Thai J Neurol Surg 2024;2(1):24-41.

Research Article

Clinical and Radiographic Outcomes of Atlanto-Axial Screw Fixation in Neurological Institute of Thailand

Aiayarch Tanawarangkoon, M.D.
Teera Tangviriyapaiboon, M.D.
Department of Neurological Surgery, Neurological Institute of Thailand

Abstract

Background and Objective: There are many techniques for atlanto-axial fixation such as posterior wiring technique with bone graft fusion, transarticular screwC1-2 fixation, C1 lateral mass with C2 pedicle screw fixation secured by rigid plate or connected by rod system, and modified techniques for C2 screw fixation. The objective of the present study is to compare clinical and radiographic outcomes of patients treated with transarticular screws (TAS) and screw-rod constructs (SRC) for posterior atlantoaxial fusion and subgroup analysis compare clinical and radiographic outcomes of patients treated with translaminar C1 lateral mass screw and sublaminar C1 lateral mass screw of the SRC group.

Material and Method: A retrospective charts review were performed using operative database and imaging records to identify all patients who underwent C1-2 screw rod construction or C1-2 transarticular screw fixation between February 2008 and December 2016 at Neurological Institute of Thailand. Forty-two patients in total were analyzed for clinical and radiographic outcomes. The patients were divided into 2 group: 9 patients in transarticular screw (TAS) fixation and 33 patients in screw rod construct (SRC). In addition, the patients in the SRC group were divided into two groups: 10 patients who were treated with translaminar C1 lateral mass screw and 19 patients who were treated with sublaminar C1 lateral mass screw.

Result: Forty-two patients were included in the present study, there are no statistically significant differences were found between the TAS and the SRC groups in ΔADI [0.82 (-0.29-4.87) VS 0.05 (0-1.75), *P* = 0.488], ΔPADI [1.20 (-0.77-4.52) VS 0.05 (0-1.26), *P* = 0.554], ΔNDAASC [1.85(0.87-6.16) VS 1.67(0.34-5.20), *P* = 0.46], ΔNDAASC% [13.45 (5.35-79.59) VS 13.39 (1.89-50.73), *P* = 0.594], operative time [150 (132.5-347.5) min VS 203 (157-254.5) min, *P* = 0.453], Blood loss [200 (100-500) ml VS 250 (135-400) ml, *P* = 0.963] and hospital stay [14 (8.5-24) days VS 10 (6.5-17) days, *P* = 0.167], postoperative NCSS at 1 year (*P* = 0.438), the percentage of postoperative NCSS at 1 year (*P* = 0.419) and postoperative JOA score at 1 year (*P* = 0.418). In the subgroup analysis of the SRC group, there was no statistically significant difference between the two groups in ΔADI [0.46 (0-2.91) VS 0.02 (0-0.81), *P* = 0.454], ΔPADI [0.36 (-0.47-1.57) VS 0.05 (0-0.66), *P* = 0.947],

Corresponding author: **Teera Tangviriyapaiboon, M.D.**
Department of Neurological Surgery, Neurological Institute of Thailand, Bangkok, Thailand

ΔNDAASC [1.28(0.24-3.92) VS 3.17(0.35-5.63), *P* = 0.461], ΔNDAASC % [6.57(1.67-30.77) VS 22.43 (1.56-62.98), *P* = 0.357], postoperative JOA score at 1 year (*P* = 0.381), postoperative NCSS at 1 year (*P* = 0.858) and the percentage of postoperative NCSS at 1 year (*P* = 0.953). Only one patient in the SRC group with sublaminar C1 lateral mass screw technique was found with postoperative occipital neuralgia and 2 patients in the SRC group with sublaminar C1 lateral mass screw technique were found with broken screws.

Conclusion: Both TAS and SRC techniques can be used for C1-2 instability since no statistically significant results were found in both group and there was low incidence of complication. Sublaminar and translaminar C1 lateral mass screw techniques showed no statistically significant differences even though sublaminar C1 lateral mass screw technique seems to yield a slightly higher rate of occipital neuralgia. The decision to use either technique of C1-2 fixation must be made after careful review of the individual patient's anatomy on imaging and the surgeon's experiences.

ADI = atlanto-dental interval, ΔADI= differences between ADI, PADI = posterior atlanto-dental interval, ΔPADI= differences between PADI, NDAASC = narrowest in A-P diameter of atlantoaxial spinal canal, ΔNDAASC= differences between NDAASC,ΔNDAASC%= percentage of differences between NDAASC, NCSS= Neurosurgical cervical spine scale14, JOA score= Japanese Orthopaedic Association score15.

Introduction

There are multiple techniques for atlanto-axial instability such as posterior wiring technique with bone graft as described by Gallie, Brooks, and Jenkins, and Dickman and Sonntag et al. Magerl and Jeanneret described transarticular screw fixation in 1979, many years later Goel and Laheri reported C1 lateral mass and C2 pedicular screws secured by rigid plate in 1994. Recently, Harms and Melcher modified Goel technique by using polyaxial C1 lateral mass and C2 pedicle screws connected by rod in 2001[1, 2].

Initially, C1-2 fixation is conducted by resecting nerve root, which has been found to cause higher incidence of occipital numbness. Consequently, the technique is later modified by preserving the C2 nerve root to reduce the said complication. However, higher incidence of occipital neuralgia is instead found when the C2 nerve root is preserved[3,4]. As a result, posterior arch C1 technique (translaminar C1 lateral mass screw) is then used to avoid C2 nerve root and to reduce blood loss due to venous plexus bleeding [2,5,6].

The objective of the present study was to compare clinical and radiographic outcomes of patients treated with transarticular screws (TAS) and screw-rod constructs (SRC) for posterior atlantoaxial fusion and to compare clinical and radiographic outcomes of patients treated with translaminar C1 lateral mass screw and sublaminar C1 lateral mass screw of the SRC group.

Method

A retrospective chart review was performed using operative database and imaging records to identify all patients who underwent C1-2 screw rod construction or C1-2 transarticular screw fixation between 1st February 2008 and 1st December 2016 at Neurological Institute of Thailand. Included patients were treated by C1-2 transarticular screw fixation and screw rod construct technique, excluded patient were treated by other procedures such as wiring or occipito-cervical fixation. In total, 42 patients were divided into 2 group; 9 patients in transarticular screw (TAS) fixation and 33 patients in screw rod construct (SRC)]. The patients in the SRC group were divided into two groups: 10 patients who were treated with translaminar C1 lateral mass screw and 19 patients who were treated with sublaminar C1 lateral mass screw.

The first priority surgical technique of atlantoaxial fixation in Neurological Institute of Thailand is TAS unless the following conditions: (1) uncorrectable C1-2 alignment and/or irreducible of C1-2 dislocation (2) small pars or high riding vertebral artery (3) defected of posterior arch C1 (4) short neck and large shoulder, which cannot be positioned for transarticular screw trajectory (5) patients refused to use iliac bone graft for wiring in the TAS technique. Demographic information of all patients was collected including gender, age, clinical presentation, duration of symptom. Preoperative evaluation data collected included causes of C1-2 instability, odontoid fracture, types of odontoid fracture, atlanto-dental interval (ADI), posterior atlanto-dental interval (PADI) and new parameter such as narrowest in A-P diameter of atlantoaxial spinal canal (NDAASC) at sagittal view of bone windows on CT scan, preoperative Japanese Orthopedic Association Score (JOA) and Neurosurgical cervical spine scale (NCSS). These collected data were then evaluated to compare clinical outcomes. Intraoperative variables collected included C1-2 fixation technique, operative blood loss (ml), the length of hospital stay. Postoperative variables were hardware failure (broken screw or rod /loosening screw), screw malposition, occipital neuralgia, occipital numbness, infection, differences between Preoperative and Postoperative ADI, differences between Preoperative and Postoperative PADI, differences between Preoperative and Postoperative AAMNSC, Fusion at 1 year after the surgery, postoperative clinical outcome at 1 year evaluated by Neurosurgical cervical spine scale(NCSS) and Japanese Orthopaedic Association (JOA) score.

