

Combined transoral exoscope and OArm-assisted approach for craniovertebral junction surgery: Light and shadows in single-center experience with improving technologies

ABSTRACT

Background: The introduction of recent innovations in the field of intraoperative imaging and neuronavigation, such as OArm Stealth Station, allows to obtain crucial intraoperative data by performing safer and controlled surgical procedures. As part of the improvement of surgical visual magnification and wide expansion of surgical corridors, the 3D-4K exoscope (EX) represents nowadays an interesting and useful tool. Transoral approach (TOA) represents the historical gold standard direct microsurgical route to ventral craniovertebral junction (CVJ).

Methods: We herein report a preliminary experience on 6 cases of 33 patients operated by TOA concerning the simultaneous application of OArm with Stealth Navigation system (Medtronic, Memphis, TN) and imaging system along with the 3D-4K EXs in TOA for the treatment of CVJ pathologies.

Results: Neither intraoperative neurophysiological changes nor postoperative infections occurred, but a neurological improvement was evident in all the patients. A complete decompression along with stable instrumentation and fusion of the CVJ was accomplished in all cases at the maximum follow-up (mean: 16.8 months).

Conclusions: With EX, the role of surgeon become self-sufficient with a better individual surgical freedom compared to endoscopic surgery and excellent 3D vision and magnification. OArm allows an absolutely reliable intraoperative support for a more effective CVJ decompression. Nevertheless, with OArm-assisted neuronavigation, it can be difficult to navigate C1 lateral masses and C2 isthmi, and to convert 3D into 2D real-time navigation, it can become quite complicate. Finally, the association of EX and OArm appears more time consuming compared to the old fashion one.

Keywords: Craniovertebral junction, exoscope, OArm neuronavigation, transoral

MASSIMILIANO VISOCCHI, PIER PAOLO MATTOGNO, PASQUALINO CIAPPETTA¹, GIUSEPPE BARBAGALLO², FRANCESCO SIGNORELLI

Institute of Neurosurgery, Operative Unit, Research Center and Master II Degree Surgical Approaches Craniovertebral Junction, Fondazione Policlinico Universitario A. Gemelli IRCCS, Catholic University, Rome, ¹Department of Neurosurgery, University of Bari, Medical School, Bari, ²Departement of Neurological Surgery, Policlinico Gaspere Rodolico University Hospital, Catania, Italy

Address for correspondence: Dr. Pier Paolo Mattogno, Institute of Neurosurgery, Operative Unit, Research Center and Master II Degree Surgical Approaches Craniovertebral Junction, Fondazione Policlinico Universitario A. Gemelli IRCCS, Catholic University, Rome, Italy.
E-mail: pierpaolo.mattogno@policlinicogemelli.it

INTRODUCTION

Craniovertebral junction (CVJ) congenital or acquired compressive pathologies can lead to acute or chronic medullary damage.

Depending on the location, size, and nature of the disease, surgical approaches to CVJ have traditionally been addressed to the ventral, dorsal, and lateral aspects through a variety of 360° surgical corridors.^[1,2]

Submitted: 13-Oct-20

Accepted: 15-Oct-20


Published: 26-Nov-20

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How to cite this article: Visocchi M, Mattogno PP, Ciappetta P, Barbagallo G, Signorelli F. Combined transoral exoscope and OArm-assisted approach for craniovertebral junction surgery: Light and shadows in single-center experience with improving technologies. J Craniovert Jun Spine 2020;11:293-9.

Access this article online

Website: www.jcvjs.com	Quick Response Code 
DOI: 10.4103/jcvjs.JCVJS_176_20	

Transoral approach (TOA) represents the historical gold standard direct microsurgical route to ventral CVJ, in particular to the anterior portion of the lower clivus, the anterior arch of C1, and the odontoid and body of C2, with differences between patients due to individual anatomical variability.^[3-8]

The introduction of recent technological innovations in the field of intraoperative imaging and neuronavigation, such as OArm Stealth Station[®] (Medtronic, Memphis, TN), allows to obtain crucial intraoperative data by performing safer and controlled surgical procedures. As part of the improvement of surgical visual magnification and wide expansion of surgical corridors, the 3D-4K Exoscope (EX) represents nowadays a very interesting and useful tool.^[9,10]

The present paper describes the preliminary experience of the simultaneous application of OArm intraoperative neuronavigation and imaging system along with the 3D-4K EX in TOA for the treatment of CVJ pathologies. In this paper, We report the operative strategy related to this updated technical support, the advantages, the tip and tricks, along with possible disappointments, are reported; light and shadows, the efficacy and safety of surgical tools used are discussed according to personal experience and current literature.

