Surgical Risk in Bicortical C1 Lateral Mass Screw Fixation Without Medial Angulation

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Abstract

Background: Bicortical C1 fixation is one of the techniques for C1 lateral mass (LM) screw fixation to address instability in the cervical spine. Although it offers greater pull-out force and reduces the risk of screw pull-out, improper placement may inadvertently compromise the retropharyngeal segment of the internal carotid artery (ICA).

Objective: To determine the parameter values for the C1 vertebra LM and the ICA location and assess their potential association with the risk of ICA injury from bicortical C1 LM screw fixation.

Materials and Methods: Patients aged ≥15 years old who had undergone computed tomography angiography of the neck at the Neurological Institute of Thailand between 2016 and 2020. The association with the risk of ICA injury was examined using logistic regression analysis.

Results: Of 256 participants, 205 individuals with completed data were included in the analysis, with a mean of 62.0 years. Several parameters were significantly different between the left and the right sides. Only 13 (6.3%) and 26 (12.7%) participants had ICA located inside the non-angulated screws line on the left or the right side, respectively. Only female was found to be associated with the risk of ICA injury in univariable analysis and remained significant in multivariable analysis (aOR 2.20, 95% CI 1.07 to 4.51 for the left side and aOR 2.21, 95% CI 1.07 to 4.57 for the right side). The angle of the screw trajectory and age were not associated with the ICA injury.

Conclusion: Since the angle of screw trajectory to the ICA was not associated with ICA injury risk, and 6.3% and 12.7% of participants were at risk of ICA injury from non-angulated screw placement on the left and right sides, bicortical C1 LM screw placement without medial angulation seemed safe for screw fixation. However, surgeons should individualize screw length based on patient-specific CTA imaging to minimize the ICA injury risk.

Keywords: Bicortical C1 screw insertion; Lateral mass; Computed tomography angiography; Retropharyngeal internal carotid artery

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Surgical fixation of the C1 vertebra is intended to address spine instability resulting from a variety of factors, including congenital conditions, fractures, tumors, infection, rheumatoid arthritis, and degeneration. There are several techniques for C1 lateral mass (LM) screw fixation. For example, although the Magerl C1-2 trans-articular screw technique offers superior biomechanical fixation, it is contraindicated in up to 20% of patients due to high-riding vertebral arteries[1]. The Goel and Laheri technique involves independent instrumentation of the C1 LM and C2 pedicle to mitigate the risk of damaging the vertebral arteries[2]. Finally, the widely used Harms and Melcher technique has been reported to have no neurovascular complications, implant failures, or fusion issues at final follow-up[3]. In addition, variations of the Goel technique incorporating C1 and C2 pars and translaminar fixation have also been reported[4-7]. Moreover, all contemporary C1-C2 fixation techniques necessitate C1 LM instrumentation[8]. The most used technique was introduced by Harms & Melcher and

What is already known about this topic?

Bicortical C1 LM screw fixation provides superior biomechanical stability but entails a potential risk of ICA injury due to its proximity to the anterior cortex. Existing evidence demonstrates substantial anatomical variability, yet data are predominantly derived from Western populations and remain limited in Asian study.

What does this study add?

This study presents CTA-based anatomical data describing the relationship between the ICA and simulated bicortical C1 LM screw trajectories in a Thai population. It demonstrates marked patient-specific variability. This study identifies female sex as an associated factor for increased predicted ICA injury risk, underscoring the need for individualized preoperative CTA planning.

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Goel & Laheri around the end of the 20th century, in which C1 LM screws are directed medially to the sagittal plane and toward the anterior arch of C1[2,3]. While bicortical C1 fixation offers greater pull-out force and reduces the risk of screw pull-out, improper placement may inadvertently compromise the retropharyngeal segment of the internal carotid artery (ICA). Indeed, it has been reported that a patient experienced recurrent ischemic stroke due to ICA injury[9]. In addition, incorrect trajectory placement of screws has led to vertebral artery injury[10,11]. Both of these complications can escalate into life-threatening conditions.

Although alternative procedures were proposed several years later, the entry point as the traditional technique remains the most used[12-14]. Many surgeons also support the increasing use of bicortical C1 fixation in osteoporotic patients[15]. The medial angulation technique is difficult to reproduce for several reasons. First, approaching from the lateral side requires more muscle dissection. Second, estimating a specific angle is challenging, especially for less experienced surgeons. Therefore, a technique without angulation that not only eliminates the need for muscle dissection and simplifies the procedure but also avoids damaging vital medial or lateral structures has been advocated. This approach, guided by bony landmarks for screw placement, minimizes posterolateral dissection and reduces the risk of injury to the venous plexus or the C2 nerve root[16-18]. However, the risk of ICA injury from this technique has not yet been elucidated.

The relationship between the ICA and the C1 LM is crucial for enabling surgeons to understand and prevent complications during screw insertion. Several studies have been conducted to evaluate the distance between the anterior cortex and the ICA (mainly in Caucasian populations)[16,19-21]. However, limited studies focusing on Asians[22,23] and Thai populations[24] have been conducted. In addition, there have been limited studies conducted on the technique without angulation. Therefore, we performed axial reconstructions using computed tomography angiography (CTA) images of the neck to explore and compare the ICA parameter values, location of the ICA, and ICA injury risk between bicortical C1 LM screws inserted medially to the sagittal plane and adopting a non-angulated screw trajectory, which could be an advantage in comparison between Asian and Western anatomical studies.

Materials and Methods

Settings and participants

Thai adult patients aged ≥15 years who had undergone neck CTA imaging for non-spinal indications at the Neurological Institute of Thailand between January 2016 and December 2020 were included in the study. Meanwhile, patients who had undergone prior cervical spine surgery or had any condition that could have distorted the C1 anatomy (e.g., tumors, infections, deformity, trauma) and scans with inadequate carotid opacification were excluded.

Study design and measurements

This cross-sectional study focused on the parameters related to the ICA assessed by performing axial reconstructions of the neck via the CTA images. The virtual screw trajectory was determined using anatomical landmarks on axial CTA reconstructions, originating at the midpoint of the LM and directed anteromedially or straight (non-angulated), simulating surgical placement according to established techniques[2,16,18]. A retrospective chart review encompassed gender and age at the time of performing CTA.

