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Cohort Study

Anterior screw fixation for type II odontoid process fractures: A single-center experience with the double Herbert screw fixation technique (Retrospective cohort study)

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ABSTRACT

Background: In type II odontoid fractures with intact transverse ligament as classified by the Anderson and D'Alonzo system, anterior screw fixation offers the best anatomical and functional results. The goal of this study is to review the results of the double screw technique in anterior odontoid surgery using a headless 3.0-mm.-diameter cannulated Herbert screw on patients with odontoid process fractures.

Methods: From January 2015 through March 2019, 12 cases of acute traumatic type II odontoid fractures were treated with double anterior screw fixation using 3.0-mm Herbert screws, slightly smaller than the standard size for Caucasian populations. The data collected included radiographic measurements, postoperative complications, union rate and clinical outcomes in follow-up examinations over an average of 24-months.

Results: The age of the 12 patients, 8 males and 4 females, ranged from 17 to 68 years (mean, 38.42 ± 20.14). The fracture type was type IIa in 4 patients (33.33%) and type IIb in 8 patients (66.67%). The period of follow-up was 15–64 months (mean, 31.42 ± 17.37). All the patients had good clinical results after surgery with no post-operative complications. Eleven cases (92%) had achieved bone union with 1 case (8%) of nonunion. In the nonunion case, the patient was a chronic smoker who continued smoking both during treatment and follow-up.

Conclusions: This series of satisfactory clinical results demonstrates that double anterior screw fixation of type II odontoid process fractures using 3.0-mm screws is highly effective in the Thai population. Headless cannulated cancellous screws provide significant biomechanical strength which is not inferior to the traditional screws

1. Introduction

Odontoid fracture of the axis, a common cervical spine injury, is challenging because of the potential for additional injury during treatment due to the complex architecture of the cranio-cervical junction [1]. The Anderson and D'Alonzo's categorization scheme divides odontoid fractures into three subtypes based on fracture morphology and healing potential which can help guide treatment. Type I fractures involve only the tip of the dens, while in type II fractures the neck of the dens is involved as well. A further subdivision of type II fractures has been described by Grauer et al. [2] in which the horizontal fracture pattern is type IIa, the anterosuperior to posteroinferior fracture pattern is type IIb, and the anteroinferior to posterosuperior fracture pattern is type IIc. A type III fracture extends from the base of the dens into the body of C2. External immobilization is used when treating a minimally displaced type IIa fracture, while anterior screw fixation is usually used in displaced type IIa and IIb fractures. Type IIC fractures are usually treated by C1–C2 instrumental fusion. However, in type II odontoid process fractures with intact transverse ligament, anterior screw fixation provides the best morphological and functional results and is the treatment of choice. Kazan et al. [3] published the first technical description of a closed anterior fixation of odontoid fractures using a percutaneous technique in a cadaveric study. To our knowledge, there have been no published reports of clinical trials of the safety and efficacy of the double anterior odontoid screw technique. The standard screw types for Caucasian populations are single and double screws with diameters of 3.5 mm, 4.0 mm or 4.5 mm, made of titanium or stainless steel, either cannulated or non-cannulated, cancellous, and half-threaded [1,4]. However, most Asians have a smaller physical frame than Caucasians and other features of their anatomy differ from that of Caucasians. The

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purpose of this research is to investigate whether 3.0 mm diameter double Herbert screws with two threads having different pitches on the distal and proximal ends and no head are useful in anterior odontoid screw fixation.

2. Materials and methods

2.1. Study design and participants

We retrospectively reviewed the records of 12 patients with traumatic type II odontoid fractures who had undergone anterior screw fixation using double Herbert screws between January 2015 and March 2019. The data were collected retrospectively and the patients' informed consent was not required. All patient information was kept confidential. The patients were not charged or harmed as a result of the study. The study was approved by the Institutional Review Board (IRB number: ORT-2564-08551) and has been reported on line following the STROCSS 2021 guideline] [5]. The study has been registered in the research registry with Unique Identifying number 7420, and is available at https://www.researchregistry.com/browse-the-registry#home/registrationdetails/61a7a37ee13308001e719670/.

2.2. Study population

The inclusion criteria were patients with an acute traumatic type II odontoid fracture with no previous treatment during the study period. Patients' presentations and symptoms included acute upper neck or suboccipital discomfort and restriction of neck mobility with or without paralysis of extremities. The indication for surgery was an acute traumatic type II odontoid fracture. The exclusion criteria were patients with a short neck, excessive cervical kyphosis, a barrel-shaped chest, chronic odontoid fractures, nonunion odontoid fractures, type I odontoid fractures, type III odontoid fractures, associated Jefferson fractures, atlantoaxial instability (anterior dens interval (ADI) > 4 mm) or atlantoaxial instability caused by degenerative processes, tumors, infections, inflammatory disorders, congenital diseases and cases of irreducible fractures.