METHODS

Our experience at the Department of Neurosurgery of Fondazione Policlinico Gemelli IRCCS, Catholic University, Rome, started in 1998 with CVJ instrumentation procedures and in 2011 with anterior decompressive transmucosal procedures both performed with classic operative microscope (OM), endoscopic microsurgical techniques, with neurophysiological (motor-evoked potential [MEP] and sensory-evoked potential [SSEP]), and neuroradiological (fluoroscopy and neuronavigation) monitoring.

Among 33 patients harboring irreducible CVJ compressive pathologies, 7 patients were operated on by transnasal approach and 25 patients underwent decompressive TOA up to date [Table 1].

For 19 TOA patients, a classic fluoroscopic monitoring along with endoscopic/OM magnification has been used.

In the past 2 years (January 2018), six patients harboring CVJ compressive pathologies underwent one-step combined anterior neurosurgical decompression and posterior instrumentation and fusion technique [Table 2]. After 3 days in

neurosurgical intensive care unit, all the patients underwent complete preoperative radiologic workup by means of magnetic resonance (MR), (computed tomography [CT]) scan, along with a 3D angiographic reconstruction of the epi-aortic vessels, and standard/dynamic X-ray evaluation of the CVJ.

Preoperative, short-lasting percutaneous tracheostomy was performed in all the six patients.

Technical armamentarium included for all – OArm-assisted Neuronavigation (Medtronic, Memphis, TN) and EX, in detail, two cases were operated with VITOM[®] 3D Exoscope (Karl Storz GmbH, Tuttlingen, Germany) and three cases were treated with ORBEYE[®] Exoscope (OLYMPUS, Tokyo, Japan). In the same operating theater, it was also available one OM for a possible use in emergency (OPMI Pentero or Carl Zeiss and Leica) and Endoscopy 0° and 30° (Karl Storz GmbH, Tuttlingen, Germany). Continuous intraoperative neuromonitoring by means of SSEPs and MEPs was performed in all the patients in both anterior and posterior procedures as well. Prophylactic antibiotics were administered intraoperatively and postoperatively (cefazoline 2 g/day). A nasogastric tube was used for enteral feeding for 1 week and percutaneous tracheostomy was removed in 10 days in all the patients. All the patients were discharged in 2 weeks.

The complete postoperative radiological set (MR imaging, CT scan, and X-ray assessment), obtained before discharge, was repeated every 3 months up to the complete bone fusion assessment.

Nurick's Grade at different time points was considered [Table 3]. Significant changes ($P < 0.05$) are marked with an asterisk according to one-way repeated-measures ANOVA.

Anterior surgical procedure

In the supine position, the head was placed in a 3-point skull fixation system (Mayfield Headrest) and the neck slightly extended.

The Crockard transoral distractor (Crockard Transoral Instrument Set; Codman and Shurtleff, Raynham, MA, USA) was inserted in the oral cavity and a preoperative 3D radiographic reconstruction with OArm Stealth Station (Medtronic, Memphis, TN) was acquired.

Under EX vision, a midline longitudinal incision on the posterior pharyngeal wall was performed, the longus colli and longus capitis muscles were mobilized laterally and held in place with tooth-bladed lateral pharyngeal retractors to expose the inferior clivus, anterior arch of C1,

Table 1: Characteristics of patient operated on by anterior transmuscular approach (transoral/transnasal) and posterior fusion

PT	Age (sex)	Primary disease	Treatment	Type of exoscope used	Posterior fixation procedure	Redo surgery	Operative time (min)	Follow-up (months)
CC 1	72 (female)	Impressio basilaris	Transoral decompression - C0-C3 reduction, instrumentation and fusion	Orbye olympus 4K	C0 C2 (laminae) C3 (lateral masses)	No	530	14
MT2	34 (female)	Down syndrome	Transoral decompression- C0-C3 reduction, instrumentation and fusion	Orbye olympus 4K	C0 C2 (laminae) C3 (lateral masses)	No	540	12
LL 3	73 (male)	Developmental anomaly C0-C1 with impressio basilaris	Transoral decompression - C0-C3 reduction, instrumentation and fusion	Orbye olympus 4K	C0 C2 (laminae) C3 (lateral masses)	No	525	14
AS 4	57 (male)	Retro-odontoid synovial cyst	Transoral decompression with cyst removal- C1-C2 reduction (goel fusion)	Storz vitom	C1 (lateral masses) C2 (isthmi)	C0 C3 (lateral masses) C4 (lateral masses)	510	18
LG 5	64 (female)	Impressio basilaris	Transoral decompression- C0-C4 reduction, instrumentation and fusion	Storz vitom	C0 C2 (lamina dx) C3 (lateral mass dx) C4 (lateral masses)	No	545	19
PC 6	67 (female)	Rheum. arthritis C2 fracture+dislocation 2cm	TransoralC1-C2 decompression combined C0-C2-C3screwing instrumentation and fusion	Storz vitom	C1(lateral masses) C2(isthmi) C3(lateral masses)	No	520	24

