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Image-Guided Navigation in Anterior Cervical Spine Surgery using a Cranial Frame

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ABSTRACT

Background Data: Cervicothoracic, high thoracic, and craniocervical instrumented anterior spinal procedures pose a considerable challenge to the surgeon, mainly because intraoperative imaging by fluoroscopy is inadequate. To a certain extent the surgeon can make use of 3D-fluoroscopy for intraoperative control of the implants. To ease this process, the surgeon can make use of the so-called cranial frame which is attached to the Mayfield clamp, in combination with navigated 3D-fluoroscopy. The use of the cranial frame for navigated anterior craniocervical approaches as in the case of transnasal procedures at the clivus and foramen magnum is quite widespread. In the literature, the use of this technique for spine approaches is limited to a few case reports.

Purpose: To present the feasibility of 3D-fluoroscopy navigation in anterior cervical spine procedures with the use of cranial frame.

Study Design: Retrospective clinical case cohort.

Patients and Methods: We present our experience in the technique of navigation in 5 patients of anterior cervical spine procedures. Anterior instrumented fusion in the cervicothoracic spine was performed in 4 patients and in the last patient anterior C1/2 fixation was performed. We used a system composed of Arcadis Orbic 3D C-arm by Siemens Medical Solutions, Erlangen, Germany, for acquisition of 3D images and the Stealth Station system by Medtronic Inc., Louisville, USA, for navigation. We used a so-called cranial frame for navigation that is fixed to the Mayfield head holder; a preoperative 3D scan was performed in some patients. The intraoperative 3D scan was performed after removal of the retractors, and additional 3D scan was beneficial in some patients during the surgical procedure.

Results: Navigation was helpful in identification of the entry points and trajectories of the screws especially in the cervicothoracic region with no need for fluoroscopy. Additional advantage of the use of this system is the possibility of performing intraoperative 3D scan after instrumentation to verify hardware placement.

Conclusion: The illustrated cases demonstrate the advantages of 3D-fluoroscopy navigation with use of the cranial frame in the upper transitional zones. Disadvantages of this method are the complex intraoperative draping and logistics and the possible inaccuracy because of long distances and spinal mobility. Carbon Mayfield may facilitate positioning but is not mandatory. (2018ESJ173)

Keywords: navigation; 3D-fluoroscopy; cranial frame; anterior cervical surgery

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INTRODUCTION

The technique of image-guided spinal navigation involves the use of Isocentric C-arm or O-arm to perform intraoperative three-dimensional (3D) images that are automatically registered and transferred to a navigational software work station.

Since the introduction of spinal navigation in 1995,[22] several studies have reported its advantages for accurately placing pedicle screws in the thoracic and lumbar spine.[9,10,25,30] The use of navigation in posterior cervical instrumentation procedures has been frequently reported.[26,33] While navigation is rarely required for anterior cervical approaches, it could help identify complex anatomy in some cases especially in revision surgery and at the transitional zones.[30] During anterior approaches to the lower cervical or upper thoracic spine, it can be difficult to visualize the anatomy with fluoroscopy.[28] In addition, anterior odontoid and anterior C1-C2 fixation procedures require biplanar fluoroscopy resulting in high radiation exposure for patients and surgical team.[32,34] Nevertheless, there remains a risk of screw misplacement especially in complex odontoid fractures with anatomical variants like high-riding vertebral artery treated anteriorly using fluoroscopic imaging.[38] Therefore, navigation could be helpful in these surgeries as well.

There is paucity of data on the use of spinal navigation in anterior cervical spine procedures. Few studies have reported initial experience in the feasibility of spinal navigation in anterior odontoid fixation procedures.[20,29,39,42] In addition, the use of navigation during anterior approaches to subaxial cervical spine has been shown to be feasible.[2,11,13,14,17,28]

PATIENTS AND METHODS

We routinely use image-guided navigation during posterior spinal fixation procedures. The system we use involves the Arcadis Orbic 3D C-arm for acquisition of 3D images and the Stealth Station system for navigation. Recently we used the same system for navigation during anterior cervical spine instrumentation in five patients. Both ethical and research committee in Barmherzige Brüder Hospital Trier approved our research and all patients agreed to give a written consent to participate in this research.