2.3. Surgical techniques

To avoid fracture dislocation and additional risks that can result from cervical hyperextension, general anesthesia was carefully administered with fiberoptic-assisted intubation and skull traction (Fig. 1A). The patients were put in the supine position on a radiolucent operating table with a cushion under their shoulders to allow the neck to extend slightly. All patients with odontoid fractures underwent preoperative skull traction with Gardner-Wells tongs using a weight of 5–10 lb. to reduce and stabilize the fracture. Before surgery, the fracture was corrected to anatomical or near-anatomical reduction under biplanar fluoroscopy (Fig.1B-D). At the C5–C6 level, a 2.5–3.0 cm incision was made along the medial border of the right sternocleidomastoid (Fig. 1E). We split the platysma and fascia of the sternocleidomastoid. Blunt dissection was done along the plane between the carotid sheath and the tracheoesophageal complex until the anterior surface of the vertebra was reached then the cervical level was checked under fluoroscopy (Fig. 1F and G). For the first Herbert screw, we aimed the guiding device (Fig. 2A and B) cephalad at the C2 anteroinferior ridge. We inserted a 2.0 mm cannulated drill bit into the guide tube and carefully passed it through the fracture line from the anteroinferior lip of the C2 to the posterior superior cortex of the odontoid tip (Fig. 2C and D). A 1.2 mm guide wire was inserted into the cannulated drill bit to measure the length of the screw. The cannulated drill bit was then removed, taking care to prevent the guide wire from progressing and injuring the spinal cord. Finally, the cannulated screw was advanced into the tapped hole. The odontoid's apical cortical bone had to be pierced by the screw to press the odontoid process fragment toward the body fragment. The guide wire and the protective tube were then taken out (Fig. 2E and F). The second Herbert screw was inserted in the same way as the first screw convergently from the contralateral side 10° from the midline. The entire process, including evaluation of the location and stability of both Herbert screws (Fig. 2G and H) was performed under fluoroscopic guidance. The day following the operation, all patients were encouraged to walk while wearing a soft cervical collar. Use of the collar, which acted as a reminder to avoid excessive cervical motion, was discontinued at 12 weeks. X-rays were taken at the 1, 3, 6, 12 and 24-month follow-ups. CT-scans of the cervical spine at 6 months were used to evaluate bone union. Descriptive

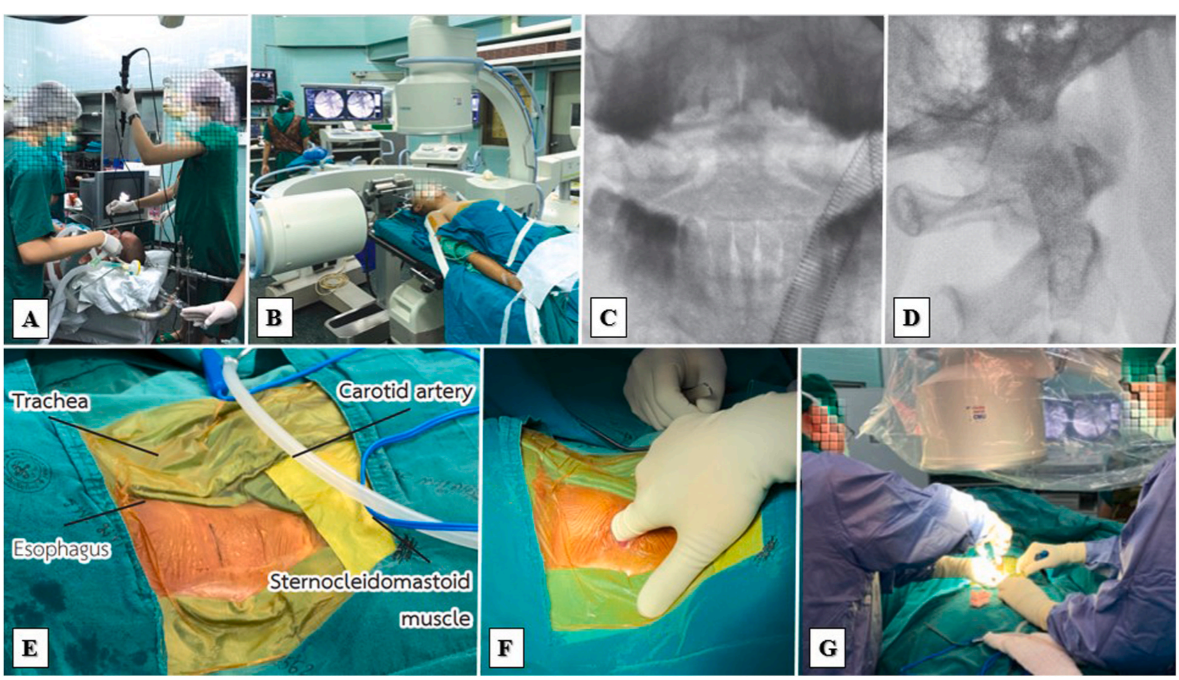

Fig. 1. Fiberoptic-assisted intubation (1A), biplanar fluoroscopy (1B), anatomic or near-anatomic reduction under biplanar fluoroscopy (1C), anatomical landmarks (1E), blunt dissection (1F), checking cervical level under fluoroscopy (1G).

