The adjustable aiming device for caspar pin insertion in anterior cervical spine surgery

Torphong Bunmaprasert, MD¹, Raphi Raphitphan, MD¹, Nantawit Sugandhavesa, MD¹, K Daniel Riew, MD² and Wongthawat Liawrungrueang, MD¹

Abstract

Background: Creating a rectangular disc space is an important step during anterior cervical discectomy and fusion or cervical total disc replacement. The study aims to determine the accuracy of Caspar pin insertion by using a novel Adjustable Caspar Pin Aiming Device in anterior cervical procedures.

Methods: Forty Caspar pins were placed using an Adjustable Caspar Pin Aiming Device in 20 human cadaveric cervical vertebral bodies from C3 to C7 after performing anterior discectomies. Accuracy of pin placement was assessed by lateral fluoroscopy, considering superior endplate slope (SE), inferior endplate slope (IE), Caspar pin slope (CP), and endplate-Caspar pin slope difference (SE/CP, IE/CP).

Results: The mean superior endplate slope (SE), inferior endplate slope (IE), and Caspar pin slope (CP) were 10.82 ± 2.3°, 10.32 ± 3.2°, and 15.58 ± 7.9°, respectively. The average superior endplate-Caspar pin slope difference (SE/CP) and inferior endplate-Caspar pin slope difference (IE/CP) were 6.6 ± 0.8° and 7.7 ± 0.8°, respectively. The greatest slope difference was observed at the superior and inferior endplates of C3. No cervical endplate violations occurred.

Conclusion: Adjustable Caspar Pin Aiming Device allowed for a highly accurate Caspar pin placement with the average endplate-Caspar pin slope difference of less than 7.7°. It results in accurate placement of the superior and inferior Caspar pins parallel to the index vertebral endplates. Furthermore, it appears to facilitate the safe and effective insertion of Caspar pins for anterior cervical procedures.

Keywords
Caspar vertebral distraction pin insertion, anterior cervical surgery, cervical spine, endplate

Date received: 25 September 2021; Received revised 14 December 2021; accepted: 16 January 2022

Introduction

Anterior cervical spine surgery, including anterior cervical discectomy and fusion (ACDF) and cervical total disc replacement (C-TDR), has proven to be an effective surgical procedure for the treatment of degenerative cervical disease.¹⁻³ This approach has various benefits, such as ventral pathology removal, nerve root decompression, and cervical lordosis restoration.⁴,⁵ Proper disc space distraction and visualization are essential steps to achieve these benefits. The creation of a rectangular disc space with parallel...

¹Department of Orthopaedics, Chiang Mai University, Faculty of Medicine, Thailand
²Department of Neurological Surgery, Weill-Cornell Medicine and Department of Orthopedic Surgery, Columbia University, The Och Spine Hospital at New York Presbyterian Hospital, New York, NY, USA

Corresponding author: Wongthawat Liawrungrueang, MD, Department of Orthopaedics, Faculty of Medicine, Chiang Mai University, Chiang Mai, Thailand 50200.
Email: mint11871@hotmail.com

Creative Commons Non Commercial CC BY-NC: This article is distributed under the terms of the Creative Commons Attribution-NonCommercial 4.0 License (https://creativecommons.org/licenses/by-nc/4.0/) which permits non-commercial use, reproduction and distribution of the work without further permission provided the original work is attributed as specified on the SAGE and Open Access pages (https://us.sagepub.com/en-us/nam/open-access-at-sage).
endplates is a desirable goal in anterior cervical procedures, especially with C-TDR.\textsuperscript{6}

Caspar pins are the commonly used tools for anterior cervical procedures, as they allow for improved visualization by widening the disc space during discectomy, correction of kyphosis by inserting the pins divergently, reduction of locked facet by gradual distraction through the pins, and facilitating the creation of a rectangular-shaped disc space by putting the pins parallel to the index vertebral endplates.\textsuperscript{6,7} However, improper pin insertion may compromise adjacent vertebral endplates. Malpositioned pins can be placed too close to the index disc or violate the adjacent disc or be placed askew, resulting in non-parallel disc distraction.\textsuperscript{8} These complications can occur when using the traditional free-hand technique without intra-operative imaging to confirm the position of the pins. Furthermore, inexperienced surgeons may require multiple insertion attempts that may compromise the vertebral bodies.\textsuperscript{9}

