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Quantitative Anatomy of Subaxial Cervical Lateral Mass

An Analysis of Safe Screw Lengths for Roy-Camille and Magerl Techniques

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Study Design. Determination of lateral mass screw lengths with Roy-Camille and Magerl techniques of screw insertion using computerized tomography in 98 young, asymptomatic North American volunteers.

Objective. To provide reliable and normative data on safe screw lengths using the Roy-Camille and Magerl techniques of lateral mass fixation in the subaxial cervical spine.

Summary of Background Data. Lateral mass screw lengths have been studied in the past using differing subject and measurement characteristics and small sample sizes. Results demonstrated considerable variation in screw length and influencing factors. Inappropriate screw lengths can result in neurovascular injury during screw insertion, facet joint damage, or inadequate fixation.

Methods. Bicortical screw lengths were bilaterally measured at each spinal level from C3–C7 in 98 young volunteers using computed tomography reconstructions through the lateral masses obtained in the plane of the screw in Roy-Camille and Magerl techniques.

Results. With both techniques, trajectories were longest at C4–C6, shorter at C3, and shortest at C7. Screw lengths were greater in males when compared with females at all levels. Average Magerl screw lengths were approximately 2.6 mm longer at C3–C6 levels, and approximately 1.3 mm longer at the C7 level when compared with Roy-Camille technique. There was minimal correlation between screw lengths and anthropometric measurements including stature, body weight, and neck length.

Conclusion. Significant variations exist at each subaxial level with either technique. We recommend the surgeon determine screw lengths for fixation at each level using preoperative sagittal oblique computed tomography scans, which provide the most accurate technique of preoperative templating for screw length.

Key words: lateral mass screw, cervical spine, anatomy, Roy-Camille, Magerl. **Spine 2008;33:893–897**

Spinal nerve roots and vertebral arteries lie in close proximity to the lateral masses and are at risk of injury during lateral mass screw insertion.[1–4] Many techniques for safe screw insertion were previously described.[5–8] Cadaveric studies demonstrated that a potential risk of spinal nerve root injury exists, although risk of vertebral artery injury is low.[9,10] Clinical studies reported a variable risk of nerve root injury during screw insertion, presenting as monoradiculopathy.[11–17] Use of the technique described by Roy-Camille *et al* is associated with risk of facet joint violation.[9,18] Regardless of technique, injuries caused by misdirected or inappropriately long screws remain a surgical concern.

Anatomic investigations attempted to quantify lateral mass geometry for Roy-Camille and Magerl screw trajectories.[18–22] Results demonstrated considerable variation in screw length and influencing factors, possibly due to differing subject and measurement characteristics and small sample sizes. For example, measurements were obtained manually[21] or using computed tomography (CT)[18,22] on human cadavers[18,21] or patients.[22] Roy-Camille screw lengths varied from a minimum of 8.8 mm[19] to a maximum of 14 to 15 mm.[21] Magerl screw lengths varied from a minimum of 11.9 ± 1.5 mm[22] to a maximum of 15 to 16 mm.[21] One study reported no significant difference in screw lengths using the Roy-Camille and Magerl techniques,[21] while other studies report significantly longer screw lengths associated with the Magerl technique when compared with the Roy-Camille technique.[18,22] Additionally, some investigations identified spinal level[18,22] and gender[18] dependence, while others reported no significant differences.[21] Recommendations by some authors to use "long" unicortical screws[17,23,24] to avoid the risk of nerve root injury introduce another dimension to the debate on safe screw lengths. Uncertainty in screw length can increase the likelihood of vertebral artery or nerve root compromise during screw insertion. Additionally, the caudal articular facet is at risk of injury if the screw length is too long.

The purpose of this study was to determine mean bicortical screw path lengths from dorsal to ventral lateral mass cortices for screws inserted using techniques initially described by Roy-Camille *et al*[8] and Magerl *et al*,[7] from CT scans of a normative population of 98 young,