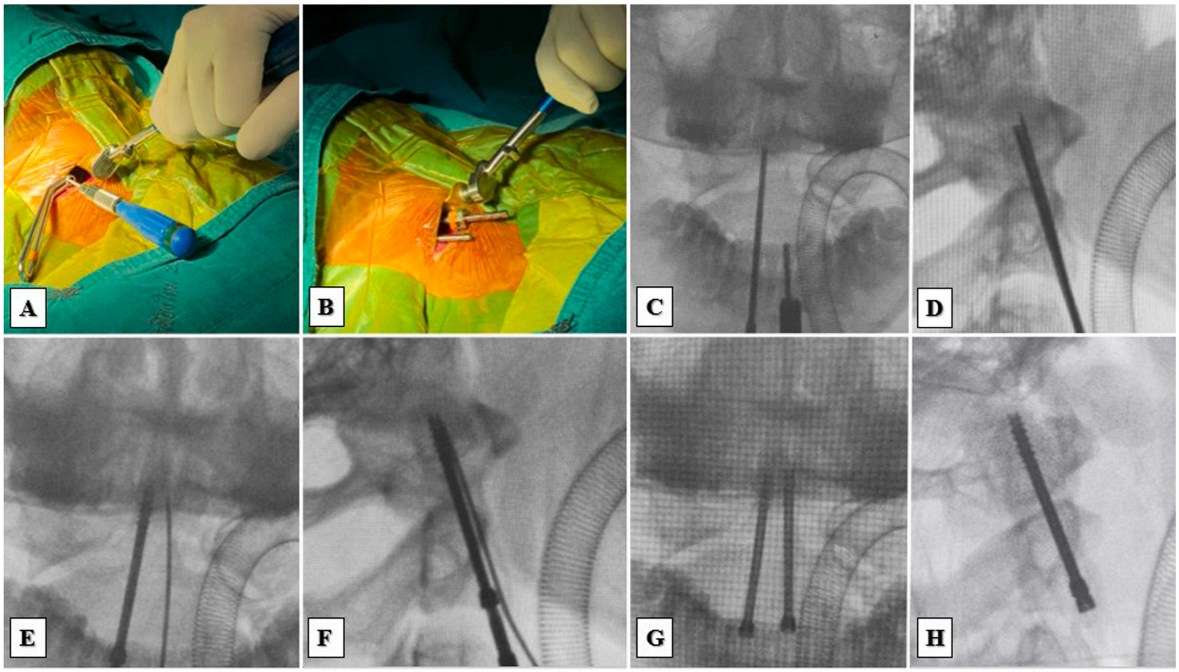

Fig. 2. Intraoperative guidance device (2A) for cannulated drill insertion (2B). The drill bit passed through the fracture line from the anteroinferior lip of C2 to the posterior superior tip of the odontoid (2C, 2D). Guide wire for the Herbert screw insertion and double screw fixation technique (2E-2H).

information about the patients for statistical analysis was obtained from the medical records.

2.4. Statistical analysis

This study relied on descriptive statistics because of the small sample size. Continuous variables are expressed as mean and standard deviation. SPSS 21 was used to conduct the statistical analysis (SPSS Inc., Chicago, IL, USA).

3. Results

3.1. Demographic data

The average age of the 12 patients in the study (8 males and 4 females) was 38.42 ± 20.14 (mean ± SD) years. Underlying diseases included 4 patients with cardiovascular disease (33.33%), 1 with diabetes mellitus (8.33%) and 7 with other underlying diseases (58.33%). There was one smoking (8.33%) and 11 non-smoking (91.67%) patients. The mechanism of injury was a motor vehicle accident in 11 cases (91.67%) and falling from height in one case (8.33%). All 12 patients had neck pain (100%). Preoperative neurological status using the American Spinal Injury Association (ASIA) Impairment Scale showed 1 ASIA C (8.33%) and 11 ASIA E (91.67%). The types of odontoid fractures as classified by Grauer [2] included 4 odontoid fractures of type IIa (33.33) and 8 odontoid fractures of type IIb (66.67). Pre-operative displacement of the odontoid fragment was 3.07 ± 0.99 mm (mean ± SD). Baseline characteristics of the patients are shown in Table 1.

Table 1
Baseline characteristics of patients.

