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Clinical Article

Comparative Analysis of Cervical Lateral Mass Screw Insertion among Three Techniques in the Korean Population by Quantitative Measurements with Reformatted 2D CT Scan Images : Clinical Research

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Objective : Our purpose of this study is to compare insertion angles and screw lengths from Roy-Camille, Magerl, and our designed method for cervical lateral mass screw fixation in the Korean population by quantitative measurement of reformatted two dimensional (2D) computed tomography (CT) images.

Methods : We selected thirty Korean patients who were evaluated with thin section CT scans and reconstruction program to obtain reformatted 2D-CT images of the transversal plane passing the cranio-caudal angle using three different techniques. We measured the minimum angle to avoid vertebral artery (VA) injury, the ideal angle and depth for bicortical screwing of cervical lateral mass. Morphometric measurements of the lateral masses from C3-C7 were also taken.

Results : In all three techniques, the mean safety angles from the VA were less than 8 degrees and the necessary depth of the screw was about 14 mm for safety to the VA and for the bicortical purchase. In our designed technique, the mean β angles of each level from C3 to C7 were 29.0, 29.8, 29.5, 26.3, and 23.9 degrees, respectively.

Conclusion : Results of this study and data from the literature indicate that differences may exist between the Korean and Western people in the length and angle for ideal lateral mass screw fixation. In addition, our technique needs further cadaveric and clinical study for safety and efficacy for being performed as alternative method for cervical lateral mass fixation.

KEY WORDS : Cervical vertebrae · Lateral mass screw · Roy-Camille technique · Magerl technique.

INTRODUCTION

Posterior instrumentation using lateral-mass screw fixation in the cervical spine is frequently indicated for managing an unstable cervical spine caused by trauma, severe degenerative conditions, or tumors. This treatment method is especially useful for patients whose spinous processes and laminae are deficient and in those patients who have had extensive, multiple-level laminectomies. Several authors have reported that posterior lateral-mass screw fixation provides an equal or greater biomechanical stability than anterior plating or posterior wiring fixation[5,12,22,28]. Furthermore, posterior lateral screw fixation is easily applied in the clinic as a result of the development of a polyaxial screw-rod system[7,13,19,21,27]. Since the first description of the technique by Roy-Camille et al.[26] in 1972, several techniques of lateral screw placement have become available. These techniques include the Roy-Camille, Louis, Magerl, Anderson, and An techniques[1,2,17,23]. Each technique has a unique entrance point for screw insertion and screw trajectory.

The anatomic structures at risk during lateral mass screwing of the cervical spine are the nerve roots, the VA, and the adjacent lateral masses[1,9,11,24,32]. According to several reported anatomic[14,18,31] and clinical studies[6,8,16,23,26,30], the two most popular types of lateral mass screw techniques are the Roy-Camille technique, in which the screw is inserted perpendicular to the posterior surface of the lateral mass, and the Magerl technique, in which the screw is directed 25 degrees laterally and parallel to the superior facet joint. The Roy-Camille technique is associated with a higher

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incidence of facet violation than the Magerl method. However, nerve root injury occurs more frequently in the Magerl method than in the Roy-Camille method[26].

The main purpose of this study was to quantitatively compare the insertion angle with respect to safety to avoid injury of VA and the screw length required for bicortical purchase among the Roy-Camille technique, the Magerl technique, and our modified technique in Korean population. We also performed a morphometric analysis of the lateral masses from C3-C7.

MATERIALS AND METHODS

This study is based on cervical spine CT scans (HiSpeed ADV, GE Medical Systems, USA) raw data obtained from 30 randomly chosen Korean patients who had been evaluated for a variety of problems ranging from post-traumatic neck pain to degenerative disease. The CT scans were performed from the C3 to the C7 at thickness and intervals of 1 mm. Two kinds of angles and distances were obtained for the Roy-Camille, Magerl, and our designed technique using the CT-based software (V-works spine simulator, Clinic3D, Seoul, Korea). We reformatted 2D-CT images of the transversal plane passing the cranio-caudal angle from three different techniques using CT-based three dimensional (3D) simulation software (V-works spine simulator, clinic3D, Seoul, Korea by Cybermed).