528±11.78 (mean operative time+SD in operated cases with exoscope and OArm), 468±7.4 (mean operative time+SD in operated cases without exoscope and OArm). SD: Standard deviation

Table 2: Subgroup of patients treated with exoscope and neuronavigation OArm-assisted

	Lights	Shadows
Exoscope	It allows a better magnification compared to the OM and an image screen transposition similar to the 4K endoscopic ones, without the need to handle any specific probe The role of surgeon become self-sufficient with a better individual surgical freedom compared to endoscopic surgery	A complex learning curve is necessary in order to spare time due to extra surgical maneuvers related to the frequent camera adjustments When facing with deep and narrow surgical fields, use of EX may lead to a decreased depth perception and increased operative time
OArm	It allows an absolutely reliable intraoperative support for a more effective CVJ decompression, allowing an appropriate and reliable real time neuronavigation OArm acquisition, comparing to fluoroscopy, permits an intraoperative direct and indirect assessment of bony and ligamentous CVJ anterior decompression	It is more time consuming and much more complex to use compared to 2D C-Arm. The planning as well as the organization of surgery results more difficult due the need to have the concomitant availability of specialized technical support It can misleads the surgeon when facing with C1-C2 posterior instrumentation procedures. In fact in some cases C1 lateral masses and C2 isthmi navigation may result very difficult and unreliable, due to extreme inclination of the target

CVJ: Craniovertebral junction, EX: Exoscope

and C2 vertebral body [Figure 1c]. Under magnification and neuronavigation, the inferior third, the anterior arch of C1, and the odontoid process along with a variable segment of the C2 body were removed using a high-speed drill and a dedicated Ultrasonic Surgical Aspirator probe (Sonopet® Ultrasonic Aspirator) [Figure 1d]. The transverse ligament, tectorial membrane, and any residual ligaments were removed, so decompressing the CVJ dura mater adequately. After that, further O-Arm acquisition was performed to verify and eventually complete decompression [Figure 1a and b]. The closure was obtained by approximating the three mucosal layers with 3-0 vicryl interrupted sutures.

Posterior surgical procedure

In the prone position, the head was placed in a 3-point skull fixation system (Mayfield headrest) and the neck slightly flexed; a preoperative 3D radiographic reconstruction with OArm (Medtronic) was acquired.

Under EX vision and magnification, by means of a midline linear incision, C0–C3 skeletonization was performed to expose posterior CVJ. With the aid of neuronavigation, a posterior instrumentation was variably performed. We used screws into the occipital crest in cases 1, 2, 3, 5, 6, and case 4 (redo surgery). On the other hands, C2 isthmic screws were put in cases 4 and 6, laminar screws in cases 1, 2, 3, 5, and

case 4 (redo surgery), in C3 lateral masses in cases 1, 2, 3, 5, 6, and case 4 (redo surgery). In one case, screws were put also in C4 (case 5) (OCT 2-VUE POIN® Nuvasive System). All the constructs were fixed with bilateral hinged rods [Table 2]. Bone Fusion was performed by decorticating the occiput and posterior arches of the cervical facet joints by high-speed drill and curettes, along with demineralized bone paste (Attrax® PUTTY Nuvasive) to stimulate bone fusion. Finally, further OArm acquisition documented the satisfactory placement of the stabilization system.

The clinical follow-up evaluation was performed according to the Nurick's Grade at different time points. According to one-way repeated-measures ANOVA, changes are considered significant when $P < 0.05$.

RESULTS

Neither intraoperative neurophysiological changes nor postoperative infections occurred, but a neurological improvement was evident in all the patients.