CTA of the neck with a slice thickness of 0.6 mm, an overlap of 0.3 mm, and the injection of 60 mL of contrast at 5 mL/second was conducted by one physician according to a specific protocol. The CT settings were 120 kV, effective mAs of 120, collimation of 32×0.625, and a pitch of 1.4. The reconstructed CTA images had a thickness of 3 mm. Analysis of the CTA images was performed using the SYNAPSE PACS SYSTEM from FUJIFILM Corporation, Tokyo, Japan. Technicians ensured optimal alignment by reconstructing a plane parallel to the anterior arch to the posterior arch in the sagittal view.

All measurements were performed on axial CTA reconstructions at the level of the midpoint of the C1 LM, which corresponds to the axial slice aligned with the inferior margin of the posterior arch of C1 on sagittal reconstruction. The sagittal reference plane was reconstructed parallel to the line connecting the anterior and posterior arches of C1. Coronal orientation was adjusted to ensure symmetric visualization of both lateral masses to maintain reproducibility.

We used angiography with bone window images. On the axial plane, we measured various parameters, including ICA angle (a), ICA-C1 angle distance (B), ICA-C1 nearest distance (C), Reference (Ref)-ICA distance (D), Ref-LM wall distance (E), C1 LM width (F), ICA-screw distance (G), screw LM length (H), and screw C1 posterior arch length (I) (Figure 1). The ICA angle could be positive (indicating divergence) or negative (indicating convergence). Measurements were performed on the left and right sides. The ‘angulation

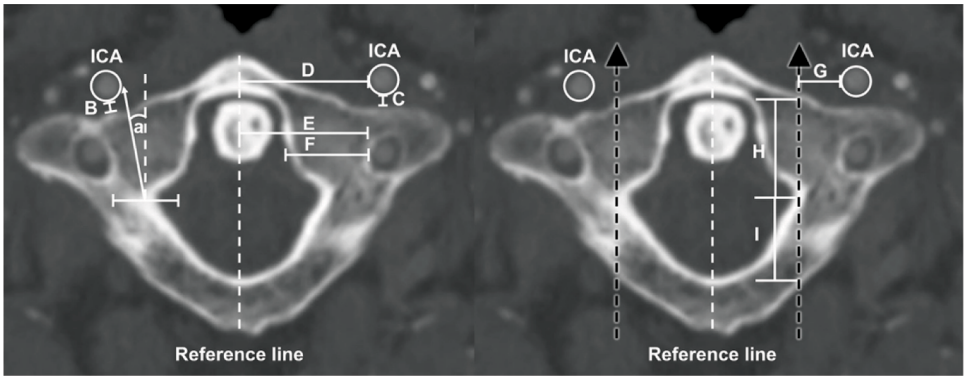

Figure 1. Measurement from axial CTA carotids at the C1 vertebra level. The ICAs are indicated by circles. A reference line (Ref) from the anterior to posterior tubercles (white dashed line) parallels the anticipated screw trajectory, bisecting the posterior cortex of the lateral mass (LM) (black dashed arrow). Angle a represents the angle between ICA and the screw trajectory. B measures the distance from the ICA to the anterior cortex along angle a, while C represents the minimum distance to the nearest cortex. From the Ref, D measures the distance to the medial wall of the ICA, while E measures the distance to the transverse foramen. F measures the width of the LM. G measures the distance from the screw trajectory to the medial wall of the ICA. H measures the screw trajectory distance within the LM, while I measures the trajectory's distance to the posterior cortex of the posterior arch.

group' was defined as participants whose ICA was located outside the non-angulated (straight anterior) screw line, specifically having an ICA angle >2°. The 'non-angulation group' included participants with an ICA angle of 0° to 2°, where the artery was located inside the line of a non-angulated screw trajectory. However, the degree of angulation of this surgical technique has not been mentioned in previous publications. Our classification follows the suggestion by Murakami et al.[22]. While the authors noted that bicortical fixation generally offers greater pull-out force compared to unicortical fixation, the specific 2° cutoff was used for anatomical classification rather than a biomechanically derived limit.

Locations of the ICAs

These were categorized using three areas: Zone 0 (outside the outer edge of the C1 LM), Zone 1 (anterior surface of the C1 LM), and Zone 2 (inside the inner edge of the C1 LM)[22]. Zone 0 and Zone 2 are defined as safety zones, whereas Zone 1 is defined as an at-risk zone[20]. The classification of each zone was presented in Figure 2.

ICA injury risk

The ICA could be at risk of injury from a drill bit or from erosion due to contact with the tip of a screw. The levels of ICA injury risk were considered as the distance from the edge of the ICA lumen to the anterior cortex of C1 along angle a (labeled B in Figure 1) and the distance from the medial edge of the ICA lumen to a perpendicular line drawn in the sagittal plane along the border of the foramen transversarium (FT) (labeled E in Figure 1)[19]. The risk of ICA injury was categorized into four levels: none (>6 mm), low (>4 to 6 mm), moderate (>2 to 4 mm), and high (≤2 mm). Figure 3 illustrates the classification of ICA injury risk according to the C1 LM screw trajectory.

Sample size consideration

The minimum sample size required for this study was calculated based on the prevalence of moderate-to-high ICA injury risk reported in a previous study[19]:

$$n = \frac{Z^2_{1-\alpha/2}\, p(1-p)}{d^2} = \frac{(1.96)^2\,(0.58)\,(1-0.58)}{(0.10)^2} = 93.58 \approx 94$$

where n is the sample size, $Z^2_{1-\alpha/2}$ is Z-statistic (1.96 at the 95% confidence level), p is the prevalence of moderate-to-high ICA injury risk (58%)[19], and d is the precision (10%).

To compensate for expected dropout or incomplete records, the sample size was increased by 10% to be at least 105 patients.