Navigation technique:

Patients were placed supine on a radiolucent spine table with the head fixated in Mayfield head holder; however, in the patients of upper cervical spine surgery a carbon head holder (Pro Med Instruments, Freiburg, Germany), attached to a carbon table, was used. A nonsterile cranial frame was tightly attached to the head holder to be used as a reference arc for navigation. C-arm was then brought into place and a 3D scan of the region of interest was performed. After acquisition, the images were automatically transferred and uploaded into the navigational station and image guidance could be started. After a sterile prep, a sterile reference arc was used instead of the nonsterile one. If other 3D images were required during surgery, a sterile drape was placed over the patient while the reference arc remained uncovered, and the C-arm was draped and brought into place and a second scan was performed. Accuracy of the navigation system was assessed by touching specific anatomic landmarks on the anterior spine such as osteophytes. This accuracy was reassessed as needed throughout the procedure. Instruments could be tracked and screws trajectories were planned. In patients of lower cervical and upper thoracic surgery, navigation was helpful in localizing the operated level, defining the borders of corpectomy; in addition, the entry points and trajectories of the screws can be planned. In patients of distorted anatomy by infection or previous surgery, navigation was used to locate the midline of the vertebral body as well as the position of the vertebral artery. However, once a significant alteration to the patients' anatomy was performed (correction of displaced C2 fracture, corpectomy, etc.) another scan was accomplished and the registration process was repeated. In addition, postoperative 3D scan was sometimes performed to verify hardware placement.

Case illustration:

3D image guidance was used in four patients to navigate the lower cervical/upper thoracic spine anteriorly. Navigation-guided instrumentation was performed using plate and screws; the instrumented levels were C7-T2, T1-T3, C4-T1, and C6-T1, respectively. *Case 1* (Figure 1) was a posttraumatic T1-fracture in a 60-year-old male with history of ankylosing spondylitis. Anterior and posterior cervical spine reconstruction was performed with C7-T2 anterior instrumented fusion followed by C4-T5 posterior instrumented fusion. In the first stage, anterior cervical approach (Smith-Robinson approach) was performed, partial corpectomy of the fractured T1 vertebra was performed, then autologous bone graft (iliac bone graft) was inserted for fusion, and then 3D image-guided C7-T2 fixation was performed using anterior plate and bicortical screws. Intraoperative 3D scan at the end of the procedure showed adequate positioning of the instrumentation. *Case 2* (Figure 2) was a 19-year-old male who presented with pathological tuberculous T2-fracture with prevertebral abscess. Surgery included image-guided anterior approach with evacuation of the prevertebral abscess and T2 corpectomy, and then it was possible with help of navigation to perform T1-T3 anterior instrumented fusion with no need for manubrium-splitting due to long neck of the patient. Intraoperative 3D scan was performed after instrumentation, and 2 screws were replaced with longer ones. *Case 3* (Figure 3) was a 70-year-old female who presented with neck pain 5 months after three-level (C4-7) anterior cervical discectomy and fusion for cervical spondylotic myelopathy. Patient presented with C5-6 and C6-7 subluxation as well as dislocation of the screws in C6 and C7. Anterior and posterior cervical spine reconstruction was performed with C7 corpectomy and C4-T1 anterior instrumented fusion, followed by C2-T4 posterior instrumented fusion. Navigation was beneficial during the anterior approach in determining the boundaries of the corpectomy; in addition, it was helpful during the anterior instrumentation. In this patient, a second 3D scan was performed after C7 corpectomy and before instrumentation because of the significant change in the anatomy that could happen after reduction. *Case 4* (Figure 4) was a 51-year-old male who presented with pathological C7-fracture and history of chronic renal failure, hyperparathyroidism, and osteomalacia. Surgery included image-guided anterior cervical approach with C7 corpectomy and C6-T1 anterior instrumented fusion with corpectomy cage and plate fixation with 4 screws in each of C6 and T1.

