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ORIGINAL ARTICLE

Risk assessment of vertebral artery injury in anterior controllable antedisplacement and fusion (ACAF) surgery: a cadaveric and radiologic study

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Abstract

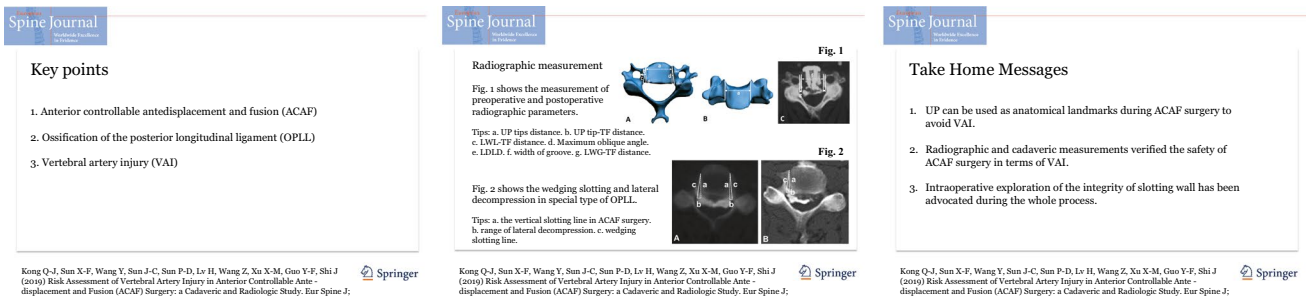
Purpose We have introduced a novel surgery technique named anterior controllable antedisplacement and fusion (ACAF) for the treatment of ossification of the posterior longitudinal ligament. As reported, the satisfactory postoperative outcome can be attributed to the larger decompression width. However, it may associate with high prevalence of vertebral artery injury (VAI) theoretically. Thus, assessment of the vulnerability of vertebral artery in ACAF is of great importance.

Methods Computed tomographic scan data of 28 patients were retrospectively studied. Seven radiographic parameters were evaluated: uncinate process (UP) tips distance, transverse foramen (TF)-UP tips distance, TF-LWL (the ipsilateral limited wedging line) distance, the limited distance of lateral decompression, the maximum oblique angle of LWL, TF-LWG (the lateral wall of groove) distance, and width of groove. Eleven fresh cadaveric spines undergoing ACAF surgery were also studied. Two anatomic parameters were evaluated: width of groove and LWG-TF distance.

Results The UP tips distance increased from C3 to C6 and tended to be larger in males. The UP tip-TF distance and LWL-TF distance were smallest at C4, but both were larger than 2 mm. Maximum oblique angle decreased from C3 to C6. Postoperatively, both radiographic and cadaveric measurements showed the width of groove was larger than UP tips distance, but LWG-TF distance was larger than 2 mm in all levels.

Conclusion UP can be used as anatomical landmarks to avoid VAI during ACAF surgery. Radiographic and cadaveric measurements verified the safety of ACAF surgery, even for those cases with wedging and lateral slotting.

Graphic abstract



Qing-Jie Kong and Xiao-Fei Sun have contributed equally to this work.

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Keywords Anterior controllable antedisplacement and fusion (ACAF) · Ossification of the posterior longitudinal ligament (OPLL) · Vertebral artery injury (VAI)

Introduction

The anterior surgical approach for decompression of the cervical spinal cord and nerve roots is widely used for degenerative disease, trauma, tumor, deformity, and infection. Most anterior approach procedures including anterior cervical discectomy and fusion (ACDF) and anterior cervical corpectomy and fusion (ACCF) are performed safely and effectively, but possible complications cannot be ignored, such as incisional hematoma, dysphagia, esophageal perforation, iatrogenic damage to neural tissue, and CSF leakage [1–3]. Iatrogenic vertebral artery injury (VAI) is a potentially devastating complication, which may result in massive hemorrhage, cardiac arrest, neurologic sequelae, or even death [4–6]. The published rate of VAI during anterior cervical surgery is 0.3–0.5% [4–8].