Surgical Procedure

Transarticular screw technique

The patient is lying in a prone position in a Mayfield head holder (Radiolucent Mayfield) with the neck in a neutral position and flexion the head on the neck in a military tuck position (Figure 1)[1]. In an anteroposterior plane, take an open mouth view x-ray and lateral radiographs before start the operation in addition to confirm proper reduction of atlantoaxial joint to anatomical alignment, and also to locate the skin entry site for the screw trajectory. All patients are prepared and draped from the suboccipital to the mid thoracic area.

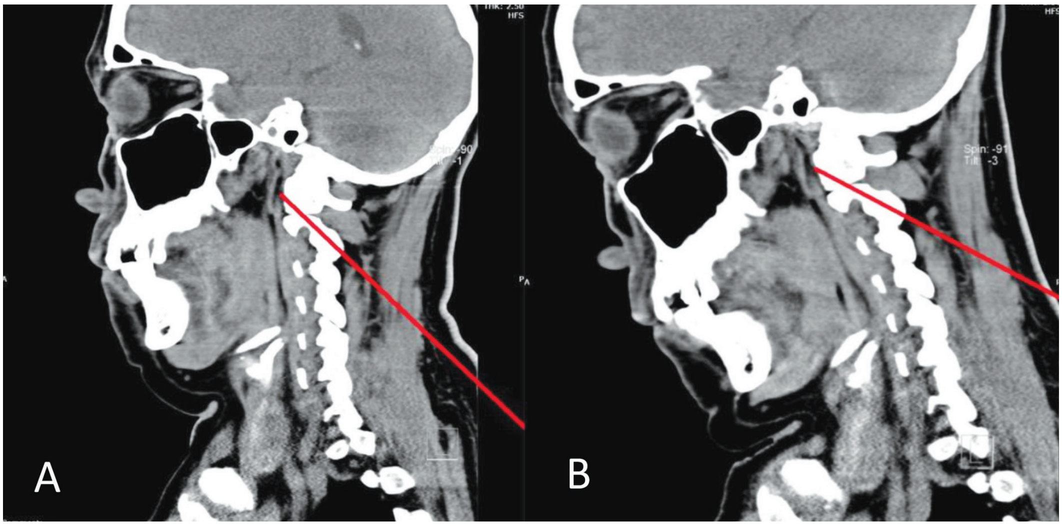

Figure 1 (A) Trajectory for a C1–2 transarticular screw if the patient is positioned without capital flexion of the head on the neck, which is a position unsuitable for the TAS technique.
(B) Trajectory for a C1–2 transarticular screw for a patient positioned with capital flexion of the head on the neck (military tuck position).

A separated midline incision is then created to expose the posterior elements of C1-C3, identify C2 lateral mass. Using No. 4 Penfield dissector, make a gentle sweeping movement C2 nerve in a rostral direction, pass Penfield dissector medially and superiorly over the pars and pedicle of C2 to determine the angle for the screw, control bleeding from epidural venous plexus on medial aspect of the pars by bipolar cautery and absorbable gelatin sponge packing.

With fluoroscopic guidance, the proper trajectory is confirmed by placing the drill or similar instrument adjacent to the neck outside of the incision by subcutaneous tunnel. This trajectory should cross the C1-C2 facet joint and end at the anterior arch of the atlas under biplane fluoroscopic vision. The percutaneous entrance site for the drill is determined, then stab incisions is created approximately 1 cm. from the midline bilaterally, a guide tube with an obturator is placed through the stab incision site and into the open surgical site at C1-C3. The tip of the guide tube is docked at the C2 entry site. The C2 entry site is identified by locating the inferior medial angle of the C2-C3 facet joint. The entry site is approximately 3 mm rostral and 3 mm lateral to these points (Figure 2). The cortical bone is drilled using a high speed-drill and marked for a K-wire entry site. The K-wire trajectory is typically 0-15 degrees medial with the superior angle visualized by fluoroscopy. The K-wire is directed down the C2 pars and pedicle complex and across the C1-C2 joint, aiming at the anterior tubercle of C1. After the K-wire is placed, drill at the same target point. A short threaded cancellous screw is placed (The screw was usually 1-3 mm shorter than the actual measured length since some degree of compression of the C1-2 joints occurs with screw placement). The same technique is repeated on the opposite side. Transarticular screw fixation with Sonntag posterior interspinous wiring procedure and iliac bone graft fusion1 are usually supplemented for added stability.

Translaminar lateral mass C1 technique or posterior arch C1 lateral mass technique (PALM) is used in patients with widening posterior arch of C1 and shallow sulcus arteriosus. The entry point for translaminar

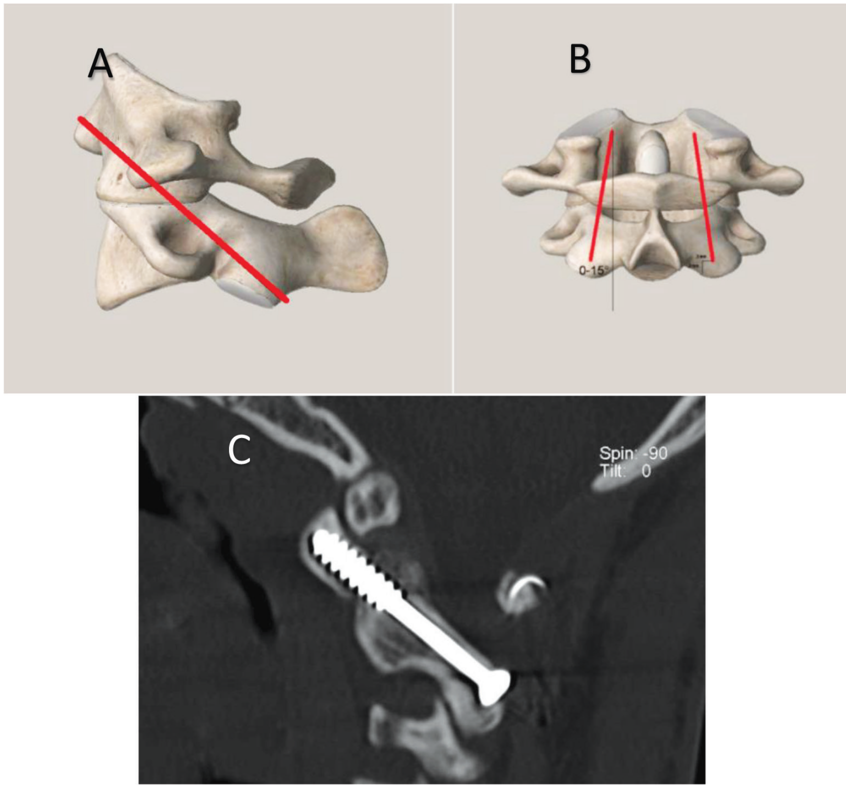

Figure 2 C1-2 Transarticular screw technique

(A) Lateral view: Trajectory for a C1–2 transarticular screw (red line).(B) Posterior view: Trajectory for a C1–2 transarticular screw (red line), The entry site is approximately 3 mm rostral and 3 mm lateral to the inferior medial angle of the C2-C3 facet joint, typically 15 degrees medial. (C) Sagittal CT scan showing C1-2 transarticular screw.