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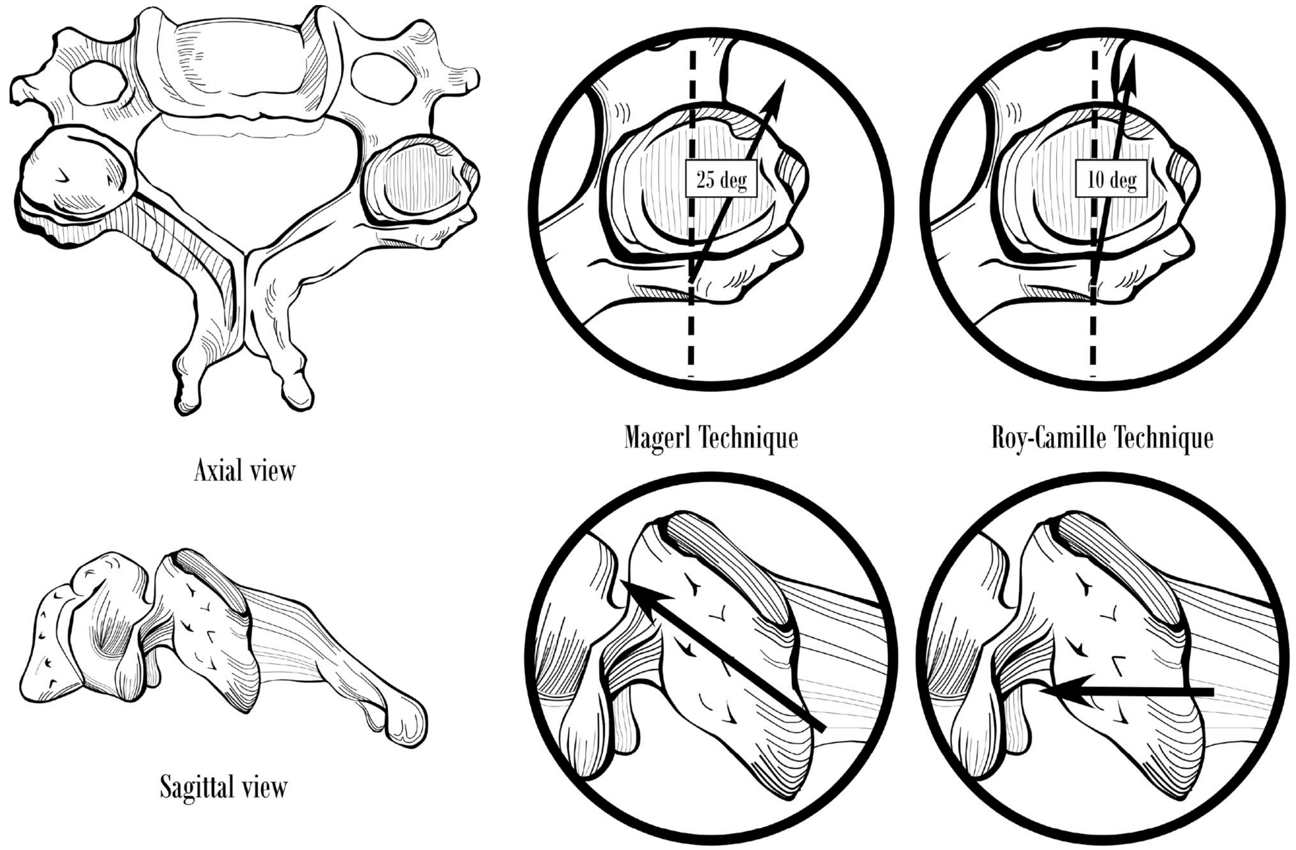

Figure 1. Diagrammatic representation of screw trajectory using Roy-Camille and Magerl insertion techniques.

asymptomatic volunteers. The large sample provides more reliable, consistent, and representative data on critical dimensions in a North American population. Additionally, differences in lateral mass dimensions based on anthropometry and gender were investigated.

■ Materials and Methods

Sixty-three males and 35 females were enrolled as part of a larger study investigating cervical spine biomechanics. Subjects with history of cervical spine pathology, symptoms suggestive of degenerative or inflammatory diseases, or evidence of infectious, neoplastic, traumatic conditions or congenital malformations of the cervical spine were excluded. Male subjects had a mean age, height, and weight of 24.6 ± 5.7 years, 180.6 ± 7.5 cm, and 83.2 ± 15.1 kg. Female subjects had a mean age, height, and weight of 25.3 ± 6.1 years, 164.3 ± 7.1 cm, and 59.2 ± 7.1 kg. Informed consent was obtained from all participants and the study was approved by the Institutional Review Board.