Characteristics	Anterior Screw Fixation using Double Herbert Screw (n = 12)	
Age (years, mean ± SD)	38.42	±20.14
Gender (Male:Female, % male)	8:4	(66.67)
Underlying diseases		
Cardiovascular disease (n, %)	4	(33.33)
Diabetes mellitus (n, %)	1	(8.33)
No underlying disease (n, %)	7	(58.33)
Smoking (n, %)	1	(8.33)
Non-smoking (n, %)	11	(91.67)
Mechanism of injury		
Motor vehicle accident (n, %)	11	(91.67)
Fall from height (n, %)	1	(8.33)
Signs and symptoms		
Neck pain (n, %)	12	(100)
Preoperative neurological status		
ASIA C (n, %)	1	(8.33)
ASIA E (n, %)	11	(91.67)
Diagnosis (Anderson and D'Alonzo classification)		
Odontoid fracture type IIa (n, %)	4	(33.33)
Odontoid fracture type IIb (n, %)	8	(66.67)
Displacement (mm., mean ± SD)	3.07	±0.99

Abbreviations: ASIA, American Spinal Injury Association; SD, standard deviation; IIa, Horizontal fracture pattern; IIb, anterosuperior to posteroinferior fracture pattern.

3.2. Radiographic measurement of Herbert screws

We determined the appropriate diameter and length of the screws for each patient based on preoperative planning CT-scans. The actual size of the screws used were as follows: sagittal screw length measurement (SSLM) 37.05 ± 3.63 mm (Fig. 3A), left coronal screw length measurement (LCSLM) 33.91 ± 3.16 mm, midline screw length measurement (MCSLM) 34.15 ± 3.37 mm and right screw length measurement (RCSLM) 33.32 ± 3.61 mm (Fig. 3B). Average axial diameters of the odontoid (isthmus) included the horizontal diameter of the odontoid (HDO) 9.24 ± 0.82 mm, vertical diameter of the odontoid (VDO) 11.22 ± 1.10 mm and cortex diameter of the odontoid (CDO) 1.98 ± 0.97 mm. All radiographic measurement data is shown in Table 2.

3.3. Intraoperative Herbert screws

A retrospective review of the intraoperative records of the 24 Herbert screws used with the double Herbert screw technique found the average length of the left and right Herbert screws were 32.18 ± 2.27 mm and 32.54 ± 2.54 mm, respectively. The diameter of all the Herbert screws was 3.0 ± 0 mm (Table 2).

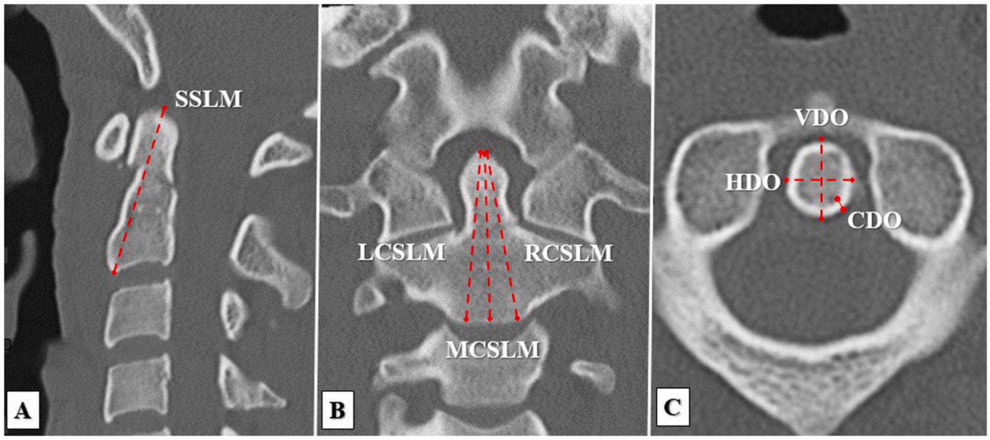

Fig. 3. Radiographic measurement (CT-scan) showing sagittal screw length measurement (SSLM) (1A), coronal screw length measurement (CSLM) including left screw length measurement (LCSLM), midline screw length measurement (MCSLM) and right screw length measurement (RCSLM) (1B), axial diameters of the odontoid (isthmus) included the horizontal diameter of the odontoid (HDO), vertical diameter of the odontoid (VDO) and cortex diameter of the odontoid (CDO) (1C).

Table 2
Preoperative radiographic measurements and actual dimensions of intra-operative screws.