Screw rod construction technique

The patient is lying in the prone position in a Mayfield head holder (Radiolucent Mayfield). The neck is kept in neutral position. A midline incision is made from the suboccipital area to spinous process of C3. The C2-C3 facet joints are exposed and the dorsal arch of C1 is exposed, revealing the vertebral artery in the vertebral groove on the superior aspect of the C1 arch (sulcus arteriosus). The C2 nerve root is identified. Bipolar cautery and hemostatic agent is used to control bleeding from the venous plexus surrounding the C2 nerve root and mobilized C2 nerve root inferiorly. The medial wall of C1 lateral mass is identified using dissector to palpate the medial limit of screw placement. The medial aspect of the transverse foramen at C1 and C2 can also be identified and serve as a lateral limit for screw placement. The entry point for the C1 lateral mass screw is divided into two techniques, translaminar lateral mass C1 technique or posterior arch C1 lateral mass technique (PALM) and sublaminar C1 lateral mass screw technique or Goel/Harms C1 lateral mass technique (GHLM).

C1 lateral mass screw is identified at the center of the C1 lateral mass. Under fluoroscope guidance the screw track is drilled with a similar 10-15 degree medial angulation while perpendicular to the posterior arch. The location of vertebral artery is confirmed by the surgeon before drilling. The hole is then tapped and the screw is placed (Figure 3).

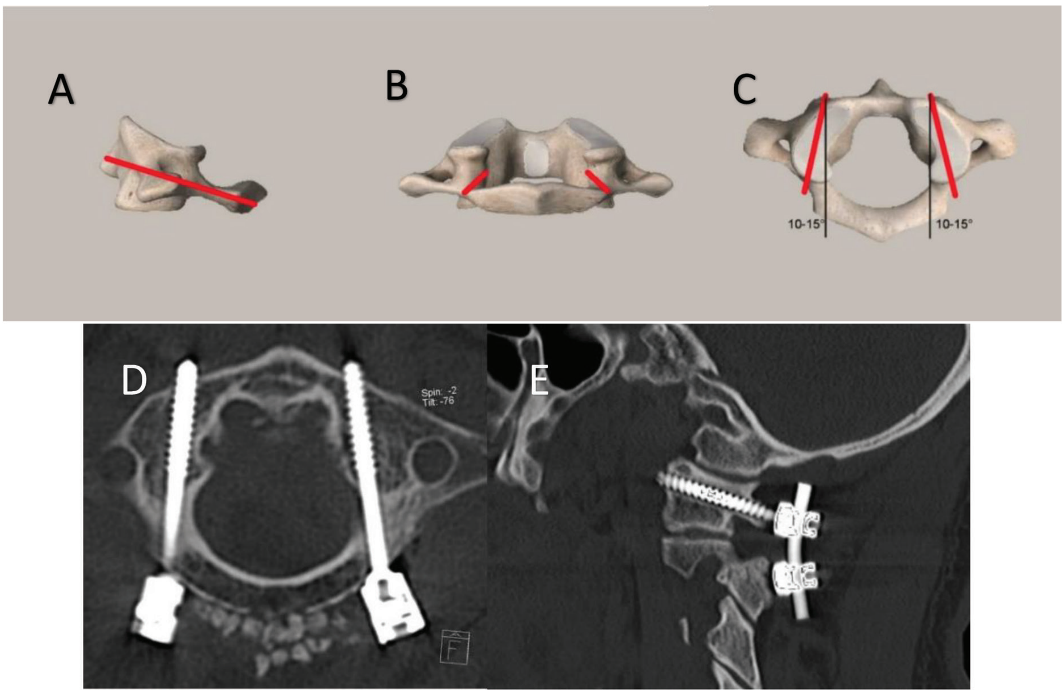

Figure 3 Translaminar C1 lateral mass screw technique
(A) Lateral view: Trajectory for a translaminar C1 lateral mass screw (red line), entry point at the center of the C1 lateral mass. (B) Posterior view: Trajectory for a translaminar C1 lateral mass screw (red line). (C) Superior view: Trajectory for a translaminar C1 lateral mass screws (red line), the entry site 10- 15 degree medial angulation while perpendicular to the posterior arch13. (D) Axial CT scan showing translaminar C1 lateral mass screws. (E) Sagittal CT scan showing translaminar C1 lateral mass screws.

For sublaminar C1 lateral mass screw technique or Goel/Harms C1 lateral mass technique (GHLM), the center of the C1 lateral mass and its intersection with the inferior portion of the lamina is identified and the screw track is drilled using fluoroscopic guidance at a 10-15 degree medial angulation, penetrating the anterior cortex of C1. The track is then tapped and the screw is placed. In this study, C2 nerve root is preserved in all patients. (Figure 4).

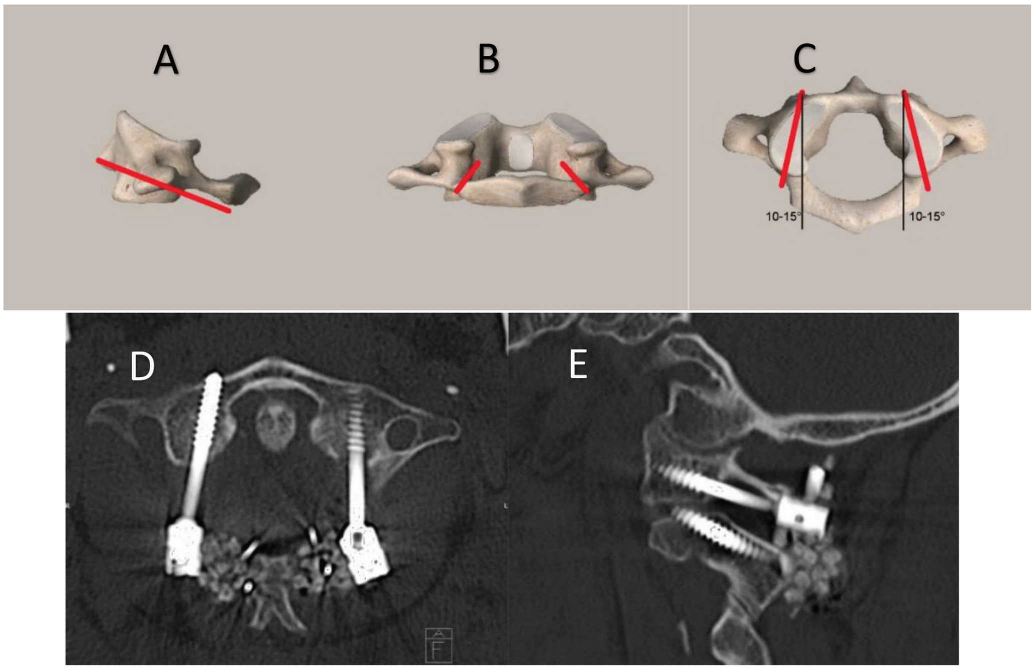

Figure 4 Sublaminar C1 lateral mass screw technique

(A) Lateral view: Trajectory for a sublaminar C1 lateral mass screw (red line), entry point at the center of the C1 lateral mass and its intersection with the inferior portion of the lamina. (B) Posterior view: Trajectory for a sublaminar C1 lateral mass screw (red line). (C) Superior view: Trajectory for a sublaminar C1 lateral mass screws (red line), the entry site 10- 15 degree medial angulation. (D) Axial CT scan showing sublaminar C1 lateral mass screws. (E) Sagittal CT scan showing sublaminar C1 lateral mass screws.