Statistical analysis

Means and standard deviations (SDs) were used for the ICA-C1 screw placement parameter values for the left and right sides. Paired t-tests were used to compare differences in the parameter values between the left and right sides. Independent t-tests and Fisher's exact tests were used to compare the parameter values, locations of the ICAs, and ICA injury risk in subgroup analyses, including angulation (angulation vs. non-angulation), sex (male vs. female), and age (<60 vs. ≥60 years old). The association of the angle of screw trajectory to ICA, age, and sex on the risk of moderate-to-high ICA injury was examined using

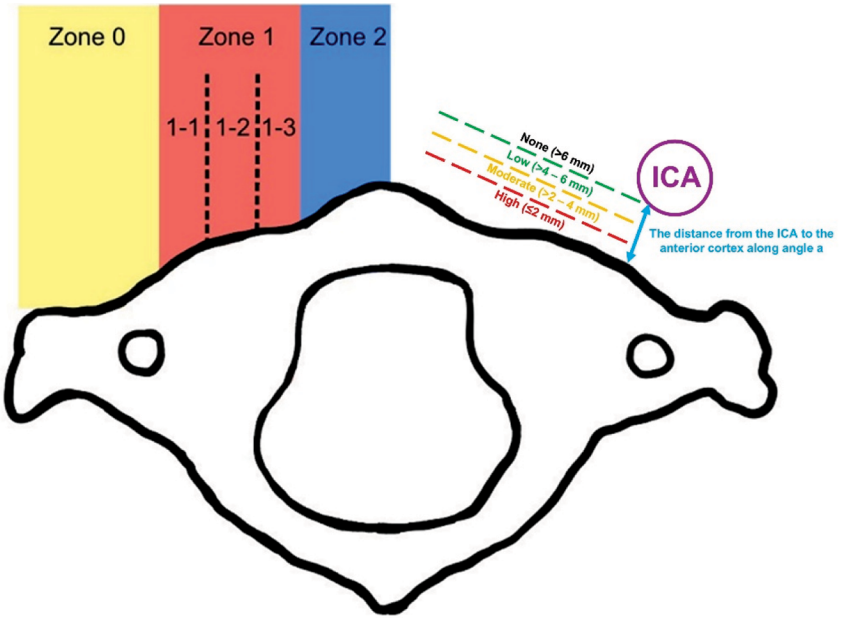

Figure 2. Locations of the ICAs and the risk of ICA injury. Zone 0 (outside the outer edge of the C1 LM), Zone 1 (the anterior surface of the C1 LM), and Zone 2 (inside the inner edge of the C1 LM). Zones 0 and 2 are defined as safe, whereas Zone 1 is defined as being at risk. Zone 1 is classified as 1-1 (lateral 1/3 of the LM), 1-2 (middle 1/3 of the LM), and 1-3 (medial 1/3 of the LM). The risk of ICA injury level was considered as the distance from the edge of the ICA lumen to the anterior cortex of C1 along the screw angle: none (>6 mm), low (>4 to 6 mm), moderate (>2 to 4 mm), and high (≤2 mm).

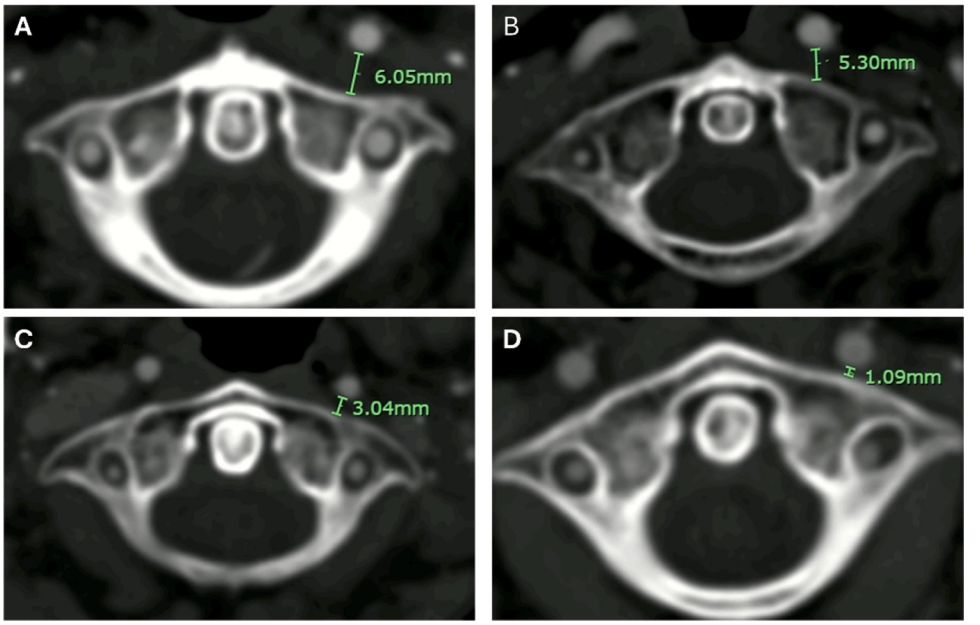

Figure 3. Representative axial CTA images demonstrating the ICA injury risk categories: none (A), low (B), moderate (C), and high (D).

logistic regression analysis. Variables with p-value less than 0.20 in the univariable analysis were included in the multivariable model[25]. All statistical analyses were two-sided with the level of significance set at 0.05.

