Medical
Research
Archives

European Society of Medicine

OPEN ACCESS

Published: March 31, 2024

Citation: Batheja D, Patel VH, et al., 2024. CT-navigated C2 Pedicle Screw insertion using dynamic reference array on C2 spinous process: A Novel Technique, Medical Research Archives, [online] 12(3). https://doi.org/10.18103/mra.v12i3.5062

DOI
https://doi.org/10.18103/mra.v12i3.5062

ISSN: 2375-1924

RESEARCH ARTICLE

CT-navigated C2 Pedicle Screw insertion using dynamic reference array on C2 spinous process: A Novel Technique

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ABSTRACT

Introduction: Spine surgeons have endeavoured to improve the accuracy of pedicle screw insertion. Computed tomography (CT) guided navigation has been helpful in precisely passing pedicle screws even further accurately but, there were shortcomings noted with the technique due to movement between reference frame and anatomical landmarks, especially in the cervical spine which led to injury of vital neurovascular structures. Thus, there was a need for developing a technique which would eliminate the inherent error due to movement in the vertebral body while passing screws.

Research Question: Can using C2 spinous process as an attachment for the reference array improve accuracy of C2 pedicle screws.

Material and Methods: We prospectively studied data of 10 patients (20 screws) in whom Computed tomography navigated C2 pedicle screws insertion was carried out using the reference array on C2 spinous process. Accuracy of pedicle screws were confirmed by post instrumentation Computed tomography scan immediately intra operatively.

Results: With the presented technique overall breach rate was 5% with one screw having a medial breach of grade 1 with no incidence of neurovascular injury or need for further revision.

Discussion and Conclusion: Results from this study shows better accuracy than other techniques described to pass C2 pedicle screws eliminating the error in movement from the cervical vertebrae and the reference frame being nearest to the C2 pedicle. Although there is a learning curve with the adoption of the navigation system, with experience, the challenges associated with Cervical pedicle screws (CPS) insertion can be overcome.

Introduction

Spine surgeons have made constant efforts to improvise on techniques to pass safer pedicle screws. Posterior cervical spine instrumentation with lateral mass screws[1, 2, 3] represent standard form of fixation in sub axial spines whereas Cervical pedicle screws (CPS)[4] provide significant higher fixation strength and biomechanical stability in cases of deformity correction, poor bone quality, and revision surgery[5]. CPS have inherent disadvantage of being technically demanding with more risk of neurovascular injury.

Increased rate of screw malposition, variable pedicle morphometry, anatomical variations in vertebral artery and vertebral body size have led to a search of image guided screws system. Free hand and fluoroscopic assisted screw placement have unacceptable high perforation rates ranging from 18- 75 % [6,7,8,9]. To overcome these, CT based navigation system came into use initially in the lumbar spine[10, 11, 12] and with its success navigated techniques have also incorporated in cervical spine [13,14].

We are aware from experience of using navigation that after the CT scan is performed and images sent for 3D reconstruction for navigation, it is the stationary reference point and the relative position of the reference balls on the instruments being used which help to navigate through the anatomical landmarks. However, if the position of the stationary reference point changes (loosening – retightening, pressure while manoeuvring) or the stationary bony landmarks move for any reason there will be an error in the navigation. These shortcomings in navigation have bothered surgeons frequently and creates lot of confusion intra-operatively with some studies showing unacceptable perforation rates despite navigating[15]. We hereby, have tried to reduce the dynamic fallacy of the stationary reference frame for pedicle screw placement in C2 vertebrae using reference frame on C2 spinous process itself.

Objective- To study if using C2 spinous process as attachment for the reference array improve accuracy of C2 pedicle screw.