Characteristics	Anterior Screw Fixation using Double Herbert Screws (n = 12)	
Preoperative radiographic screw measurement		
Sagittal screw length measurement (SSLM) (mm., mean ± SD)	37.05	±3.63
Coronal screw length measurement		
Left site screw length measurement (LCSLM) (mm., mean ± SD)	33.91	±3.16
Midline screw length measurement (MCSLM) (mm., mean ± SD))	34.15	±3.37
Right screw length measurement (RCSLM) (mm., mean ± SD)	33.32	±3.61
Axial diameter of odontoid (isthmus)		
Horizontal diameter of odontoid (HDO) (mm., mean ± SD)	9.24	±0.82
Vertical diameter of odontoid (VDO) (mm., mean ± SD)	11.22	±1.10
Cortex diameter of odontoid (CDO) (mm., mean ± SD)	1.98	±0.97
Actual length of screws (intraoperatively)		
Left Herbert screw length (mm., mean ± SD)	32.18	±2.27
Right Herbert screw length (mm., mean ± SD)	32.54	±2.54
Diameter of all Herbert screws (mm., mean ± SD)	3.0	±0

Abbreviations: SD, standard deviation.

3.4. Post-operative outcomes and complications

None of the patients had intraoperative complications. The average time for the operations using the double Herbert screw technique was 92.72 ± 20.41 min (including the general anesthesia time) with an average blood loss of 40.90 ± 24.67 ml. All post-operative radiographic CT scans showed no malposition, no screw pullout/displacement, no broken screws and no distal threads or tips of screws penetrating the cortex of the bone. All the patients had good clinical results after surgery with no postoperative complications. The final neurological status of all 12 patients was ASIA E. Post-operative radiographic CT-scans showed bone fusion in 11 cases (92%) with nonunion in only 1 case (8%). It was discovered that the nonunion case had a long history of smoking, including during treatment. A radiographic CT-scan of a patient who received a double Herbert screw (patient No. 3) is shown in Fig. 4. The pre-operative characteristics and post-operative outcome of that patient are shown in Table 3. All patients received follow-up examinations for an average of more than 24 months.

4. Discussion

According to previous studies, the yearly incidence of cervical spine injury is 1.88–12.4 per 100,000 persons, with upper cervical spine injuries accounting for 2–25% of all cervical spine injuries [6,7]. Odontoid fractures account for 18–20% of cervical injuries, with Anderson-D'Alonzo type II fractures accounting for 65–74% [8,9]. Odontoid fractures are the most frequent type of cervical spine fracture among the elderly [9]. The appropriate treatment method for this type of injury in elderly individuals is still under discussion [10]. A cervical orthosis and a halo device are two options for non-operative treatment. Alternative operative options include anterior screw fixation or dorsal spondylodesis using posterior C1–C2 fusion (Goel-Harms technique) and posterior C1–C2 transarticular screw fixation (Magerl's technique) [10]. A disadvantage of posterior C1–C2 fusion is that the segment's cervical mobility is limited as a result of the decreased neck range of motion. A variety of procedures have been used to treat unstable dens fractures internally. Alternative atlantoaxial fixation systems, however, eliminate all C1–C2 movement. Anterior odontoid screw fixation is an osteosynthetic procedure that gives rapid stabilization while preserving complete C1–C2 mobility [11]. Prior to surgery, a thin-section computed tomography (CT) scan is required to assess the bone architecture and to identify any irregularities that might prohibit screw placement. The success of anterior double Herbert screws for type II odontoid fractures was determined by a preoperative planning CT scan that included anatomical matching the diameter of the odontoid process and screw diameter. The majority of the published evidence related to this procedure is based on case studies. Although not all patients with Type II odontoid fractures are eligible for anterior odontoid screw fixation, for those patients who are eligible, the reported union rates are substantial, ranging from 80% to 100% [11]. A favorable fracture line (anterosuperior to posterosuperior fracture pattern) and satisfactory fracture reduction and alignment are also indications for anterior odontoid screw fixation. Contraindications include severe cervicothoracic kyphosis, severe osteoporosis, late fractures, and ligament transverse rupture as they suggest the possibility of a comminution fracture [12].

Jenkins et al. [13] reported odontoid fractures could be treated safely and effectively with anterior odontoid screw fixation and that there was no difference in the rates of successful union using one- or two-screw fixation procedures. However, the group in the Jenkins et al. study who were treated with a single screw were on average 10 years younger than the group given double screws. Platzer et al. [14] reported

