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ABSTRACT

Background: The incidence of fractures in the upper cervical spine is a common entity among elderly patients. The incidence depends on the health care system and the adopted protocols for a computer tomogram in the emergency unit, in order to assure an easier and earlier detection. Injuries to the vertebral artery could occur with devastating consequences, due to this type of fracture. The aim of the current surgical strategies is to stabilize the fractures and avoid further injuries to the vertebral arteries.

Methods: We adopted a previously hypothesized method for intraoperative imaging of the vertebral artery when performing an O-Arm navigated cervical osteosynthesis. Three patients were included in this group: one patient with dens fracture type II after Anderson and D'Alonzo, one patient with a complex C1/C2 fracture and dissection of the vertebral artery on the left side and one patient with a kyphotic deformity due to Larynx carcinoma Metastasis in C4-C6. After positioning the patients, a 100 ml contrast was applied prior to the primary O-Arm scan, thus obtaining real-time imaging of the vertebral artery in the navigational CT series.

Results: A total of 18 screws were placed. None of the screws bridged the vertebral canal. The average operative time was 174 mins. No new neurological deterioration was observed in the postoperative period.

Conclusions: With the development of this technique, it is possible to reduce the surgery-related injury of the vertebral artery to 0%. Further studies are necessary to assess the feasibility of this technique. This technique could be especially helpful in the cases of distorted anatomical relations.

INTRODUCTION

The incidence of fractures in the upper cervical spine in elderly patients (>65 years) after trauma lies between 1,26% and 3% (Squarza, Uggetti et al. 2019). The precise incidence of those fractures is hard to be determined because it depends on the health care system in every

Keywords

vertebral artery,
cervical osteosynthesis,
hangman fracture,
spinal fractures,
spine,
cervical vertebrae



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country and the adopted protocols for emergency computer tomogram (CT) in every emergency department. Robinson et al. reported an increase in the incidence of C2 fractures from 3 to 6 per 100 000 from 1997 to 2014 (Robinson, Olerud et al. 2017), which corresponds to the development of strict protocols for emergency CT of cervical spine in the elderly population. CT has turned to be golden standard for detection of fractures of the upper cervical spine with ability to detect up to 99% of the fractures (Acheson, Livingston et al. 1987). Due to the alternations of the in the upper cervical spine, including reduced bone density and increased rigidity, upper cervical spine is more susceptible to flexion, extension, rotation traumas.

The incidence of the vertebral artery injuries (VAI) after trauma is reported to be between 0, 5% and 88% (Willis, Greiner et al. 1994, Gleizes, Jacquot et al. 2000, Fassett, Dailey et al. 2008, Mueller, Peters et al. 2011) The majority of those VAI remain clinically silent, but this injury could lead to major stroke and neurological deterioration. The mortality rate following VAI reported in the literature varies from 8% to 18% (Fusco and Harrigan 2011). Up to 70% of the traumatic VAI have an associated cervical spine fracture (Miller, Fabian et al. 2001). Three major diagnostic methods are available for detection of VAI, including duplex ultrasonography (sensitivity 38,5%, specificity 100%), magnetic resonance angiography (sensitivity 43%, specificity 97%) and computer tomography angiography (CTA) (sensitivity 53%, specificity 99%) (Eastman, Chason et al. 2006, Harshavardhana and Dabke 2014), whereas the duplex ultrasonography is not reliable for detection of intimal tears. The treatment options of VAI include: 1. Observation, 2. Anticoagulation, 3. Surgery (Nizare, Abdelali et al. 2013, Harshavardhana and Dabke 2014).

The treatment modalities for upper cervical spine fractures (c-spine) vary from halo-fixation to surgery, including fixation with hooks and rods, wiring, transarticular screws fixation, lateral mass screw fixation or ventral fusion (Vergara, Bal et al. 2012). For the treatment of C1/C2 fractures, the lateral screw fixation (Goel/Harms technique) and the transarticular screw fixation (Magerl technique) have shown a superior fusion rate, thus gaining more acceptances among the spine surgeons. Both of these techniques could be performed free-hands, with C-arm fluoroscopy or with navigation for 3D

imaging (O-Arm, C-Arm with integrated navigation). The postoperative complications rate in Goel/Harms technique is reported up to 10,6% and in Magerl technique up to 21%(Neo, Sakamoto et al. 2005). The risk for vertebral artery injury, when performing either of both techniques is between 8% and 9,5% (Yeom, Buchowski et al. 2013, Pavlov, Mirchev et al. 2020) when using C-Arm fluoroscopy. To our knowledge, the incidence of vertebral injury during dorsal stabilization with O-Arm navigation or free-hands is unknown.