CT scans of the neck were obtained in 3-mm increments (Siemens Somatom Plus 4, Siemens Inc., Germany) with the subject supine and the neck in neutral position. Images reconstructed at 1.5-mm intervals and reformatted into axial planes parallel to vertebral body endplates were used to acquire geometric data. Lateral mass dimensions were obtained using National Institutes of Health Image J, a public domain Java image analysis and processing program.[25]

Lateral mass width was bilaterally measured at each spinal level from C3–C7 as the largest distance from medial to lateral borders. Screw lengths were bilaterally measured using sagittal oblique slices through the lateral masses in the plane of the screw for Roy-Camille and Magerl techniques. For the Roy-Camille technique, reconstructions were formatted in a plane through the midpoint of the lateral mass posterior surface and oriented 10° laterally. Bicortical Roy-Camille screw length was measured as the distance between dorsal and ventral cortices along a line initiating at the supero-inferior midpoint and directed perpendicular to the posterior surface (Figures 1 and 2A). For the Magerl technique, reconstructions were formatted in a plane 1.0-mm medial to the center of the lateral mass posterior surface and oriented 25° laterally. Bicortical Magerl screw length was measured as the distance between dorsal and ventral lateral mass cortices along a line initiating at the supero-inferior midpoint and directed parallel to the superior articular facet (Figures 1 and 2B).

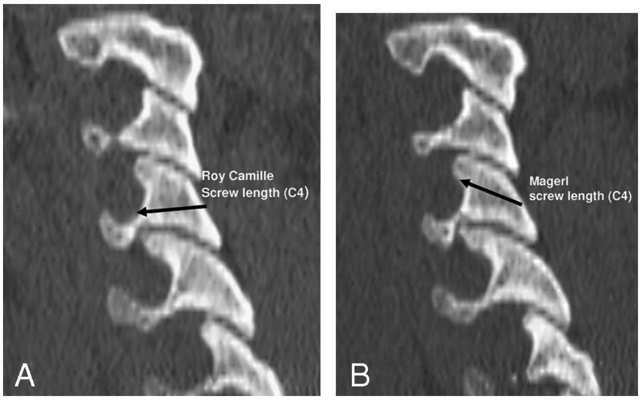

Figure 2. Computerized tomographic reconstruction of the lateral mass in the plane of screw insertion using Roy-Camille (**A**) and Magerl (**B**) techniques. These images were used to measure bicortical screw length.

Mean and standard deviation were computed for lateral mass width, and Roy-Camille and Magerl screw lengths at each subaxial cervical level. Three-factor analysis of variance determined statistically significant differences ($P < 0.05$) in lateral mass width and screw lengths based on gender, spinal level (C3–C7), and side (right and left). Fisher's least significant difference *post hoc* analysis determined significant differences ($P < 0.05$) between individual spinal levels. Student *t*-tests determined significant differences ($P < 0.05$) between Roy-Camille and Magerl screw lengths. Correlations between continuous variables of height, weight, neck length, lateral mass width, Roy-Camille screw length, and Magerl screw length were assessed using correlation coefficients. Intraobserver and interobserver repeatability was assessed by quantifying coefficient of repeatability.[26] For intraobserver repeatability, all 3 measurements were repeated for 10 volunteers by the primary observer. For interobserver repeatability, all 3 measurements were repeated for 15 volunteers by an independent secondary observer.

Results

CT scans of 490 subaxial cervical vertebrae from 98 volunteers were analyzed. Lateral mass widths, and Roy-Camille and Magerl screw lengths were measured for 980 lateral masses. Measurement differences between right and left sides were not significantly different for either screw length. Therefore, analysis presented herein grouped both sides.

Lateral Mass Width. Lateral mass width (8.0–16.1 mm) was significantly dependent ($P < 0.05$) on gender and spinal level (Table 1). Mean width was greater in males at all levels and greatest at C6 for males (12.8 mm) and females (11.1 mm). Lateral mass width demonstrated limited correlation with volunteer height (r = 0.446), weight (r = 0.472), and neck length (r = 0.232).

Roy-Camille Screw Length. Roy-Camille screw length (6.3–16.7 mm) was significantly dependent ($P < 0.05$) on gender and spinal level (Table 2). Mean Roy-Camille screw length was greater in males at all subaxial levels and greatest at C5 for males (12.9 mm) and at C4 for females (11.5 mm). Roy-Camille screw length was shortest at C7 for males (9.8 mm) and females (8.5 mm). *Post hoc* analysis revealed that Roy-Camille screw length at each spinal level was significantly different from all other levels with the exception of C4 relative to C5 and C6. Roy-Camille screw length demonstrated limited correlation with volunteer height (r = 0.338), weight (r = 0.317), and neck length (r = 0.181).