Navigation-guided anterior instrumentation of the upper cervical spine was performed in a patient with C2 traumatic fracture. In *Case 5* (Figure 5), the patient was a 90-year-old male who presented with posttraumatic dislocated type II Anderson-D'Alonzo dens fracture. Closed reduction of the dislocated fracture was not possible through positioning of the head; therefore, the strategy was to perform open reduction through an anterior approach followed by instrumentation. The technique we used in old patients with odontoid fractures involves anterior approach to the cervical spine and insertion of lag-screw in the dens followed by insertion of 2 transarticular screws in C1-C2 joints. After performing anterior cervical approach, open reduction was performed through pressure on C2 and navigation-guided insertion of one dens screw was performed. Because of the significant change that could happen after reduction, a second 3D scan was performed and image-guided navigation was used to complete the instrumentation; a second dens screw and two anterior transarticular C1-C2 screws were inserted using navigated K-wires. The operation time was 117 minutes.

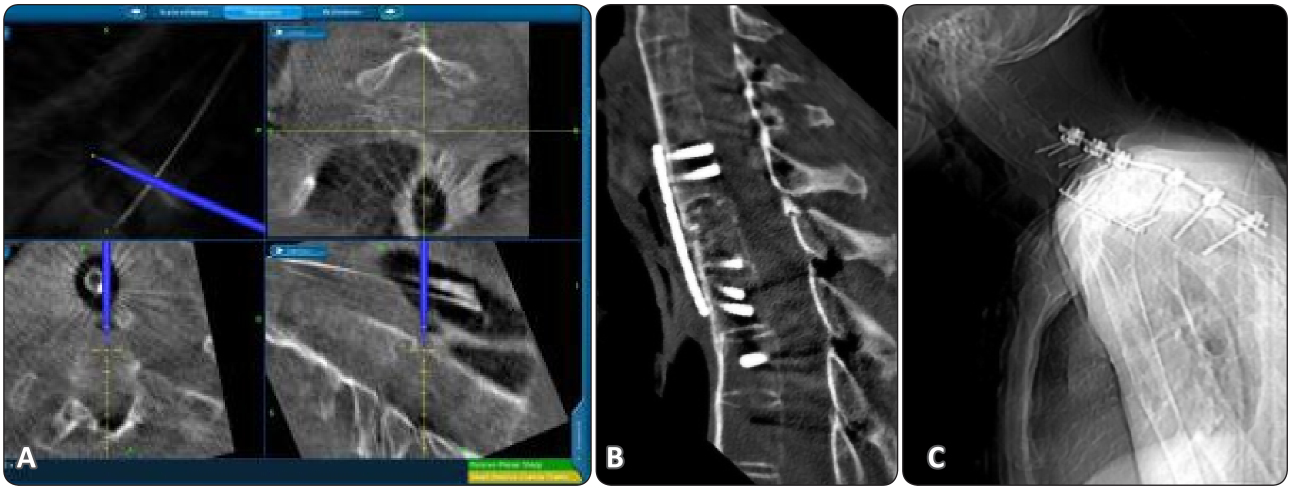

Figure 1. Traumatic T1-fracture in a case of ankylosing spondylitis, treated with navigation-guided anterior C7-T2 fixation followed by posterior fixation. (A) Screenshot taken intraoperative during instrumentation. (B) Postoperative CT scan and (C) plain X-ray showed the anteroposterior instrumentation.