We already suggested a possible novel technique for the intraoperative visualization of the vertebral artery using hybrid technique from two visualization modalities: O-Arm navigation and CT-Angiography (CTA) (Weller, Rossitch et al. 1999). The core of this technique lies in the administration of intravenous contrast (as for a common CTA) before the intraoperative CT, which is performed by the O-Arm navigation. The aim of this hybrid technique is to bring the intraoperative injuries of the vertebral artery to 0% (Pavlov, Mirchev et al. 2020). To our knowledge, this technique has not been published up to the date of the submission of this paper and we would present the first three cases, utilizing this method.

MATERIAL AND METHODS

In our pilot group, three patients were included: Case1, Case 2 and Case 3. A number of possible contraindications have to be considered: known allergic reaction to contrast, uncooperative patients and pregnant patients. In none of the patients, contraindications for this hybrid technique were found. Consent of the patients was obtained prior to surgery. To perform this surgical technique, the following protocol was used(Pavlov, Mirchev et al. 2020):

1. Indications/Contra-indications for this technique, careful anamnesis has to be taken for allergies against contrast.
2. Prone positioning, patient is positioned in the carbon Mayfield clamp, in order to reduce the artifacts from the intraoperative CT
3. O-Arm navigational system positioning over the targeted area, the position is saved and the O-arm needs to be brought to parking position, in order to ensure a maximal working space for the surgeon.

4. Surgical approach to the target area (C1/C2 complex or upper cervical spine)
5. Re-positioning of the O-Arm navigation over the area of interest
6. Bolus manual application of contrast-100ml through central line, 5 seconds before the intraoperative scan for optimal visualization of the vertebral artery and eliminating the venous contrast artefacts.
7. Ventilation pause and carrying out an intraoperative CT scan, then the data is transferred to the surgeon's monitor
8. Screws insertion under 3D guidance with intraoperative visualization of the vertebral artery
8. Ventilation is paused and another intraoperative CT scan is carried out to verify the correct position of the screws.
9. Wound closure

CASE 1

Diagnosis: Dens fracture Type II Anderson and D'Alonzo

Surgical strategy: Dorsal osteosynthesis in Goel/Harms technique C1-C2

Brief summary of the patient's history: A 95-years old patient, in a good clinical condition, presents herself in our emergency room after falling from her sofa backwards. She complained pain in the dorsal region of the c-spine without neurological deficits. The anamnesis showed pre-existing strokes in the left and right medial cerebral artery.