Ossification of the posterior longitudinal ligament (OPLL) is frequently related to cervical myelopathy [9]. Although anterior and posterior decompression surgeries are both reported to treat patients with myelopathy caused by OPLL, controversy still exists over the surgical options [10, 11]. Recently, we have designed a novel technique named anterior controllable antedisplacement and fusion (ACAF) surgery that can achieve anterior direct decompression without cutting the OPLL [12]. The key procedure of ACAF is bilateral longitudinal osteotomies to isolate the vertebral-OPLL complex (VOC) from the surrounding bony tissue.

In our previous research report, we found that ACAF could get a larger decompression width than ACCF [13, 14]. Therefore, the risk of vertebral artery injury (VAI) in ACAF is higher than that in ACCF theoretically. However, more than 100 OPLL patients in our hospital underwent ACAF, and there were no instances of VAI. Herein, the objective of this study was to assess the risk of VAI in ACAF procedure through cadaveric and radiologic study.

Materials and methods

Clinical sample and radiographic parameters

Computed tomographic (CT) scanning of the cervical spine was obtained retrospectively from consecutive 28 patients with OPLL who underwent ACAF at more than 3 levels at our department from June 2017 to May 2018. There were 14 men and 14 women, with a mean age of 57.93 years (range 38–76 years). Patients with cervical congenital deformities and traumas were excluded.

The preoperative CT images were saved in Digital Imaging and Communications in Medicine (DICOM) file format and measured by the MIMICS software. The cervical vertebras in operative levels were reconstructed into 3D models for further parameter calculation. Surgical procedure has been described previously in detail [12]. Bilateral osteotomy for complete isolation of the VOC from the surrounding structure is a critical process. Uncinate process (UP) has been a landmark to maintain midline orientation to avoid VAI. During osteotomies, vertical slotting was conducted generally (Fig. 4). For patients with OPLL of lateral type and wide-base type, wedging slotting and lateral decompression may be preferred (Fig. 1). However, the degree of wedging has been limited by the risk of nerve root injury and VAI. To protect the nerve root, the slotting has been limited to no more than the most lateral point of posterior wall of vertebral body. Then the limited wedging line (LWL) was defined as the line connecting the anterior point of UP tips and the most lateral point of posterior wall of vertebral body. Five preoperative radiographic parameters were evaluated (Fig. 2): UP tips distance (distance between the bilateral UP tips), UP tip-TF distance (distance between UP tips and the medial margin of the ipsilateral transverse foramen), LWL-TF distance (distance from the medial margin of the transverse foramen to the ipsilateral limited wedging line), maximum oblique angle (angle formed by the junction of the limited wedging line and the vertical line), the limited distance of lateral decompression (LDLD). The postoperative CT images were measured without building 3D models. Two radiographic parameters were evaluated (Fig. 2): width of groove and lateral wall of groove (LWG)-TF distance (distance between lateral wall of groove and the medial margin

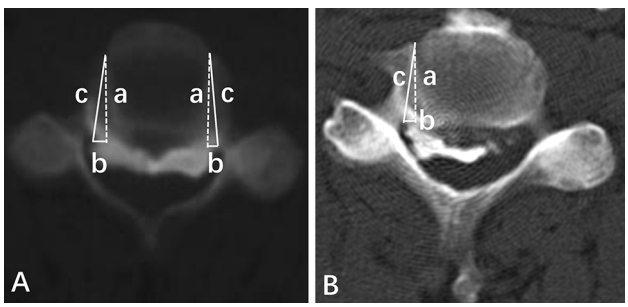

Fig. 1 Wedging slotting and lateral decompression in special type of OPLL. **a** Wide-base type of OPLL. a. The conventional slotting line in ACAF surgery. b. Range of lateral decompression. c. Wedging slotting line. **b** Lateral type of OPLL. a. The conventional slotting line in ACAF surgery. b. Range of lateral decompression. c. Wedging slotting line.