The C2 screw can be placed in pedicle, pars and lamina. The first choice of C2 screw fixation is transpedicular screw fixation for more contract surface of screw and bone. For C2 pedicle screw fixation, the entry point of C2 is targeted based on the transitional corner, which is the more cephalad portion of the lamina and the C2 isthmus. Using a high-speed drill, the entry point is marked 4 mm. lateral to and 4 mm. caudal to transitional point. The direction is approximately 20-30 degree in a medial and cephalad direction to the medial border at the C2 pars interarticularis under fluoroscopy guidance. After making a tapering hole, 3.5 mm. polyaxial screw is inserted (Figure 5). If the pedicle is small, the second choice will be pars screw. A C2 pars screw is placed in a trajectory similar to that of a C1-C2 transarticular screw, except that it is much shorter (Figure 6). If the pedicle is small and high riding vertebral artery, it is unsuitable to use pedicle screw and pars screw. Laminar screw should be used instead. The laminar screw C2, using crossing screw is placed directly onto the cancellous bone of the lamina of C2, a high-speed drill is then used to open a small cortical window at the junction of C2 spinous process and lamina on the right, close to the rostral margin of the C2 lamina.

With a hand drill, the contralateral lamina is drilled to 24–30 mm. depth. To avoid any injuries on the spinal canal, the trajectory of insertion is kept slightly less than the downslope of the lamina to ensure that any possible cortical breakthroughs occur dorsally through the laminar surface, rather than ventrally into the spinal canal. Additionally, a small ball probe is used to palpate the length of the hole to verify that no cortical breakthroughs into the spinal canal has occurred. Polyaxial screw is then inserted along the same trajectory. In the final position, the screw head is marked at the junction of the spinous process and C2 laminar on the left, close to the caudal aspect of the lamina. Using of the same technique as above, a screw is then placed onto the right lamina, with the screw head remaining on the left side of the spinous process (Figure 7).

Rods are contoured and then secured to the remaining screw heads in the construct. Local autograft or artificial bone graft are packed around the remaining exposed bone surfaces and into the decorticated facet complexes.

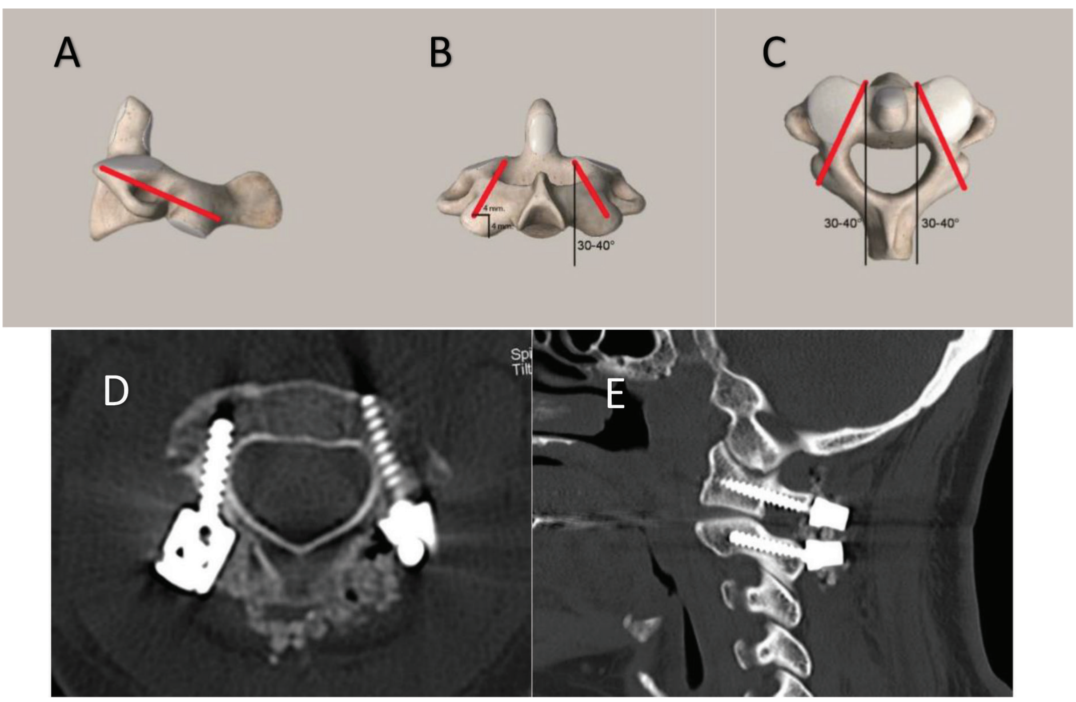

Figure 5 C2 pedicle screw technique

(A) Lateral view: Trajectory for C2 pedicle screw (red line). (B) Posterior view: Trajectory for C2 pedicle screw (red line), the entry points of C2 is marked 4 mm. lateral to and 4 mm. caudal to transitional point, which is the more cephalad portion of the lamina and the C2 ischmus. (C) Superior view: Trajectory for C2 pedicle screw (red line), The direction was approximately 20–30 degree in a medial and cephalad direction to the medial border at the C2 pars interarticularis. (D) Axial CT scan showing C2 pedicle screws. (E) Sagittal CT scan showing C2 pedicle screws.

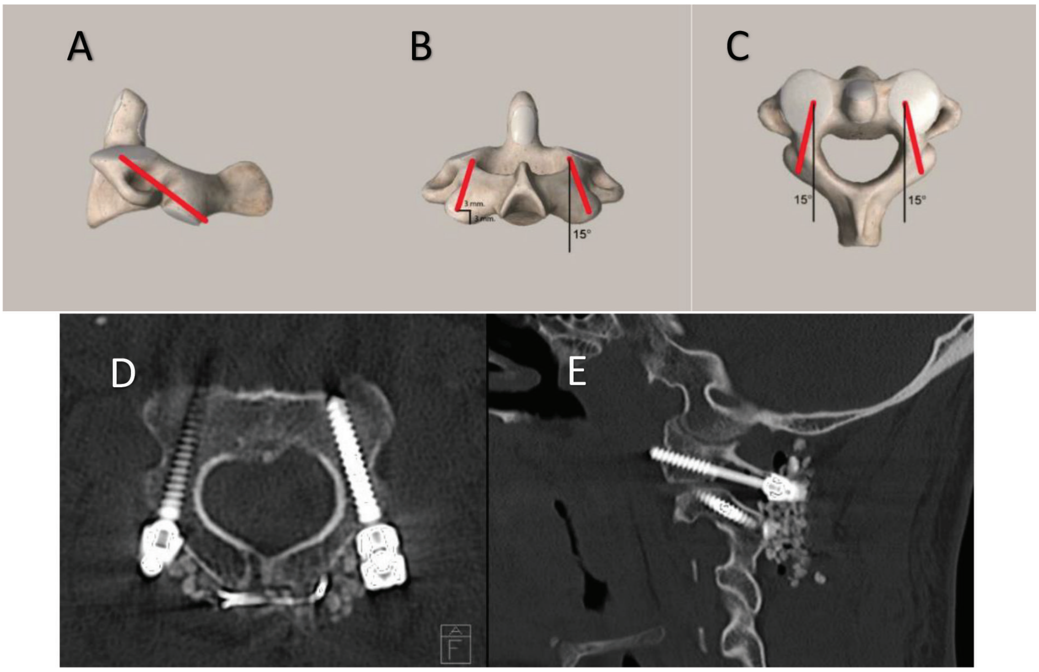

Figure 6 C2 pars screw technique

(A) Lateral view: Trajectory for C2 pars screw (red line). (B) Posterior view: Trajectory for C2 pars screw (red line), the entry site is approximately 3 mm rostral and 3 mm lateral to the inferior medial angle of the C2-C3 facet joint, typically 15 degrees medial. (C) Superior view: Trajectory for C2 pars screw (red line). (D) Axial CT scan showing C2 par screws. (E) Sagittal CT scan showing C2 pars screws.