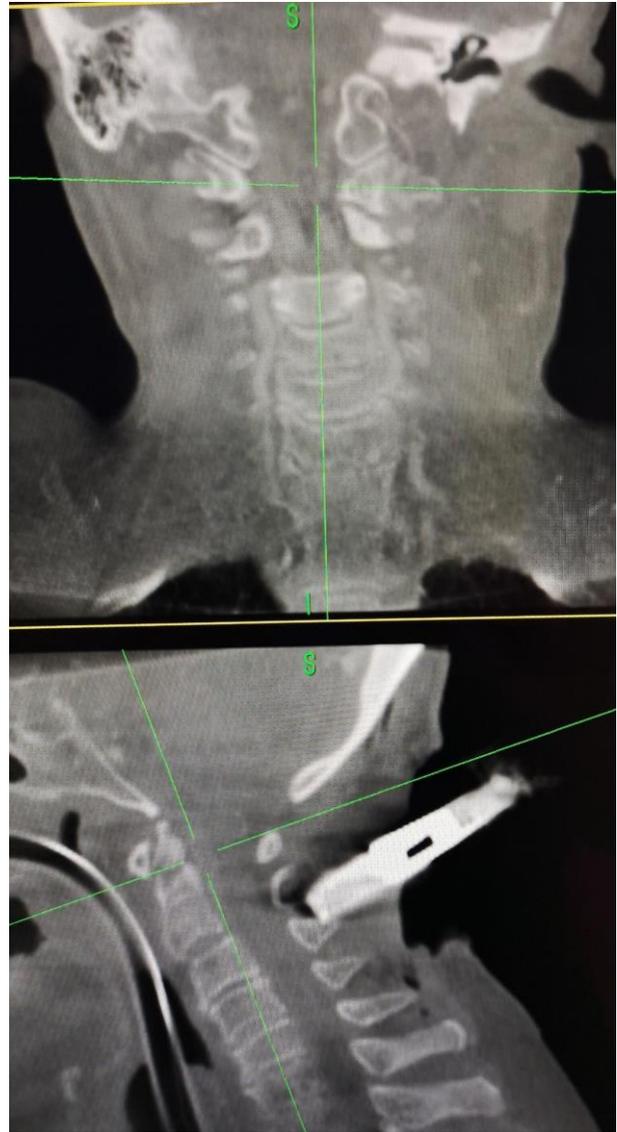


Figure 1 and 2. 3D Data with intraoperative imaging of the vertebral artery

The trauma scan depicted dens fracture type II after Anderson and D'Alonzo classification. The surgery was indicated and after obtaining patient's consent, the surgery was carried out on the 2nd day after the admission of the patient.

The indication for applying contrast, during the surgery, in this patient was based on the pre-existing strokes, suggesting progressive atherosclerosis, and a sufficient kidney function (glomerular filtration rate- 71ml/min and creatinine 1,3 mg/dl).

The application of contrast allowed a good intraoperative imaging of the vertebral artery, optimal length of the screws was chosen without risking a vascular injury (Fig 1-3).



Figure 3. 3D Intraoperative navigation with direct imaging of the vertebral artery

CASE 2

Diagnosis: Complex C1 fracture (Jefferson fracture II)/ C2 fracture (Hangmann fracture) and a. vertebralis dissection links

Surgical strategy: Dorsal fusion in Goel/Harms technique C1/C2 and massa lateralis screws in C3

Brief summary of the patient's history: A 79-year old patient presented at our emergency room after a 6 fall from a roof. The patient complained pain in the dorsal region of the cervical pain without radiculopathy or myelopathy. The neurological examination showed normal neurological status. The anamnesis depicted no pre-existing health issues.

The trauma scan depicted a complex C1/C2 fracture, where the consecutive CTA showed a dissection of the vertebral artery on the left side. Because of the dissection of the vertebral artery, the patient was put on antiplatelet therapy with aspirin. Surgery was indicated and after obtaining the patient's consent, it was carried out on the 7th day.

The indication for applying a contrast in this patient was based on the previous traumatic injury of the vertebral injury on the left side and preserved

kidney function (glomerular filtration rate- 69ml/min and creatinine 1,5 mg/dl).

During surgery, after the application of contrast and after carrying out the intraoperative CT, the occlusion of the left vertebral artery was still visible (Fig. 4).

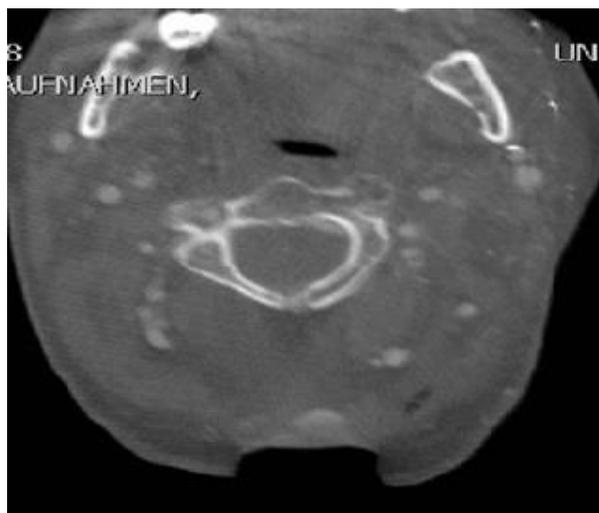


Figure 4. Intraoperative CT Navigation with contrast, performed with O-Arm, where dissection of the left vertebral artery is still visible

Polyaxial screws on both sides in massa lateralis and in the pedicles were placed. The postoperative condition of the patient deteriorated due to postoperative delirium, which was treated with atypical antipsychotic (Risperidone) and Benzodiazepines (Diazepam).