Table 1. Lateral Mass Width (mm) for Subaxial Cervical Spine

	Males		Females	
	Mean	SD	Mean	SD
C3	11.1	1.3	10.0	1.0
C4	11.4	1.2	10.3	1.1
C5	12.4	1.2	11.0	1.2
C6	12.8	1.4	11.1	1.4
C7	11.8	1.2	10.3	1.4

Table 2. Subaxial Cervical Lateral Mass Screw Lengths (mm)

	Roy-Camille Screw Length				Magerl Screw Length			
	Males		Females		Males		Females	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
C3	11.7	1.5	11.0	1.5	14.0	1.7	13.2	1.7
C4	12.6	1.5	11.5	1.3	15.1	1.7	13.8	1.4
C5	12.9	1.5	11.4	1.4	15.6	1.8	13.9	1.4
C6	12.4	1.5	11.1	1.6	15.6	2.1	14.0	2.1
C7	9.8	1.3	8.5	1.2	11.4	1.8	9.6	1.5

Magerl Screw Length. Magerl screw length (6.3–20.4 mm) was significantly dependent ($P < 0.05$) on gender and spinal level (Table 2). Mean Magerl screw length was greater in males at all subaxial levels and greatest at C6 for males (15.6 mm) and females (14.0 mm). Magerl screw length was shortest at C7 for males (11.4 mm) and females (9.6 mm). *Post hoc* analysis revealed that Magerl screw length at each spinal level was significantly different from all other spinal levels with the exception of C5 relative to C6. Magerl screw length demonstrated limited correlation with volunteer height (r = 0.275), weight (r = 0.275), and neck length (r = 0.128).

Roy-Camille *Versus* Magerl Screw Length. Magerl trajectory was significantly longer ($P < 0.05$) than Roy-Camille trajectory for males and females at all spinal levels. Average Magerl screw lengths were approximately 2.6 mm longer at C3–C6 levels, and approximately 1.3 mm longer at the C7 level.

Intraobserver and Interobserver Repeatability. Coefficients of repeatability for intraobserver and interobserver repeatability were an average of 8% and 10%, respectively, of mean values for the 3 measures (Table 3). Intraobserver repeatability was an average of 17% less than interobserver repeatability.

Discussion

Cervical spine fixation using lateral mass screws has equivalent or superior biomechanical stability over posterior wiring techniques without risk of spinal canal en-

Table 3. Coefficients of Repeatability for Intraobserver and Interobserver Repeatability

	Lateral Mass Width (mm)	Roy-Camille Length (mm)	Magerl Length (mm)
Intraobserver			
Coefficient of repeatability	0.89	1.01	0.89
Percent of mean	8.0%	9.3%	6.8%
Interobserver			
Coefficient of repeatability	1.13	1.12	1.12
Percent of mean	10.5%	10.4%	8.7%

try and can be implemented even when the spinous process and lamina are deficient.[27–32] The technique reduces the need for halo immobilization and allows earlier neck mobilization.[14,16,17] However, insertion of lateral mass screws is associated with some risk of spinal nerve root, vertebral artery, or caudal facet joint injury caused by excessively long or misdirected screws. Regardless of technique, it is necessary that appropriate screw lengths be selected to avoid potential complications. In an attempt to provide normative data, this study was conducted to quantify lateral mass width and screw length for Roy-Camille and Magerl techniques in a large sample of young, asymptomatic volunteers.

A number of clinical studies reported patient outcomes after posterior cervical spine fixation using lateral mass screws. These studies reported that spinal nerve root injury leading to postoperative monoradiculopathy was the most common complication.[11–14] In the most comprehensive study of 100 patients with stabilization using rod-screw systems, screw placement using a technique similar to Magerl resulted in 4.0% of patients with new radiculopathy symptoms and no spinal cord or vertebral artery injuries.[11] Other studies with smaller patient populations also reported complications after lateral mass screw fixation. In 78 patients with stabilization using plate-screw fixation, the An technique,[5] similar to the Magerl technique, resulted in 7.7% and 1.3% of patients with postoperative radiculopathy and facet joint violation, respectively.[13] In 21 patients with stabilization using plate-screw fixation, the Magerl technique resulted in 19.0% and the Roy-Camille technique resulted in 4.8% of patients with postoperative radiculopathy.[12] In 24 patients with stabilization using plate-screw fixation, the Roy-Camille technique resulted in 25% of patients with neurologic complications.[14] Most of these investigators have attributed screw-related neurologic complications to unduly long bicortical screws.