The following techniques were evaluated : the Roy-Camille method, Magerl method, and our designed method. We decided to use the three different sagittal angles for each procedures to gain the horizontal reconstructed images. In Roy-Camille method, the sagittal angle was a perpendicular plane to the lateral mass of each cervical spine. In Magerl method, the angle was parallel to the facet joint of each cervical spine. In our designed method, the sagittal plane passes through the center of the posterior arch of the spine (Fig. 1A). The entry point for Roy-Camille's method was the mid-point on the posterior surface of the lateral mass. In contrast, for Magerl's method, the entry point was 1 mm superior and medial from the mid-point on the posterior surface of the lateral mass. Finally, for our designed method, the entry point was just 1 mm medial from the mid-point (Fig. 1B).

With quantitative measurements of cervical spine using above-mentioned 2D reconstructed axial images, We obtained the angle (α) and the depth (d) that can preserve the vertebral artery from the injury (α : minimal angle to avoid vertebral artery injury between the line 'd' and the line from entry point to lateral margin of transverse foramen, d : the perpendicular distance to posterior surface of lateral mass from entry point to posterior surface of transverse foramen) and we also obtained the angle (β) and the depth (t) for screwing in the ideal bicortical purchase (β : adequate angle to bicortical purchase between the line 'd' and the line from spinous process tip to penetrating entry point of

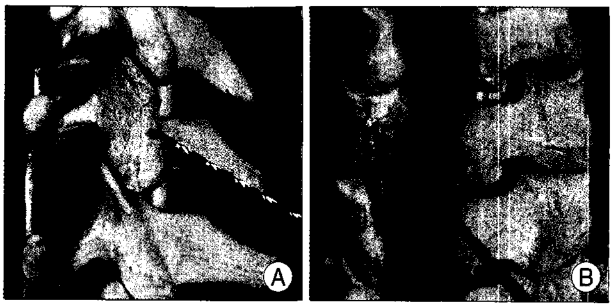

Fig. 1. A cervical spine model showing the trajectory of our modified technique. A : Lateral view of a cervical spine model showing the trajectory of modified technique : in our modified method, the sagittal plane passes through the center of the posterior arch of the spine. B : Posterior view of a cervical spine model showing the trajectory of our technique : in our modified method, the entry point was just 1 mm medial from the mid-point. *the screw fixation equipment is leaned forward to the tip of the spinous process.

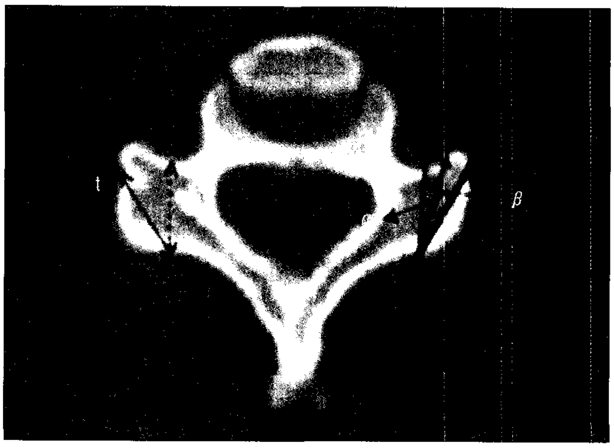

Fig. 2. Reformatted 2D horizontal computed tomography scan image of cervical spine. α : the minimal angle needed to avoid vertebral artery violation, β : the adequate angle for bicortical screw fixation, d : the maximum depth needed to avoid vertebral artery violation, t : the minimal depth for bicortical screw fixation.