The postoperative c-spine CT showed an optimal placement of all screws.

CASE 3

Diagnosis: Larynx carcinoma Metastasis C4-C6, cervical instability and kyphotic deformity C4-C6

Surgical strategy: Dorsal osteosynthesis (massa lateralis and pedicle screws) C3-D1

Brief summary of the patient's history: The case of the 57-years old patient with larynx carcinoma was discussed at Neuro-Oncological Board due to a new metastasis in the c-spine with progressive deformity. The patient complained pain in the middle cervical spine with irradiation of the pain in shoulders. The neurological examination showed intact neurological status. The patient had tracheostoma because of the larynx carcinoma, making a ventral approach to the C-Spine not possible.

An MRI and CT of the c-spine showed destructive process in C4 to C6 with kyphosis, without tumour bridging in the spinal canal. After interdisciplinary discussion of this case, regarding life-expectancy, neurological outcome and patient's will, surgery was indicated.

After obtaining patient's consent, the surgery was carried out on the 3rd day after admission.

The indication for applying intraoperative contrast was based suspicion of tumour infiltration on left vertebral canal C4-C6.

The intraoperative CT-navigation with contrast depicted a tumour mass from C4 to C6, infiltrating the left vertebral canal, without pressuring the artery.

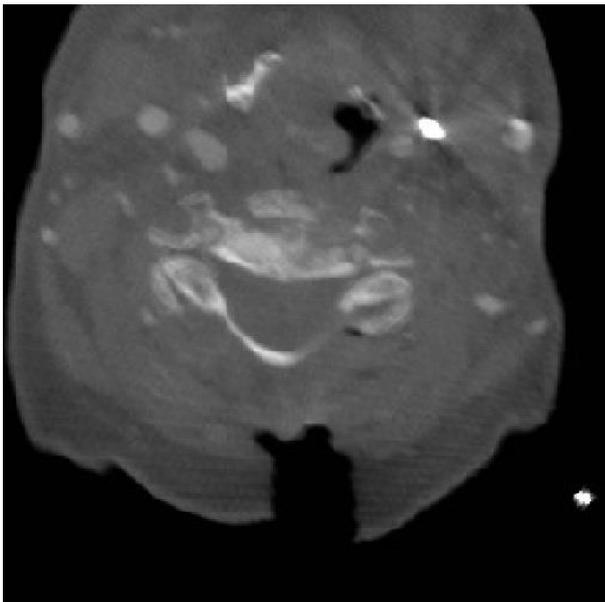


Figure 4. Tumour infiltration in the left vertebral canal C5

After the screw insertion, a second scan was carried out. The second scan depicted a perfect positioning of the screws, unfortunately the vertebral artery was not visible any longer (94 minutes after the initial scan) Fig.8.

Postoperatively the patient recovered well and was discharged on the 7th day.

RESULTS

A total of 18 screws were placed (massa lateralis or pedicle screws). None of them breached the walls of vertebral canal. The average operative time was 174 minutes in the three surgeries.

Using this imaging technique, the vertebral artery was depicted from segment V1 to segment V3, without discontinuity in any of the vertebrae levels. On the second scan, in none of the cases, the vertebral artery was visible any longer.

DISCUSSION

The interest of fusion techniques in intraoperative neuroimaging exists for a long time, especially when vascular structures are involved. Leng *et al.* were the first to describe the fusion between intraoperative three-dimensional rotational angiography and flat panel detector computed tomography for cerebrovascular navigation. (Leng, Rubin *et al.* 2013) In this case report, the treatment of a patient harbouring two aneurysms was described, using this fusion/hybrid technique. Although, it is not obligatory to use this technique, this method adds to the arsenal of surgical strategies, which could be used for intraoperative support. Since both the c-spine trauma and the stabilisation technique independently add up to the risk of VAI, it is mandatory to utilize all the possible techniques to preserve the functional vertebral artery, in order to avoid further neurological deterioration. In all patients, where VAI is suspected, aggressive actions need to be taken, in order to confirm the diagnosis because of its therapeutic significance.