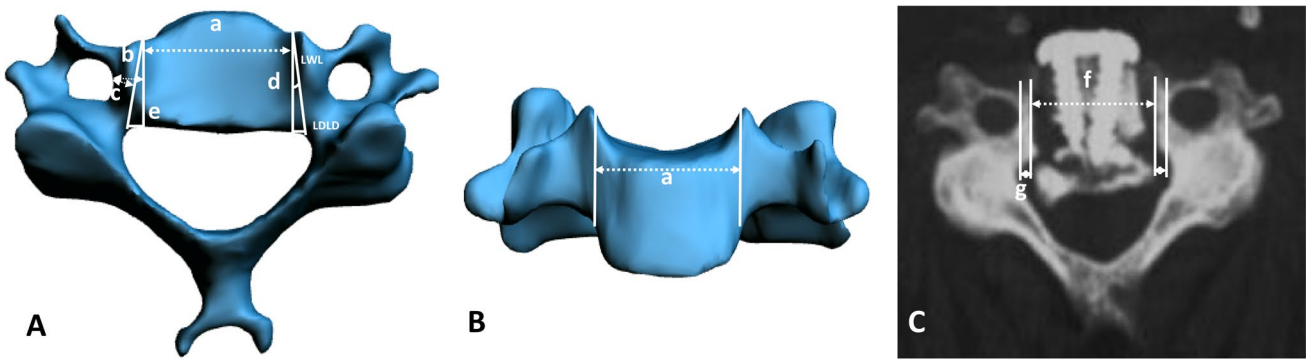

Fig. 2 Schematic figures of radiographic parameters of cervical vertebra. **a** Preoperative radiographic parameters on a C5 vertebral 3D model in axial view: a. UP tips distance. b. UP tip-TF distance. c. LWL-TF distance. d. Maximum oblique angle. e. LDLD. **b** Preoperative radiographic parameters on a C5 vertebral 3D model in A-P view: a. UP tips distance. **c** Postoperative radiographic parameters on a C4 vertebral CT scan: f. width of groove. g. LWG-TF distance. *UP* Uncinated process, *TF* transverse foramen, *LWL* the limited wedging line, *LDLD* the limited distance of lateral decompression, *LWG* the lateral wall of groove

of the ipsilateral transverse foramen). All radiographs were independently analyzed by three experienced spine surgeons on both sides of cervical vertebras in operative levels.

Cadaveric sample and anatomic parameters

Eleven fresh cadaveric spines (the death time less than 6 months) were included in this study. No cervical congenital deformities and traumas were found in these samples. There were six men and five women, with a mean death age of 39.7 years (range 21–55 years). All of them underwent ACAF surgery with the procedures performed as described above. Bilateral osteotomies have been conducted with the UPs as landmark for maintaining midline to avoid excessive lateral decompression. Two anatomic parameters were evaluated postoperatively (Fig. 3): width of groove and LWG-TF distance (distance between lateral wall of groove and the medial margin of the ipsilateral transverse foramen). The parameters were measured precisely from C3 to C6.

All measured parameters are expressed as the mean ± SD. Pair *t* test was used to compare radiographic parameters between left and right side. Unpaired *t* test was used to compare radiographic and cadaveric parameters between male and female groups. Statistical analysis was performed using SPSS21.0 (International Business Machines Corporation, Armonk, NY, USA). The significance level was set at $P < 0.05$.

