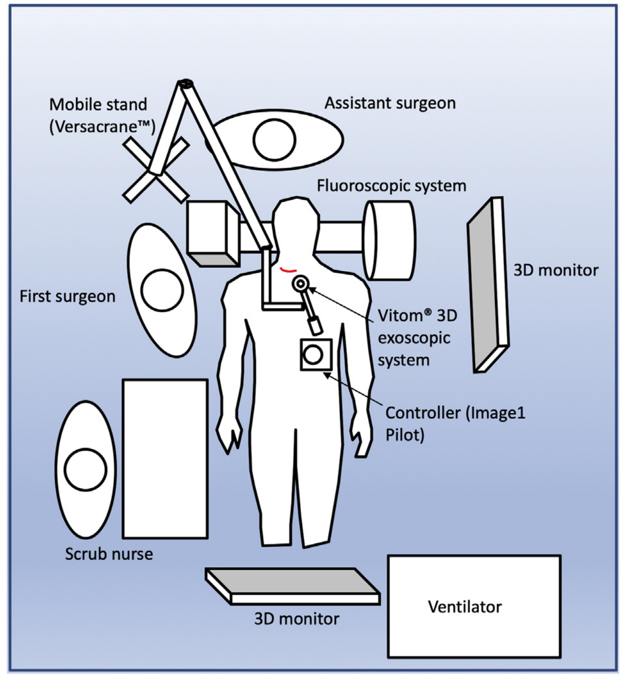

Figure 5. Schematic representation of operating theater layout used in the 2 described cases of anterior cervical discectomy and fusion.

With provision of written informed consent, C4-C5 and C5-C6 ACDF was performed using a 3D exoscope.

The postoperative course was uncomplicated, and the patient was discharged 3 days after surgery. After surgery, she experienced immediate symptom improvement. A postoperative CT scan and radiograph demonstrated decompression of the neural structures (Figure 3B).

3D Exoscopic System

The Vitom (Karl Storz) 3D exoscope is a visualization system able to generate 3D real-time videos, useful in several surgical disciplines. The system consists of a small and easy to handle optical device with a light source and a double camera, allowing for generation of 3D videos. The camera can be covered with a sterile drape and placed within the surgical field (Figure 4A). Magnification, focus, light intensity, image quality, and image orientation, in addition to further advanced options, are controlled by a "joystick-like" controller termed the Image1 Pilot (Karl Storz; Figure 4B). This device can be draped with a sterile transparent cover, positioned near the first surgeon, and fixed to the surgical table using a holding articulated arm.

The holding system designed for the Vitom 3D exoscope (Karl Storz) is a gas spring-supported arm mounted on a mobile stand (Versacrane [Karl Storz]; Figure 4C). It allows for adequate weight compensation for the Vitom 3D exoscope (Karl Storz) and can be easily positioned according to the surgical requirements. The images generated by the Vitom 3D exoscope (Karl Storz) are transmitted to $\geq$1 3D screens (Figures 5 and 6). In the case of surgical procedures requiring 2 surgeons in different positions, with different views of the surgical field, two 3D monitors should be used, changing the image orientation appropriately

Figure 6. Theater setup used during 3-dimensional, high-definition exoscopic-assisted anterior cervical discectomy and fusion.

for each screen. The 2 patients reported in the present study had received information about the use of the 3D exoscope, which was included in the informed consent procedure for surgery. A specific informed consent form was not necessary, because the use of different visualization tools does not imply a variation in the surgical technique and would not affect the invasiveness of the procedure.

Video

Video available at www.sciencedirect.com

Operating Room Setup and Surgical Steps

The position of the different devices used in the 2 cases are graphically shown in Figure 5. The standard positioning for ACDF was used in both cases, and a right-sided anterior cervical approach was performed. The surgeon was standing on the patient's right side and the assistant on the surgeon's left side, cranially to the patient's head. A C-arm fluoroscopic system was placed under the surgical bed, left in place during surgery, and set for lateral—lateral intraoperative fluoroscopic imaging. The Versacrane (Karl Storz) holding system was positioned in the corner between the 2 surgeons (Figure 6). The Vitom 3D camera (Karl Storz) was then positioned on the surgical sterile field caudally to the skin incision. The camera orientation was adjusted to allow for oblique visualization of the surgical field and to avoid any visual interference from the surgical instruments. Two 3D screens were used. The first monitor was placed in front of the first surgeon at a distance of ~1.5 m, and the second was positioned caudally to the surgical table, allowing visualization for the assisting surgeon. The Image1 Pilot was fixed to the surgical table by its angulated arm and placed over the sterile field caudally to the camera in a position easily reachable by the first surgeon (Figure 6).