The preoperatively obtained CT/CT-Angiography is a valid method for intraoperative navigation in trauma cases. Fiorenza *et al.* conducted a retrospective study in a series of 21 patients, who underwent a posterior upper cervical spine fixation using a navigational system with intraoperative single level vertebral registration on preoperative CT/CT-Angiography (Fiorenza and Ascanio 2019). No neurovascular damage occurred in any of the patients. In the treatment of upper cervical trauma cases, however, it is not mandatory to conduct a preoperative CT-Angiography (Lockwood, Smith *et al.* 2016). The development of strict protocols for CT-Angiography in trauma patients is still in development. Lockwood *et al.* presented one of the most significant studies for CT-Angiography in patients with upper cervical spine, up to date (Lockwood, Smith *et al.* 2016). Using the Denver Criteria (Biffl, Moore *et al.* 1999, Kerwin, Bynoe *et al.* 2001, Cothren, Moore *et al.* 2003, Parks and Croce 2012) for high risk fracture pattern, the authors analysed 1435 patients, where only combined C1-C2

fractures, subluxations and transverse foramen involvement were predictive for VAI. The odds for developing of VAI were 3,8, 4,8 and 6,3 respectively. Of the 1435 patients with cervical spine fractures, only 10 (0,7%) suffered from posterior circulation stroke(Lockwood, Smith et al. 2016).

The preoperative CT-Angiography gives the surgeons valuable information about the position of the vertebral artery and its position the osseous structures. However, it is interesting to point out, that many studies have shown, that VAI shown in preoperative CT-Angiography and applying treatment (anticoagulation or antiplatelet therapy) does not prevent stroke (Eastman, Chason et al. 2006, Scott, Sharp et al. 2014, Lockwood, Smith et al. 2016). This data would suggest that the obtained CT-Angiography would not have any effect on the neurological outcome of the patients after trauma. The use of our suggested technique shows a real-time intraoperative visualization of the vertebral artery. One must consider that the patient's head is fixated in a rigid collar for the CT-Angiography and prior to the operation, the collar is taken off and patient's head needs to reclined and fixated in Mayfield for the posterior fixation. In this manoeuvre, the position of the vertebral artery does not change in respect to the osseous anatomy, however its blood flow could be changed because of kinking due to fractures (George and Carpentier 2001, Berti, Zafar et al. 2018). Our suggested technique could provide the surgeon with certainty, that prior to the screw insertion, that both of the vertebral arteries are intact. O-Arm navigation has also shown to reduce the operative time, in comparison with the preoperative scans with image guidance (Costa, Cardia et al. 2011) and to reduce the radiation exposure compared to fluoroscopic guidance(Costa, Cardia et al. 2011, Nottmeier, Pirris et al. 2013). Performing intraoperative CT at the end of the procedure, reduces the need to return the patients to the operating room.(Van de Kelft, Costa et al. 2012)

Associated atlas and axis fractures account for 3% of acute cervical spine lesions and 12% of the upper cervical spine lesions (Jung, Jung et al. 2010), where the normal anatomy of the C1/C2 complex is altered, with possible displacement of the vertebral artery. In those cases, even with conventional O-Arm navigation, an injury of the vertebral artery is

possible, even with 99,9% accuracy of the screw positioning(Bydon, Martin Ma et al. 2014).