Materials and methods

Approval was obtained from institutional board. Ten consecutive patients who underwent posterior cervical spine instrumentation with O-arm navigation based C2 pedicle screw insertion were included in this study technique. The sample size was decided based on previous studies[10] conducted with the same research question we haven't used any statistical analysis for the same. Patients were admitted on the day of surgery, underwent surgery with the described technique hereafter. The screw position were checked immediately once all the screws were inserted with help of intra operative CT. The CT was studied by the surgeons themselves and if there was a breech was then further referred to the radiologist for confirmation. Patients were discharged from the hospital at average of 4 days post operative. 2 patients took average of 8 days post op to be discharged due to medical optimisation. All patients were followed up at 3 and 9 months after surgery.

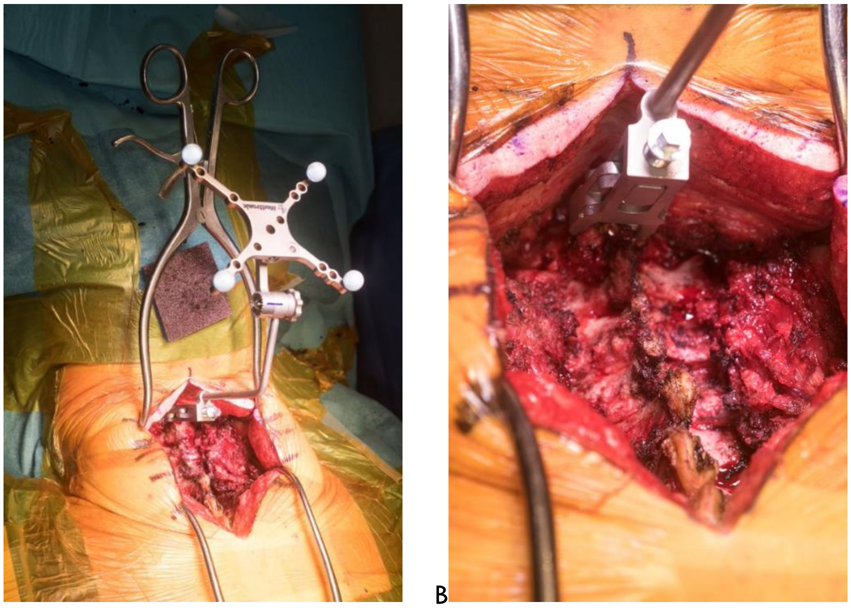
SURGICAL TECHNIQUE

After obtaining informed consent, patients were intubated under general anaesthesia. Mayfield frame was then applied in supine position and patients were positioned prone on Allen table. Gentle traction was applied with shoulder strapping. A standard midline posterior incision was made over the posterior cervical spine extending as per the anticipated level of instrumentation. Subperiosteal dissection was carried out as per the requirements of the surgery, extending over the lateral mass.

NAVIGATION TECHNIQUE

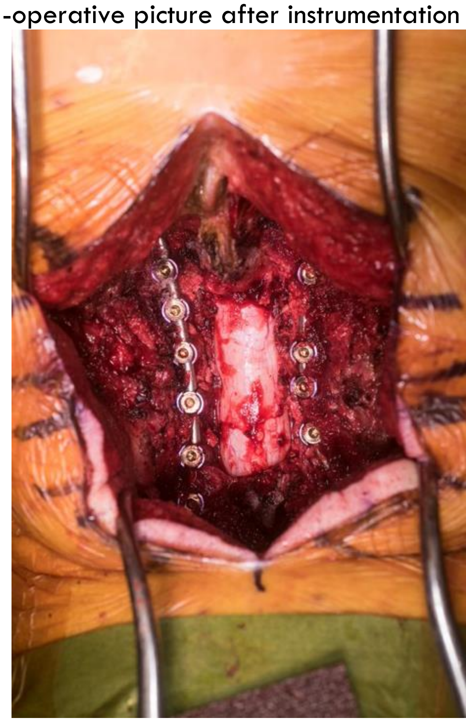
A dynamic reference array with multiple reflective spheres was placed on the tip of spinous process of C2 vertebra itself. It is important to ensure reference frame limb does not touch the skin to minimise any undue tension on frame limb which can lead to change of screw trajectory while instrumenting (fig 1 and 2). The O-arm was centred over the desired region of spine, the standard AP (Antero Posterior) and Lateral localising radiographs were obtained. Intraoperative spin was then obtained with automatic registration which identifies and confirm every level. This, consequently, led to the acquisition of high-resolution images of the concerned area. These required images were then transferred over to the stealth station and location of instrumentation was projected on to reconstructed images. Screw planning was performed on the images on stealth station and trajectory was mapped out on intraoperative images.