All surgical steps (i.e., from skin incision to wound closure) were performed with the assistance of the Vitom 3D exoscope (Karl Storz) and recorded. Surgery was performed in accordance with to the standard microsurgical technique. In particular, after completing exoscope-assisted discectomy, the magnification and focus were adjusted to allow for proper drilling of the posterior part of vertebral body, with the aim of achieving complete and adequate decompression of the neural structures. Therefore, the posterior osteophytes were drilled and removed. During this surgical step, the V-shape drilling of the posterior part of superior and inferior one third of the caudal and cranial vertebral bodies, respectively (previously reported in 2017), was performed by tilting the camera. Moreover, lateral drilling of the posterior—medial surface of the uncinate processes, crucial to achieving satisfactory radicular decompression, was also performed with the assistance of the Vitom 3D camera (Karl Storz). The posterior longitudinal ligament was identified and removed, and the thecal sac was exposed. Decompression of the neural structures was verified using a micro-hook and dissector, and the endplates were then properly prepared for cage insertion. Zero-P cage plates (DePuy Synthes, West Chester, Pennsylvania, USA) were implanted under the direct vision of the Vitom 3D camera (Karl Storz) and fluoroscopically verified. We did not experience any difficulties during cage insertion, because the specific instruments did not conflict with the Vitom camera (Karl Storz) despite their length, unlike what usually will occur when using the OM. The Vitom 3D camera (Karl Storz) can be positioned more caudally and at a greater distance during this step, allowing for clear and focused visualization of the surgical field (Figure 6).

Supplementary Video 1 demonstrates how the Vitom 3D exoscope (Karl Storz) provides a high-quality 3D view of the surgical field, similar to that with a standard surgical microscope. allowing us to perform the surgical steps effectively and safely.

DISCUSSION

Although the use of exoscopes in neurosurgery dates back to the mid-1990s,[12] the first reported applications of the Vitom system (Karl Storz) in surgery were in gynecology in 2011.[13,14] In 2012, Mamelak et al.[15] reported their experience with the application of the Vitom visualization system (Karl Storz) in resecting a pineal tumor, using the supracerebellar, infratentorial route. They emphasized the good maneuverability of the system compared with the OM, which allowed for the maintenance of a comfortable position for the surgeon and avoided the need to overextend arms, which will usually be required by these challenging surgical approaches when performed with the OM.[15] Also in 2012, Shirzadi et al.[16] investigated the potential advantages of the Vitom system (Karl Storz) for in spine surgery. They performed a comparative analysis compared with the OM.[16] They could not demonstrate the superiority of either tool, because the surgical results were the same.[16] However, they noted the good image quality and ease of handling with the Vitom system (Karl Storz).[16] Subsequently, additional clinical experience with the Vitom system (Karl Storz) were reported, and its application was extended to urology and pediatric surgery.[17]

In 2014, Birch et al.[18] reported their experience with a small case series of 5 patients who had undergone the infratentorial supracerebellar approach for pineal tumors. They reported the superiority of the Vitom system (Karl Storz) compared with the OM with regard to surgeon comfort and minimizing the lack of stereopsis, considered by some investigators to be a "minor drawback."[18]

Recently, Krishnan et al.[10] reported a study describing the use of the Vitom system (Karl Storz) in several neurosurgical procedures, both spinal and cranial. Based on their institutional experience, the investigators reported that the exoscope has better potential than the microscope for visualization around corners. They also highlighted the need for technical and technological improvements to allow the exoscope to become the next-generation visualization tool. For example, the adjustments and refocusing maneuvers with the mechanical arm can be difficult and time-consuming.[10]