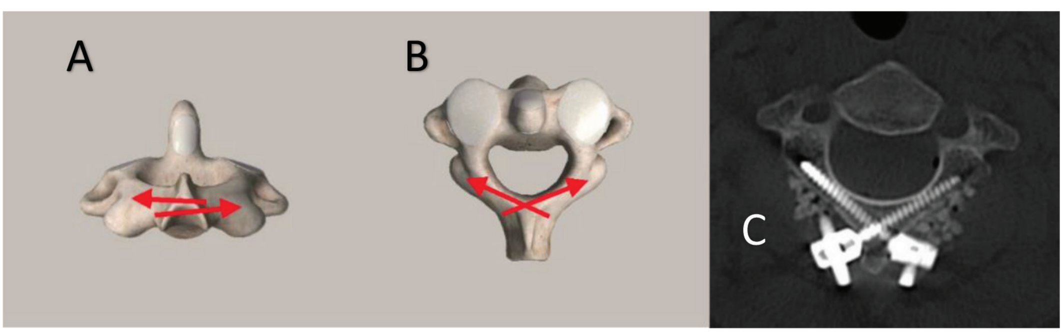

Figure 7 C2 laminar screw technique

(A) Posterior view: Trajectory for C2 pars screw (red arrow), using crossing screw placed directly onto the cancellous bone of the C2 lamina. Right side, the screw at rostral margin of the C2 lamina and the caudal aspect of the lamina at the left side. (B) Superior view: Trajectory for C2 pars screw (red arrow). (C) Axial CT scan showing C2 laminarscrews.

Radiographic evaluation

Plain film C-spine AP and lateral view and CT scan bone window is performed on all patients. The evaluated parameter in preoperative imaging were atlanto-dental interval (ADI), posterior atlanto-dental interval (PADI). The parameter was measured in neutral position. In this report, the narrowest an-teroposterior (AP) diameters between C1-2 spinal canal viewed at sagittal view of CT bone was referred to as "narrowest in A-P diameter of atlantoaxial spinal canal (NDAASC)". Postoperative data collected were ADI, PADI, NDAASC, differences between ADI (ΔADI), differences between PADI (ΔPADI), differences between NDAASC (ΔNDAASC), percentage of differences between NDAASC (ΔNDAASC%). (Figure 8)

Plain film C-spine AP and lateral view are performed all cases at postoperative 1-2 day and CT bone is performed on 37 patients (88%).

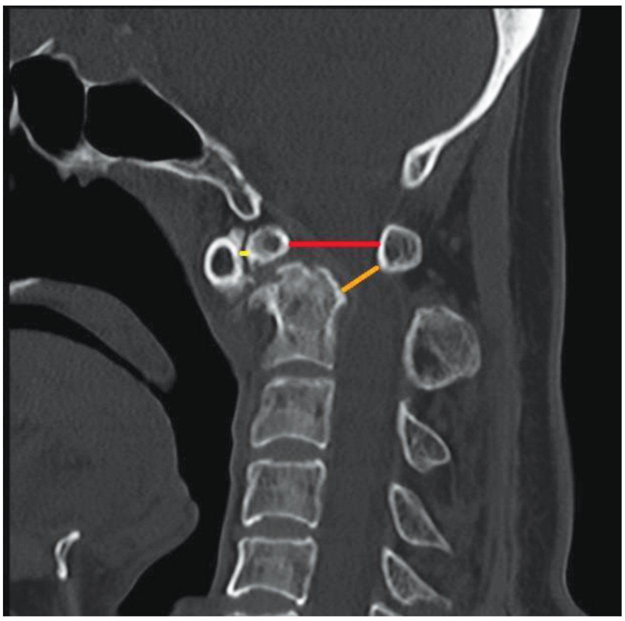

Figure 8 Radiographic parameter
1) Yellow line: Atlanto-dental interval (ADI)
2) Red line: Posterior atlanto-dental interval (PADI)
3) Orange line: Narrowest in A-P diameter of atlantoaxial spinal canal (NDAASC)

Follow-up and outcome

The median follow-up length was 1 year and 5 months (10 months – 3 years 7months).
Only patients who had been followed-up for at least one year were used for analysis.

Bony fusion is defined by 1) demonstrating bridging bone between C1-2 or continuous cortical bone between C1-2. 2) At flexion and extension plain film c-spine, with no movement of C1-2.

JOA and NCSS were used to compare preoperative and postoperative for each group and preoperative baseline and postoperative clinical outcome between the TAS and the SRC group.

The estimated NCSS percentage of improvement of the neurological status at the initial and follow-up examination can be calculated by the following formula:

$$A\ (\%) = (T_F - T_i / 14 - T_i) \times 100$$

A is percentage of improvement

T_i is total scores in the initial examination

T_F is total scores in the follow-up examination

Statistics analysis

Man-Whitney test was used for continuous variables and the Chi-square test for categorical variables. Wilcoxon signed ranks test was used to analyze the preoperative and postoperative continuous variables. Baseline characteristic data were used to derive the percentage for gender, and median with interquartile range was used for nonparametric univariate statistics for quantitative variables. Statistical significances in all analyses are defined at $p < 0.05$. All statistical analysis is performed using SPSS version 16.0.

Result

Patient Characteristics

Patient demographics were well balanced between the TAS and SRC groups (Table 1). Overall, the vas majority of the patients in the present study were male (25, 59.5%), and their mean age was in the fourth decade of life. Causes of C1-2 instability were traumatic subluxation (50%), a non-traumatic subluxation (31%), infection (7.1%), Os odontoidium (4%), and rheumatoid (2.4%). The median duration of symptoms was 90 days (20-212). On admission, 20 patients (47.6%) suffered from neck pain only, 14 patients (33.3%) had neck pain with myelopathy, 7 patients (16.7%) had myelopathy only (only 1 of 7 was quadriplegia) and 1 patient (2.4%) was asymptomatic.

Table 1 Patient baseline characteristics in the transarticular screws (TAS) and the screw-rod constructs (SRC) group

	TAS (9)	**SRC (33)**	***P* value**
Sex			0.716
Male (%)	6(66.7)	19(57.6)	
Female (%)	3(33.3)	14(42.4)	
Age (median,year)	51(47-59)	47(34-64.5)	0.57
Onset duration (median,day)	90(11-365)	90(25.5-182)	0.746
Clinical Presentation			0.354
Neck pain	5	15	
Neck pain with myelopathy	2	12	
Myelopathy	1	6	
Asymtomatic	1	0	
Cause			0.145
Traumatic subluxation	6	15	
Non-traumatic subluxation	1	12	
Infection	2	1	
Os odontoidium	0	4	
Rheumatoid	0	1	
Odontoid Fracture			0.438
None	2	15	
Type I	1	4	
Type II	5	13	
Type III	1	1	
Preoperative ADI (mm.)	1.68(1.305-6.75)	1.62(0.905-5.73)	0.592
Preoperative PADI (mm.)	15.44(9.525-19.51)	16.57(12.56-20.065)	0.51
Preoperative NDAASC (mm.)	13.75(8.875-16.09)	12.8(9.525-16.495)	0.902
Preoperative NCSS	12(12-12)	12(10-12)	0.207
Preoperative JOA score			0.312
Grade 0 (16-17)	7	19	
Grade 1 (12-15)	1	12	
Grade 2 (8-11)	0	0	
Grade 3 (0-7)	1	2	

ADI: Atlanto-dental interval, PADI: posterior atlanto-dental interval, NDAASC: narrowest in A-P diameter of atlantoaxial spinal canal, NCSS: Neurosurgical cervical spine scale, JOA score: Japanese Orthopaedic Association score.