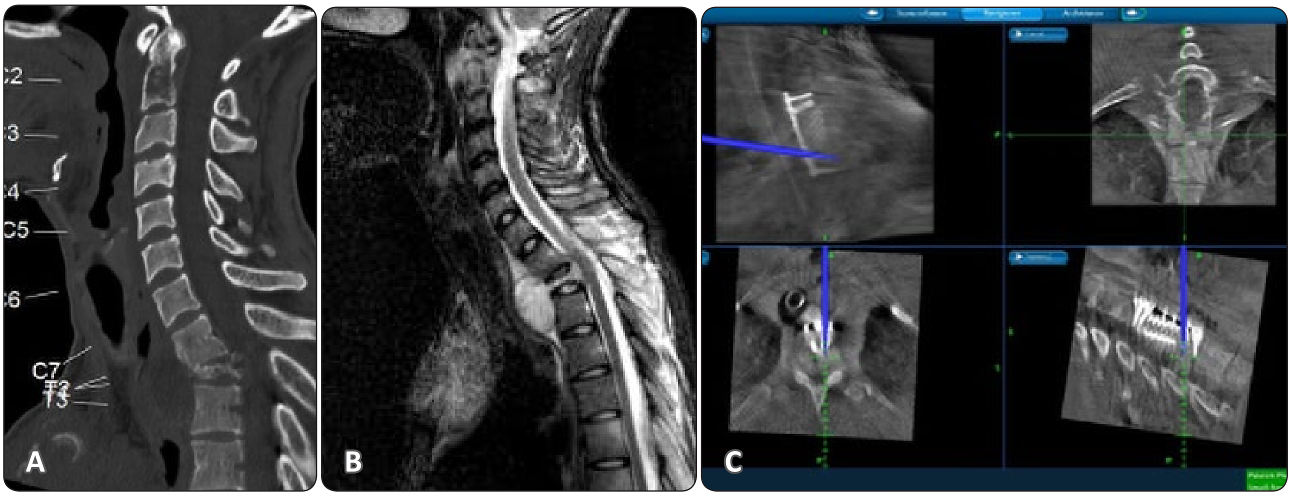

Figure 2. Tuberculosis T2-fracture with prevertebral abscess. (A) Preoperative CT and (B) MRI showing pathological fracture and prevertebral abscess. (C) Intraoperative 3D scan after instrumentation to check the accuracy of hardware placement.

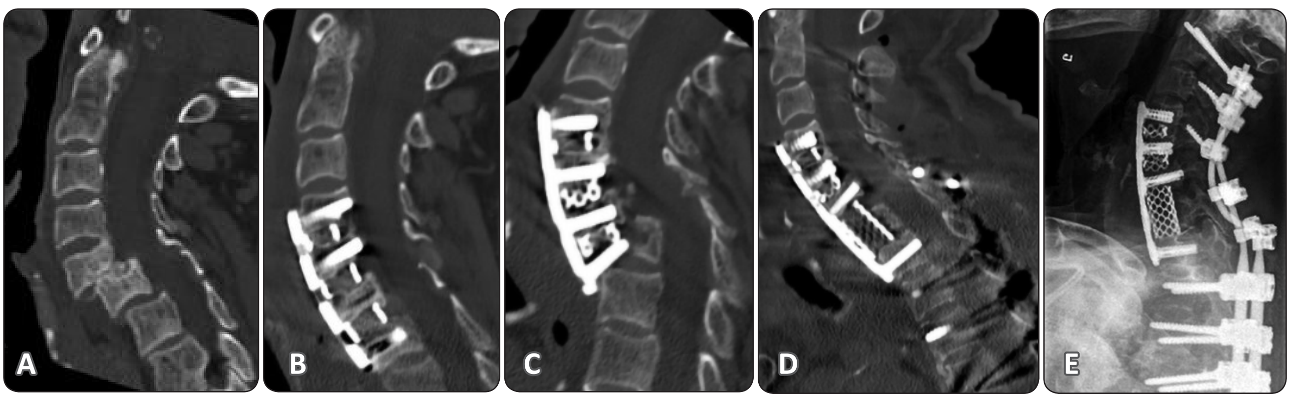

Figure 3. Instrumentation failure after ACDF C4-7. (A) Preoperative CT and (B) CT immediately after the 1st surgery. (C) Instrumentation failure with C6-7 dislocation. (D,E) Postoperative CT and plain X-ray after anteroposterior fixation.