Figure 1 – a & b - Intra operative picture showing position of dynamic reference frame on C2 vertebrae spinous process. Skin should not be touching reference frame to reduce any tension on vertical limb of the frame



A B

Fig. 2 - Final intra-operative picture after instrumentation and decompression

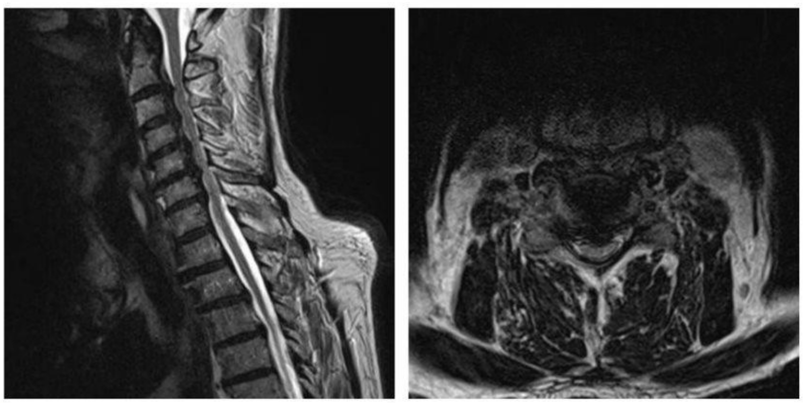


Entry point for the pedicle screws were made after visualising the trajectory on the stealth station's axial and sagittal images. A navigated awl was used to make a starting point based on screw trajectory. A navigated probe was then used to complete the screw track. Pedicles were probed manually by a ball tip probe to feel for any obvious breech. Pedicle width was determined based on measured width on the axial images on scans. Screw length was determined using navigated ball tip probe on axial image. After screws were placed, a second intraoperative O arm scan was done to confirm the position of the screws. Final screw position was evaluated with intraoperative 3-D CT scan (Fig 4). Insertion of remaining lateral mass screws was done using free hand technique. Also, in some of the cases, we were able to insert C7 and T1 pedicle screws using the same reference frame on C2 as and when required.

Fig 3. - 78-year-old male patient presented with severe progressive myelopathy A)pre op lateral view of Xray of cervical spine. B) Pre op CT scan showing discontinuous OPLL. C) Sagittal and axial view of MRI spine at level showing central stenosis. D) intra operative axial image showing position of Dynamic reference array. E) post op Ap and Lateral x-rays showing restoration of cervical lordosis and accurate placement of C-2 pedicle screws

Figure 3 A

Figure 3B



3C

3D

3E

Results

A total of 10 patients underwent CT navigated C-2 pedicle screw insertion using the technique described. The average age was 70.33 years (range 59-81) and seven patients were male (M:F-7:3). Most of our patients underwent this procedure for severe progressive myelopathy with evidence of Ossified Posterior Longitudinal Ligament (OPLL) in two patients. The average pre op mJOA (modified Japanese Orthopaedic Association) score was 11 and mean duration of surgery was 304.22 mins (range 239 – 380 mins) including setup, positioning, and operative time. Table 1 shows detailed demographics of the patients included in this study.