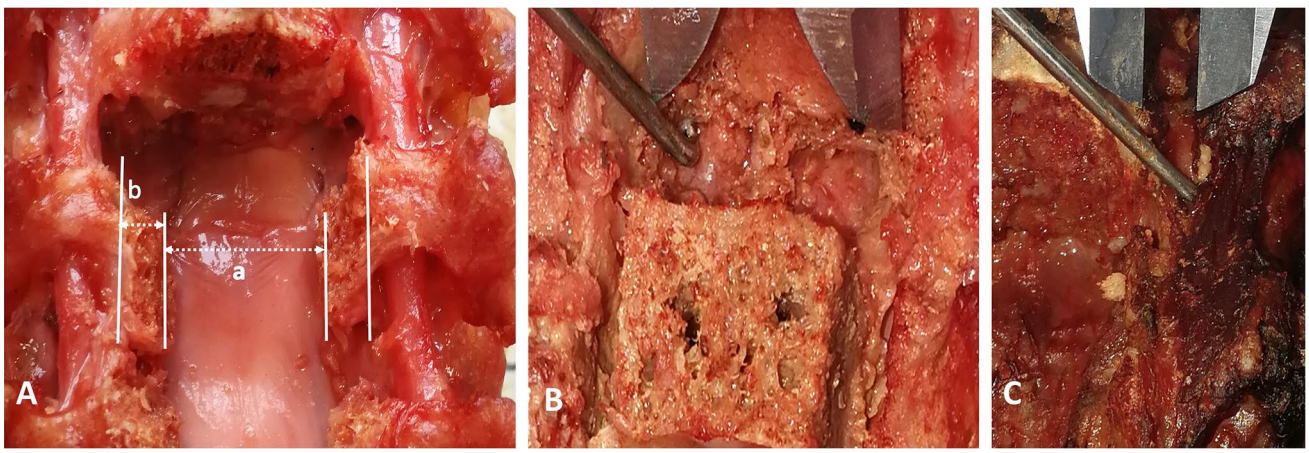

Fig. 3 Schematic figures of anatomic parameters of cervical vertebra. **a** Postoperative anatomic parameters on cadaveric sample which underwent the ACAF surgery: a. width of groove. b. LWG-TF distance. **b** Schematic figure for measuring width of groove. **c** Schematic figure for measuring LWG-TF distance. *TF* Transverse foramen, *LWG* the lateral wall of groove

Results

The UP tips distance increased from C3 to C6 (17.79 ± 2.06 mm at C3, 18.96 ± 1.45 mm at C4, 19.58 ± 1.46 mm at C5, 20.97 ± 1.51 mm at C6). The UP tip-TF distance was smallest at C4 (3.16 ± 0.54 mm) and increased cranially and caudally. Similar distribution was found in the LWL-TF distance (2.34 ± 0.28 mm at C3, 2.21 ± 0.44 mm at C4, 2.48 ± 0.51 mm at C5, 2.94 ± 0.49 mm at C6). Maximum oblique angle decreased from C3 to C6 (7.68° ± 1.67° at C3, 6.81° ± 2.13° at C4, 6.64° ± 1.85° at C5, 5.56° ± 1.74° at C6). The limited distance of lateral decompression was largest at C5 level (1.70 ± 0.74). The width of groove was larger than UP tips distance at each level. Accordingly, LWG-TF distance was smaller than UP tip-TF distance, but all of them were larger than 2 mm (Table 1).

All radiographic parameters were bilateral symmetry except UP tip-TF distance (3.20 ± 0.62 mm vs. 3.66 ± 0.69 mm, left vs. right) and LWL-TF distance at C5 level (2.25 ± 0.54 mm vs. 2.72 ± 0.59 mm, left vs. right) (Table 2). The UP tips distance tended to be larger in males than in females, and significance was identified at C3 and C4 levels. UP tip-TF distance and LWL-TF distance were significantly larger in males in the lower subaxial cervical spine (C5 and C6). No significant difference was found between genders in terms of maximum oblique angle. The limited distance of lateral decompression tended to be larger in males, and significance was identified at C5 level. There were no significant differences in the width of groove between gender categories. Postoperative LWG-TF distance tended to be larger in males, but no statistically significant was found (Table 3).

In the cadaveric samples, the width of groove was 19.28 mm ± 1.78 mm at C3 level, 20.01 mm ± 1.64 mm at C4 level, 21.34 mm ± 1.96 mm at C5 level, and 22.98 mm ± 2.14 mm at C6 level, but no significant differences were found between gender categories. Postoperative LWG-TF distance was significantly larger in males in the upper subaxial cervical spine (C3 and C4) on both sides (Table 4).