TAS Versus SRC

Radiological result

The diagnosis was verified with plain film and CT scan in all patients and 24 patients (57%) had additional MRI scan preoperative.

Fracture odontoid process was present in 25 patients (59.5%), and widening ADI at neutral lateral plain film and neutral CT scan was present in 17 patients (40%). In all patients, the median of pre-operative ADI was 1.65(1.095-6.21), preoperative PADI was 16.56(12.42-19.81) and preoperative NDAASC was 13.26(9.66-16.46).

No statistical significances were found in the comparison of TAS and SRC groups in ΔADI [0.82 (-0.29- 4.87) VS 0.05(0-1.75), *P* = 0.488], ΔPADI [1.20 (-0.77-4.52) VS 0.05(0-1.26), *P* = 0.554], ΔNDAASC [1.85 (0.87-6.16) VS 1.67 (0.34-5.20), *P* = 0.46], ΔNDAASC% [13.45 (5.35-79.59) VS 13.39 (1.89-50.73), *P* = 0.594]. (Table 2).

Table 2 Postoperative outcome in the transarticular screws (TAS) and the screw-rod constructs (SRC) group

	TAS (8)	**SRC (33)**	***P* value**
ΔADI (mm.)	0.82 (-0.29-4.87)	0.05 (0-1.75)	0.488
ΔPADI (mm.)	1.20 (-0.77-4.52)	0.05 (0-1.26)	0.554
ΔNDAASC (mm.)	1.85 (0.87-6.16)	1.67 (0.34-5.20)	0.46
ΔNDAASC (%)	13.45 (5.35-79.59)	13.39 (1.89-50.73)	0.594
Fusion*	9 (100)	28 (96.6)	1
Postoperative NCSS 1 y**	14 (13-14)	14 (14-14)	0.438
Postoperative NCSS 1 y %**	100 (70-100)	100 (100-100)	0.419
Postoperative JOA score 1 y**			0.418
Grade 0 (16-17)	6	22	
Grade 1 (12-15)	1	1	
Grade 2 (8-11)	0	0	
Grade 3 (0-7)	0	0	

ADI: atlanto-dental interval, PADI: posterior atlanto-dental interval, NDAASC: narrowest in A-P diameter of atlantoaxial spinal canal, NCSS: Neurosurgical cervical spine scale, JOA score: Japanese Orthopaedic Association score.
*Four patients were excluded in the SRC group due to no postoperative follow up imaging.
**Two patients in the TAS group and 10 patients in the SRC group were excluded due to discontinuity of follow-up before 1 year.

Follow up and outcome

No statistically significant differences were observed in operative time [150 (132.5-347.5) min VS 203 (157-254.5) min, *P* = 0.453], blood loss [200 (100-500) ml VS 250 (135-400) ml, *P* = 0.963] and hospital stay [14 (8.5-24) days VS 10 (6.5-17) days, *P* = 0.167] both TAS and SRC group, respectively. (Table 3)

Table 3 Intraoperative outcome of the transarticular screws (TAS) and the screw-rod constructs (SRC) group

	TAS (9)	SRC (33)	*P* value
Operative time (min)	150(132.5-347.5)	203(157-254.5)	0.453
Blood loss (ml)	200(100-500)	250(135-400)	0.963
Hospital Stay (day)	14(8.5-24)	10(6.5-17)	0.167

At the mean of the follow-up lengths of 3.55 and 1.3 years for the TAS and SRC groups, respectively, no statistically significant differences were observed in fusion [9 (100%) VS 28 (96.6%), *P* = 1], postoperative NCSS at 1 year (*P* = 0.438), percentage of postoperative NCSS at 1 year (*P* = 0.419) and postoperative JOA score at 1 year (*P* = 0.418). (Table 2)

In TAS technique, the comparison of preoperative and postoperative radiologic outcome in ADI showed no statistically significant results [1.68 (1.3-6.75) VS 1.77 (1.36-1.91), *P* = 0.11], which resembled the results found for PADI [15.44 (9.53-19.51) VS 17.18 (16.32-20.68), *P* = 0.208], while NDAASC showed significant widening spinal canal [13.75 (8.86-16.09) VS 16.03 (15.5-19.2), *P* = 0.008]. (Table 4)

Follow-up and outcome

In TAS technique, JOA at 1 year follow-up showed no statistically significant differences when compared to preoperative JOA while NCSS showed significant improvement at postoperative 1 year. (Table 4)

Table 4 Preoperative and postoperative comparison of the transarticular screws (TAS) group

	Preoperative	Postoperative	*P* value
ADI (mm.)	1.68 (1.3-6.75)	1.77 (1.36-1.91)	0.11
PADI (mm.)	15.44 (9.53-19.51)	17.18 (16.32-20.68)	0.208
NDAASC (mm.)	13.75 (8.86-16.09)	16.03 (15.5-19.2)	0.008
NCSS*	12 (12-12)	14 (13-14)	0.024
JOA score*			0.18
Grade 0 (16-17)	6	6	
Grade 1 (12-15)	0	1	
Grade 2 (8-11)	0	0	
Grade 3 (0-7)	1	0	

ADI: Atlanto-dental interval, PADI: posterior atlanto-dental interval, NDAASC: narrowest in A-P diameter of atlantoaxial spinal canal, NCSS: Neurosurgical cervical spine scale, JOA score: Japanese Orthopaedic Association score.

*At 1 year of follow up

The SRC group shows statistically significant decrease ADI [1.62 (0.91-5.73) VS 1.08 (0.8-1.59), *P* = 0.001], while there was an increase for PADI [16.57 (12.56-20.07) VS 18.89 (15.92-20.96), *P* = 0.021], NDAASC had signi-ficantly widening spinal canal [12.8 (9.53-16.5) VS 15.75 (13.34-19.14), *P* < 0.001]. (Table 5)

Follow-up and outcome

There was a statistically significant result in postoperative JOA (*P* = 0.015) and postoperative NCSS at 1 year (*P* < 0.001) when compared with preoperative data. (Table 5)

Table 5 Preoperative and postoperative comparison of the screw-rod constructs (SRC) group

Preoperative	Postoperative	*P* value	
ADI (mm.)	1.62 (0.91-5.73)	1.08 (0.8-1.59)	0.001
PADI (mm.)	16.57 (12.56-20.07)	18.89 (15.92-20.96)	0.021
NDAASC (mm.)	12.8 (9.53-16.5)	15.75 (13.34-19.14)	< 0.001
NCSS*	12 (10-12)	14 (14-14)	< 0.001
JOA score*			0.015
Grade 0 (16-17)	16	22	
Grade 1 (12-15)	7	1	
Grade 2 (8-11)	0	0	
Grade 3 (0-7)	0	0	

ADI: Atlanto-dental interval, PADI: posterior atlanto-dental interval, NDAASC: narrowest in A-P diameter of atlantoaxial spinal canal, NCSS: Neurosurgical cervical spine scale, JOA score: Japanese Orthopaedic Association score.
*At 1 year of follow-up

There were no statistically significant differences of baseline characteristic between translaminar C1 lateral mass screw fixation and sublaminar C1 lateral mass screw fixation (Table 6) and no statistically significant differences in ΔADI [0.46 (0-2.91) VS 0.02 (0-0.81), *P* = 0.454], ΔPADI [0.36 (-0.47-1.57) VS 0.05 (0-0.66), *P* = 0.947], ΔNDAASC [1.28 (0.24-3.92) VS 3.17 (0.35-5.63), *P* = 0.461], ΔNDAASC % [6.57 (1.67-30.77) VS 22.43 (1.56-62.98), *P* = 0.357] (Table 7).