All the patients had on table post-op CT scan to confirm position of screws (Fig 4). The medial and lateral displacement of the C2 pedicle screws was defined as previously described by Gertzbein and Robbins [16]: grade 0, no breach; grade 1, breach of less than 2 mm; grade 2, breach of more than 2 mm and less than 4 mm; grade 3, breach of more than 4mm. Patients were reviewed clinically with follow up at 3 months and 1 year.

The overall breach rate in this study was 5% with one screw having a medial breach of grade 1 out of 20 screws inserted. There was no incidence of neurovascular injury or need for revision surgery for screw malposition.

[1]**Table 1:** Summary of total number of patients, screws and errored screws.

Total patients	10	
Total screws studied	20	
Error in screw	Grade 0	0
	Grade 1	1
	Grade 2	0
	Grade 3	0

[1] Summary of total number of patients, screws and errored screws.

Figure 4A - Intraoperative stealth images on navigation system while inserting screws
4B - post op scan images.

Figure 4A

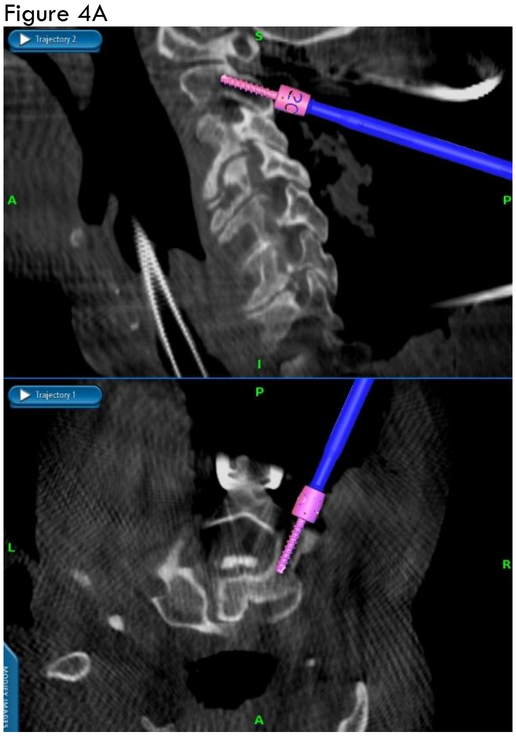


Figure 4B

Discussion

C2 pedicle screws have been inserted using Harms and Melcher technique[17] which has been widely accepted as a safe and effective method. Since breach in pedicle screws in cervical spine can lead to sinister outcomes, it becomes prudent to identify track breach before placing screws and thus avoiding malposition. Lehman el al [18] deduced from their study in 2004 that detection of breaches with palpation alone has an accuracy in range of 38% - 74%. This indicated a positive role of image guidance in inserting screws.

Yukawa et al [19] reported a grade 2 and grade 3 screw misplacement rate of 13.1% in 620 cervical pedicle screw fixations using a fluoroscopy-assisted technique, while the misplacement rate in C2 and C3 was even higher (21.6%). Thus, the accuracy and technical advances in CPS placement in the cervical spine using the intraoperative O-arm was investigated. Ishikawa et al [20] first reported on the accuracy of CPS placement using the O-arm. They investigated 108 screws, and the malposition rate between C2 and C7 levels was 11.1%, including 2.8% of Grade 2.

Rahmathulla et al [21] in their experience have pointed out pitfalls in navigating screws with O arm. One of the errors with navigation technique is the movement between reference frame and the vertebrae during the instrumentation after the images are procured. They also encountered inaccuracy when the distance between the reference frame and level of working increased, up to 3 mm in 7% patients when instrumentation was 3 levels away.

Upper cervical spine constitutes about 60 to 70% off all cervical spine movement and putting a reference frame either on the skull, Mayfield frame, posterior arch of C1 or spinous process of C3 often leads to movement between either C1- C2 or C2-C3 articulation while attempting to insert a pedicle screw. A study done by Smith et al [22] where in spinous process of C3 was used as a reference point reported total 8 C2 pedicle screws, they encountered two Grade 1 and four Grade 2 breaches, which accounts to 75% error. They concluded that excessive movement in the upper cervical spine along with inherent navigation errors could be the cause of screw misplacement.

