Biomechanical evaluation of cervical lateral mass fixation: a comparison of the Roy-Camille and Magerl screw techniques

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Object. The purpose of this study was to assess human cervical spine pullout force after lateral mass fixation involving two different techniques: the Roy-Camille and the Magerl techniques. Although such comparisons have been conducted previously, because of the heterogeneity of results and the importance of this procedure in clinical practice, it is essential to have data derived from a prospective and randomized biomechanical study involving a sufficient sample of human cervical spines. The authors also evaluated the influence of the sex, the vertebral level, the bone mineral density (BMD), the length of bone purchase, and the thickness of the anterior cortical purchase.

Methods. Twenty-one adult cervical spines were harvested from fresh human cadavers. Computerized tomography was performed before and after placing 3.5-mm titanium lateral mass screws from C-3 to C-6. Pullout forces were evaluated using a material testing machine. The load was applied until the pullout of the screw was observed. A total of 152 pullout tests were available, 76 for each type of screw fixation. The statistical analysis was mainly performed using the Kaplan–Meier survival method.

The mean pullout force was $266 \pm 124$ N for the Roy-Camille technique and $231 \pm 94$ N for the Magerl technique ($p < 0.025$). For the C3–4 specimen group, Roy-Camille screws were demonstrated to exert a significantly higher resistance to pullout forces ($299 \pm 114$ N) compared with Magerl screws ($242 \pm 97$ N), whereas no difference was found between the two techniques for the C5–6 specimen group (Roy-Camille $236 \pm 122$ N and Magerl $220 \pm 86$ N). Independent of the procedure, pullout strengths were greater at the C3–4 level ($271 \pm 114$ N) than the C5–6 level ($228 \pm 105$ N) ($p < 0.05$).

No significant correlation between the cancellous BMD, the thickness of the anterior cortical purchase, the length of bone purchase, and maximal pullout forces was found for either technique.

Conclusions. The difference between pullout forces associated with the Roy-Camille and the Magerl techniques was not as significant as has been previously suggested in the literature. It was interesting to note the influence of the vertebral level: Roy-Camille screws demonstrated greater pullout strength (23%) at the C3–4 vertebral level than Magerl screws but no significant difference between the techniques was observed at C5–6.

KEY WORDS • lateral mass • cervical spine • bone screw • biomechanical testing • spinal fixation • pullout strength

Posterior cervical plate–augmented lateral mass fixation is currently used to achieve posterior internal fixation of the lower cervical spine. This cervical posterior fixation device has been proven to restore the stability of the cervical motion segment after traumatic or postlaminectomy injuries. Since Roy-Camille, et al., first described the technique in 1972, many authors have discussed technical variations by which to improve its mechanical competence or anatomical safety.

According to the authors of numerous anatomical studies, there are two principal procedural types involved in lateral mass screw fixation: the Magerl technique (directed above the projection of the nerve root) and the Roy-Camille technique (directed below the projection of the nerve root close to the junction of the transverse process with the lateral mass).

Only few comparative biomechanical studies have been published and these have yielded heterogeneous results. Montesano, et al., comparing these two different techniques of screw placement, found that the Magerl technique provided greater resistance and had a higher load to failure (585 N) than the Roy-Camille technique (152 N); however, only three spines per surgical technique were used and only one technique per spine was tested (that is,
no randomization). The results obtained in a study of bovine cervical spines by Errico, et al., 6 were similar but the difference of pullout strengths between the two techniques was considerably smaller (Roy-Camille technique 471 N and Magerl technique 607 N); additionally, bone strength was greater for the Roy-Camille orientation (46.7 N/mm) than for the Magerl orientation (36.1 N/mm). Choueka, et al., 2 evaluated the flexion failure of posterior cervical lateral mass fixation in a cadaveric model. Although the Magerl screw sustained a significantly higher moment to failure than the Roy-Camille screw for the superior screw hole position, there was no such significant difference in flexion failure load for the inferior screw hole position. In this study the principal mode of screw insertion failure was the fracture of the pedicle or the lateral mass, whereas it is the pullout of the screw in the most biomechanical 30 and clinical 5, 12, 31 studies.