Table 6 Patient baseline characteristics in sublaminar and translaminar C1 lateral mass screw technique

	Translaminar (10)	Sublaminar (19)	*P* value
Preoperative ADI (mm.)	1.975 (0.59-5.58)	1.57 (0.91-5.18)	0.89
Preoperative PADI (mm.)	15.825 (13.14-21.45)	18.58 (12.54-19.43)	0.748
Preoperative NDAASC (mm.)	14.14 (11.30-14.90)	11.11 (8.24-17.12)	0.359
Preoperative NCSS	12 (11-12)	12 (10-12)	0.12
Preoperative JOA score			0.519
Grade 0 (16-17)	7	11	
Grade 1 (12-15)	3	6	
Grade 2 (8-11)	0	0	
Grade 3 (0-7)	0	2	

ADI: Atlanto-dental interval, PADI: posterior atlanto-dental interval, NDAASC: narrowest in A-P diameter of atlantoaxial spinal canal, NCSS: Neurosurgical cervical spine scale, JOA score: Japanese Orthopaedic Association score.
*Four patients in the SRC group did not have postoperative follow-up imaging.

Follow-up and outcome

One patient in the sublaminar C1 lateral mass screw fixation group had no fusion, he underwent an operation to revision and occipito-cervical fixation [10 (100%) VS 15 (93.8%), *P* = 1]. Postoperative clinical follow- up at 1 year in JOA (*P* = 0.381), NCSS (*P* = 0.858) and NCSS% (*P* = 0.953) showed no significant differences in both groups (Table 7).

Table 7 Postoperative outcome in Sublaminar and translaminar C1 lateral mass screw technique

	Translaminar (10)	Sublaminar (19)	*P* value
ΔADI (mm.)	0.46 (0-2.91)	0.02 (0-0.81)	0.454
ΔPADI (mm.)	0.36 (-0.47-1.57)	0.05 (0-0.66)	0.947
ΔNDAASC (mm.)	1.28 (0.24-3.92)	3.17 (0.35-5.63)	0.461
ΔNDAASC (%)	6.57 (1.67-30.77)	22.43 (1.56-62.98)	0.357
Fusion*	10 (100)	15 (93.8)	1
Postoperative NCSS 1 y**	14 (14-14)	14 (14-14)	0.858
Postoperative NCSS 1 y %**	100 (100-100)	100 (100-100)	0.953
Postoperative JOA score 1 y**			0.381
Grade 0 (16-17)	7	13	
Grade 1 (12-15)	1	0	
Grade 2 (8-11)	0	0	
Grade 3 (0-7)	0	0	

ADI: Atlanto-dental interval, PADI: posterior atlanto-dental interval, NDAASC: narrowest in A-P diameter of atlantoaxial spinal canal, NCSS: Neurosurgical cervical spine scale, JOA score: Japanese Orthopaedic Association score.
*Four patients in the sublaminar group were excluded due to not having postoperative follow-up imaging.
**Two patients in the translaminar group and 6 patients in the sublaminar group were excluded due to discontinuity of follow-up before 1 year.

Complication rates

There are very low complication rates, and no deaths and infection occurred in either group (Table 8). Only one patient in the SRC group treated with sublaminar C1 lateral mass screw technique was found with postoperative occipital neuralgia, and the symptom was improved after selective nerve root block (SNRB) Right C2 root 3 months after the surgery. Two patients in the SRC group with sublaminar C1 lateral mass screw technique were found with broken screws. One of the two patients was found with a broken screw one month after the surgery, the patient was given conservative treatment and significant fusion was found 9 months after the surgery. The other patient with Down's syndrome and os odontoideum, was found with a broken screw 9 months after the surgery due to a widening gap between odontoid and body of axis at post-operation and due to active movement of the neck after being discharged from the hospital. The patient then underwent an operation to he underwent an operation to revision and occipito-cervical fixation. Both patients did not show any signs of pain from the broken screws when returning for check-ups. (Table 9).

Table 8 Complication in the transarticular screws (TAS) and the screw-rod constructs (SRC) group

	TAS (9)	SRC (33)
Infection	0	0
Occipital neuralgia	0	1
Occipital numbness	0	0
Hardware failure	0	2

Table 9 Complication in translaminar and sublaminar C1 lateral mass screw groups

	Translaminar (10)	Sublaminar (19)
Infection	0	0
Occipital neuralgia	0	1
Occipital numbness	0	0
Hardware failure	0	2

Illustrative Cases

This patient was a 60-year-old female with a history of trauma and chronic neck pain. Imaging revealed evidence of C1-C2 instability with odontoid process fracture. She underwent C1-2 fixation by SRC technique (C1: sublaminar lateral mass screw technique, C2: translaminar screw fixation technique). Preoperative data showed ADI 1.02 mm, PADI 18.58 mm, NDAASC 8.24 mm, postoperative data showed ADI 1.02 mm, PADI 18.89 mm, NDAASC 13.43 mm. Preoperative and postoperative JOA scores were similar at 17. Preoperative and postoperative NCSS was 12 and 14, respectively. The NCSS improved at 100%. (Figure 9).