In our study, the reference frame was attached on the spinous process of C2 vertebra, this gives a live reference as the frame moves with any movement in the C2 vertebra while navigating. The error occurring because of the relative incongruency in movements (the reference frame being static against a mobile vertebra moving due to pressure from the surgeon to pass the screws) is nullified.

Also, our technique reduces the error due to increasing distance between the frame and the surgical level as we are working at the same level (C2 pedicle screws with frame on C2 vertebra). We believe this is the reason for our series to have the least malposition rate of C2 pedicle screws in the current literature.

Our technique also gives the advantage of not carrying out the dissection to C3 if only a C1-2 fixation is planned. Even though the number of screws studied with our technique is less we believe the results will remain the same as the inherent error of movement of C2 vertebra is used here to synchronize the navigation. The navigation images displayed on screen are virtual representation of human anatomy. Therefore, it is also important to check whether virtual reality displayed by navigation system matches with surgical reality or not.

Our study did not have a large sample size and thus is one of the major drawbacks. But, considering this technique itself being sound should be able to extrapolate the same results over larger population and is the next research question. Our study is also limited by no randomization or comparing with other surgical procedure. There is no concern of any changes during follow-up as we are not following up any clinical improvement. What we are concerned is the accuracy of screw position and the assessment of screw position is done intra-operatively and if needed any changes could have been done before closure.

Conclusion

The use of O-arm-based 3D navigation has shown to improve the accuracy and safety of CPS insertion. With our technique, the accuracy of C2 pedicle screw insertion can be improved even further. Although there is a learning curve with the adoption of the navigation system, with experience, the challenges associated with CPS insertion can be overcome. It is also important to verify virtual reality with surgical reality before starting instrumentation and this technique minimises that gap

[2]**Table 2:** Patient demographics

S no.	Age/ Sex	Diagnosis	Date of procedure	Pre-op mJOA score	Surgery	Duration of surgery (mins)	Blood loss (ml)	Post op CT (breach)	Post-op complication
1	62/M	Moderate progressive cervical myelopathy	16-7-2019	12	C2-C6 posterior decompression and fusion	270	500	No	Nil
2	60/F	Severe progressive cervical myelopathy	10-9-2019	11	C2- T2 posterior decompression and fusion	320	200	No	Nil
3	73/F	Moderate Progressive cervical Myelopathy-OPLL	11-12-2019	12	C2- T1 posterior decompression and fusion	380	200	No	Pulmonary Thromboembolism – managed with anticoagulation
4	78/M	Severe progressive cervical myelopathy secondary to C1- C2 instability due to C2 fracture non-union	03-07-2019	8	Occipito - C4 fusion	239	200	No	Nil
5	72/F	Severe Progressive	21-07-20	11	C2-C5	258	< 100	No	Nil

[2] Patient demographics , mJOA – Modified Japanese Orthopaedic Association Score

S no.	Age/ Sex	Diagnosis	Date of procedure	Pre-op mJOA score	Surgery	Duration of surgery (mins)	Blood loss (ml)	Post op CT (breach)	Post-op complication
		cervical myelopathy							
6	78/M	Moderate Progressive cervical myelopathy-OPLL	1-09-20	12	C2-T1	292	< 100	No	Nil
7	70/M	Severe Progressive cervical myelopathy	1-10-20	11	C2-C6	295	< 100	No	Nil
8	81/M	Severe Progressive cervical Myelopathy	15-12-20	10	C2- C7	326	350	No	Nil
9	59/M	Moderate Progressive Cervical Myelopathy	22-12-2020	12	C2-C5	358	500	No	Gr 1 perforation on 1 side
10	70/M	Moderate Progressive Cervical Myelopathy	24-12-2020	12	C2-C6	304	< 100	No	Nil

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