Table 3: Nurick's grade at different time points

Case	Preoperative	1 month	6 month	1 year	Maximum follow up
1 CC	3	2	2	2	2
2 MT	4	4	3	3	3
3 LL	3	3	2	2	2
4 AS	2	2	1	1	1
5 LG	2	2	1	1	1
Mean	2.8	2.6	1.8*	1.8*	1.8*
SD	0.83	0.89	0.83	0.83	0.83

*Significant changes ($P < 0.05$) are marked with an asterisk (one-way repeated-measures ANOVA). SD: Standard deviation

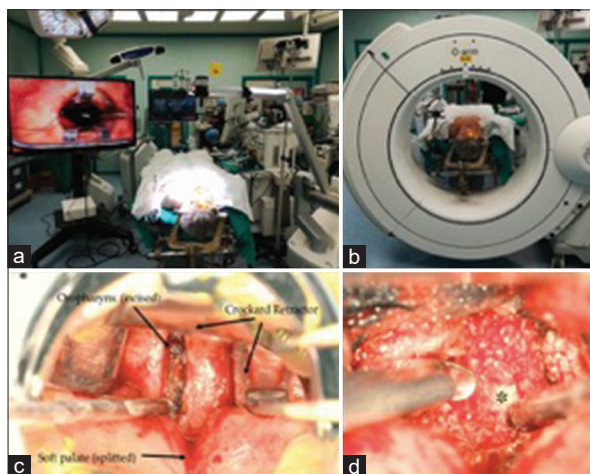


Figure 1: (a) Operating theater with Orbeye® Exoscope system and Medtronic Stealth Station® system. (b) OArm® medtronic acquisition. (c) Exoscopic vision of midline oropharynx incision with Crockard® spreader. (d) Intraoperative exoscopic view of odontoid ultrasonic fragmentation and suction: the dural layer (black star) is partially exposed

A complete decompression along with stable instrumentation and fusion of the CVJ was accomplished in all the cases at the maximum follow-up (mean: 16.8 months) [Table 1]. In two cases (case 1 and 3), OArm navigation allowed to identify residual compression was not clearly visible using the microscope alone. No dysphagia, dysphonia, and nasal regurgitation of fluids were present at the latest follow-up except the progressive disappearance of nasal regurgitation in case 2, harboring a Down Syndrome, with severe preoperative disturbances. Postoperative X-rays and CT showed a correct (except for patient 4 in whom it was suboptimal) hardware system positioning. MR confirmed the effective decompression of neural structures in all the patients, with a variable reduction of the bulbomedullary junction hyperintensity when present [Figure 2].

In four cases, it was not possible to navigate C1 lateral masses and C2 isthmi due to target the obliquity unfitting with the neuronavigation optical system, so misleading the surgeon and strongly suggesting to change surgical strategy intraoperatively (occipitocervical with C2 laminar and C3 lateral masses screwing). In another case (case 4), it was possible to navigate and to perform both C1 lateral masses and C2 isthmi screwing, resulting in suboptimal screws placement at the immediate postoperative assessment. In this case, the hardware dislodgment occurred 2 months later requiring the only posterior redo surgery performed in the present series.

The mean operation time (overall considering the two procedures) was 528 min ± 11.78 in cases with EX and OArm

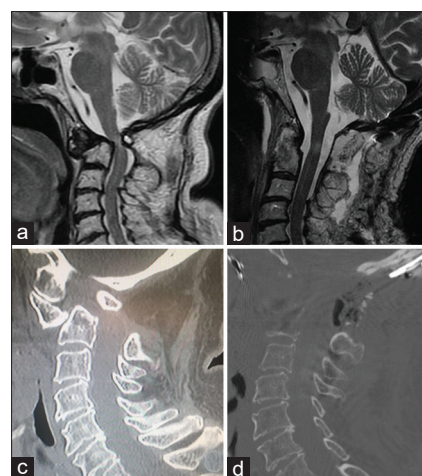


Figure 2: Pre- and postoperative sagittal MRI (a and b) and CT scan (c and d) showing severe atlantoaxial disalignment with detachment of the odontoid with severe stenosis caudally to the foramen magnum and myelopathy (a and c). Panel b and d show anterior decompression of C1, removal of os odontoides, with marked enlargement of the occipital foramen and disappearance of the stenosis. MRI: Magnetic resonance imaging, CT: Computed tomography

and 468 min \pm 7.4 in cases previously published without EX and OArm (difference 60 min). No clinical worsening was reported. All the patients significantly improved according to the Nurick Score at the maximum follow-up [Figure 3 and Table 3].