Table 2 Comparison of radiographic parameters between left and right sides

	Left	Right	*P*
UP tip-TF distance			
C3 (*n* = 16)	3.51 ± 0.65	3.33 ± 0.51	0.405
C4 (*n* = 26)	3.25 ± 0.55	3.07 ± 0.66	0.204
C5 (*n* = 26)	3.20 ± 0.62	3.66 ± 0.69	0.026*
C6 (*n* = 18)	3.76 ± 0.76	3.84 ± 0.87	0.716
LWL-TF distance			
C3 (*n* = 16)	2.29 ± 0.38	2.40 ± 0.46	0.609
C4 (*n* = 26)	2.12 ± 0.52	2.30 ± 0.48	0.124
C5 (*n* = 26)	2.25 ± 0.54	2.72 ± 0.59	0.001*
C6 (*n* = 18)	2.77 ± 0.51	3.12 ± 0.85	0.295
Maximum oblique angle			
C3 (*n* = 16)	8.64 ± 3.24	6.73 ± 1.67	0.188
C4 (*n* = 26)	7.53 ± 3.24	6.09 ± 1.87	0.095
C5 (*n* = 26)	6.68 ± 2.90	6.61 ± 2.44	0.948
C6 (*n* = 18)	6.29 ± 2.99	4.83 ± 1.85	0.225
LDLD			
C3 (*n* = 16)	1.81 ± 0.85	1.46 ± 0.44	0.335
C4 (*n* = 26)	1.57 ± 0.72	1.52 ± 0.49	0.822
C5 (*n* = 26)	1.79 ± 0.77	1.62 ± 0.75	0.532
C6 (*n* = 18)	1.68 ± 0.82	1.28 ± 0.44	0.165
LWG-TF distance			
C3 (*n* = 16)	2.40 ± 0.85	2.98 ± 1.01	0.209
C4 (*n* = 24)	2.11 ± 0.63	1.94 ± 1.33	0.674
C5 (*n* = 26)	2.83 ± 1.11	2.50 ± 1.26	0.372
C6 (*n* = 16)	4.04 ± 1.40	3.84 ± 0.87	0.744

Discussion

Ossification of the posterior longitudinal ligament (OPLL) is a common degenerative spine disease that causes neurologic dysfunction in middle-aged and elderly patients [15]. Surgical treatment is usually required for patients with progressive myelopathy. Anterior approach (ACCF and ACDF) can provide direct decompression to the spinal cord and achieve satisfied neural outcomes, but with a high complication rate [1–3]. Iatrogenic VAI is a rare but

Table 1 Radiographic parameters of patients who underwent ACAF surgery

	C3	C4	C5	C6
UP tips distance (mm)	17.79 ± 2.06	18.96 ± 1.45	19.58 ± 1.46	20.97 ± 1.51
UP tip-TF distance (mm)	3.42 ± 0.47	3.16 ± 0.54	3.43 ± 0.55	3.80 ± 0.69
LWL-TF distance (mm)	2.34 ± 0.28	2.21 ± 0.44	2.48 ± 0.51	2.94 ± 0.49
Maximum oblique angle (°)	7.68 ± 1.67	6.81 ± 2.13	6.64 ± 1.85	5.56 ± 1.74
LDLD (mm)	1.64 ± 0.65	1.55 ± 0.59	1.70 ± 0.74	1.48 ± 0.65
Width of groove (mm)	19.20 ± 1.33	21.45 ± 2.29	21.42 ± 2.22	21.90 ± 1.65
LWG-TF distance (mm)	2.69 ± 0.68	2.03 ± 0.76	2.67 ± 0.96	3.94 ± 0.76

Table 3 Comparison of radiographic parameters between male and female

	Female	Male	*P*
UP tips distance			
C3 ($n=16$)	16.60 ± 1.61	19.77 ± 1.55	0.034*
C4 ($n=26$)	18.08 ± 1.22	19.71 ± 1.38	0.047*
C5 ($n=26$)	18.93 ± 1.31	20.13 ± 1.56	0.167
C6 ($n=18$)	20.00 ± 0.98	21.74 ± 1.65	0.108
UP tip-TF distance			
C3 ($n=16$)	3.50 ± 0.64	3.28 ± 0.20	0.512
C4 ($n=26$)	2.96 ± 0.57	3.33 ± 0.53	0.251
C5 ($n=26$)	3.00 ± 0.47	3.80 ± 0.34	0.005*
C6 ($n=18$)	3.31 ± 0.73	4.19 ± 0.49	0.068*
LWL-TF distance			
C3 ($n=16$)	2.34 ± 0.38	2.35 ± 0.15	0.968
C4 ($n=26$)	2.00 ± 0.53	2.39 ± 0.32	0.127
C5 ($n=26$)	2.13 ± 0.36	2.79 ± 0.46	0.015*
C6 ($n=18$)	2.53 ± 0.37	3.28 ± 0.35	0.016*
Maximum oblique angle			
C3 ($n=16$)	8.38 ± 1.53	6.52 ± 1.81	0.168
C4 ($n=26$)	6.53 ± 2.02	7.05 ± 2.51	0.690
C5 ($n=26$)	5.77 ± 1.20	7.39 ± 2.20	0.135
C6 ($n=18$)	5.79 ± 2.50	5.38 ± 1.43	0.766
LDLD			
C3 ($n=16$)	1.69 ± 0.42	1.55 ± 0.47	0.719
C4 ($n=26$)	1.36 ± 0.49	1.71 ± 0.41	0.225
C5 ($n=26$)	1.34 ± 0.41	2.01 ± 0.52	0.039*
C6 ($n=18$)	1.29 ± 0.52	1.63 ± 0.41	0.363
Width of groove			
C3 ($n=16$)	19.00 ± 0.80	19.53 ± 2.34	0.736
C4 ($n=24$)	20.75 ± 0.85	22.15 ± 3.28	0.352
C5 ($n=26$)	20.98 ± 1.81	21.79 ± 2.76	0.556
C6 ($n=16$)	20.67 ± 1.40	22.64 ± 1.63	0.134
LWG-TF distance			
C3 ($n=16$)	2.37 ± 0.60	3.22 ± 0.68	0.113
C4 ($n=24$)	1.81 ± 0.33	2.24 ± 1.08	0.386
C5 ($n=26$)	2.15 ± 1.07	3.11 ± 0.73	0.083
C6 ($n=16$)	3.40 ± 0.49	4.26 ± 0.83	0.159