Because of the heterogeneity of results of these previous studies and the importance of this surgical technique in clinical practice 5, 20, 33 it appeared essential to undertake a randomized biomechanical study involving a sufficient sample of human cervical spines.

Materials and Methods

Cervical Specimens

Twenty-six adult cervical spines were harvested from fresh human cadavers obtained from the Department of Anatomy of Claud Bernard University. Each segment included C-2 to T-1 vertebrae. Computerized tomography scanning was performed on a Somatom 4 plus Siemens (Siemens Medical Systems, Erlangen, Germany) with an acquisition of 2-mm-thick slices. The same scanning protocol was followed for both morphological CT scans and those obtained to assess placement of screws.

The screws were cortical 3.5-mm titanium threaded rods (Scient‘x, Guyancourt, France), specially designed for this study (Fig. 1). The use of special threaded rods provided an excellent connection between the screw and the upper jaw of the testing machine.

The material testing machine (Trayvou, Rhône, France) involved a load sensor (maximum load capacity ~1200 N) to improve its precision.

Morphological CT Scans

After harvesting cervical spines from cadavers, the first CT scan was obtained for the following purposes: 1) to eliminate pathologically affected cervical spines (tumoral, traumatic, or degenerative; those affected by degenerative conditions were excluded only when arthrodesis was present at more than one level); 2) to measure the thickness of the anterior cortical purchase according to each technique (Fig. 2); and 3) to measure the VB cancellous BMD of each vertebra. The relationship between the BMD measured on the CT scan (in Hounsfield units) and the real BMD (in milligrams/cubic centimeter) was allowed using a semianthropomorphic spine phantom for the calibration of the CT scans. The technique has been previously described. 16, 25

Surgical Procedure

The cervical spine was placed prone with the neck in neutral position. After a standard posterior approach to the lower cervical spine, the C3–6 posterior arches were exposed. The articular capsules were removed, allowing an excellent view of the facet joint line and the lateral side of the lateral mass.

The entrance point was identified on the posterior surface of the lateral mass according to the insertion technique (Fig. 3). All screw holes were drilled using a 2.2-mm drill bit. Using a calliper gauge, the length of the screw thread inserted inside the lateral mass was then precisely measured. Bicortical purchase was the objective, allowing the screw tip to penetrate 1 or 2 mm beyond the distal cortex. As demonstrated previously by Heller, et al., 11 bicortical purchase confers approximately 30% greater resistance to pullout force than a unicortical purchase. A 3.5-mm threaded rod was inserted using either Magerl or Roy-Camille orientation as previously described. 12, 27

Lateral mass screws were randomized to the left or right side. Randomization was achieved using a permutation table. In this way, each vertebra received was treated by both surgical techniques. The same surgeon (C.B.) inserted all articular screws to minimize the effect of technical variation.
Checking CT Scan

A second CT study was acquired to confirm proper placement of the screws. In particular, sagittal and transverse orientations of lateral mass screws were verified (Fig. 4). In addition, the length of effective bone purchase between the posterior and anterior cortices of lateral mass was measured for each screw.

Biomechanical Testing

Biomechanical evaluation consisted of pullout testing performed in the material testing machine. The pullout load was achieved by generating a downward displacement of the lower plate of the testing machine, on which the vertebral case was fixed (Fig. 5). An adjustable vice allowed the alignment of screw’s axis with that of the testing machine.

For these loading tests, each of the C-3 to C-6 vertebrae was carefully isolated from the cervical spine segment. Each vertebra was then firmly fixed using pedicle and posterior arch wiring techniques (Fig. 6) with respect to lateral masses. In two cases, the vertebrae were not separated: in one because of the presence of a degenerative arthrodesis and in the other because of the presence of a transarticular screw. In these cases separation of vertebrae could have damaged the anchorage of lateral mass screws.

