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ORIGINAL ARTICLE

Proposal for a new trajectory for subaxial cervical lateral mass screws

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Abstract

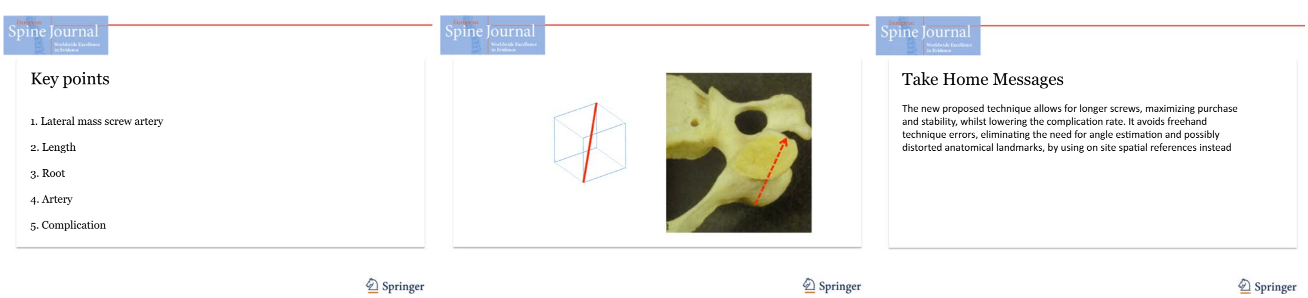
Purpose Lateral mass screws combined with rods are the standard method for posterior cervical spine subaxial fixation. Several techniques have been described, among which the most used are Roy Camille, Magerl, Anderson and An. All of them are based on tridimensional angles. Reliability of freehand angle estimation remains poorly investigated. We propose a new technique based on on-site spatial references and compare it with previously described ones assessing screw length and neurovascular potential complications.

Methods Four different lateral mass screw insertion techniques (Magerl, Anderson, An and the new described technique) were performed bilaterally, from C3 to C6, in ten human spine specimens. A drill tip guide wire was inserted as originally described for each trajectory, and screw length was measured. Exit point was examined, and potential vertebral artery or nerve root injury was assessed.

Results Mean screw length was 14.05 mm using Magerl's technique, 13.47 mm using Anderson's, 12.8 mm using An's and 17.03 mm using the new technique. Data analysis showed significantly longer lateral mass screw length using the new technique (p value < 0.00001). Nerve potential injury occurred 37 times using Magerl's technique, 28 using Anderson's, 13 using An's and twice using the new technique. Vertebral artery potential injury occurred once using Magerl's technique, 8 times using Anderson's and none using either An's or the new proposed technique. The risk of neurovascular complication was significantly lower using the new technique (p value < 0.01).

Conclusion The new proposed technique allows for longer screws, maximizing purchase and stability, while lowering the complication rate.

Graphical abstract



Keywords Lateral mass screw · Length · Root · Artery · Complication

Introduction

Subaxial cervical spine posterior stabilization is frequently required for managing disorders such as trauma, deformity, inflammatory disease, infection, severe osteoarthritis or

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neoplasia, whether alone or in combination with anterior procedures. Several fixation methods have been described, including wiring, plating and the use of bars with hooks or screws [1–3]. The use of lateral mass screws is probably the standard method of fixation for posterior cervical spine stabilization [3–6] Lateral mass screw fixation was first described by Roy Camille in 1972 [7, 8]; since then, several techniques have been described, mainly by Magerl [9], Anderson [10] and An [11]. These techniques can be divided into those where screw trajectories are perpendicular to the posterior bone cortex, aiming below the nerve root (Roy Camille) and those where the screw follows an oblique direction from medial to lateral and caudal to cephalad, aiming above it (Magerl, Anderson, An) [12]. Vertebral artery or root injury during screw insertion is a rare complication (1%) but remains a major concern as it can be potentially devastating, specially the latter as the posterior ramus lies directly in front of the lateral mass [2, 3, 12–15]. Several studies compared these techniques and concluded that screws inserted with techniques using a perpendicular trajectory were shorter than those inserted in an oblique direction and that the risk of joint violation decreased with cephalad angulation [14, 16, 17].

Screw length is a main purchase, stability and pull-out resistance [18, 19] variable, so the ideal trajectory should allow maximal length while keeping the insertion as safe as possible to avoid vertebral artery or dorsal ramus injury.

Bicortical purchase is another stability factor although it increases the risk of complications and some surgeons advocate unicortical application instead [6, 12, 16].