There are few reported recommendations for Caspar pin placement. Hillard et al.\textsuperscript{10} suggested placing the pins perpendicular to the posterior margin of the vertebral body. The cranial pins were usually positioned at the upper third of the vertebral body, and the caudal pins were placed at the lower third of the vertebral body. Another study demonstrated that the Caspar pins should be inserted straight, perpendicular to the vertebræ in the coronal plane. In the sagittal plane, the caudal pins should be inserted at roughly 15° of cephalad angulation, but the cranial pin should be inserted more directly without as much cephalad angulation. Caspar pins should be placed as far as possible from the disc space without violating the adjacent disc space.\textsuperscript{6} Few published studies have reported the methods of creating parallel Caspar pin placement without intra-operative fluoroscopy. While the prior study stated the attempts to use the aiming device to guide the pin direction, nevertheless, the variabilities of the body and disc heights made the former Caspar Pin Aiming Device in trouble.\textsuperscript{8}

We have therefore invented a novel Adjustable Caspar Pin Aiming Device with the concept of inserting Caspar pins parallel to the vertebral endplates. This device facilitates the insertion of the Caspar pins without using fluoroscopic guidance and can adjust the distance between two pins to match each vertebral height. This study aims to determine the accuracy and safety of Caspar pin insertion using this aiming instrument in anterior cervical procedures to improve the accuracy of pin placement and minimize radiation exposure during pin insertion.

**Methods**

**Developing adjustable Caspar pin aiming device**

The Adjustable Caspar Pin Aiming Device consists of 3 parts: pin sleeves, an adjustable disc spacer, and an adjustable distance between the sleeve and the spacer (Figure 1). Chen et al.\textsuperscript{11} analyzed the geometry of the sagittal cervical spine in Asian patients. They found that the average superior and inferior endplate slopes were cranially angulated 7.5°. A few cadaveric studies have reported that the mean disc height ranges from 3.3 to 4.6 mm.\textsuperscript{12,13} Yukawa et al.\textsuperscript{14} examined cervical spine morphology in Asian populations. They found that the minimum vertebral body height was 11.2 mm. Therefore, the aiming device was created with 6 mm diameter sleeves compatible with the diameter of the hexagonal part of the Caspar pin. The parallel pin sleeves were attached with an 8° cranial angulation. The adjustable spacer that fits into the disc is wedge-shaped with 8° of cranial angulation. Its tip is 2 mm thick on each side for a total of 4 mm (cranial-caudal dimension), but because it is wedge-shaped, it can fit into a disc space that is less than 4 mm in height. It is 10 mm deep. The distance between the pin sleeve and spacer is 6 mm (Figure 2).

**Specimens and Caspar pin insertion**

This study was approved by the University’s Institutional Review Board (IRB number: ORT-2562–06749). The study was performed on five human cadaveric specimens, including 20 vertebral bodies from C3 to C7. The mean age was 67.2 years (ranging from 57 to 74 years). Samples with a history of cervical spine surgery, severe cervical spine deformity, and severe cervical spine trauma were not included. All dissections were performed by two of the authors. The cadavers were placed in a supine position with a roll placed transversely under the scapulae to create slight neck extension, and shoulders were secured down with tape. An anterolateral (Smith-Robinson) approach was performed from the right side with a longitudinal incision.\textsuperscript{14} Discectomies were performed at C3–4 to C6–7. Anterior osteophytes were removed during discectomies. Lateral imaging of the cervical spine was obtained with fluoroscopy. Once a perfect lateral X-ray was achieved, the cadaver head was secured tightly with tape to maintain the position.\textsuperscript{6,16} Caspar pins were inserted sequentially by using the Adjustable Caspar Pin Aiming Device starting from C3-4 to C6-7. The adjustable spacer was applied to the index disc space before the pin insertion. An intradiscal part of the device served as the primary guide for the angulation of the device. Because the disc space and the endplate of the caudal vertebra is typically angled several degrees cranially, the intradiscal part of the device naturally guided the pins at the same angulation.