* $p < 0.05$, female vs male

Table 4 Cadaveric parameters of samples who underwent ACAF surgery

	T ($n=11$)	*F* ($n=5$)	*M* ($n=6$)	*P*
Width of groove				
C3	19.28 ± 1.78	19.48 ± 2.26	19.12 ± 1.47	0.757
C4	20.01 ± 1.64	20.20 ± 1.85	19.86 ± 1.61	0.755
C5	21.34 ± 1.96	20.95 ± 2.24	21.67 ± 1.85	0.572
C6	22.98 ± 2.14	22.01 ± 1.66	23.79 ± 2.28	0.181
LWG-TF distance (left)				
C3	4.20 ± 0.79	3.54 ± 0.53	4.75 ± 0.47	0.003*
C4	4.27 ± 0.67	3.78 ± 0.77	4.68 ± 0.68	0.017*
C5	4.82 ± 0.51	4.64 ± 0.35	4.97 ± 0.61	0.326
C6	5.37 ± 0.84	5.51 ± 1.06	5.25 ± 0.69	0.636
LWG-TF distance (right)				
C3	4.13 ± 0.86	3.38 ± 0.55	4.75 ± 0.47	0.002*
C4	4.26 ± 0.68	3.76 ± 0.08	4.68 ± 0.68	0.015*
C5	4.83 ± 0.51	4.66 ± 0.35	4.97 ± 0.61	0.355
C6	5.84 ± 1.21	5.76 ± 1.15	5.91 ± 1.37	0.851

* $p < 0.05$, female vs male

catastrophic complication. It may cause serious outcomes, such as VA occlusion, formation of an arteriovenous fistula, a pseudoaneurysm, or massive bleeding, which could result in stroke or even death [4–6]. The published rate of VAI during anterior cervical surgery is 0.3–0.5% [4–8]. Recently, we introduced a novel technique named ACAF surgery that can achieve anterior direct decompression without cutting the OPLL [12]. As reported previously, the satisfactory postoperative outcome can be attributed to the larger decompression width [13, 14]. However, it may associate with high prevalence of VAI theoretically. Thus, assessment of the vulnerability of vertebral artery in ACAF is of great importance.

The iatrogenic VAI most commonly arises from the shift of the decompression process to the lateral, because of the losing of the midline by surgeon [16]. UP has been advocated as anatomical landmarks to maintain midline orientation [14, 17, 18]. In fact, we usually used UP as landmark for longitudinal osteotomies in ACAF procedures. Experience suggested width of the VOC in ACAF should be larger than the width of the anterior cervical plate (16 mm in most of the commercially available plates). In the present research, the UP tips distance increased from C3 (17.79 ± 2.06 mm) to C6 (20.97 ± 1.51) and tended to be larger in males, which means sufficient for the decompression in ACAF. Compared with previous studies [16, 17, 19], UP tips distance in our study seemed to be smaller. This can be explained by the ethnic differences and the diverse methodology, for their data came from cadavers or dry bones. Coincidentally, UP tip-TF distance (UP-VA distance) differed according to diverse methodology [16–23]. Even in different cadaveric studies, it ranged from 0.8 to 5.8 mm at C3 level, 1.3 to 4.08 mm at C4 level, 1.6 to 3.8 mm at C5 level, and 1.4 to 3.79 mm at C6 level as a result of different anatomic measurements [18, 20]. The study showed that UP tip-TF distance was smallest at C4 and increased cranially and caudally, which correlated well with previous report [23]. In all radiographic studies, The UP tip-TF distance was larger than 2 mm, which indicated UP tips can be used as anatomic landmark. Notably, we found UP tip-TF distance was significantly smaller on the left side at C5 level. Thus caution is needed especially on left during decompression approach. However, high variability