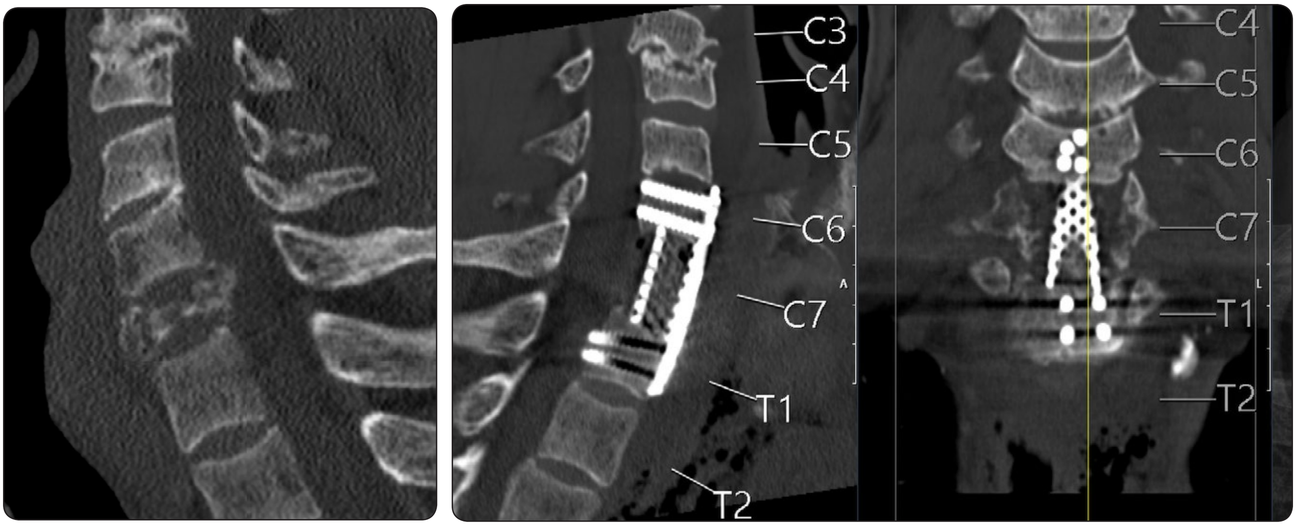

Figure 4. In this case of pathological C7-fracture, it was possible with the help of navigation to perform C6-T1 fusion using cage, plate, and screws with placement of 4 screws in each vertebral body as a trial to support the construct in a patient with pathological bone due to chronic renal failure, osteomalacia, and hyperparathyroidism.