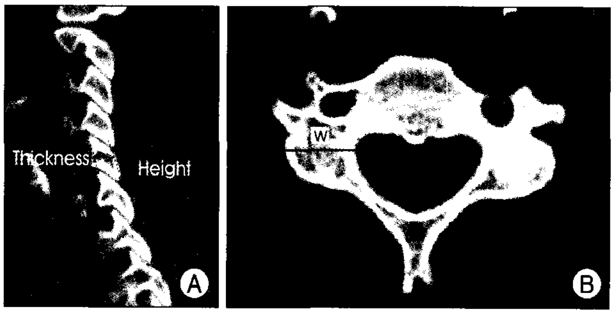

Fig. 3. Reformatted 2D computed tomography scan images of cervical spine. A : A reformatted 2D sagittal plane of midline of cervical lateral mass. Thickness : length of the perpendicular line between dorsal and ventral surface of lateral mass, Height : length of the vertical line between superior and inferior border of lateral mass. B : A reformatted 2D axial plane of cervical spine. w : the widest width of lateral mass.

our designed method, t : the distance from entry point to cortical surface of lateral mass according to our screwing trajectory on reformatted 2D reconstructed axial plane) (Fig. 2). Our designed method was developed to create a horizontal angle on the horizontal plane so that the screw axis would be attached to each level of the spinous process. However, we also measured the greatest possible angle that would not fracture the lateral mass.

We also performed a morphometric analysis of the lateral masses from C3-C7 by taking measurements of the width, height, and thickness on a true sagittal CT slice that passed by the center of the lateral mass. The height was the distance between the two adjacent joints on the posterior aspect of the lateral mass and the thickness was the distance between the dorsal and ventral cortex of the center of the lateral mass (Fig. 3).

Statistical Analysis

All statistical analysis were performed with Statistical Package for the Social Science (SPSS) Windows Version 12.0. For the statistical analysis, we used a repeated measure one factor analysis to determine the difference among three methods and one-way analysis of variances were performed to compare the angle and depth of virtual screw fixation among the surgical techniques, as well as the vertical level. All p-values were two-sided and were considered statistically significant when $p<0.001$.

RESULTS

Thirty cervical spines were included in the statistical analysis. The average age of the patients was 47.2±15.7 years old. There were 20 male and 10 female patients. Three-hundred lateral masses from C3 from C7 were analyzed for the morphometric study. The mean α angle, d depth, β angle, and t depth were measured.

We found no significant differences in the angle(α, safe angle) that would avoid violation of VA among three procedures. These mean safety angles were less than 8 degrees. However, we found that these safety angles exceeded 10 degrees in 4.7% of the Roy-Camille methods (no description on table). In our designed method, the mean α angle of each level (C3-C7) was largest in C7 (6.7°) followed by C5 (6.2°), C6 (6.2°), C3 (5.2°) and C4 (4.8°), respectively (Table 1).

The mean adequate angle for bicortical screw fixation (β) was larger in our designed method among other methods at the C3-C6 levels. In our method, the mean β angles of each level from C3 to C7 were 29.0, 29.8, 29.5, 26.3, and 23.9 degrees, respectively (Table 2).

The maximum depth needed to avoid VA violation (d) exceeded 13.5 mm in Magerl and our designed technique, compared to the less than 13.5 mm depth required when using Roy-Camille method at the C3-C6 levels. At the C7 level, d was about 13 mm (Table 3).

Table 1. The safe angle (α) to avoid violation of vertebral artery

		Roy-Camille mean (S.D*)	Magerl mean (S.D)	Modified mean (S.D)	F (p)†	Multiple comparison
Spine	C3	5.165° (2.014)	4.378° (2.572)	5.218° (2.272)	3.016° (0.053)	-
	C4	4,187° (2,349)	4.572° (2.944)	4.830° (2.8.6)	0.265° (0.768)	-
	C5	5.885° (2.014)	5.700° (3.102)	6.148° (2.542)	0.693° (0.502)	-
	C6	5.715° (2.856)	5.980° (2.866)	6.133° (2.492)	0.598° (0.551)	-
	C7	7.167° (2.545)	6.325° (2.854)	6.685° (2.173)	1.841° (0.163)	-
F (p)‡		7.368° (0.000)§	5.473° (0.000)§	5.205° (0.000)§		
Multiple comparison		(C4, 3, 6, 5)<C7	(C4, 3)<(C5, 6, 7)	(C4, 3)<(C6, 5)<C7		

*standard deviation. †result of repeated measure one factor analysis. ‡result of one way analysis of variances. § statistically significant with $p<0.01$