presents in the UP tip location relative to transverse foramen [23], a following large-scale study was recommended.

The postoperative width of groove was larger than UP tips distance at each level in CT images. Partly, the results can be attributed to the use of drill (generally, the groove is about 3 mm wide on each side). Correlated with the wider postoperative groove, LWG-TF distance was smaller than UP tip-TF distance, but all of them were still larger than 2 mm, which indicated the safety of ACAF. One noteworthy finding was that the postoperative interforaminal distance (sum of the width of groove and twofold LWG-TF distance) was larger than the preoperative one (the sum of UP tips distance and twofold UP tip-TF distance). The issues of whether the interforaminal distance was enlarged and its influence to the VA should be elucidated in the following research. As shown in the study, the postoperative LWG-TF distance was larger in cadaveric measurements than in radiographic measurements. The measured values cannot match well between different methods, which suggested that individual and measuring deviation should not be ignored. For example, the UP tip-TF distance was reported to be 1.0 mm at C7, 1.4 mm at C6, 1.6 mm at C5, 1.3 mm at C4, and 0.8 mm at C3, in a cadaveric study by Pait et al. [20]. The same distance was found to be 2.98 ± 0.46 mm at C6, 3.12 ± 0.62 mm at C5, 3.21 ± 0.60 mm at C4, and 3.56 ± 0.83 mm at C3 level in Malla's radiographic study [22]. Actually, our postoperative measurements were close to the distance from the most anteromedial point of uncinate process to vertebral artery in study by Kim et al., and it implies that the practical slotting located in the medial of UP tips. And this has been further verified by the postoperative residual UP in some cadaveric samples (Fig. 4). Therefore, the safety of ACAF in terms of VAI can be verified in both radiographic and cadaveric results.

For patients with OPLL of lateral type and wide-base type, wedging slotting may be preferred (Fig. 1). According to our experience, unintentional wedging slotting also occurred during osteotomy. Excessive wedging may be related to nerve root injury and VAI. To protect the nerve root, the slotting has been limited to no more than the most lateral point of posterior wall of vertebral body. Then the limited wedging line (LWL) was defined as the line connecting the anterior point of UP tips and the most lateral point of posterior wall of vertebral body. The present study showed that LWL-TF distance was also larger than 2 mm at all levels, which indicated the safety of wedging slotting in ACAF. The angles formed by the junction of the limited wedging line and the vertical line were $7.68° \pm 1.67°$ at C3 level, $6.81° \pm 2.13°$ at C4 level, $6.64° \pm 1.85°$ at C5 level, and $5.56° \pm 1.74°$ at C6 level. This indicated that the permissible oblique angle decreased from C3 to C6. Another method to deal with the wide-type OPLL is as follows: slot vertically to the posterior vertebral wall and 1-mm Kerrison rongeur is used to remove the ossification laterally until the margin of OPLL (Fig. 1). As reported in this study, the distance of lateral decompression has been limited to $1.64 \text{ mm} \pm 0.65$ mm at C3 level, $1.55 \text{ mm} \pm 0.59$ mm at C4 level, $1.70 \text{ mm} \pm 0.74$ mm at C5 level, and $1.48 \text{ mm} \pm 0.65$ mm at C6 level.