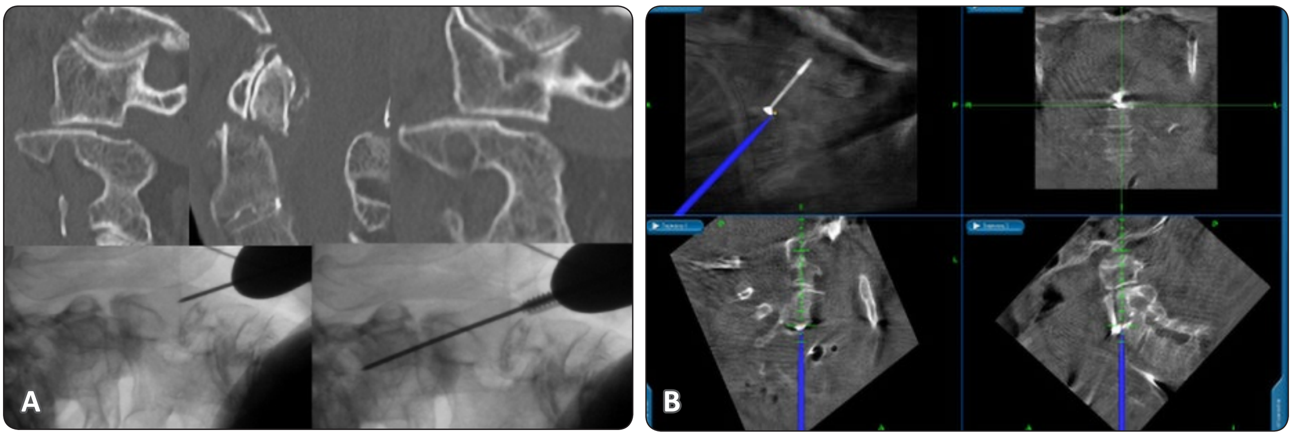

Figure 5. Type II Anderson-D'Alonzo dens fracture. (A) Preoperative CT scan and intraoperative fluoroscopy showing k-wire guided insertion of a dens screw. (B) Intraoperative 3D scan after open reduction and insertion of one dens screw, for planning of navigation-guided modified transarticular C1/C2 fixation.

DISCUSSION

In 1995, Nolte et al.[21] introduced the first clinical application of spinal navigation for placement of pedicle screws in the lumbar spine; the technique they used was based on preoperative CT scan and required intraoperative registration. Five years later, the same group introduced a new technique of image-guided spinal navigation based on intraoperative fluoroscopy imaging associated with automatic image registration.[23] The 3D technique is recently widely utilized for spinal navigation; the technique involves the use of Isocentric C-arm or O-arm to perform intraoperative 3D images that are automatically registered and transferred to a navigational software work station. In addition to the advantage of automated registration with no need of manual registration, the intraoperative 3D navigation allows imaging of the patient in the desired surgical position with actual anatomical relationships. This advantage is particularly important in patients who were operated upon in the prone position as in the posterior approach; however, it is less important in ventral approaches as patients are operated upon in the supine position and the preoperative CT is performed also in supine position.[37]

Several studies have reported that the use of image-guided navigation improves the safety and accuracy of pedicle screw placement in spine surgery.[1,6,15,16,18,25,31,41] While its use during posterior cervical spine instrumentation procedures is very useful due to the complex anatomy as well as the relevant anatomic individual variability of the cervical spine, navigation in this mobile region of the spine is more challenging.[3,35]

The application of navigation guidance for ventral spine approaches has been described.[4,5,7,19,24,27,28,36,40] The difficulties with this technique are related to the reference frame, which should be fixated close to the intended operative site and should be positioned so that it does not interfere with the operative tools. During posterior cervical surgery, the reference frame of the navigation could be fixated to one of the cervical spinous processes. However, it is possible that the frame will move, if it is fixated to cervical spinous process.[12] Therefore, some authors recommended its fixation to the Mayfield headholder.[8]

Our experience in performing navigation-guided posterior cervical fixation procedures showed that fixation of the reference frame of the navigation to the Mayfield head holder in cases with problematic fixation to the spine showed satisfactory accuracy. Therefore, we performed our initial cases of navigation-guided ventral craniocervical and cervicothoracic surgeries with use of the cranial frame, later even combined with a radiolucent head holder. It is important to note that, in the patients of lower cervical and upper thoracic procedures, navigation was used to identify the entry points of the screws and minor error could be accepted in these patients; however, in patients of upper cervical instrumentation, correctness of the navigation was mandatory. Therefore, in the patient of C2 fracture, fluoroscopy was used in addition to the navigation as a second check.