Ethical approval

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Neurological Institute of

Table 1. Comparison of ICA-C1 vertebra screw placement parameters by side of the neck

Parameter	Symbol	Mean±SD (range)		p-value†
		Left (n=205)	Right (n=205)	
ICA angle (°)	a	14.4±7.7 (0 to 46)	11.7±7.6 (0 to 28)	<0.001*
ICA-C1 angle distance (mm)	B	4.3±1.8 (0.8 to 10.7)	5.0±2.1 (1.0 to 12.6)	<0.001*
ICA-C1 nearest distance (mm)	C	3.9±1.7 (0.8 to 10.2)	4.6±2.0 (1.0 to 12.5)	<0.001*
Ref-ICA distance (mm)	D	21.5±3.6 (10.5 to 30.0)	21.2±3.6 (10.5 to 30.0)	0.195
Ref-LM wall distance (mm)	E	22.1±2.0 (12.3 to 28.9)	22.6±2.1 (13.3 to 36.5)	<0.001*
LM width (mm)	F	14.0±1.7 (8.8 to 19.5)	14.1±1.7 (9.3 to 18.1)	0.498
ICA-screw distance (mm)	G	5.7±3.0 (0 to 16.7)	4.8±3.2 (0 to 18.8)	<0.001*
Screw LM length (mm)	H	17.3±1.6 (13.5 to 24.6)	17.3±1.8 (8.8 to 24.5)	0.700
Screw posterior arch length (mm)	I	11.8±1.8 (5.2 to 18.3)	11.6±1.9 (6.8 to 18.4)	0.009*

ICA=internal carotid artery; LM=C1 lateral mass; Ref=reference line; SD=standard deviation
† p-value derived from paired t-test, * p<0.05

Thailand (approval number 015/2564). Patient consent was waived due to the retrospective nature of the study and the use of de-identified data, as approved by the institutional review board. Written informed consent for publication was not required, as no identifiable patient data are included.

Results

Characteristics of the participants

A total of 256 participants were recruited for this study. Of these, 41 participants with invalid CTA results and 10 participants without either left- or right-side CTA results were excluded. Therefore, only 205 individuals were included in the analysis. Most of the participants were male (66.3%) and over 60 years old (57.6%, 62.0±14.5).

ICA-C1 screw placement parameter values

These were compared between sides, sex, and age of the participants. Most of them (except for the distance from the reference line to the ICA and LM width) were significantly different between the left and the right sides. The mean ICA-C1 screw angle on the left side was wider than that on the right side (14.4±7.7° vs. 11.7±7.6°), with ranges of 0° to 46° and 0° to 28°, respectively. The mean ICA-C1 screw distance was 3.9±1.7 mm (range 0.8 to 10.2) on the left side compared to 4.6±2.0 mm (range 1.0 to 12.5) on the right side. The mean LM length was 17.3 mm for both sides. The mean posterior arch length recorded values of 11.8 mm for the left side and 11.6 mm for the right side (Table 1).

ICA location and injury risk

The locations of the ICAs with respect to the C1 LM and the risk of ICA injury are provided in Table 2. The ICAs of more than half of the participants were located on the anterior surface of the LM (Zone 1) and were at risk of ICA injury (53.7% and 65.8% for the left and right sides, respectively). Some participants had a moderate-to-high risk of ICA injury (21.0% and 20.5% on the left and the right side, respectively).

Table 2. ICA location with respect to the C1 lateral mass and the risk of ICA injury

	Criteria	n (%)	
		Left	Right
ICA location			
Safety			
• Zone 0	Outside the LM outer edge	93 (45.3)	69 (33.7)
• Zone 2	Inside the LM inner edge	2 (1.0)	1 (0.5)
At-risk			
• Zone 1	LM anterior surface	110 (53.7)	135 (65.8)
- Zone 1-1	Lateral 1/3 of LM	96 (46.8)	102 (49.7)
- Zone 1-2	Middle 1/3 of LM	12 (5.9)	31 (15.1)
- Zone 1-3	Medial 1/3 of LM	2 (1.0)	2 (1.0)
Risk level			
None	Distance anterior to LM >6 mm	121 (59.0)	115 (56.1)
Low	Distance anterior to LM >4 to 6 mm	41 (20.0)	48 (23.4)
Moderate	Distance anterior to LM >2 to 4 mm	32 (15.6)	37 (18.1)
High	Distance anterior to LM ≤2 mm	11 (5.4)	5 (2.4)

ICA=internal carotid artery; FT=foramen transversarium; LM=C1 lateral mass

ICA-C1 screw placement parameters and ICA injury risk by angulation

Several left- and right-sided ICA parameters were significantly different between the angulation groups. Only 13 (6.3%) and 26 (12.7%) of the participants had an ICA located inside the non-angulated screws line on the left or the right side, respectively (Table 3), which might have increased the risk of ICA injury

Table 3. Comparison of ICA-C1 vertebra screw placement parameters and ICA injury risk by ICA location to non-angulated screw placement

		ICA location to non-angulated screw placement		p-value
		ICA outside non-angulated line	ICA inside non-angulated line	
ICA parameter; mean±SD (range)				
Left		(n=192)	(n=13)	
• ICA angle (°)	a	15.4±7.0 (3 to 46)	0.9±1.0 (0 to 2)	<0.001†*
• ICA-C1 angle distance (mm)	B	4.2±1.7 (0.8 to 10.7)	6.1±2.0 (2.2 to 9.1)	<0.001†*
• ICA-C1 nearest distance (mm)	C	3.9±1.6 (0.8 to 10.2)	5.3±1.9 (2.0 to 8.3)	0.002†*
• Ref-ICA distance (mm)	D	21.9±3.4 (2.5 to 30.8)	16.2±2.3 (12.2 to 20.0)	<0.001†*
• Ref-LM wall distance (mm)	E	22.0±2.0 (12.3 to 28.9)	22.2±1.5 (20.1 to 25.1)	0.734†
• LM width (mm)	F	14.1±1.7 (8.8 to 19.5)	13.9±2.0 (9.2 to 16.9)	0.722†
• ICA-screw distance (mm)	G	6.1±2.8 (1 to 16.7)	0.4±0.5 (0 to 1.1)	<0.001†*
• Screw LM length (mm)	H	17.3±1.6 (13.5 to 24.6)	11.7±1.4 (15.7 to 19.8)	0.370†
• Screw posterior arch length (mm)	I	11.9±1.8 (5.2 to 18.3)	11.0±1.7 (7.8 to 14.5)	0.094†
Right		(n=179)	(n=26)	
• ICA angle (°)	a	13.3±6.7 (3 to 28)	0.4±0.6 (0 to 2)	<0.001†*
• ICA-C1 angle distance (mm)	B	4.8±2.0 (1.0 to 12.6)	6.7±2.4 (1.9 to 11.2)	<0.001†*
• ICA-C1 nearest distance (mm)	C	4.3±1.9 (1.0 to 12.5)	6.1±2.2 (1.0 to 10.0)	<0.001†*
• Ref-ICA distance (mm)	D	21.9±3.0 (13.3 to 30.0)	15.9±2.4 (10.5 to 19.8)	<0.001†*
• Ref-LM wall distance (mm)	E	22.5±2.1 (13.3 to 36.5)	22.8±1.9 (18.6 to 26.4)	0.484†
• LM width (mm)	F	14.1±1.7 (9.3 to 18.1)	14.1±1.4 (11.6 to 17.0)	0.988†
• ICA-screw distance (mm)	G	5.5±2.8 (0.9 to 18.8)	0.3±0.5 (0 to 2.0)	<0.001†*
• Screw LM length (mm)	H	17.3±1.7 (11.7 to 24.5)	17.2±2.2 (8.8 to 20.4)	0.905†
• Screw posterior arch length (mm)	I	11.7±1.9 (7.5 to 18.4)	10.7±1.4 (6.8 to 13.3)	0.012†*
ICA location; n (%)				
Left		(n=192)	(n=13)	<0.001‡*
• Safety zone		95 (49.5)	0 (0.0)	
• At-risk zone		97 (50.5)	13 (100)	
Right		(n=179)	(n=26)	<0.001‡*
• Safety zone		70 (39.1)	0 (0.0)	
• At-risk zone		109 (68.9)	26 (100)	
ICA risk level; n (%)				
Left		(n=13)	(n=13)	0.151‡
• None		115 (59.9)	6 (46.2)	
• Low		35 (18.2)	6 (46.2)	
• Moderate		3 1(16.2)	1 (7.7)	
• High		11 (5.7)	0 (0.0)	
Right		(n=179)	(n=26)	0.047‡*
• None		100 (55.9)	15 (57.7)	
• Low		40 (22.3)	8 (30.8)	
• Moderate		36 (20.1)	1 (3.8)	
• High		3 (1.7)	2 (7.7)	