We attempted to insert the pins into the center of the vertebral bodies. In the coronal plane, we chose a midpoint between the longus colli muscles as the initial landmark and confirmed it by exposing the uncinate processes and finding the midpoint between the two sides. Then AP fluoroscopic imaging was used to confirm that the pins were indeed located in the midline. In the sagittal plane, the device was able...
to adjust the pin entry point proximally or distally until the pin was at the midpoint between the index and adjacent discs. A lateral X-ray was obtained to confirm this (Figure 3).

**Measurement**

The vertebral endplate slope, and the Caspar pin slope were measured, using the method described by Chen et al., in the following manner: The anatomical landmarks of the vertebral body, including anterosuperior (A), posterosuperior (B), anteroinferior (C), posterooinferior (D), and the tips of the Caspar pins were marked manually using Surgimap Spine. Superior endplate slope (SE): the angle formed by AB and AC lines, subtract that value from 90°. Inferior endplate slope (IE): the angle formed by CD and AC lines, subtract that value from 90°. Caspar pin slope (CP): the angle formed by EF and AC lines, then subtract that value from 90°. Superior endplate—Caspar pin slope difference (SE/CP): Cobb angle formed by HG and KL lines. Inferior endplate—Caspar pin slope difference (IE/CP): Cobb angle formed by JI and KL lines, and Caspar pin—Caspar pin difference (CPs/CPi): The parallel of Caspar pins was
measured using the Cobb angle between proximal and distal pin (Figure 4).

Other parameters, including vertebral body height, AP diameter of the vertebral body, disc height, and AP diameter of the disc space, were measured using methods that have been reported in literature.14,19 Furthermore, all parameters were measured by the authors for three times, and then the average was recorded to reduce interobserver and intraobserver measurement errors.

Statistical analysis
Statistical analysis was performed using STATA software version 12.0. Normally distributed continuous variables were reported as mean and standard deviation. The two-sample t-tests were used to compare the parameters between two groups, and one-way ANOVA was used to compare the means of three samples. A two-sample t-test with Bonferroni correction was used to test the mean differences between each pair of the three samples. A significant difference was considered if the p-value was less than 0.05.

Results
The average height and AP diameter of the vertebral body were 11.71 ± 1.1 mm and 16.02 ± 1.4 mm, whereas the average of height and AP diameter of the disc space were 7.02 ± 1.2 mm and 17.08 ± 1.5 mm, respectively. These parameters are shown in Table 1.
Forty Caspar pins were inserted using the Adjustable Caspar Pin Aiming Device in 20 vertebral bodies from C3 to C7. The mean of the superior endplate slope (SE), inferior endplate slope (IE), and Caspar pin slope (CP) were 10.82 ± 2.3°, 10.32 ± 3.2°, and 15.58 ± 7.9°, respectively (Table 2). The data revealed no significant difference between SE and IE (10.82 ± 2.3° vs. 10.32 ± 3.2°, p = 1.00). However, the CP was significantly larger than SE and IE (10.82 ± 2.3° vs. 10.32 ± 3.2° vs. 15.58 ± 7.9°, p < 0.05). A significantly greater slope was also observed in CP at both the proximal pins of C3 and C4.

Focusing on the slope difference, the average superior endplate-Caspar pin slope difference (SE/CP) and inferior endplate-Caspar pin slope difference (IE/CP) were 6.6 ± 0.8° and 7.7 ± 0.8°, respectively (Table 3). The data showed there was no difference between SE/CP and IE/CP (6.6 ± 0.8° vs. 7.7 ± 0.8°, p = 0.35). The greatest slope difference was observed at both SE and IE of C3. The mean of Caspar pin-Caspar pin slope difference (CPs/CPi) was 2.5° (Table 4). Cervical endplate violation was not found in any of the specimens.