Using cadaveric models or postoperative medical imaging, other studies identified the risk of associated complications after insertion of lateral mass screws.[9,12,18,24] Risks included screws that violated neural or arterial integrity, or that may have violated integrity in the presence of overpenetration or longer screws. Those investigations identified differing injury risks for Roy-Camille and Magerl techniques. Overall risk of nerve root injury across the 4 studies was 5.2% for the Roy-Camille and 22.6% for the Magerl techniques. Overall risk of facet joint violation was 14.2% for the Roy-Camille and 6.1% for the Magerl techniques. Risk of vertebral artery injury was 4.7% for the Magerl technique. Screws did not approach the vertebral artery for the Roy-Camille technique or the spinal cord for either technique. Therefore, the primary risk for the Roy-Camille technique is facet joint violation and the primary risk for the Magerl technique is nerve root injury, although these risks are not reflected by clinical outcome studies cited above. Differing risks are primarily due to screw orientation. As the Roy-Camille trajectory is perpendicular to the dorsal cortex of the lateral mass, the screw emerges from the ventral cortex near the ventral facet joint aspect. Slight variation in sagittal angle may result in violation of facet joint integrity. As the Magerl trajectory is parallel to the superior articular surface, the screw emerges from the ventral cortex near the neural foramen, where the nerve root exits the spinal canal. Present screw lengths account for minimum length for bicortical insertion. Some authors recommend unicortical insertion of lateral mass screws to reduce the risk of neural or arterial involvement. Because of the lack of bicortical purchase, unicortical screws may provide inadequate mechanical stability, particularly under cyclic loading in osteoporotic bone. A mechanical investigation of bicortical *versus* unicortical screws reported that bicortical screws resulted in stiffer spinal bending response than long and short unicortical screws, although the difference was only statistically significant for short unicortical screws.[23] Another study reported greater axial pullout strength for bicortical screws, although the difference did not attain statistical significance.[24] Because of superior mechanical stability under single-cycle loading and stiffer response under repeated loading, bicortical lateral mass screws remain a superior option for posterior spinal stabilization.

Roy-Camille and Magerl screw lengths reported here are in line with previous investigations of spinal anatomy.[18,21,22] Without regard to gender and spinal level, mean screw lengths were greater than one study using 40 Asian patients,[22] less than another North American study using fourteen human cadaver specimens,[21] and approximately equal to a third European study using 20 human cadaver specimens.[18] Although differences in population characteristics may account for these minor geometrical differences, present data also demonstrated minimal correlation to anthropometrical measurements including stature, body weight, and neck length. Conversely, screw trajectory lengths were significantly dependent on spinal level. Data for both techniques demonstrated the following trends: greatest trajectory length at C4–C6 levels, slightly decreased length at C3, and shortest length at C7. Screw lengths were generally 1.5 mm longer in males and around 2 mm longer with the Magerl technique. Significant variations exist at each subaxial level with either technique, making it inappropriate to assume that a uniform screw length (14 or 16 mm) will lead to unicortical fixation, as recommended previously.[17,23,24] We recommend that the surgeon determine screw lengths for fixation at each level using preoperative sagittal oblique CT scans, which provide the most accurate technique of preoperative templating for screw length.

Measurements from this study represent mean bicortical screw lengths for Roy-Camille and Magerl techniques of lateral mass screw insertion from C3–C7 in the largest reported database of a young North American population. Actual implant sizes required for bicortical purchase may vary slightly depending on screw pitch and the screw head design. Measurements in a symptomatic, older population with cervical spondylosis may be marginally different due to presence of osteophytes and/or bony remodeling. Gender, race, and anthropometric characteristics may lead to additional variation.

■ Key Points

- Lateral mass screw lengths for Roy-Camille and Magerl techniques of screw insertion were determined using computed tomography scans of a normative population of 98 young, asymptomatic North American volunteers.
- Screw lengths were greater in males when compared with females at all levels. Average Magerl screw lengths were approximately 2 mm longer at all levels when compared with Roy-Camille technique.
- Significant variations in screw lengths were found at all subaxial levels with either technique.
- We recommend that surgeons before surgery template lateral mass screw length on CT scans for determination of safe screw lengths at each level.

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