ICA=internal carotid artery; LM=C1 lateral mass; Ref=reference line; SD=standard deviation
† p-value derived from independent t-test, ‡ p-value derived from Fisher's exact test, * p<0.05

during non-angulated screw placement.

The mean ICA-C1 distances for the non-angulation group (5.3 mm, range 2.0 to 8.3 mm on the left side and 6.1 mm, range 1.0 to 10.0 mm on the right side) were longer than those for the angulation group (3.9 mm, range 0.8 to 10.2 mm on the left side and 4.3 mm, range 1.0 to 12.5 mm on the right side). Meanwhile, the ICA-screw distances on both sides for the non-angulation group were shorter than those for the respective sides in the angulation group. Screw LM length was no different between the angulation group on both sides, whereas the screw posterior arch length was slightly

lower on the right side for the non-angulation group (10.7 vs. 11.7 mm).

The ICAs for both the left and right sides of the participants in the non-angulation group were all located in the at-risk zone. However, when considering the risk of ICA injury, approximately half of them were not at risk (46.2% on the left side and 57.7% on the right side). In addition, the proportion of participants with a moderate-to-high level of ICA injury risk was lower on the right side (p=0.047).

ICA-C1 screw placement parameters and ICA injury risk by sex

Most of the parameter values were significantly higher in males than in females on both the left and right sides. However, the ICA angles were the same, and the distance from the screw to the ICA in males was significantly longer on the left side only. The screw length and screw LM-arch length were not consistent between the sides. The screw LM length was slightly longer on the left side, and the screw posterior arch length was longer on the right side in females. The location of the ICA was not significantly different between the two sexes. However, the female participants had a significantly higher moderate-to-high level of ICA injury risk on both the left (p=0.001) and right (p=0.023) sides compared to the male participants (Table 4).

ICA-C1 screw placement parameters and ICA injury risk by age

The ICA angle, distance from the reference line to the ICA, and the distance from the screw to the ICA on the left side were slightly lower in the participants aged ≥60 years old than those who were younger. However, the right-sided parameter values were not significantly different between the age groups. The distance from the screw to the ICA in the older group was significantly longer on the left side only. The screw LM length and screw posterior arch length were not different between the age groups on both sides. Meanwhile, the location of the ICA and the ICA injury risk were not significantly different between the two groups (Table 5).

Association between ICA angle, age, and sex on the risk of ICA injury

According to Table 6, although a higher screw angle and distance between the ICA and the anticipated screw line were associated with a lower risk of moderate-to-high injury to the ICA on the left side, the significance was not sufficient to include these variables in the multivariable analysis. Only being female associated with the risk of ICA injury in the univariable analysis remained significant in the multivariable analysis (adjusted odds ratio [aOR] 2.20, 95% confidence interval [CI] 1.07 to 4.51, p=0.032 for the left side and aOR 2.21, 95% CI 1.07 to 4.57, p=0.032 for the right side), whereas age was not associated with the risk of ICA injury.

Discussion

In this observational study, we analyzed 205 axial reconstructions from CTA images to assess the risk of ICA injury from screw insertion without angulation. The mean ICA-C1 screw angle was 14.4° and 11.7° for the left and right sides, respectively. The minimum angle was 0° for both sides. The mean ICA-C1 distance was 3.9 mm with a minimum of 0.8 mm for the left side and 4.6 mm with a minimum of 1 mm for the right side. These latter findings indicate a small margin of anterior cortex perforation when selecting the C1 LM screw length. These values are consistent with previous reports, where the mean ICA angle ranged from 9.8 to 13.1 mm, and the mean ICA-C1 distance ranged from 2.9 to 4.8 mm[16,19-23]. Our findings closely align with those for a Japanese population but differ slightly from those for a Western population, possibly due to ethnic differences. Although there are several techniques for C1 LM screw fixation, most surgeons recommend inserting the screw at a medial trajectory of approximately 0° to 10°. In general, a medial trajectory requires more lateral dissection of the soft tissue behind the cervical spine, which carries the risk of massive bleeding from venous plexus injury lateral to the screw entry point. Therefore, the aim of the present study is to explore the risk of ICA injury when not inserting the screw medially to avoid tissue dissection that could cause venous plexus injury.