The displacement rate was 0.0892 mm/second, and displacement was applied until failure of screw insertion. For each screw the mode of failure was noted—that is, either pure pullout or lateral mass fracture. In each test, a load–displacement curve was recorded using a computerized data collection system as is typically used in these loading tests.\(^9,17,29\) The top of the curve was considered to indicate the maximal pullout load, and this value was used for the statistical analysis.

Statistical Analysis

We performed a prospective comparative randomized study to determine the optimal pullout resistance of screws placed using the Roy-Camille and the Magerl techniques. The vertebra was the statistical unit in the analysis. Only C3–6 vertebrae were analyzed. The major end point was the maximal pullout load, defined as censored data. Survival curves were calculated using the Kaplan–Meier method, and intergroup comparison was performed using the log-rank test. In addition, mean values of pullout loads in the two groups were compared using the Student t-test for paired values. A simple linear regression analysis was conducted to assess the contribution of thickness of the anterior cortical purchase, bone purchase length, and cancellous BMD. Student t-tests were performed to compare the pullout load grades based on sex and vertebral level. All probability values were two-sided and were considered statistically significant when less than 0.05.

Results

Three cervical spines with very advanced degenerative disease were excluded from this study. Two other speci-
mens were used for the preliminary tests. Twenty-one cervical spines were included in the statistical analysis. There were 11 male and 10 female individuals, and the mean age of the cadavers from whom they were obtained was 73 ± 6 years.

A total of 152 pullout tests were available, 76 for each type of screw fixation technique. Nine pullout tests were invalid because of misalignment between axis of the screw and that of the material testing machine in three, VB fracture in two, posterior arch fracture in two, and wire breakage in two cases.

**Pullout Forces**

The mean forces required for screw pullout were $266 \pm 124$ N and $231 \pm 94$ N for the Roy-Camille and Magerl techniques, respectively (Table 1 and Fig. 7 upper). The difference was found to be significant in two different statistical analysis tests (paired groups tests and log-rank test with survival curves).

Regarding the influence of the vertebral level (Fig. 7 lower left), for the C3–4 Roy-Camille screws demonstrated a significantly higher resistance to pullout loads ($299 \pm 114$ N) compared with Magerl screws ($242 \pm 97$ N at the same level), whereas no significant difference was found between the two surgical techniques at C5–6 (Roy-Camille $236 \pm 122$ N and Magerl $220 \pm 86$ N) (Fig. 7 lower right). These results correlated to a significant lesser biomechanical competence of the Roy-Camille technique at C5–6 ($236 \pm 121$ N) than at C3–4 ($299 \pm 121$ N). There was, however, no significant difference for C3–4 ($242 \pm 101$ N) and C5–6 ($220 \pm 87$ N) screws applied using the Magerl technique.

![Fig. 4. Computerized tomography scans. a and b: The transverse orientation of lateral mass screws and the length of bone purchase were verified on the checking CT scan for the Roy-Camille (a) and the Magerl (b) screw techniques. c and d: The sagittal orientation of lateral mass screws was verified on the checking CT scan for the Roy-Camille (c) and the Magerl (d) screw techniques.](image1)

![Fig. 5. Trayvou material testing machine. 1, dynamometer face; 2, load sensor; 3, upper pullout jaw; 4, extraction rod of articular screw; 5, vertebra case; 6, adjustable vice; 7, lower plate; 8, control screw of lower plate displacement; 9, motor.](image2)
Because of the size of the sample (76 tests/four cervical levels [19]) the statistical analysis for each isolated vertebral level (C-3, C-4, C-5, and C-6) became difficult. The difference was still significant only at C-4 with pullout forces for the Roy-Camille technique at approximately 310 N and for the Magerl technique at approximately 230 N (Table 2, Fig. 8).