An anomalous vertebral artery is thought to increase the risk of injury during cervical spine surgery [4–6]. Cadaveric reports have shown a 2.7% incidence of a tortuous course [24]. For those patients, the traditional landmarks are no longer useful, and the risk of injury increases even if lateral

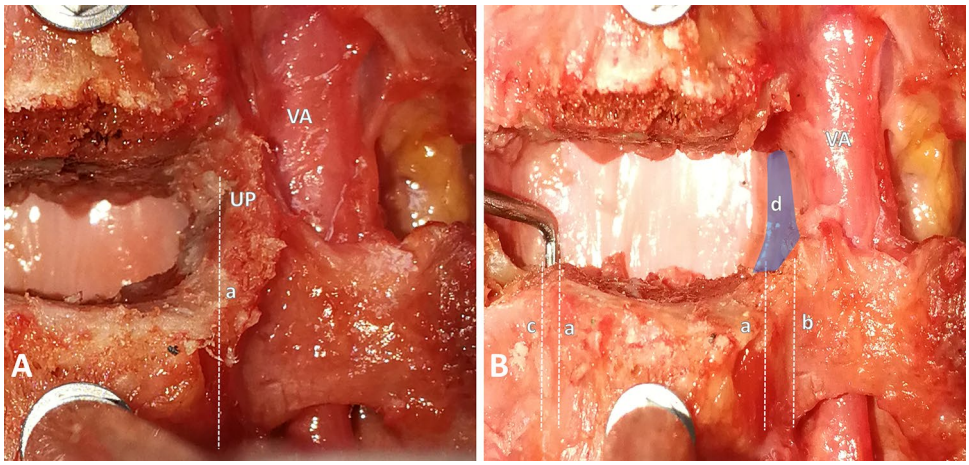

Fig. 4 Anatomic schematic figure of the relationship between ACAF slotting position and VA. **a** Schematic figure after single space decompression. a. The practical slotting line which located in the medial of UP tip in ACAF surgery. **b** Schematic figure after removal of the UP tip: a. the practical slotting line in ACAF surgery. b. The medial margin of TF. c. The projection line of the medial margin of pedicle. The nerve hook here is against the medial margin of pedicle. The distance between (a) and (c) is LDLD. d. Region of the resected UP tip. *UP* Uncinated process, *VA* vertebral artery, *TF* transverse foramen, *LDLD* the limited distance of lateral decompression.

decompression progresses within generally accepted safe limits [25]. Then the importance of evaluating the VA on preoperative MRI or CT scans should be widely recognized by the surgeons. In fact, the routine MRI or CT scans will give much information besides the abnormal VA, such as the size of the transverse foramens and asymmetry or deformity of vertebral body [6]. For example, the deformation and enlargement of transverse foramens suggest a deviation of the vertebral artery, and this may be a preliminary finding of suspected vertebral artery tortuosity. If the MRI or CT finding suggests any possible vertebral artery tortuosity and migration, further evaluation will be necessary. Digital subtraction angiography (DSA) is the gold standard, but computed tomography angiography (CTA) is less invasive with less contrast media used. Magnetic resonance angiography (MRA) is noninvasive and does not require contrast media, but with a lower sensitivity compared with CTA (47% vs. 53%) [26]. Usually, CTA or MRA is recommended. As the cost and radiation exposure were taken into consideration, CTA or MRA is not performed routinely. According to our experience, several tips may be useful to prevent VAI. First is to avoid coarse drilling. Coarse drilling may result in excessive lateral movement when drilling the vertebra, disk, or foramen to achieve decompression, especially with bone softening secondary to tumor or infection [27]. Second is to keep the midline during surgery. UP is served as an anatomical landmark for longitudinal osteotomies. As described in this article, the grove was created approximately at the medial border of the transverse foramina during ACAF. However, in many degenerative cases, the UP tip can be relatively hard to locate because of excessive osteophyte proliferation [28]. Alternatively, we used the base of UP as the landmark and investigated the applied anatomy of UP and its surrounding structures. Third is intraoperative exploration of the integrity of slotting wall during lateral osteotomies, and we speculated that this step was crucial to prevent VAI in previous cases.

Conclusion

UP can be used as anatomical landmarks to maintain midline orientation during ACAF surgery to avoid VAI. Radiographic and cadaveric measurements verified the safety of ACAF surgery, even for those patients with OPLL of lateral type and wide-base type undergoing wedging slotting. Intraoperative exploration of the integrity of slotting wall has been advocated during the whole process.

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Compliance with ethical standards

Conflict of interest The authors have declared that no potential conflicts of interest in this research.

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