The comparison of ICA-C1 parameters in our study shows that several of them had different values for the left and right sides. The ICA angle and ICA-screw distance on the left side were higher, whereas the distance from the ICA to the C1 screw line, the distance from the ICA to C1, and the distance from the reference line to the C1 LM wall were all slightly lower. Therefore, we suggest considering the parameters for each side separately.

We also considered the location of the ICA and the risk of ICA injury. The location of the ICA in relation to C1 varied. Our findings show that the ICAs of more than half of the participants were located in a zone with a risk of injury (53.7% on the left side and 65.8% on the right side). These findings are consistent with

Table 4. Comparison of ICA-C1 vertebra screw placement parameters and ICA injury risk by sex

		Female (n=69)	Male (n=136)	p-value
ICA parameter; mean±SD (range)				
Left				
• ICA angle (°)	a	13.3±8.0 (0 to 46)	15.0±7.5 (0 to 34)	0.129†
• ICA-C1 angle distance (mm)	B	3.9±1.8 (0.8 to 10.7)	4.5±1.7 (1.4 to 9.1)	0.009†*
• ICA-C1 nearest distance (mm)	C	3.5±1.7 (0.8 to 10.2)	4.2±1.6 (1.2 to 8.3)	0.005†*
• Ref-ICA distance (mm)	D	20.2±3.0 (12.2 to 30.8)	22.2±3.7 (2.5 to 29.3)	<0.001†*
• Ref-LM wall distance (mm)	E	20.9±2.0 (12.3 to 24.6)	22.6±1.7 (17.6 to 28.9)	<0.001†*
• LM width (mm)	F	13.4±1.7 (8.8 to 19.5)	14.4±1.6 (10.5 to 18.0)	<0.001†*
• ICA-screw distance (mm)	G	4.8±2.8 (0 to 15.7)	6.1±3.0 (0 to 16.7)	0.003†*
• Screw LM length (mm)	H	17.0±1.5 (14.1 to 20.3)	17.4±1.6 (13.5 to 24.6)	0.041†*
• Screw posterior arch length (mm)	I	11.5±1.8 (7.1 to 16.3)	12.0±1.8 (5.2 to 18.3)	0.054†
Right				
• ICA angle (°)	a	11.5±7.1 (0 to 26)	11.8±7.8 (0 to 28)	0.774†
• ICA-C1 angle distance (mm)	B	4.6±1.9 (1.0 to 11.1)	5.2±2.2 (1.4 to 12.6)	0.034†*
• ICA-C1 nearest distance (mm)	C	4.2±1.7 (1.0 to 9.9)	4.8±2.1 (1.0 to 12.5)	0.032†*
• Ref-ICA distance (mm)	D	20.2±2.9 (13.3 to 27.6)	21.6±3.7 (10.5 to 30.0)	0.003†*
• Ref-LM wall distance (mm)	E	21.8±2.4 (18.2 to 36.5)	22.9±1.8 (13.3 to 26.9)	0.001†*
• LM width (mm)	F	13.2±1.7 (10.1 to 18.1)	14.5±1.6 (9.3 to 18.1)	<0.001†*
• ICA-screw distance (mm)	G	4.3±2.7 (0 to 11.0)	5.1±3.3 (0 to 18.8)	0.057†
• Screw LM length (mm)	H	17.0±1.6 (12.4 to 20.4)	17.4±1.8 (8.8 to 24.5)	0.109†
• Screw posterior arch length (mm)	I	11.2±1.8 (6.8 to 16.7)	11.8±1.9 (7.5 to 18.4)	0.032†*
ICA location; n (%)				
Left				0.103‡
• Safety zone		26 (37.7)	69 (50.7)	
• At-risk zone		43 (62.3)	67 (49.3)	
Right				0.165‡
• Safety zone		19 (27.5)	51 (37.5)	
• At-risk zone		50 (72.5)	85 (62.5)	
ICA risk level; n (%)				
Left				0.001‡*
• None		31 (44.9)	90 (66.2)	
• Low		16 (23.2)	25 (18.4)	
• Moderate		13 (18.9)	19 (14.0)	
• High		9 (13.0)	2 (1.4)	
Right				0.023‡*
• None		29 (42.0)	86 (63.2)	
• Low		20 (29.0)	28 (20.6)	
• Moderate		17 (24.6)	20 (14.7)	
• High		3 (4.4)	2 (1.5)	

ICA=internal carotid artery; LM=C1 lateral mass; Ref=reference line; SD=standard deviation
† p-value derived from independent t-test, ‡ p-value derived from Fisher's exact test, * p<0.05

those from a study in the USA (58% and 74% on the left and right sides, respectively)[20]. However, when considering the ICA injury risk, some participants had a higher level on the left side than on the right side (5.4% vs. 2.4%). We hypothesize that this could be related to the angulation from the screw line to the ICA. Note that the entry point of the LM screw in the present study was the mid-point of the lateral mass. This is because if the entry point is lateral to the mid-point of the lateral mass, there is a risk of vertebral artery injury in the FT. In addition, if the entry point is medial to the mid-point of the lateral mass, there is also the risk of spinal cord injury in the spinal canal.

The position of the ICA in the present study was

Table 5. Comparison of ICA-C1 vertebra screw placement parameters and ICA injury risk by age