Independent of the technique, pullout forces were found to be higher for male (271 ± 110 N) than female specimens (219 ± 80 N) (p < 0.005) (Fig. 9 left). This influence of sex was also observed for each surgical procedure (Table 1).

Independent of the screw technique used, the maximal pullout load was found greater at C3–4 (271 ± 114 N) than at C5–6 (228 ± 105 N, p < 0.025) (Fig. 9 right). No difference was observed between the right and the left side.

Mode of Failure

The most common mode of failure for both techniques was pure pullout of the screw, the incidence of which was 70.1 and 84.4% for the Roy-Camille and the Magerl techniques, respectively. Lateral mass fracture occurred more frequently in cases involving the Roy-Camille technique (29.9%) than the Magerl technique (15.6%) (p < 0.05). Neither pedicle fracture nor VB fracture was observed. An association was found between BMD (p < 0.01), thickness of the anterior cortical purchase (p < 0.05), and the presence of a lateral mass fracture.

Morphological Data

As to angulations of screws, there was less than a 2˚ difference between CT scanning—documented angulations of Roy-Camille screws (11.3˚ laterally and 1.3˚ inferiorly) and theoretical data (10˚ laterally and perpendicular to the posterior surface of lateral mass sagittally). In cases of Magerl screws, the placement of which is more difficult, the difference was approximately 5˚ in both planes (20.2˚ laterally and 37.7˚ superiorly when theoretical data are 25˚ laterally and 45˚ superiorly).

The length of bone purchase, verified on the CT scan, was significantly greater when the Magerl technique was used.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Roy-Camille</th>
<th>Magerl</th>
<th>p Value</th>
</tr>
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<tbody>
<tr>
<td>No. of tests</td>
<td>76</td>
<td>76</td>
<td></td>
</tr>
<tr>
<td>Mean pullout load (N)</td>
<td>266 ± 124</td>
<td>231 ± 94</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>288 ± 116</td>
<td>254 ± 112</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Female</td>
<td>238 ± 104</td>
<td>199 ± 79</td>
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Fig. 6. The vertebral case. The vertebra is firmly fixed using a pedicle and posterior arch wiring technique (1.1-mm wire).

Fig. 7. Graphs. Survival curves for lateral mass screws inserted using the Roy-Camille and the Magerl technique.
Roy-Camille and Magerl screw techniques

**TABLE 2**

<table>
<thead>
<tr>
<th>Technique</th>
<th>Pullout Strength (N)</th>
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<tbody>
<tr>
<td></td>
<td>C-3</td>
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<tr>
<td>Roy-Camille</td>
<td>291 ± 123</td>
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<tr>
<td>Magerl</td>
<td>256 ± 112</td>
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<tr>
<td>p value</td>
<td>NS</td>
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* NS = not significant.

used (14.1 ± 2.6 mm) than the Roy-Camille technique (10.7 ± 1.6 mm). Results based on vertebral level are summarized in Table 3. Independent of fixation technique, bone purchase was longer at C5–6 (13.7 ± 2 mm) than at C3–4 (12.8 ± 1.8 mm) (p < 0.05).

The thickness of the anterior cortical purchase was significantly greater (1.2 mm) at the junction between transverse process and lateral mass, which corresponded to the anterior purchase achieved using the Roy-Camille technique, than at the anterosuperolateral angle of the lateral mass (1 mm), which corresponded to the anterior purchase achieved using the Magerl technique (p < 0.05).

The mean cancellous BMD measured using CT scanning was 194 ± 59 Hounsfield units. No difference was observed for each level from C-3 to C-6 (p = 0.48), whereas it was higher for specimens obtained in males than for females (p < 0.005).

Regarding these morphological data, statistical analysis found no significant correlation between the cancellous BMD (p = 0.15), thickness of anterior cortical purchase (p = 0.22), length of bone purchase (p = 0.61), and the maximal pullout load.