Table 2. The adequate angle (β) for bicortical fixation

		Roy-Camille mean (S.D*)	Magerl mean (S.D)	Modified mean (S.D)	F (p)†	Multiple comparison
Spine	C3	21.533° (5.020)	21.352° (4.701)	29.012° (5.093)	69.300° (0.000)§	(R, M)<K
	C4	20.547° (4.655)	22.607° (5.151)	29.819° (5.222)	60.642° (0.000)§	(R, M)<M<K
	C5	21.563° (4.922)	23.367° (5.370)	29.516° (4.110)	50.213° (0.000)§	(R, M)<M<K
	C6	21.870° (4.378)	22.540° (4.689)	26.271° (4.442)	22.006° (0.000)§	(R, M)<K
	C7	22.528° (4.766)	22.710° (4.810)	23.86° (3.607)	1.949° (0.147)	
F (p)‡		1.341 (0.255)	1.310 (0.270)	18.500 (0.000)§		
Multiple comparison				C7<C6, 5<(C3, 5, 4)		

*standard deviation, †result of repeated measure one factor analysis, ‡result of one way analysis of variances, §statistically significant with $p<0.01$. R : Roy-Camille method, M : Magerl method, K : Modified method

Table 3. The maximum depth (d) to avoid vertebral artery injury

	Roy-Camille mean (S.D*)	Magerl mean (S.D)	Modified mean (S.D)	F (p)†	Multiple comparison
Spine C3	13.415 mm (0.890)	14.043 mm (1.250)	14.037 mm (1.013)	18.122 (0.000)§	R<(M, K)
C4	13.450 mm (0.919)	14.083 mm (1.281)	13.963 mm (0.876)	12.546 (0.000)§	R<(M, K)
C5	13.710 mm (1.092)	14.046 mm (0.966)	13.865 mm (0.879)	3.265 (0.042)	
C6	13.317 mm (1.150)	13.831 mm (1.238)	13.680 mm (1.060)	8.606 (0.000)§	R<(M, K)
C7	13.024 mm (1.248)	13.562 mm (1.091)	13.073 mm (1.147)	7.556 (0.001)§	(R, K)<M
F (p)†	3.178 (0.014)	2.114 (0.079)	8.995 (0.000)§		
Multiple comparison	(C7, 6, 3)<(C4, 5)		C7<(C6, 5, 4, 3)		

*standard deviation, †result of repeated measure one factor analysis, †result of one way analysis of variances, §statistically significant with $p<0.01$. R : Roy-Camille method, M : Magerl method, K : Modified method

Table 4. The minimum depth (t) for bicortical fixation

	Roy-Camille mean (S.D*)	Mager l mean (S.D)	Modified mean (S.D)	F (p)†	Multiple comparison
Spine C3	13.374 mm (0.787)	13.523 mm (0.957)	13.829 mm (0.578)	5.425 (0.006)§	R<K
C4	13.409 mm (0.930)	13.795 mm (1.075)	13.891 mm (0.493)	6.431 (0.002)§	R<(M, K)
C5	13.555 mm (1.032)	13.879 mm (0.773)	13.734 mm (0.425)	2.840 (0.063)	
C6	13.205 mm (0.844)	13.493 mm (0.814)	13.476 mm (0.628)	2.900 (0.059)	
C7	13.088 mm (1.112)	13.282 mm (0.848)	13.312 mm (0.619)	1.366 (0.259)	
F (p)†	2.119 (0.079)	4.077 (0.003)§	11.434 (0.000)§		
Multiple comparison		C7<(C6, 3, 4, 5)	(C7, 6)<(C5, 3, 4)		

*standard deviation, †result of repeated measure one factor analysis, †result of one way analysis of variances, §statistically significant with $p<0.01$. R : Roy-Camille method, M : Magerl method, K : Modified method

Table 5. Descriptive morphometric analysis of height, thickness and width from C3 to C7

	Roy-Camille mean (S.D*)	Thickeness mean (S.D)	Width mean (S.D)
Spine C3	12.569-14.921 mm	10.579-12.617 mm	11.122-13.798 mm
C4	12.594-14.592 mm	10.69 -13.026 mm	11.064-13.93 mm
C5	12.181-14.305 mm	10.697-13.127 mm	11.349-13.807 mm
C6	11.619-14.011 mm	10.983-13.367 mm	10.983-13.367 mm
C7	11.338-14.028 mm	10.933-13.273 mm	11.471-13.705 mm

*standard deviation

The minimal depth for bicortical screw fixation (t) ranged from 13.7 mm to 13.9 mm at the C3, C4, and C5 levels in our method. The t values of Magerl and our designed method were bigger than Roy-Camille method. At the C6 and C7 levels, the t values ranged from 13.3 mm to 13.5 mm and there was no statistically significant differences among three procedures (Table 4).