		Age <60 years (n=87)	Age ≥60 years (n=118)	p-value
ICA parameter; mean±SD (range)				
Left				
• ICA angle (°)	a	16.2±8.0 (2 to 46)	13.1±7.1 (0 to 28)	0.004†*
• ICA-C1 angle distance (mm)	B	4.1±1.7 (0.8 to 8.6)	4.5±1.8 (1.3 to 10.7)	0.099†
• ICA-C1 nearest distance (mm)	C	3.7±1.6 (0.8 to 8.0)	4.1±1.7 (1.0 to 10.2)	0.114†
• Ref-ICA distance (mm)	D	22.5±3.2 (10.5 to 30.8)	20.9±3.7 (2.5 to 27.9)	0.002†*
• Ref-LM wall distance (mm)	E	22.2±1.9 (17.5 to 26.6)	22.0±2.1 (12.3 to 28.9)	0.508†
• LM width (mm)	F	14.0±1.6 (10.5 to 18.0)	14.1±1.8 (8.8 to 19.5)	0.638†
• ICA-screw distance (mm)	G	6.5±3.2 (1.1 to 16.7)	5.1±2.8 (0 to 13.0)	0.001†*
• Screw LM length (mm)	H	17.3±1.7 (14.1 to 24.6)	17.3±1.5 (13.5 to 23.4)	0.680†
• Screw posterior arch length (mm)	I	11.9±1.8 (5.2 to 18.3)	11.8±1.7 (7.1 to 16.7)	0.644†
Right				
• ICA angle (°)	a	12.8±7.1 (0 to 27)	10.8±7.8 (0 to 28)	0.068†
• ICA-C1 angle distance (mm)	B	4.8±2.1 (1.5 to 12.6)	5.1±2.1 (1.0 to 12.6)	0.287†
• ICA-C1 nearest distance (mm)	C	4.4±2.0 (1.0 to 11.7)	4.7±2.0 (1.0 to 12.5)	0.251†
• Ref-ICA distance (mm)	D	21.7±3.2 (13.7 to 28.6)	20.8±3.7 (10.5 to 30.0)	0.068†
• Ref-LM wall distance (mm)	E	22.8±2.3 (18.6 to 36.5)	22.4±2.0 (13.3 to 26.4)	0.226†
• LM width (mm)	F	14.1±1.7 (10.3 to 18.1)	14.1±1.8 (9.3 to 18.1)	0.859†
• ICA-screw distance (mm)	G	5.2±2.8 (0 to 11.8)	4.5±3.4 (0 to 18.8)	0.147†
• Screw LM length (mm)	H	17.4±1.7 (13.9 to 24.5)	17.1±1.8 (8.8 to 22.9)	0.258†
• Screw posterior arch length (mm)	I	11.6±1.9 (7.5 to 16.9)	11.5±1.9 (6.8 to 18.4)	0.642†
ICA location; n (%)				
Left				0.204‡
• Safety zone		45 (51.7)	50 (42.4)	
• At-risk zone		42 (48.3)	68 (57.6)	
Right				0.372‡
• Safety zone		33 (37.9)	37 (31.4)	
• At-risk zone		54 (62.1)	81 (68.6)	
ICA risk level; n (%)				
Left				0.142‡
• None		53 (60.9)	68 (57.6)	
• Low		15 (17.3)	26 (22.0)	
• Moderate		11 (12.6)	21 (17.8)	
• High		8 (9.2)	3 (2.6)	
Right				0.131‡
• None		51 (58.6)	64 (54.2)	
• Low		15 (17.2)	33 (28.0)	
• Moderate		17 (19.6)	20 (17.0)	
• High		4 (4.6)	1 (0.8)	

ICA=internal carotid artery; LM=C1 lateral mass; Ref=reference line; SD=standard deviation
† p-value derived from independent t-test, ‡ p-value derived from Fisher's exact test, * p<0.05

applied to patients who had undergone CTA of the cervical ICA for reasons other than spinal disease. The examination was performed in the supine position, while the patients were placed in the prone position for surgery. The position of the ICA was slightly away from the anterior arch of C1 due to gravity, which made the surgery for the LM screw C1 safer. If the surgical position was rotated or the head was articulated further, the position of the ICA would change. Since inserting the bicortical C1 screw based on the preoperative image can lead to ICA injury, judicious use of the bicortical C1 screw is recommended. As mentioned above, the surgical position for LM screw placement at C1 is usually in the prone position, so the position of the

Table 6. Association between ICA angle, age, and sex on the risk of moderate-to-high ICA injury

Variables	Univariable analysis			Multivariable analysis		
	OR	95% CI	p-value†	aOR	95% CI	p-value†
Left side						
ICA angle	0.95	0.91 to 0.99	0.032*	1.01	0.88 to 1.14	0.920
ICA-screw distance	0.85	0.75 to 0.96	0.012*	0.86	0.60 to 1.23	0.403
Age	0.99	0.97 to 1.01	0.375			
Sex			0.007*			0.032*
• Male	1.00			1.00		
• Female	2.56	1.29 to 5.10		2.20	1.07 to 4.51	
Right side						
ICA angle	0.96	0.91 to 1.00	0.071	0.94	0.85 to 1.04	0.218
ICA-screw distance	0.91	0.81 to 1.02	0.098	1.06	0.83 to 1.34	0.657
Age	0.99	0.96 to 1.01	0.269			
Sex			0.034*			0.032*
• Male	1.00			1.00		
• Female	2.12	1.06 to 4.22		2.21	1.07 to 4.57	

OR=odds ratio; aOR=adjusted odds ratio; CI=confidence interval; ICA=internal carotid artery
† p-value derived from binary logistic regression, * p<0.05

ICA should not change much.

We found that an increased angle of screw was associated with a lower risk of moderate-to-high injury to the ICA on the left side only in the univariable analysis. However, according to the subgroup analysis, we found that several ICA-C1 screw placement parameters were different between the groups. The mean ICA-C1 distances for the non-angulation group on the left and right sides were longer than those for the angulation group, whereas the ICA-screw distances on both sides for the non-angulation group were shorter than those for the angulation group. Interestingly, although more than half of the ICAs in the non-angulation group were located in the at-risk zone, the ICA injury risk in almost all of them was either zero or low, which was significantly higher than in the angulation group. For the non-angulation technique, the screw trajectory distance within the C1 LM and the trajectory's distance to the posterior cortex of the posterior arch should be considered to avoid injury to the ICA. In our study, the mean C1 LM lengths were 17.3 mm for both sides, and the mean posterior arch lengths for the left and right sides were 11.8 and 11.6 mm, respectively. However, since the angle of screw trajectory was associated with the ICA injury risk, surgeons should individualize screw length based on patient-specific CTA imaging.