Tumours of the craniocervical junction (CCJ) represent a challenging entity for the neurosurgeon(Bydon, Martin Ma et al. 2014). Bydon et al. showed that the rate of vertebral artery involvement significantly effects the rate of radical resections of the tumours, located in the CCJ. The patients without involvement of the artery had a total resection, statistically significant to those with involvement of the vertebral artery. Pirotte et al. and Talacchi et al. showed that aiming for a total resection of the tumors in CCJ, which involve the vertebral artery, is related to many postoperative complications, including lateromedullary infarction, respiratory failure, cranial nerve palsy, etc.(Pirotte, Brotchi et al. 2010, Talacchi, Biroli et al. 2012). With this technique for intraoperative imaging of the vertebral artery, it could be possible to increase the percentage of tumor resection, extending the life-expectancy, tumor-free period. Kern et al. were the first to use O-Arm navigational system in 2014 for resection of a chordoma in CCJ, however no angiography was performed at the time(Kern, Indro et al. 2014). Because of the distortion of the normal bony structures due to the tumor, it is difficult to appreciate intraoperatively many important landmarks. The use of O-Arm navigation has proven to be a valuable tool in the tumor resection process.

The developed in John Hopkins University algorithm by Sciubba et al.(Sciubba, Mavinkurve et al. 2006), proved successful in treatment of hemangioblastomas in the cervical spine. 3D digital subtraction angiography provides high-resolution images of the vascular structures, however often it does not provide reliable anatomical information about the nearby osseous structures, or in the cases, when it does, resolution of the vascular anatomy in the immediate vicinity of bone sacrificed. (Sciubba, Mavinkurve et al. 2006) The authors used a novel angiographic reconstruction by combining two separate sequences of images of bone and blood vessels in a single 3D Fusion Imaging series. Although, only two case reports were presented by the authors, the need for a better osseous intraoperative imaging is noted. Su et al. already used this fusion technique between O-Arm and on-table angiography for the resection of the occipitocervical tumor in 12/2020, independently from our published hypothetical usage of this

method in 02/2020(Pavlov, Mirchev et al. 2020, Su, Prezerakos et al. 2020). This facilitates safe resection by mapping the surgical field occult to direct vision.

There are two major factors for injury of the vertebral artery, when performing a cervical osteosynthesis: High riding vertebral artery (HRVA), as an anatomical variant and narrow pedicle of the C2 vertebrae(Wang, Xia et al. 2013, Wajanavisit, Lertudomphonwanit et al. 2016). Both of these factors could be present in the setting of spinal trauma or tumor in the CCJ.

Morin et al. demonstrated the close relationship between traumatic brain injury (TBI) and the cervical spine involvement (Morin, Langevin et al. 2016) and thus the neurological outcome. Outcomes from TBI can be temporary or permanent dysfunction of cognition, motor function, physiology, and psychology (Blennow, Hardy et al. 2012) and post-TBI neurological disorders such as posttraumatic epilepsy, chronic traumatic encephalopathy and dementia (Papa, Mendes et al. 2012, Cotter, Kelso et al. 2017). The resulting costs for the treatment of these patients are increased exponentially. The patients with extracranial involvement (c-spine fractures, lung contusion, etc.) have worse outcome, compared to the patient without additional injuries(Konar, Pavlov et al. 2020).

The learning curve for a posterior fixation in the upper cervical spine represents a steep due to the complex anatomy of the CCJ, subaxial spine and its neurovascular relations (Heo, Lee et al. 2019). The proposed technique could improve the learning curve, making the posterior fixation easier for the young neurosurgeons. With the better understanding of the anatomic relations of the bones to the neurovascular structures, one would improve the operating time and minimize the blood loss.

CONCLUSIONS

With the development of this technique, we do not aim to set it as a "golden standard" for the treatment of pathologies in the c-spine. We would suggest that this technique would be "good to know" in the cases, where it is needed. Since we present only a technical note, no statistical analysis is carried out.

In the setting of polytrauma or multitrauma, where a cervical dorsal osteosynthesis is required, all measures for reducing the risk for additional injuries need to be considered. The procedure-associated

risk for additional neurological deficit, due to injury of the vertebral artery, must be kept as low as possible. This technique offers the possibility for a real-time intraoperative imaging of the vertebral artery and thus protecting it.

This is a pilot cohort of patients with very promising results. Further studies will be carried out to confirm the diminished rate of VAI, to compare the average blood loss, operation time, perioperative mortality and morbidity between the patients undergoing c-spine dorsal osteosynthesis with and without this technique.

DISCLOSURES

No disclosures

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