DISCUSSION

3D-4K exoscope

In recent years, surgery has been enriched with the introduction of new tools, which are representing a “revolution” in operating techniques. In the neurosurgical field, the EX represents one of the technological innovations that most attracts a growing interest among neurosurgeons: EX has characteristics not inferior to the most modern surgical microscopes, featuring high definition (HD) magnification, an immersive vision of the operating field, a wide focal distance, and the presence of built-in filters very useful in the course of oncologic surgical procedures (i.e., 5-ALA, indocyanine).

In addition, 3D technology allows the surgeon to recover and improve the stereopsis that is generally experienced with OM. Moreover, the holding arm allows extreme freedom of movement and modification of the surgical corridor, enhanced by the possibility of making micromovements and adjustments through a foot pedal controller.^[9-11] In terms of ergonomics and surgical setup, the EX is much less bulky and manageable than the OM and allows surgeons to have more surgical space and a more ergonomically correct position for both the first surgeon and the assistant surgeon.^[12,13]

Several papers in the literature present preliminary experiences in the application of EX to microneurosurgery, both in studies on animal and cadaveric models, and *in vivo*, specifically in the field of neuroncology, vascular surgery, skull base surgery, and minimally invasive spine surgery.^[14-22]

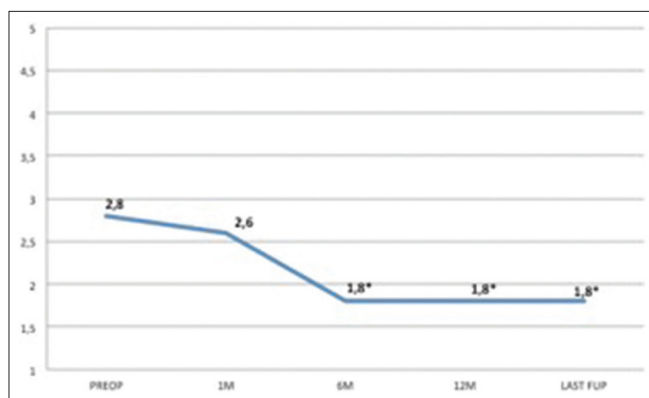


Figure 3: Nurick's Grade at different time points. Significant changes ($P < 0.05$) are marked with an asterisk in the graph

After an initial adaptation phase and a learning curve, the surgeons' first impression shows excellent feedback, both in terms of a wide range of movements and an evident improvement in terms ergonomics and the possibility of surgical angles not possible with the traditional OM.^[12,13]

Concerning spine surgery, several papers have described the use of EX mainly for noninstrumented or instrumented posterior thoracolumbar approaches; significantly fewer reports describe anterior approaches to the cervical spine.^[14]

To our knowledge, only a case series of 3D Ex-assisted TOA for oropharyngeal cancers or infection is reported in the literature.^[15]

The two surgical EXs we used in our procedures were the VITOM[®] Exoscope (Karl Storz, Tuttlingen, Germany) and the ORBEYE[®] Exoscope (Olympus, Tokyo, Japan). Recent papers compare the technical characteristics, advantages, and disadvantages of the two EXs.^[11] Both instruments feature the telescopic function with HD-4K 3D magnification, with a comparable zoom capability ($\times 8$ – 30 Vitom vs. $\times 26$ Orbeye). However, in our experience, ORBEYE[®] displayed a significantly greater focal length (220–550 vs. 20–50 mm). with this feature, although it is more recumbent, it can be placed distant from the operating field and is not intrusive or hindering for surgeons. Furthermore, ORBEYE[®] EX is equipped with a pneumatic arm with assisted movement; for this reason, it is much easier to mobilize than VITOM[®]; furthermore, through the foot pedal, it is possible to carry out very useful coaxial micromovements of the optics.

In our experience, both the instruments have satisfied in terms of use, magnification, and 3D definition although the presence of the fixed arm of VITOM[®] represented the major limit, during the procedures, for the need to often mobilize the surgical viewing angle.

OArm neuronavigation and intraoperative system

In spinal surgery, the introduction of OArm system has improved the safety of instrumentation procedures, allowing much more accurate intraoperative neuronavigation than traditional techniques;^[10] moreover, the setting with intraoperative imaging allows a real-time verification of the effectiveness of the procedure, such as in cases of medullary decompression or the correct positioning of arthrodesis systems.^[23,24]

In CVJ surgery, OArm acquisition, comparing to fluoroscopy, has the obvious advantage of a better definition with a resulting easier screws insertion; furthermore, it permits

an intraoperative direct and indirect assessment of bony and ligamentous CVJ anterior decompression. In two of six cases, after OArm acquisition, the craniocaudal decompression was augmented because it proved to be suboptimal in an absolutely reliable and anatomically detailed way. Otherwise, in our previous experience concerning fluoroscopic monitoring of TOA, the use of Iopamiro, as contrast filler of the surgical cavity, allowed in a quite fair way to, indirectly, evaluate possible residual compression at the CVJ [Figure 4].^[4,25] However, it does not provide a real-time visualization.