We also found that several ICA-C1 screw placement parameter values were different between the sexes and after age stratification (<60 vs. ≥60 years old). The screw line, ICA-C1 distance, Ref ICA distance, Ref-LM wall distance, and LM length were significantly higher in males than in females, both on the left and right sides. In addition, the screw LM length and screw posterior arch length in females were slightly higher than in males. Meanwhile, some of the parameter values (i.e., ICA angle, Ref-ICA distance, and ICA-screw distance) were slightly lower on the left side of the older participants than the younger ones. Interestingly, injury risk was significantly different between the sexes. The results from logistic regression analysis also show that sex was associated with the moderate-to-high ICA injury risk. Even so, the differences in ICA-C1 distance parameter values between the sexes and age groups should be considered to prevent ICA injury during C1 screw placement.

Our findings are consistent with those in the existing literature[16,20-23], highlighting the importance of assessing preoperative imaging thoroughly. Estimating the size of the posterior LM cortex can differ when directly visualizing it during surgery compared to estimation based on CTA reconstruction. The surgical technique of individual surgeons can vary, particularly concerning the lateral entry point and the medial and cranial angulation of the screw, which could result in longer screw fixation.

The advantage of the present study is the consideration of differences in the ICA-C1 parameter values between the left and right sides. Consequently, interpretation using the CTA images separately could provide safer screw placement for the patients. This study is the first to compare the ICA location

and injury risk of the non-angulation technique with the traditional angulation technique. However, there are some limitations in this study. First, CTA scans are performed in the supine position, whereas operations are conducted in the prone position. This could potentially alter the ICA's position relative to the C1 LM. Although the CTA measurements for each patient were observed and interpreted by one physician under a specific protocol, inconsistencies between the observations and interpretation might have occurred. A future study regarding intra-observer reliability for CTA measurements should be conducted. In addition, we did not consider the impact of neck flexion, extension, and rotation on the ICA's location, and variations in patient positioning could introduce differences in the relationship between the ICA and the C1 LM. Second, there were only a few participants with 0°-angulated ICAs. Thus, comparing the values for the ICA-C1 parameters, ICA location, and the ICA risk of injury between the non-angulation and angulation groups should be considered cautiously, and a further study with a larger sample size should be conducted. Third, we only examined ICA angulation, sex, and age. Other variables potentially related to the ICA and C1 or potential anatomical variability related to body size, ethnicity, and vascular comorbidities should be included in a future study. Fourth, the injury risk classification relies solely on distance cut-offs without clinical outcome correlation. A future study considering differences in the clinical conditions of the patient should be conducted. Fifth, the patients included in this study were only those who had undergone CTA without suboptimal contrast opacification for non-spinal indications. Thus, selection bias in the sample or imaging quality might have affected the findings of our study. Next, a direct biomechanical comparison was not conducted in the current study. Nevertheless, previous studies have addressed this topic. Eck et al.[26] conducted a cadaveric biomechanical study to compare unicortical versus bicortical C1 LM screw usage; they found that bicortical screws had significantly greater pull-out strength than unicortical screws (807 vs. 588, p=0.008), thus suggesting improved biomechanical fixation with bicortical purchase. In addition, a comprehensive review by Oitment et al.[27] highlighted that bicortical screw constructs generally provide enhanced fixation strength compared to unicortical screws due to increased bone engagement, especially in osteoporotic bone, albeit this must be carefully balanced against the elevated risk of neurovascular complications. These reports support the biomechanical rationale for applying bicortical fixation in certain patients. Finally, since we could not identify the hypoglossal nerve using CTA in the present study, we could not assess the risk of hypoglossal nerve injury from the bicortical screw C1 fixation procedure. However, the location of the hypoglossal nerve is lateral to the ICA in the retropharyngeal space, so when the chance of ICA injury from the bicortical screw C1 fixation is low, the likelihood of hypoglossal nerve injury should be lower than that of ICA injury. Since this study was a retrospective cross-sectional design conducted on data from a single tertiary neurological center, the findings cannot be generalized or used to establish causal relationships or temporal associations. The investigation of screw angulation and placement should be further investigated via an appropriately designed study.

Conclusion

Since the angle of screw trajectory to the ICA was not associated with a risk of moderate-to-high ICA injury, and 6.3% and 12.7% of participants had ICA located inside of the non-angulated screw placement line on the left and right sides, bicortical C1 LM screw placement without medial angulation seemed safe for screw fixation. However, we found some parameters related to the LM and ICA were different between angle groups and patients' characteristics. Interestingly, we also found that being female was associated with a higher risk of moderate-to-high level of ICA injury risk. Therefore, characteristics of patients (e.g., sex and age) and screw specifications should be additionally considered to minimize the ICA injury risk. Surgeons should individualize screw length based on patient-specific CTA imaging. Overall, the data support the safety and viability of this technique, emphasizing the need for a nuanced approach.

Limitation and future research

C1-C2 cervical spine surgeries are typically performed in the prone position, which may cause the ICA to shift away from the spine due to the effects of gravity. In contrast, this study examines the position of the ICA in subjects in the supine position, where the anatomical landmarks may differ. Nevertheless, this research provides neurosurgeons with crucial data to confirm the safety profile of C1 LM screw placement. Future studies should incorporate prospective clinical data and intraoperative validation to better define the safety profile of non-angulated bicortical C1 LM screw placement. In addition, detailed characterization and phenotyping of anatomical variations would provide meaningful insight.

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Authors' contributions

TT conceptualized, investigated, and designed the study, performed the statistical analysis, drafted the manuscript, reviewed, and edited the manuscript. SP investigated and designed the study, performed the statistical analysis, reviewed, and edited the manuscript. EJ performed the statistical analysis and reviewed and edited the manuscript. VW investigated the study and reviewed and edited the manuscript. All authors read and approved the final manuscript.

Clinical trial registration

Not applicable. This study is not a clinical trial; therefore, registration is not required.

Conflicts of interest

The authors declare no conflict of interest.

Data availability statement

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

Ethics approval and consent to participate

This study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Neurological Institute of Thailand (Ref. no. 015/2564). Written informed consent was waived due to the anonymous data recorded in this study.

Use of artificial intelligence

No artificial intelligence (AI) tools were used in the preparation, writing, or editing of this manuscript. All content, including conceptualization, data analysis, interpretation, and language composition, was developed entirely by the authors.

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