In 2011, Lee et al.[17] used Iso-C image-guided navigation system in performing multiple oblique corpectomy in the subaxial cervical spine. They compared 11 patients in whom image-guided navigation was used with a control group of 11 patients who were operated upon without navigation. Image-guided navigation resulted in faster and more complete multiple oblique corpectomy. They used two-dimensional navigation because the 3D navigation was associated with significant retractor artifact. In our experience, the use of 3D navigation in ventral cervical spine surgery is possible and removal of the retractor before performing the 3D scan is helpful, but not completely necessary to avoid artifact. The accuracy of the navigation should be reassessed repeatedly by touching specific anatomical landmarks and intermittent fluoroscopy could be used whenever possible to check the accuracy of the navigation. In addition, if significant anatomical change happened intraoperatively (like after reduction of a fracture, following corpectomy or insertion of bone graft, etc.), a second 3D scan should be performed before carrying out the procedure.

Pirris and Nottmeier[28] reported on utilizing 3D image guidance for 22 patients of anterior subaxial cervical spine surgical procedures. In their study, they used two different systems for image-guidance; one system included the BrainLAB (BrainLAB, Westchester, Illinois) system in conjunction with the Arcadis Orbic Isocentric C-arm (Siemens Medical Solutions, Erlangen, Germany), and the other system included the Stealth (Medtronic Inc., Littleton, Massachusetts) system paired with the O-arm (Medtronic). The authors reported that the O-arm provided wider field and better image clarity. They reported the feasibility of the procedure by fixating the reference arc to the head holder and performing the 3D images prior to placing any retractors to avoid artifacts. They reported the usefulness of navigation in performing corpectomy in patients in which the anterior cervical anatomy was distorted by tumor, infection, or previous surgery; in addition, they used the navigation to mark entry points for anterior cervical screws. In our four patients of subaxial ventral approaches, we have found that navigation was very beneficial to the surgical procedure. It helps us with localization of the operated levels in the cervicothoracic junction where fluoroscopy is very difficult due to shoulder artifact. Navigation was important to determine the entry points for screws, and it was even possible to insert 4 screws in each vertebral body in the patients of pathological fractures (Cases 1 and 4). In addition, determination of the boundaries of corpectomy was critical especially in cases of infection and recurrence.

Summers et al. performed anterior odontoid fixation in 9 patients with odontoid fracture under image-guided navigation; they used Iso-C 3D unit paired with Stealth system, and they fixated the navigation reference arc to a radiolucent head frame. Image acquisition for trajectory planning was performed intraoperatively after removal of the retractor system. The authors recommended performing intermittent lateral fluoroscopy during placement of the K-wire and drill with no need to perform A-P fluoroscopy; in addition, 3D scan was performed after screws placement to verify screws position[39].

Martirosyan et al.[42] compared navigation-guided anterior screw fixation of odontoid fractures in 26 patients with biplanar fluoroscopy-guided anterior screw fixation in 25 patients. Clinical outcomes and surgical complication rates were similar between the groups. The navigation-guided group was associated with higher rates of fusion and lower duration of surgery than the biplanar fluoroscopy group[20]. Similar results were observed in another study in which 29 patients of navigation-guided odontoid screw fixation were compared with a historical cohort of fluoroscopy-guided fixation; in addition, shorter fluoroscopy times were observed in the navigation-guided group as compared with the historical controls (42.9 versus 68.1 seconds). In our patient of navigated anterior C1/C2 fixation, we performed an open reduction of the fracture and one dens screw was inserted; thereafter, 3D scan was performed before insertion of the transarticular screws. Although it was time-consuming compared to the 2D-fluoroscopy, it helped with the difficult anatomy in this case, because of actual 3D imaging after repositioning.

Although the aim of our study was to share our initial experience in a recent and critical topic and we might have added some special points in this technique, but the limitations are the retrospective nature of the study as well as the few numbers of patients presented. We think that including this technique in a prospective study in the future is very important to show its advantages and the drawbacks.