Finally, the possibility to convert the intraoperative neuronavigated 3D modality into 2D real-time OArm monitoring is very uncomfortable due to the poor space available for the surgeon (also in the presence of EX) and the need of complex, time-consuming, and ineffective surgical maneuvers required.

Therefore, sufficient experience in posterior CVJ complex surgery and confidence with OArm navigation are needed to safely perform this procedure, as demonstrated by a longer (60 min) mean operation time of this series compared to the personal previous data published.

Finally, by reviewing the current literature, this is the first report of a clinical simultaneous OArm intraoperative neuronavigation along with the 3D-4K EX use in TOA. Lights and shadows of both are discussed below and summarized in Table 2.

3D-4K exoscope lights

1. EX allows a better magnification compared to the OM and an image screen transposition similar to the 4K endoscopic ones, without the need to handle any specific probe
2. In such a condition, the role of surgeon become self-sufficient with a better individual surgical freedom compared to endoscopic surgery.

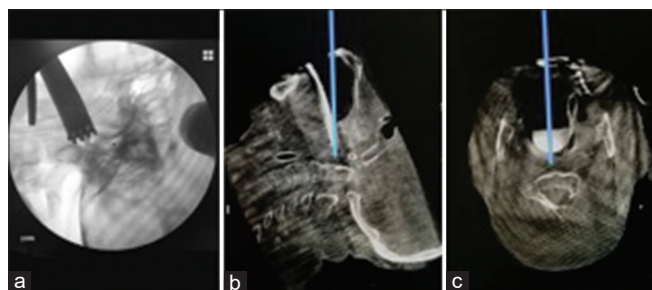


Figure 4: (a) Metrizamide fluoroscopic intracavitary assessment of the degree of bone removal at C1–C2. (b) Intraoperative OArm neuronavigation tracking in sagittal reconstruction. (c) Intraoperative OArm neuronavigation tracking in axial reconstruction

3D-4K exoscope shadows

1. A complex learning curve is necessary to spare useless time-consuming extra surgical maneuvers related to frequent camera adjustments
2. When facing with deep and narrow surgical field, as transoral surgery, the use of EX may lead to a decreased depth perception and consequently increase the operative time.

OArm neuronavigation system lights

1. OArm allows an absolutely reliable intraoperative support for a more effective CVJ decompression. In fact, it allows a reliable decompression assessment and an appropriate and reliable real-time neuronavigation compared to preoperative neuroradiological CT and/or MR neuronavigation
2. OArm always allows axial, sagittal, and coronal intraoperative reconstructions compared to standard preoperative neuroradiological CT and/or MR neuronavigation, which rarely has a preoperative coexisting navigable axial, sagittal, and coronal image assessment.

OArm neuronavigation system shadows

1. OArm is more time consuming and much more complex to use compared to 2D C-Arm as well as preoperative neuroradiological CT and/or MR assessment neuronavigation
2. The planning as well as the organization of surgery results more difficult due the need to have the concomitant availability of specialized technical support
3. OArm can mislead the surgeon when facing with C1–C2 posterior instrumentation procedures. In some cases, navigation of C1 lateral masses and C2 isthmi appears quite impossible; infact the extreme inclination of the target can make difficult to the wand to communicate with the receiver (main antenna of the neuronavigation system); in such a situation, it seems very complicated to convert 3D into 2D real-time navigation due to the limited space offered to the surgeon by the OArm compared to the one offered by the C-Arm continuous fluoroscopy.

CONCLUSIONS

Although light and shadows of such an association are shown in our experience, the possible advantages of the simultaneous use of 3D-4K EX and OArm intraoperative neuronavigation deserve consideration.

Adding technology to technology does not always add knowledge.

Nevertheless, the operative improvement of 3D-4K EX and OArm association in the future TOA will provide further tips and tricks parallel to the progressive growth of personal experience.

Future experiences dealing with such simultaneous applications in CVJ surgical field will provide new knowledge, so implementing current literature and proposing more effective suggestions to overcome actual shadows.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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