**Discussion**

Caspar distraction can aid in maintaining visual clarity and working space during anterior cervical spine surgery. There is no consensus in previous studies regarding the ideal trajectory for Caspar pin placement. In our opinion, the
ideal pin placement when performing arthroplasty is in the middle of the coronal plane and as far away from the operative disc as possible, without violating the adjacent discs. The pins can be placed closer to the operative disc when an adjustable feature may be useful. It may also be useful when performing cervical disc arthroplasty, when it is preferable to have the pins as far from the disc space without violating the adjacent disc space, when performing cervical disc arthroplasty, so as not to interfere with the jigs used for the procedure. However, this recommendation is only suitable for a single-level arthroplasty procedure; when the pins span multiple levels, the proximal or distal pin may be at risk of cutting out of the vertebral body with repeated and prolonged distraction. A previous version of the Caspar Pin Aiming Device was found to be useful, particularly in one-level or two-level disc operations. However, that device had a flat, straight plate portion that was not adjustable, which made it unusable for patients with small cervical vertebrae, or collapsed discs or for multilevel operations.8 We, therefore, developed a novel Adjustable Caspar Pin Aiming Device and tested it to determine its accuracy and reliability for placing pins parallel to the vertebral endplates of the operative disc space.

We found that the device was accurate and easy to use. Our findings showed that the mean vertebral body height was 11 mm. The distance between the pin sleeve and the adjustable spacer was 6 mm. We found that most of the Caspar pins were inserted into the middle of the vertebral body. Of note, all of our pins were placed reasonably parallel to each other and there were no violations of either the index or adjacent discs. Our results suggest that this aiming device provides a safe entry point for the pins, which we recommend to be 6 mm from each side of the vertebral endplate. We did not need to utilize the adjustable feature of the spacer because the pin sleeve was positioned properly for all cases after putting the spacer in the disc space. However, when used for a very large individual, the adjustable feature may be useful. It may also be useful when performing cervical disc arthroplasty, when it is preferable to have the pins as far from the operative disc as possible, without violating the adjacent endplate. The average Caspar pin slope was 15°, whereas the average vertebral endplate angle was 10°. The only level where there was a greater than 10° difference between the pin and the endplate was at C3, where the difference was greater for the proximal than the cranial pins should be positioned at the upper third of the vertebral body, and the caudal pins placed at the lower third of the vertebral body. Makhni et al.6 recommended placing the Caspar pins as far as possible from the disc space without violating the adjacent disc space, when performing cervical disc arthroplasty, so as not to interfere with the jigs utilized for the procedure. However, this recommendation is only suitable for a single-level arthroplasty procedure; when the pins span multiple levels, the proximal or distal pin may be at risk of cutting out of the vertebral body with repeated and prolonged distraction. A previous version of the Caspar Pin Aiming Device was found to be useful, particularly in one-level or two-level disc operations. However, that device had a flat, straight plate portion that was not adjustable, which made it unusable for patients with small cervical vertebrae, or collapsed discs or for multilevel operations.8

### Table 2. Vertebral endplate slope and Caspar pin slope.

|          | SE (n = 40) | IE (n = 40) | CP (n = 40) | p-value  |
|----------|-------------|-------------|-------------|----------|
| C3       | 13.14 ± 2.6 | 13.08 ± 3.1 | 27.8 ± 6.7  | <0.05    |
| C4d      | 11.64 ± 1.2 | 10.62 ± 2.3 | 14.6 ± 2.1  | <0.05    |
| C4p      | 11.38 ± 1.2 | 9.42 ± 1.7  | 23.32 ± 3.7 | <0.05    |
| C5d      | 9.9 ± 1.1   | 8 ± 1.2     | 13.38 ± 1.7 | <0.05    |
| C5p      | 10.04 ± 1.2 | 8.36 ± 1.7  | 15.02 ± 2.3 | <0.05    |
| C6d      | 11.12 ± 3.9 | 10.22 ± 3.9 | 8.12 ± 4.8  | 0.53     |
| C6p      | 10.2 ± 2.2  | 10.28 ± 4.5 | 15.44 ± 6.8 | 0.19     |
| C7       | 9.16 ± 2.0  | 12.56 ± 3.3 | 6.96 ± 6.7  | 0.18     |
| Average  | 10.82 ± 2.3 | 10.32 ± 3.2 | 15.58 ± 7.9 | <0.05    |