*Discussion*

**Biomechanical Testing Methodology**

Concerning the fixation of the vertebra within the vertebral case, polymethylmethacrylate, which is typically used in these type of loading tests, could not be used in this study because of the placement of bicortical screws. The tip of the screw would have come in contact with the polymethylmethacrylate and probably this would have influenced the pullout force. Pedicle and posterior arch wiring provided a satisfactory fixation, respecting both the lateral mass and the screw insertion zone.

The screw’s axis had to be perfectly aligned with that of the testing machine (Fig. 10). Representing the main critical point of these tests, it had to be perfectly achieved to determine the purest possible pullout strength without any unwanted flexion moment. The vice’s locking steering knuckle provided the verticality of the threaded rod. The vertical threaded rod could then be aligned with the axis of the testing machine with the displacement of vice on the lower plate in the (x and y) plane, and with the axial displacement of vertebral case along vice jaws. This alignment difficulty is an important aspect of these types of loading tests because of the possibility of unwanted flexion moment on the screw insertion, which must be avoided. In practice it was difficult to apply a pure pullout force without a pullout strength eccentricity angle of approximately 1 or 2˚.

**Statistical Analysis**

We were satisfied by the original use of the Kaplan–Meier method (survival curves) for the statistical analysis of biomechanical results. This method is not greatly influenced by extreme values, and proved to provide interesting results in our study.

**Pullout Strength Testing**

Overall the mean pullout load was approximately 250 N. This value is slightly lower than that reported in most biomechanical studies concerning the pullout resistance of lateral mass screws, which is more often greater than 300 N. The relatively high mean age (73 ± 6 years) of this study’s individuals, most of whom had suffered from osteoporosis before death, can probably explain this difference.

Concerning the comparative biomechanical study, screws placed using the Roy-Camille technique demonstrated significantly higher pullout forces than Magerl screws. Results reported in a few other comparative studies are not concordant with ours. The Roy-Camille technique has never been reported to create greater resistance than the Magerl technique, even if the difference could vary considerably from one study to another. These studies, however, were conducted to evaluate bovine cervical spine, in which the morphological features of lateral masses are very different from human lateral masses, or the studies were composed of a small sample (six spines). Choueka, et al., examined flexion failure of lateral mass fixation, not focusing on pullout resistance.

Regarding several biomechanical parameters, we can assert that the Roy-Camille technique involves screw insertion into a zone of greater mechanical bone quality than the Magerl technique. First, Roy-Camille screws demonstrated a higher pullout resistance than Magerl screws, although the difference was little (~35 N). Second,
the anterior cortical bone purchase created in the Roy-
Camille technique was thicker than that of the Magerl ori-
entation. Third, we observed a higher incidence of lateral
mass fracture as mode of failure when screws were insert-
ed using the Roy-Camille technique.

The insertion of screws in a zone of greater osseous
mechanical quality can explain why the Roy-Camille
technique had a higher load-to-failure rate than the Magerl
technique, although the latter technique created longer
bone purchase.

Moreover, the obliqueness of the Magerl screw fixation
likely generates unfavorable biomechanical conditions
(Fig. 11). The longitudinal orientation of osteons within
the compact bone offers greater resistance to pullout load
directed perpendicular to the posterior surface of the later-
al mass than to pullout load with a 45˚ obliqueness. Ad-
ditionally, the increased entry points of the screw’s thread
on the cortical bone surface, secondary to the Magerl
screw’s obliqueness, weakens the region where the screw
is inserted. When the screw placed perpendicular to
the surface of the compact bone, there is only one entry point
of the screw’s thread.

Contrary to previously published data, 23 the length of
the bone purchase did not appear to be the main predictive fac-
tor of pullout resistance of bicortical lateral mass screws.