The heights of C3 to C7 were became smaller in decreasing order at C3 to C7 and the values were 12.6 mm-13.7 mm. The thicknesses became bigger from C3 to C7 and the values were 11.6 mm-12.1 mm. The widths also became bigger and the values were 12.4 mm-12.6 mm (Table 5).

DISCUSSION

Since the advent of cervical lateral mass screw fixation by Roy-Camille in 1972[4,26], the technique for screw insertion has been consistently modified to optimize bone purchase and to minimize the risk of iatrogenic injury. Several techniques for lateral screw placement are available, including Roy-Camille, Louis, Magerl, Anderson, and An techniques[1,2,17,23]. Each technique has a unique entrance point for screw insertion and screw trajectory. These posterior lateral screw fixation techniques have been easily applied in a clinical setting due to the development of a poly-axial screw-rod system[7,13,19,21,27]. The anatomic structures at risk during lateral mass screwing of the cervical spine are the nerve roots, the VAs, and the adjacent lateral masses[1,9,11,24,32]. As reported previously[14,18], the main anatomic risk when using the Roy-Camille technique is violation of the adjacent lateral mass especially at the lower part of the cervical spine at C5 to C6. Screws violating the articular surfaces should be avoided. Mechanical conflict with the facet joints may produce neck pain, adjacent segment degeneration, and screw pullout. Roy-Camille screws are unlikely to cause nerve root injury because they point midway between the nerve bundles. For the Magerl technique the main risk is nerve root damage. The technical challenge is to not be too high, thus avoiding of facet joint, and also to not be too low, thus avoiding root injury. Barrey et al.[3] reported that the Magerl technique appeared to be safer at C5 and C6 than at C3 and C4. In a comparative study, Xu et al.[32] found 95% of nerve violation occurred with the Magerl technique.

In particular, young spinal surgeons performing these procedures should obtain detailed information from C-arm fluoroscopy because of associated risks such as nerve injury or violation of facet joints and the difficulty of accurately measuring distance and angle. Our designed technique is performed for fixating the lateral mass screw by using adjacent anatomical structures visually recognized during the operation, rather than C-arm fluoroscopy with risk of radiation. This technique is similar to an existing operation, called An's technique, which has an entry point, a sagittal angle (15°) of screw trajectory, and a lateral angle (30°) of trajectory[1]. However, our designed technique differs from An's technique in the way that it uses the adjacent anatomical structures to estimate the angle for the screw trajectory during operation.

Ebraheim et al.[9,11] evaluated the relationship between the VA foramen and the midpoint of the cervical lateral mass. According to results from these studies an orientation of 15° laterally seems sufficient to avoid the vertebral artery. In our study, we also found that the lateral angle needed to avoid the VA injury exceeded 10 degrees in 4.7% of the Roy-Camille methods. Therefore, the Roy-Camille screw should be placed in the center of the posterior aspect of the lateral mass, perpendicular to the vertebral plane with a 15° lateral angulation rather than 10 degrees[3].