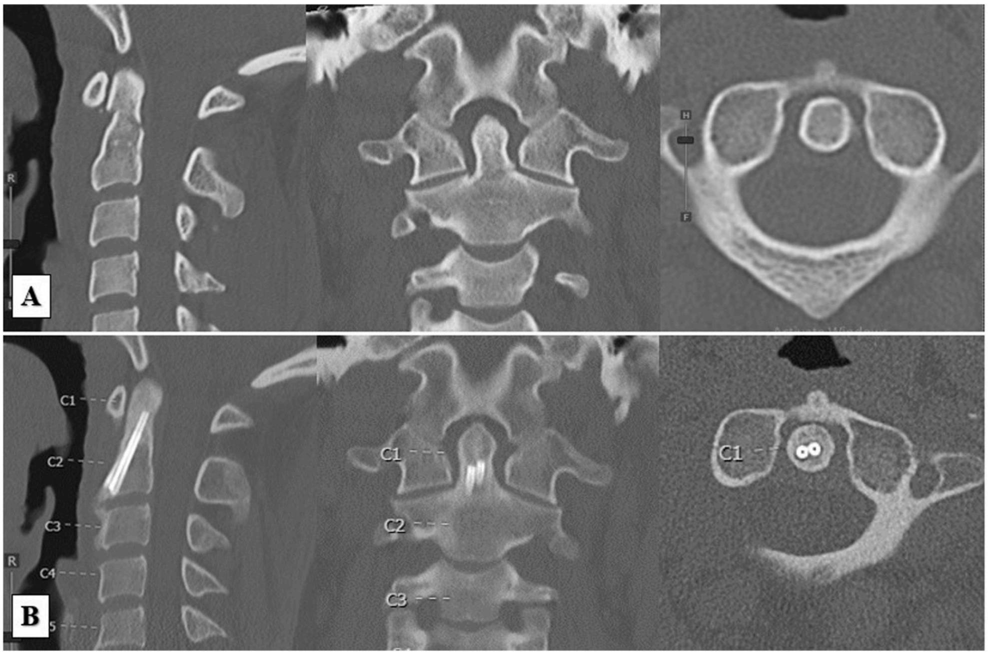

Fig. 4. Preoperative CT-scan (2A) of a 20-year old female with acute neck pain following MVA (ASIA E) diagnosed with odontoid type IIb (anterosuperior to posteroinferior). She received anterior screw fixation with double Herbert screws (Zimmer®). Postoperative CT-scan (2B) showing union of the odontoid process at the 1-year follow-up.

excellent success rates (96%) with double screws, which is in concordance with the high success rate we found in our patients who had double screws implanted (92%). It seems reasonable to assume that adding a second screw increases rotational stability in the osteopenic bones of elderly patients and thus results in a greater chance of fusion [14]. In principle, double odontoid screws for elderly patients should improve the structure's rotational stability. Furthermore, two previous studies [11,14] reported results similar to ours and several other investigations have reported that double-screw fixation has a considerable benefit over single-screw fixation. However, because of the higher prevalence of comorbidities and lower bone density associated with the elderly, the recommended therapy for Type II odontoid fractures in senior individuals is still being debated [11].

Using anterior odontoid screws for older individuals with type II odontoid fractures has shown anterior screw fixation to be a safe alternative with a low incidence of postoperative complications which achieves high fusion rates [8]. Overall, our patients had good clinical results after surgery, with bone fusion in 11 cases (92%) and nonunion in 1 case (8%). In the nonunion case, the patient had a long history of smoking, including during treatment, and we concluded that the nonunion of his odontoid fractures was likely associated with his heavy smoking [15]. In the present study, the age of the participants (average 38.4 years) was not found to be associated with any post-operative dysphagia symptoms. Marciano et al. [16] have, however, reported that in patients aged over 65 type II odontoid screw fixation is a strong predictor of post-operative dysphagia.

A key factor in successful preoperative surgical planning for anterior odontoid screws is a radiographic CT scan [17]. However, as the odontoid screw's trajectory is anteroinferior to posterosuperior and the CT scan is two-dimensional (2D), imaging needs to be evaluated and measured in the sagittal, coronal, and horizontal views. The length of the surgical screw used must not exceed the preoperatively planned measurement to avoid spinal cord damage. If a surgeon has to use a depth gauge to measure the length of the screws intraoperatively, it is an indication of insufficient preoperative planning. By using CT scans, surgeons can reduce the risk of a measurement error or a missed trajectory tract.

This study found that the length of the double Herbert screws actually used intraoperatively was less than the preoperatively determined length calculated using multi-directional CT scans, indicating that there was virtually no risk of spinal cord injury from the screw or of the tip of the screw piercing the distal cortex of the tip of the odontoid. However, the authors also used intraoperative fluoroscopy-assistance for Herbert screw insertion for increased patient safety. Additionally, the fractures were adjusted to anatomic or near-anatomic proportions prior to surgery to help ensure appropriate fixation. These results support the study's hypothesis that double Herbert screws with a diameter of 3.0 mm are extremely successful in achieving union and achieving effective outcomes in populations such as Thais and other Asians who generally have smaller physical frames.

5. Limitations

There were some limitations in this study. The data were retrospectively collected from the hospital database. Additionally, the data were collected from a single center, so the sample size was relatively small. The selection criteria were clearly defined prior to the start of the study to ensure that biases were avoided. Only isolated odontoid fractures of Anderson-D'Alonzo type II who had undergone the double Herbert screws fixation technique were included. The operations were performed by a highly experienced spine surgeon. A prospective study with a larger sample is needed to properly evaluate the clinical effectiveness and safety of this surgical fixation method.