**p** = proximal pin; **d** = distal pin.

### Table 3. Endplate-Caspar pin slope difference.

|          | SE/CP (n = 40) | IE/CP (n = 40) | p-value |
|----------|----------------|----------------|---------|
| C3       | 14.8 ± 2.4     | 14.26 ± 2.4    | 0.88    |
| C4d      | 3.2 ± 0.8      | 3.8 ± 0.4      | 0.51    |
| C4p      | 12.22 ± 1.6    | 13.6 ± 1.8     | 0.58    |
| C5d      | 3.76 ± 0.9     | 5.94 ± 0.8     | 0.11    |
| C5p      | 4.86 ± 1.4     | 8.52 ± 2.4     | 0.23    |
| C6d      | 3.28 ± 1.1     | 2.44 ± 0.6     | 0.52    |
| C6p      | 5.68 ± 2.2     | 5.22 ± 1.4     | 0.87    |
| C7       | 4.72 ± 0.8     | 7.46 ± 1.8     | 0.21    |
| Average  | 6.6 ± 0.8      | 7.7 ± 0.8      | 0.35    |

**p** = proximal pin; **d** = distal pin.

### Table 4. Caspar pin-Caspar pin slope difference.

|          | CPs/CPi (n = 20) |
|----------|-----------------|
| C3/4     | 2.48 ± 0.86     |
| C4/5     | 3.04 ± 1.97     |
| C5/6     | 2.6 ± 1.41      |
| C6/7     | 1.96 ± 0.66     |
| Average  | 2.52 ± 1.28     |

CPs = Caspar pin slope (Superior endplate); CPi = Caspar pin slope (Inferior endplate)
Table 5. The aiming device was utilized and tested by three Orthopedic surgeons.

| Parameters                                      | First surgeon | Second surgeon | Third surgeon | Average (mean ± SD) |
|------------------------------------------------|---------------|----------------|---------------|---------------------|
| Levels of vertebral body                        | C3 C4 C5 C6 C7 | C3 C4 C5 C6 C7 | C3 C4 C5 C6 C7 | All levels          |
| Superior endplate slope (SE) degree             | 11.8 11.3 10.7 13.2 8.2 | 16.5 10.7 10.2 13.6 11.7 | 14.4 11.7 8.5 6.7 7.3 | 11.10 ± 2.70        |
| Inferior endplate slope (IE) degree             | 17.6 11.3 11.2 10.2 15.4 | 12.7 9.0 6.8 10.3 14.4 | 13.6 11.6 6.7 7.8 13.3 | 11.46 ± 3.14        |
| Caspar pin slope (CP) degree                    | 30.7 16.5 13.8 15.3 2.2 | 27.3 14.7 14.5 10.2 9.8 | 30.9 11.7 11.8 13.9 3.1 | 15.09 ± 8.59        |
| Superior endplate-Casar pin slope difference (SE/CP) | 18.6 7.6 4.5 14.1 6.0 | 11.3 6.5 4.3 8.4 1.6 | 18.9 4.3 4.1 5.8 4.6 | 8.04 ± 5.33         |
| Inferior endplate-Casar pin slope difference (IE/CP) | 12.0 8.1 4.9 9.4 13.2 | 14.3 8.1 7.8 9.8 4.8 | 20.7 2.5 6.5 4.8 10.1 | 9.13 ± 4.61         |
distal pin. This is due to the increasing lordosis at the upper cervical levels, such that the device does not fit the hyperlordotic alignment. Makhni et al. also suggested that the cephalad pin should be inserted with less cephalad angulation. We recommend inserting the Caspar pin carefully at C3 or at any hyperlordotic segment.

The average disc height in our study was greater than that of a previous study by Choi et al. Our mean disc height was 7 mm, whereas it was 5 mm in their study. We obtained lateral cervical spine X-rays after performing discectomies, after which the disc height was measured. This may be the reason why the disc height was higher in our study. The average vertebral endplate slope was greater in our study than in a previous study. Chen et al. reported that the average endplate slope was 7.5° of cranial angulation, whereas it was 10° in our study. Therefore, we recommend that 10° cranial angulation be the trajectory for Caspar pin insertion when using a traditional free-hand technique.