We also noted that differences varied according to the
treated vertebral levels. Whereas at C3–4 the observed
difference was more than 50 N, it was not significant at
C5–6. This is probably due to the variability affecting the
morphology of lateral masses along the lower cervical
spine, which decreases in thickness from C-3 to C-7. 1,37
The fact that the greatest pullout strength, independent of
the screw technique, was found at C-4 has already been
noted in several studies. 1,14,28 In fact, the vertebral level
and the sex represent the main factors predicting pullout
resistance.

In this study C-7 was not evaluated. Lateral mass fixa-
tion is not satisfactory at this level because of the thinness
of its lateral masses; 1,36 a transpedicular screw is preferable.

Morphological Data

Bone purchase (Roy-Camille 10.7 mm and Magerl 14.1
mm) was found to be less extensive than that reported in
the literature. 23 We were able to measure this parameter
precisely by using CT scanning. Xu, et al.,36 performed
recently an anatomical study in which they found that the
path of the screw length ranged from 11 to 15 mm when
using the Magerl technique.

Computerized tomography scanning has demonstrated
that the thickness of the anterior cortical purchase was
thicker when using the Roy-Camille fixation technique.
This interesting morphological aspect has never been
noted in the literature and would require an additional his-
tological study.

Concerning the cancellous BMD, our findings were
consistent with those of Heller, et al.,11 who found no sig-
nificant association between pullout resistance and BMD
for lateral mass screws. It is likely that the quality of the
compact bone, in particular the thickness of anterior and
posterior cortices, may have a more important influence in
the holding strength of screws. The association between
the BMD and pullout resistance, however, has been
reported for pedicle and anterior vertebral screws placed
in the lumbar region. 18,26

Conclusions

Concerning the pullout resistance of lateral mass screws,
we found only a 35-N difference between those placed
using the Roy-Camille and the Magerl techniques, where-
as a 130- and 430-N difference has been reported by Errico,
et al.,6 and Montesano, et al.,22 respectively. Moreover, in

<table>
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<th>Technique (mm)</th>
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<tbody>
<tr>
<td>Roy-Camille</td>
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<tr>
<td>Magerl</td>
</tr>
<tr>
<td>mean (all levels)</td>
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<tr>
<td>C3–4</td>
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<tr>
<td>C5–6</td>
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* Measurements were made between the posterior and the anterior cort-
ices of the lateral mass.
our study a significantly higher resistance to pullout forces was associated with Roy-Camille screw fixation.

The vertebral level was clearly influential, with Roy-Camille fixation creating greater pullout strength (23%) at C3–4 than Magerl screws, but with no significant difference between the two techniques at C5–6.

These findings need to be examined in association with morphological and anatomical data to adjust the surgical technique to the vertebral level.

Acknowledgment

We thank Scient’x (Guyancourt, France) for designing the threaded rods.

FIG. 10. Diagram showing the biomechanical assembly. The axis of the threaded rod had to be perfectly aligned with that of the machine. 1, upper hinge joint; 2, load sensor; 3, upper hinge joint; 4, self-locking upper jaw of the test machine; 5, extraction rod of the articular screw; 6, vertebra case + fixation system (wiring techniques); 7, adjustable vice with presence of a locking device; 8, vice fixation by means of screws; 9, lower plate = (x,y) plane; 10, lower hinge joint; 11, control screw of the lower plate displacement along the z axis. *, ball-and-socket joint; -- --, axis of the strength machine = (z) plane.

FIG. 11. Diagrams representing lateral mass screws of each technique (Roy-Camille, [A] and Magerl [B]) and its relation to the osteonic system of the compact bone. Arrows correspond to the pullout forces. The obliqueness generated by the angulation of the Magerl technique is probably responsible of unfavorable biomechanical conditions with regard to the longitudinal orientation of osteons within the cortical bone. Moreover, the increase of entry points of the screw’s thread on the surface of the cortical bone, related to the obliqueness of the Magerl screw, generates a weakness of the insertion zone of the screw.
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