Table 3
Pre-operative characteristics and post-operative patient outcomes.

No.	Sex	Age (yrs.)	Mechanism of injury	Signs and symptoms	Preoperative neurologic status	Final neurologic status	Diagnosis	Fracture pattern	Headless screws instruments	Blood loss	Operative time including general anesthesia (min)	Complications	Out-come	Follow-up (months)
1	Male	63	MVA	Neck pain	ASIA E	ASIA E	Odontoid type IIb	Anterosuperior to posteroinferior.	Skippa®	100	90	none	Union	60
2	Male	28	MVA	Neck pain	ASIA C	ASIA E	Odontoid type IIa	Horizontal	Zimmer®	20	60	none	Union	64
3	Female	20	MVA	Neck pain	ASIA E	ASIA E	Odontoid type IIb	Anterosuperior to posteroinferior.	Zimmer®	50	90	none	Union	50
4	Female	24	Fall down	Neck pain	ASIA E	ASIA E	Odontoid type IIb	Anterosuperior to posteroinferior.	DePuy Synthes (AO)	50	60	none	Union	24
5	Male	17	MVA	Neck pain	ASIA E	ASIA E	Odontoid type IIb	Anterosuperior to posteroinferior.	DePuy Synthes (AO)	20	120	none	Union	36
6	Male	26	MVA	Neck pain	ASIA E	ASIA E	Odontoid type IIb	Anterosuperior to posteroinferior.	DePuy Synthes (AO)	50	105	none	Non-union	19
7	Male	61	MVA	Neck pain	ASIA E	ASIA E	Odontoid type IIb	Horizontal	DePuy Synthes (AO)	20	90	none	Union	20
8	Male	68	MVA	Neck pain	ASIA E	ASIA E	Odontoid type IIb	Anterosuperior to posteroinferior.	DePuy Synthes (AO)	20	90	none	Union	19
9	Female	34	MVA	Neck pain	ASIA E	ASIA E	Odontoid type IIa	Horizontal	DePuy Synthes (AO)	50	100	none	Union	18
10	Female	36	MVA	Neck pain	ASIA E	ASIA E	Odontoid type IIa	Horizontal	DePuy Synthes (AO)	20	90	none	Union	15
11	Male	18	MVA	Neck pain	ASIA E	ASIA E	Odontoid type IIb	Anterosuperior to posteroinferior.	DePuy Synthes (AO)	50	125	none	Union	20
12	Male	66	MVA	Neck pain	ASIA E	ASIA E	Odontoid type IIa	Anterosuperior to posteroinferior.	DePuy Synthes (AO)	40	90	none	Union	32

6. Conclusions

Double anterior screw fixation of type II odontoid process fractures using screws of an appropriate size for the local population is highly effective in helping to ensure a good fit. This study demonstrated satisfactory clinical results in the Thai population using 3.0-mm. cannulated cancellous screw, including biomechanical and invasiveness benefits, which are not inferior to traditional screws.

Provenance and peer review

Not commissioned, externally peer-reviewed.

Ethical approval

The Institutional Ethics Committee of the Faculty of Medicine, Chiang Mai University approved the study protocol (IRB number: ORT-2564-08551).

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Author contribution

Suthipas Pongmanee(SP): Review & Editing, Data curation.
Sitthikorn Kaensuk(SK): Resources, Data curation.
Peem Sarasombath(PS): Review literature, Review & Editing.
Borvornsake Rojdumrongrattana(BR): Review literature, Data curation.
Noparoot Kritworakarn (NK): Review literature, Data curation.
Wongthawat Liawrungrueang (WL): Review literature, Conceptualization, Methodology, Visualization, Data analysis, Artwork design, Writing-original draft, Editing and revision the final version for publication.

Consent

Written informed consent was obtained from the patient for this study and accompanying images. A copy of the written consent is available for review by the Editor-in Chief of this journal upon request.

Registration of research studies

1. Name of the registry: Researchregistry.com.
2. Unique Identifying number or registration ID: researchregistry7420.
3. Hyperlink to your specific registration (must be publicly accessible and will be checked): https://www.researchregistry.com/browse-the-registry#home/registrationdetails/61a7a37ee13308001e719670/

Guarantor

Wongthawat Liawrungrueang, MD.

Declaration of competing interest

All authors report no conflict of interest in this study.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.amsu.2022.103337.

References

[1] Y.-L. Chi, X.-Y. Wang, H.-Z. Xu, Y. Lin, Q.-S. Huang, F.-M. Mao, W.-F. Ni, S. Wang, L.-Y. Dai, Management of odontoid fractures with percutaneous anterior odontoid screw fixation, Eur. Spine J. 16 (2007) 1157–1164, https://doi.org/10.1007/s00586-007-0331-0.