The introduction of 3D technology appears to be an important advancement in the development process of the Vitom visualization system (Karl Storz). The availability of stereoscopic vision overcomes one of the most relevant pitfalls of the previous Vitom system (Karl Storz) compared with the OM. In 2017, Oertel and Burkhardt[19] reported the results of the application of the Vitom 3D system (Karl Storz) in 11 spinal and 5 cranial procedures. They found an image quality comparable to that of the OM and suggested the use of the Vitom 3D system for less complex cranial surgical procedures.[19] Additional recent reports focused on the clinical use of the Vitom

3D system (Karl Storz),[20,21] emphasizing the advantages of 3D visualization combined with 4K image quality. Recently, Kwan et al.[22] focused on the application of the 3D exoscope system as a visualization tool during spinal procedures. They reported 4 cases of ACDF performed with exoscopic assistance, highlighting the advantages of the 3D exoscope in terms of ergonomics compared with the OM for spinal surgery. However, the report by Kwan et al.[22] did not provide surgical details regarding the different steps of ACDF (i.e., neck dissection, discectomy, endplates preparation, osteophyte drilling, cage insertion) performed with 3D exoscopic assistance.

We used the new 3D, HD visualization tool for anterior cervical discectomy and fusion. The Vitom 3D exoscopic camera (Karl Storz) was used during neck dissection, discectomy, osteophytectomy, and implant insertion. In particular, drilling of the posterior osteophytes is a key and delicate surgical step and usually requires the application of microsurgical techniques with adequate magnification and proper microscope angulation. V-shaped drilling of the posterior part of both the superior and the inferior one third of the caudal and cranial vertebral bodies, respectively, with the associated osteophytes, and extended lateral drilling of the posterior—medial surface of the uncinate process is crucial to achieving satisfactory neural structure decompression, even in multilevel ACDF cases.

One of the main advantages of Vitom 3D exoscope-assisted surgery (Karl Storz) compared with OM-assisted surgery is the possibility to generate 3D videos with the same surgical view and image quality used intraoperatively by the first surgeon. Therefore, the didactic capabilities and value of the surgical videos recorded with the 3D exoscope will be definitively greater, especially for training purposes.

The other advantages of the Vitom 3D exoscope (Karl Storz) are related to its small size compared with OMs. This allows for the comfortable use of the exoscope from the early steps of the ACDF surgical approach, such as cervical soft tissue dissection, neural structure decompression, and cage insertion, which requires free maneuverability of the screw and cage holders under direct vision. Such features provide excellent 3D visualization of the surgical anatomy, which will be very useful for residents and students observing the surgical procedure.

To date, neurosurgeons have used the OM both to perform surgery and to train other surgeons. However, although the microscope provides excellent illumination and magnification, its use has been mainly limited to 2 people: the surgeon and the assistant, the only ones who can really appreciate the quality and details of the surgical field images generated by the OM. In the operating room, the scrub nurse and visitors can watch the surgery on monitors but with only 2-dimensional images. Therefore, their perception of the surgical field depth and anatomical details could be lacking. In contrast, the 3D Vitom exoscope (Karl Storz) will allows the scrub nurse and staff in the operating room to easily follow the surgical procedure on 3D monitors, with better quality images and increased anatomical detail.

CONCLUSION

We believe that 3D Vitom exoscope-assisted surgery (Karl Storz) can be an alternative to microscope-assisted surgery in ACDF, providing equal surgical effectiveness and safety and high-quality visualization for surgeons, residents, and operating room staff.

ACKNOWLEDGMENTS

We wish to thank the Scientific Bureau of the University of Catania for language support.