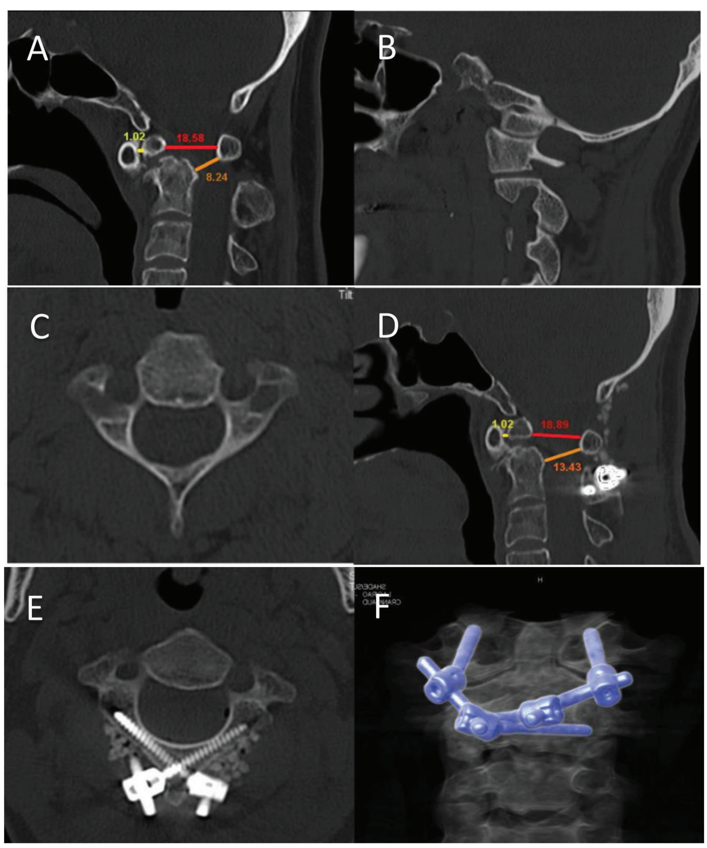

Figure 9 Illustrative Cases
Image showing that C1-2 spinal canal was narrow but PADI was not narrow and/or ADI is not wide.
(A): Image showing radiographic parameter in preoperative sagittal CT scan; ADI 1.02 mm. (yellow line), PADI 18.58 (red line), NDAASC 8.24 mm. (orange line) (B): Preoperative sagittal CT scan, high riding vertebral artery at C2, unsuitable for pars screw. (C) Preoperative axial CT scan, small bilateral C2 pedicle, its improper for pedicle screw. (D): Radiographic parameter in postoperative sagittal CT scan; ADI 1.02 mm. (yellow line), PADI 18.89 (red line), NDAASC 13.43 mm. (orange line) (E) Postoperative axial CT scan showing C2 laminar screws. (F) CT bone multiplanar reconstruction (MPR) showing C1 lateral mass screws with C2 lamina screws connected by rods.

Discussion

Transarticular screw technique as described by Magerl and Jeanneret in 1979, is a popular technique but its limitation is from high riding vertebral artery. C1-C2 screw fixation is used for C1-2 instability. Fusion using C1 lateral mass screw and C2 pedicle screw and plates is pioneered by Goel et al.[7] Later, Harms and Melcher[8] described C1 lateral mass screws connected to C2 pars or pedicle screw using rod. The modified technique for circumventing the limitation of anatomic variation such as C2 laminar screw, described by Wright and Leonard[9,10]. In a meta-analysis, Elliott et al.[11] reports a slightly higher rate of fusion with the SRC technique. In this study, C1-2 transarticular screw technique and C1-2 SRC technique were compared. The results of the two techniques did not show any statistically significant results in ΔADI, ΔPADI, ΔNDAASC, ΔNDAASC%, fusion rate, postoperative JOA at 1 year, postoperative NCSS at 1 year and postoperative NCSS% at 1 year. Both the TAS and the SRC technique showed significant outcomes in ADI, NDAASC, and NCSS, and a significant result in PADI and JOA was found in the SRC group when the preoperative and postoperative data were compared.

For the C1-2 screw fixation technique, the first method used was C2 nerve root resection but this method is often followed by occipital numbness complications. Modified technique for reducing this complication using C2 nerve root preservation technique but followed by occipital neuralgia complication. Elliott et al.[4] reported C2 nerve root section resulted in greater symptomatic numbness (11.6% VS 1.3%, $P < 0.0001$) but less neuropathic pain (0.3% VS 4.7%, $P = 0.0002$) compared with C2 preservation. The modified technique of sublaminar C1 lateral mass screw technique is developed to preserve C2 nerve root and used a long lag screw to prevent C2 nerve root irritation. Transarticular screw or posterior arch C1 lateral mass screw was technique used to prevent C2 nerve root irritation. In this study, C2 nerve root preservation technique was used in all patients and the analysis of sublaminar C1 lateral mass screw technique and translaminar C1 lateral mass screw technique in the SRC technique showed no significant differences and no incidence of postoperative occipital numbness between the two groups. Only one patient of sublaminar C1 lateral mass screw group using the SRC technique was found with occipital neuralgia (0.03%), which is less than the results found in previous studies.

Complication

In this study, the incidence of infection, vertebral artery injury, screw malposition, morbidity, and mortality were not found. One patient was found with occipital neuralgia of the GHLM technique. Her symptom occurred at postoperative and was slightly improved by medication, this symptom resolved after selective nerve root block (SNRB) at 3 months postoperation. Hardware failure occurred in 2 patients of the SRC group. The first of the two patients was a 62-year-old male who was found with a broken right C2 screw at 1 month after the surgery, after conservative management and follow-up, fusion of C1-2 was found at 10 months after the surgery. The other patient was a 7-year-old boy with Down's syndrome and os odontoideum who was found with a broken right C1 screw at 9 months after the surgery, he underwent remove screw at C1 with occipital- C2 fixation. No neurologic symptom and neck pain at over time of follow up. In previous meta-analysis[11] comparing TAS and SRC technique, no significant difference was shown in 30 days mortality (0.8% VS 0.6%) or neurological injury (0.2% VS 0%). There was a high incidence of vertebral artery injury (4.1% VS 2.0%, P = 0.02) and malposition screws (7.1% VS 2.4%, P < 0.001%).

Study limitation

Our study has several limitations, namely, a small number of cases were included in each group, the patients were not randomly assigned to each group, and the follow-up period was relatively short.

Conclusion

Both TAS and SRC techniques can be used for C1-2 instability because no statistically significant results were found in both groups and there was a low incidence of complication. Sublaminar and translaminar C1 lateral mass screw technique showed no statistically significant results. Sublaminar C1 lateral mass screw technique seems to yield a slightly higher rate of occipital neuralgia. The decision to use either technique of C1-2 fixation must be made after a careful review of the individual patient's anatomy on imaging and the surgeon's experiences.

References

1. Mummaneni PV, Haid RW. Atlantoaxial fixation Overview of all techniques. Neurol India. 2005;53(4):408-15.
2. Moisi M, Fisahn C, Tkachenko L, Jeyamohan S, Reintjes S, Grunert P, et al. Posterior arch C-1 screw technique: a cadaveric comparison study. J Neurosurg Spine. 2017; 26(6):679-83.
3. Yamagata T, Takami T, Naito K, Ohata K. C2 nerve root resection to achieve safe and wide exposure of lateral atlantoaxial joints in posterior C1-2 instrumented fixation: technical note. Neurol Med Chir (Tokyo). 2013;53(12):914-9.
4. Elliott RE, Kang MM, Smith ML, Frempong-Boadu A. C2 Nerve Root Sectioning in Posterior Atlantoaxial Instrumented Fusions: A Structured Review of Literature. World Neurosurgery. 2012:78(6):697-708.
5. Lin JM, Hipp JA, Reitman CA. C1 lateral mass screw placement via the posterior arch: a technique comparison and anatomic analysis. Spine J. 2013;13(11):1549-55.
6. Lee SH, Kim ES, Eoh W. Modified C1 lateral mass screw insertion using a high entry point to avoid postoperative occipital neuralgia. J Clin Neurosci. 2013; 20(1):162-7.
7. Ma W, Feng L, Xu R, Liu X, Lee AH, Sun S, et al. Clinical application of C2 laminar screw technique. Eur Spine J. 2010;19(8):1312-7.
8. Harms J, Melcher RP. Posterior C1–C2 Fusion with Polyaxial Screw and Rod Fixation. Spine (Phila Pa 1976). 2001;26(22):2467-71.
9. Wright NM. Posterior C2 fixation using bilateral, crossing C2 laminar screws: case series and technical note. J Spinal Disord Tech. 2004;17(2):158-62.
10. Wright NM. Translaminar rigid screw fixation of the axis. Technical note. J Neurosurg Spine. 2005;3(5):409-14.
11. Elliott RE, Tanweer O, Akwasi B, Morsi A, Ma TS, Frempong-Boadu A, et al. Outcome Comparison of Atlantoaxial Fusion with Transarticular Screws and Screw-Rod Constructs: Meta-Analysis and Review of Literature. Clinical Spine Surgery: 2014;27(1):11-28.