There are some limitations to our study. First, our study was performed on cadavers with a relatively small sample size, making assumptions of in vitro data into clinical context challenging. We used 10° of slope difference as being clinically significant based on the authors’ experiences. However, it is difficult to determine if this degree of the slope difference is clinically significant. Second, we encountered some difficulty obtaining true lateral x-rays of the lower cervical levels because some cadavers had a rigid cervical spine, shoulders, and a short neck. Nevertheless, we were able to obtain images that were adequate enough to make measurements and to determine if there were any endplate violations. Third, we did not test the device on a multi-racial cadaver group. The study was performed in an Asian country, with Asian cadavers. We actually believe that this is an advantage and not a limitation. Because Asians tend to be of a shorter height than many other races, if it can be used in smaller individuals, it would be even easier and safer to use in larger individuals. Moreover, the aiming device was utilized and tested by three spine surgeons in our department. We evaluated the radiographic parameters (Figure 4) for all cases (Table 5). For the three surgeons, the average CP, SE-CP, and IE-CP angles were consistent with the study’s results. Another limitation is that we did not evaluate the post-operative alignment on AP views to determine the coronal balance post-operatively. Finally, it is possible that distracting the disc space with the aiming device in a grossly unstable spine has the potential to result in a rotational deformity. We did not observe any significant abnormal translation or rotation in our series but none of our cadavers were grossly unstable. Although the disc was removed, the intact posterior elements still provided stability to the cervical spine. Therefore, we would advise caution if the device is utilized for an unstable spine. The same would obviously hold true when using a standard free-hand technique for Caspar pin placement.

Potential disadvantages of this aiming device are: firstly, it is not suitable for a hyperlordotic segment because the pin sleeve cannot be placed perpendicularly to the anterior surface of the vertebral body. This may lead to an improper trajectory of the Caspar pin, especially at C3. Likewise, with an extremely kyphotic segment, the device may not sit properly. Therefore, this aiming device is only appropriate for segments with a normal lordosis or neutral alignment. Second, this device may not be applicable for the surgeons who prefer to insert the Caspar pins before performing discectomies as the guiding tubes require the intradiscal part of the device. Third, this device also cannot be used for a severely narrowed disc space, especially with a disc height of less than 4 mm. Finally, this is a preliminary study using a prototype of the Adjustable Caspar Pin Aiming Device. Further refinements may be made to be suitable for any cervical spine.

Conclusion
In a cadaveric model, we tested a novel Adjustable Caspar Pin Aiming Device and found that it allowed for accurate and reproducible Caspar pin placement with an average endplate-Caspar pin slope difference of less than 7.7°. It resulted in pin placement parallel to the index disc’s endplates. Our data suggests that in disc segments with normal alignment, it can facilitate a reproducible, accurate, and safe insertion of Caspar pins. However, it may not be appropriate for pin placement at the C3 vertebral body or with any segment that is either hyperlordotic or kyphotic.

Acknowledgements
This research article was presented at the Conference: APSS-APPOS 2021, The 13th Combined Meeting of Asia Pacific Spine Society and Asia Pacific Paediatric Orthopaedic Society, 9–12 June 2021, Kobe International Conference Center. All authors thank the Department of Orthopaedics, Faculty of Medicine, Chiang Mai University, for their support.

Author contribution
All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by TB, RR, NS, KDR and WL. The first draft of the manuscript was written by TB, KDR and WL. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Declaration of conflicting interests
The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding
The author(s) received no financial support for the research, authorship, and/or publication of this article.
Ethical approval
This study was conducted in accordance with the Declaration of Helsinki and with approval from the Ethics Committee and Institutional Review Board of Faculty of Medicine, Chiang Mai University (Institutional Review Board (IRB) approval, IRB Number: ORT-2562–06749). Informed consent was obtained from the individuals who had donated their bodies or their next of kin. Informed written consent was provided by every participant.

Informed consent
Human cadaveric was provided informed consent regarding publishing data and photographs.

Data availability
The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Consent to participate
Informed consent was obtained from all individual participants and/or parents included in the study. Informed Consent Additional informed consent was obtained from all individual participants for whom identifying information is included in this article.