As demonstrated previously by Heller et al.[15] a bicortical purchase provides a greater pullout resistance for lateral mass screws with a gain of approximately 30%. According to our CT scan results, the ideal lateral angles that maximize the depth for bicortical purchase and avoid vertebral artery injury are within a range of 20.5° to 22.5° in transversal reformatted images of the virtual sagittal trajectory for the Roy-Camille procedure and within a range of 21.4° to 23.4° for Magerl technique. The mean screw path length between the ventral and dorsal cortices of the lateral mass for the bicortical purchase was about 13.5 mm at C3-6 and 13.0 mm at C7 in the transversal reformatted images of the virtual sagittal trajectory for the Roy-Camille procedure and about 14 mm at C3-6 and 13.6 mm at C7 for the Magerl technique. A study by Yoon et al.[33], based on a patient cohort from Korean presented results that conflict with ours. In their study, the recommended ideal lateral angle in CT scan to maximize depth and avoided injuring the VA was 19.6° on average, and the maximal depth of the screw was 13.5 mm on average when using the Magerl technique. However, the originally recommended lateral angle in the Magerl procedure is 25 degrees. Also, Ebraheim et al.[10] reported that the mean screw path length in the Magerl technique was within the range 15-16 mm at C3-C6 and had a mean value of 13.8 mm at C7.

According to our study, the ideal lateral angle at the maximized bicortical purchase depth that still avoided VA injury was about 29° on average based on CT scans. This finding is similar to the angles found using the An techniqe (30°). In fact, the main purpose of this lateral angling is to avoid nerve root injury. Selection of a screw with the proper length is also critical for avoiding iatrogenic injury to the adjacent nerve root. Safe screw lengths for the Roy-Camille and Magerl techniques vary markedly in the literature. Although Ebraheim et al.[10] reported that a safe screw length was 14-15 mm for the Roy-Camille technique and 15-16 mm for the Magerl technique at C3-C6. These differences were due to the relatively straight sagittal angle used in Roy-Camille method compared to the relatively oblique sagittal angle used in Magerl method. The mean screw path length for bicortical purchase in our modified technique decreased from cephalad to caudal, with a range of 13.5-13.9 mm at C3-C6 and a mean value of 13.3 mm at C7. Ebraheim et al.[10] also suggested that safe screw penetration of the ventral cortex into the spinal nerve should be 1 mm at C3-C6. Therefore, we suggest that a safe screw length for the bicortical purchase of the ventral and dorsal cortex of the lateral mass that avoids injury to the adjacent spinal nerve is 13.5-14.9 mm at C3-C6 and 13.3-14.3 mm at C7 when using the our technique. In fact, there were variations at spinous process of middle or lower cervical vertebrae such as spina bifida, lopsided spinous process angle, and so on. In our study, many spina bifida were founded on C3-C6 level (64%, 77%, 70% and 30%, respectively) and lopsided spinous process were founded on C3, C5 level (10% and 7%, respectively). Statistically, there were no significant difference on our measured angles or distances, although there were variations (These findings were not described in result).

The use of intraoperative fluoroscopy to guide screw placement is being widely practiced to minimize the risk of iatrogenic neurovascular injury and facet joint disruption[14,20]. It is generally thought that multiple lateral views will allow for greater precision in the screw trajectory. Although Roche et al.[25] suggested that lateral mass screws could be safely positioned by adhering to the protocols described by An et al.[10] without intraoperative fluoroscopy, the authors insist that, before considering the use of this technique, the operator must have already received advanced training in spinal surgery. In addition, Weinstein et al.[29] reported that the number of years of experience in spinal surgery appeared to be less important than familiarity with the regional anatomy and the specific technique used. When attempting to accurately measure 15 degrees for the superior angle and 30 degrees for the lateral angle, there are many chances for error. However, our designed technique for lateral mass screw fixation, which uses surgically-exposed surrounding anatomical structures such as the posterior arch and the spinous process, may be applied even without fluoroscopic guidance by young surgeons with less advanced training in spinal surgery. Furthermore, it is difficult to quantify the extent to which the operation time is shortened by the procedure, because this will vary with different operators and the complexity of individual cases. Nevertheless, our belief is that the time taken for the operation can be shortened.

We only studied difference in angles and depths of the lateral mass screw among three procedures by virtual trajectory on the reconstructed transversal images from thin section CT scans. Therefore, future studies should include cadaveric and clinical studies to compare the risk of injury to the VA and the nerve root as well as the rate of bicortical purchase among these procedures.

CONCLUSION

Some differences may exist between Korean and Western people in the length and angle for ideal lateral mass screw fixation and these should be examined in future studies. Also, our designed technique using anatomical structures rather than fluoroscopic guidance can alternatively be performed and may allow safe and effective lateral mass fixation in the cervical spine.

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