REFERENCES

1. Cloward RB. The anterior approach for removal of ruptured cervical disks. *J Neurosurg*. 1958;15:602-617.
2. Smith GW, Robinson RA. The treatment of certain cervical-spine disorders by anterior removal of the intervertebral disc and interbody fusion. *J Bone Joint Surg Am*. 1958;40A:607-624.
3. Mayfield FH. Cervical spondylosis: observations based on surgical treatment of 400 patients. *Postgrad Med*. 1965;38:345-357.
4. Robinson RA. Fusions of the cervical spine. *J Bone Joint Surg Am*. 1959;41A:1-6.
5. Scoville WB. Types of cervical disk lesions and their surgical approaches. *JAMA*. 1966;196:479-481.
6. Hankinson HL, Wilson CB. Use of the operating microscope in anterior cervical discectomy without fusion. *J Neurosurg*. 1975;43:452-456.
7. Albanese V, Certo F, Visocchi M, Barbagallo GMV. Multilevel anterior cervical diskectomy and fusion with zero-profile devices: analysis of safety and feasibility, with focus on sagittal alignment and impact on clinical outcome: single-institution experience and review of literature. *World Neurosurg*. 2017;106:724-735.
8. Barbagallo GM, Romano D, Certo F, Milone P, Albanese V. Zero-P: a new zero-profile cage-plate device for single and multilevel ACDF: a single institution series with four years maximum follow-up and review of the literature on zero-profile devices. *Eur Spine J*. 2013;22(suppl 6):S868-S878.
9. Adogwa O, Elsamadicy A, Reiser E, et al. Comparison of surgical outcomes after anterior cervical discectomy and fusion: does the intra-operative use of a microscope improve surgical outcomes. *J Spine Surg*. 2016;2:25-30.
10. Krishnan KG, Schöller K, Uhl E. Application of a compact high-definition exoscope for illumination and magnification in high-precision surgical procedures. *World Neurosurg*. 2017;97:652-660.
11. Gildenberg PL, Ledoux R, Cosman E, Labuz J. The exoscope—a frame-based video/graphics system for intraoperative guidance of surgical resection. *Stereotact Funct Neurosurg*. 1994;63:23-25.
12. Gildenberg PL, Labuz J. Stereotactic craniotomy with the exoscope. *Stereotact Funct Neurosurg*. 1997;68(Pt 1):64-71.
13. Vercellino GF, Erdemoglu E, Kyeyamwa S, et al. Evaluation of the VITOM in digital high-definition video exocolposcopy. *J Low Genit Tract Dis*. 2011;15:292-295.
14. Vercellino GF, Chiantera V, Gaßmann J, et al. Prospective comparison of loop excision under colposcopic guidance versus Vitom guidance. *Geburtshilfe Frauenheilkd*. 2012;72:945-948.
15. Mamelak AN, Drazin D, Shirzadi A, Black KL, Berci G. Infratentorial supracerebellar resection of a pineal tumor using a high definition video exoscope (VITOM®). *J Clin Neurosci*. 2012;19:306-309.
16. Shirzadi A, Mukherjee D, Drazin DG, et al. Use of the video telescope operating monitor (VITOM) as an alternative to the operating microscope in spine surgery. *Spine (Phila Pa 1976)*. 2012;37:E1517-E1523.
17. Frykman PK, Duel BP, Gangi A, Williams JA, Berci G, Freedman AL. Evaluation of a video telescopic operating microscope (VITOM) for pediatric surgery and urology: a preliminary report. *J Laparoendosc Adv Surg Tech A*. 2013;23:639-643.

18. Birch K, Drazin D, Black KL, Williams J, Berci G, Mamelak AN. Clinical experience with a high definition exoscope system for surgery of pineal region lesions. *J Clin Neurosci*. 2014;21:1245-1249.

19. Oertel JM, Burkhardt BW. Vitom-3D for exoscopic neurosurgery: initial experience in cranial and spinal procedures. *World Neurosurg*. 2017;105:153-162.

20. Rossini Z, Cardia A, Milani D, Lasio GB, Fornari M, D'Angelo V. VITOM 3D: preliminary experience in cranial surgery. *World Neurosurg*. 2017;107:663-668.

21. Beez T, Munoz-Bendix C, Beseoglu K, Steiger HJ, Ahmadi SA. First clinical applications of a high-definition three-dimensional exoscope in pediatric neurosurgery. *Cureus*. 2018;10:e2108.

22. Kwan K, Schneider JR, Du V, et al. Lessons learned using a high-definition 3-dimensional exoscope for spinal surgery. *Oper Neurosurg (Hagerstown)*. 2019;16:619-625.

Conflict of interest statement: The authors declare that the article content was composed in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received 13 April 2019; accepted 6 June 2019

Citation: World Neurosurg. (2019) 130:e244-e250.
https://doi.org/10.1016/j.wneu.2019.06.049

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***

1878-8750/$ - see front matter © 2019 Elsevier Inc. All rights reserved.