ORCID iD
Wongthawat Liawrungrueang https://orcid.org/0000-0002-4491-6569

References
1. Lavelle WF, Riew KD, Levi AD, et al. Ten-year outcomes of cervical disc replacement with the BRYAN cervical disc: results from a prospective, randomized, controlled clinical trial. Spine 2019 May 1; 44(9): 601–608.
2. Zheng B, Hao D, Guo H, et al. ACDF vs TDR for patients with cervical spondylosis - an 8 year follow up study. BMC Surg 2017 Nov 28; 17(1): 113.
3. Zou S, Gao J, Xu B, et al. Anterior cervical discectomy and fusion (ACDF) versus cervical disc arthroplasty (CDA) for two contiguous levels cervical disc degenerative disease: a meta-analysis of randomized controlled trials. Eur Spine J 2017 Apr; 26(4): 985–997.
4. Rong X, Lou J, Li H, et al. How to choose when implants of adjacent height both fit the disc space properly in single-level cervical artificial disc replacement. Medicine 2017 Jul; 96(29): e6954.
5. Deora H, Kim SH, Behari S, et al. Anterior surgical techniques for cervical spondylotic myelopathy: world federation of neurosurgical societies Spine committee recommendations. Neurorspine 2019 Sep; 16(3): 408–420.
6. Makhni MC, Osorio JA, Park PJ, et al. Cervical disc arthroplasty: tips and tricks. Int Orthop 2019 Apr; 43(4): 777–783.
7. Liu K and Zhang Z. A novel anterior-only surgical approach for reduction and fixation of cervical facet dislocation. World Neurosurg 2019 Aug; 128: e362–e369.
8. Bunmaprasert T, Luangkittikong S, Tosinthiti M, et al. The aiming device for cervical distractor pin insertion: a proof-of-concept, feasibility study. BMC Musculoskeletal Disorders 2021 Jul 30; 22(1): 648.
9. Alonso F, Rustagi T, Schmidt C, et al. Failure patterns in standalone anterior cervical discectomy and fusion implants. World Neurosurg 2017 Dec; 108: 676–682.
10. Hillard VH and Apfelbaum RI. Surgical management of cervical myelopathy: indications and techniques for multilevel cervical discectomy. Spine J 2006 Dec; 66 Suppl): 242S–251S.
11. Chen H, Zhong J, Tan J, et al. Sagittal geometry of the middle and lower cervical endplates. Eur Spine J 2013 Jul; 22(7): 1570–1575.
12. Truumees E, Demetropoulos CK, Yang KH, et al. Effects of disc height and distractive forces on graft compression in an anterior cervical corpectomy model. Spine 2008 Jun 1; 33(13): 1438–1441.
13. Paït TG, Killefer JA and Arnautovic KI. Surgical anatomy of the anterior cervical spine: the disc space, vertebral artery, and associated bony structures. Neurosurgery 1996 Oct; 39(4): 769–776.
14. Yukawa Y, Kato F, Suda K, et al. Age-related changes in osseous anatomy, alignment, and range of motion of the cervical spine. Part I: radiographic data from over 1,200 asymptomatic subjects. Eur Spine J 2012 Aug; 21(8): 1492–1498.
15. Cheung KMC, Mak KC and Luk KDK. Anterior approach to cervical spine. Spine 2012 Mar 1; 37(5): E297–E302.
16. Leven D, Meaike J, Radcliffe K, et al. Cervical disc replacement surgery: indications, technique, and technical pearls. Curr Rev Musculoskeletal Med 2017 Jun; 10(2): 160–169.
17. Akbar M, Terran J, Ames CP, et al. Use of surgimap spine in sagittal plane analysis, osteotomy planning, and correction calculation. Neurosurg Clin N Am 2013 Apr; 24(2): 163–172.
18. Langella F, Villafaña JH, Damilano M, et al. Predictive accuracy of surgimap surgical planning for sagittal imbalance: a cohort study. Spine 2017 Nov 15; 42(22): E1297–E1304.
19. Choi SH, Lee H, Cho JH, et al. Radiological parameters of undegenerated cervical vertebral segments in a Korean population. Clin Orthop Surg 2017 Mar; 9(1): 63–70.