CONCLUSION

The illustrated cases show that navigation-guided surgery for ventral cervical spine instrumentation surgery is technically possible with good results. They demonstrate the advantages of 3D-fluoroscopy navigation with use of the cranial frame in the upper transitional zones. Disadvantages of this method are the complex intraoperative draping and logistics and the possible inaccuracy, because of long distances and spinal mobility. Carbon Mayfield may facilitate positioning but is not mandatory.

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الملخص العربي

التصفح الموجه بالصور في جراحة العمود الفقري الامامي باستخدام اطار الجمجمه

البيانات الخلفيه: تشكل جراحات تثبيت العمود الفقري الأماميه في منطقة الفقرات الصدريه العلويه والمناطق الانتقاليه بين الجمجمه و الفقرات العقيه و بين الفقرات العقيه و الفقرات الصدريه تحديا كبيرا للجراح وذلك لصعوبة التصوير الاشعاعي في هذه الأجزاء من العمودالفقري. هناك امكانية لاستخدام الملاحه ثلاثية الأبعاد في بعض هذه الجراحات. وتستلزم الملاحه الجراحيه استخدام اطار يتم تثبيته بالقرب من مكان اجراء الجراحه. وقد يقوم الجراح باستخدام الاطار القحفي الذي يتم تثبيته في جهاز تثبيت الرأس المسمي مايفيلد. وقد سبق استخدام الاطار القحفي في الملاحه الجراحيه لمنطقة التقاء الجمجمه بالفقرات العنقيه من خلال الجيب الانفي المخروطي. كما أنه قد سبق نشر عدد محدود من الحالات التي تم فيها استخدام هذه التقنيه في جراحات العمود الفقري العنقي والصدري الأماميه.

الغرض: تقديم امكانية الملاحه ثلاثية الأبعاد للتنظير في جراحات العمود الفقري العنقي الأمامي مع استخدام الاطار القحفي.

تصميم الدراسه: نقدم تجربتنا في تقنية الملاحه في خمسة حالات من جراحات العمود الفقري العنقي الأمامي, تم اجراء أربعة حالات تثبيت في منطقة التقاء الفقرات العنقيه بالفقرات الصدريه من الأمام وفي الحاله الأخيرة تم اجراء تثبيت للفقرات العنقيه الأولي والثانيه من الأمام.

المرضي والطرق: استخدمنا نظاما يتكون من جهاز التصوير الاشعاعي لاقتناء الصور ثلاثية الأبعاد بالاضافه الي جهاز الملاح الجراحي, كذلك استخدمنا الاطار القحفي والتي تم تثبيتها علي جهاز تثبيت الجمجمه المسمي مايفيلد. تم اجراء التصوير ثلاثي الأبعاد قبل بدء الجراحه أو أثناء الجراحه بعد ازالة المباعدات وفي بعض الحالات كان اجراء تصوير ثلاثي الأبعاد مرة أخري أثناء الجراحه ضروريا.

النتائج: كانت الملاحه مفيده في تحيد نقاط الدخول ومسارات المسامير خاصة في منطقة التقاء الفقرات العنقيه بالفقرات الصدريه دون الحاجه الي التصوير الاشعاعي المتكرر أثناء الجراحه. وتعتبر امكانية اقتناء صور ثلاثية الأبعاد بعد اجراء جراحة التثبيت للتأكد من صحة وضع الأجسام المعدنيه ميزه اضافيه لهذه التقنيه.

الاستنتاج: توضح الحالات المقدمه في هذا البحث مزايا الملاحه ثلاثية الأبعاد للتنظير في جراحات العمود الفقري الأماميه في المناطق الانتقاليه مع استخدام الاطار القحفي. وتكمن مساوئ هذه التقنيه في التعقيدات الخاصه بالتعقيم والمحافظه عليه اثناء التصوير الاشعاعي, هذا بالاضافه الي احتمالية عدم الدقه نظرا لبعد المسافه بن مكان الجراحه والاطار القحفي وامكانية حركة العمود الفقري العنقي أثناء الجراحه.