[2] J.N. Grauer, B. Shafi, A.S. Hilibrand, J.S. Harrop, B.K. Kwon, J.M. Beiner, T. J. Albert, M.G. Fehlings, A.R. Vaccaro, Proposal of a modified, treatment-oriented classification of odontoid fractures, Spine J. 5 (2005) 123–129, https://doi.org/10.1016/j.spinee.2004.09.014.

[3] S. Kazan, R. Tuncer, M. Sindel, Percutaneous anterior odontoid screw fixation technique. A new instrument and a cadaveric study, Acta Neurochir. 141 (1999) 521–524, https://doi.org/10.1007/s007010050334.

[4] S.-H. Lee, J.-K. Sung, Anterior odontoid fixation using a 4.5-mm Herbert screw: the first report of 20 consecutive cases with odontoid fracture, Surg. Neurol. 66 (2006) 361–366, https://doi.org/10.1016/j.surneu.2006.04.018, discussion 366.

[5] G. Mathew, R. Agha, Strocss Group, Strocss 2021: strengthening the reporting of cohort, cross-sectional and case-control studies in surgery, Int. J. Surg. 96 (2021) 106165, https://doi.org/10.1016/j.ijsu.2021.106165.

[6] T. Morita, T. Takebayashi, H. Irifune, H. Ohnishi, S. Hirayama, T. Yamashita, Factors affecting survival of patients in the acute phase of upper cervical spine injuries, Arch Orthop Trauma Surg 137 (2017) 543–548, https://doi.org/10.1007/s00402-017-2655-5.

[7] A.M. Levine, C.C. Edwards, The management of traumatic spondylolisthesis of the axis, J Bone Joint Surg Am 67 (1985) 217–226.

[8] S. Yuan, B. Wei, Y. Tian, J. Yan, W. Xu, L. Wang, X. Liu, The comparison of clinical outcome of fresh type II odontoid fracture treatment between anterior cannulated screws fixation and posterior instrumentation of C1-2 without fusion: a retrospective cohort study, J. Orthop. Surg. Res. 13 (2018) 3, https://doi.org/10.1186/s13018-017-0702-0.

[9] A.-M. Wu, H.-M. Jin, Z.-K. Lin, Y.-L. Chi, X.-Y. Wang, Percutaneous anterior C1/2 transarticular screw fixation: salvage of failed percutaneous odontoid screw fixation for odontoid fracture, J. Orthop. Surg. Res. 12 (2017) 141, https://doi.org/10.1186/s13018-017-0640-x.

[10] D. Pal, P. Sell, M. Grevitt, Type II odontoid fractures in the elderly: an evidence-based narrative review of management, Eur. Spine J. 20 (2011) 195–204, https://doi.org/10.1007/s00586-010-1507-6.

[11] A.T. Dailey, D. Hart, M.A. Finn, M.H. Schmidt, R.I. Apfelbaum, Anterior fixation of odontoid fractures in an elderly population, J. Neurosurg. Spine 12 (2010) 1–8, https://doi.org/10.3171/2009.7.SPINE08589.

[12] A.D. Henry, J. Bohly, A. Grosse, Fixation of odontoid fractures by an anterior screw, J Bone Joint Surg Br 81 (1999) 472–477, https://doi.org/10.1302/0301-620x.81b3.9109.

[13] J.D. Jenkins, D. Coric, C.L. Branch, A clinical comparison of one- and two-screw odontoid fixation, J. Neurosurg. 89 (1998) 366–370, https://doi.org/10.3171/jns.1998.89.3.0366.

[14] P. Platzer, G. Thalhammer, R. Ostermann, T. Wieland, V. Vécsei, C. Gaebler, Anterior screw fixation of odontoid fractures comparing younger and elderly patients, Spine (Phila Pa 32 (2007) 1714–1720, https://doi.org/10.1097/BRS.0b013e3180dc9758, 1976.

[15] R.G. Pearson, R.G.E. Clement, K.L. Edwards, B.E. Scammell, Do smokers have greater risk of delayed and non-union after fracture, osteotomy and arthrodesis? A systematic review with meta-analysis, BMJ Open 6 (2016), e010303, https://doi.org/10.1136/bmjopen-2015-010303.

[16] R.D. Marciano, B. Seaman, S. Sharma, T. Wood, C. Karas, K. Narayan, Incidence of dysphagia after odontoid screw fixation of type II odontoid fracture in the elderly, Surg. Neurol. Int. 9 (2018) 84, https://doi.org/10.4103/sni.sni_231_17.

[17] Computed tomographic evaluation of odontoid process: implications for anterior screw fixation of odontoid fractures in an adult population - PubMed (n.d.), https://pubmed.ncbi.nlm.nih.gov/21691900/. (Accessed 1 November 2021).