All the previous techniques require a tridimensional orientation, sometimes difficult to assess intraoperatively and can lead to an incorrect trajectory with the inherent risk of neurovascular damage. Reliability of freehand angle estimation remains poorly investigated [15, 20]. Besides, landmarks, or even the lateral mass itself, are usually distorted making it difficult to find the correct entry point described in previous trajectories (1 or 2 mm from the "midpoint"), especially when using 2-mm drill bit.

The purpose of the authors is to describe a new technique for screw insertion following a trajectory not based on coronal and sagittal theoretical angles but on on-site spatial references and compare it with the oblique most frequently used ones.

Our hypothesis is that the proposed new trajectory achieves longer screw insertion, maximizing purchase and stability while minimizing neurovascular complications.

Materials and methods

The study and procedures were approved by the institutional review board and ethics committee before the beginning.

Samples

We selected ten human dry spines for this study. We certify that in all of the cadaveric samples were no signs of anatomic anomalies (for example, malformations) and no past of fracture to prevent bias. All of them were provided by the department of morphological sciences of our Medicine Faculty. No epidemiologic data about the donors were available, but we judged it unnecessary for this study as it compares lateral mass screw trajectories by reproducing all the studied techniques in each specimen, so no bias should be generated.

Description of the new proposed trajectory

The lateral mass is a leaning diamond-shaped prisma (distorted cube) with a longer length from anterior to posterior than medial to lateral. Instead of using angles to reproduce the appropriate direction of the screws, we advocate taking posterior cortices as a reference and build such distorted cube mentally and then imagine the diagonal from the medial lower area of the posterior ridge to the upper lateral of the anterior ridge.

The nerve root lies in front of the anterior wall of the lateral mass and projects from superior and medial to inferior and lateral. With our proposed technique, the exit point is above the projection of the root and laterally far away from the artery. Thus, we avoid errors made during angle-based freehand screw insertion (Figs. 1, 2; Table 1).

Technique and trajectory measurement

We work in the dissection classroom, with a table adapted to prevent bone movement. This table facilitates angle measurement preventing the selection of different reference planes for angle measurement.

To recreate real anatomy, in each spine, cables were inserted mimicking vertebral arteries and nerve roots, trying to reflect their real trajectory.

We selected Magerl, Anderson and An [9–11] trajectories as the reference, and we compare them to our trajectory. We alternate all of them sequentially and bilaterally in each cervical vertebra from C3 to C6, so the same number of vertebras was measured with each method.

For the recreation of the trajectory, we used a small cannulated screw set (Smith and Nephew small cannulated screw system, Cordova USA). With the help of a 1.1-mm drill guide, a 1.1-mm stainless steel drill tip wire was inserted bicortically into the lateral mass according to the original description of each trajectory (Magerl, Anderson and An) and the new proposed one (Fig. 3). To prevent confusion in the entry point for other trajectories, the holes

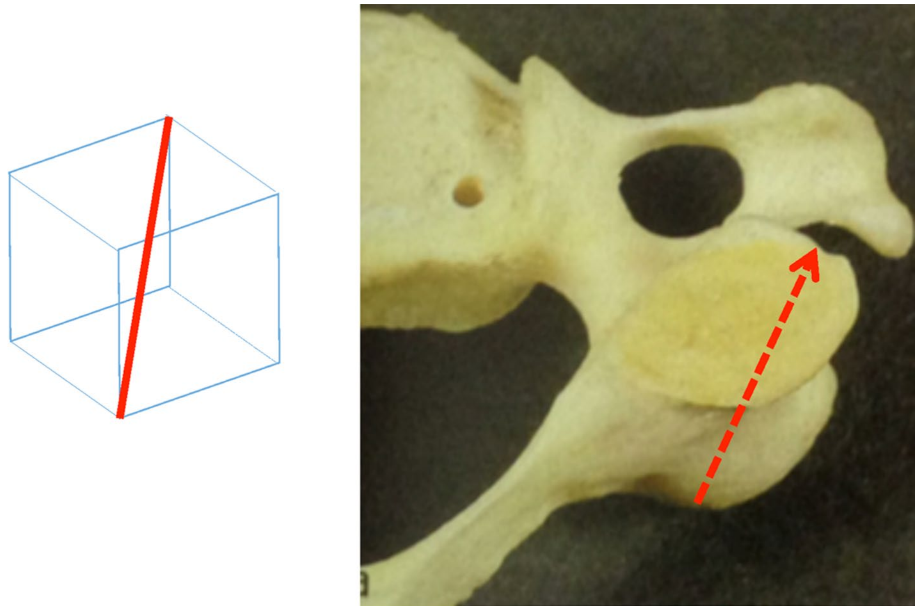

Fig. 1 The lateral mass is a leaning cubic-shaped prisma. The new proposed technique, taking posterior cortices as a reference, is the diagonal from the medial lower area of the posterior ridge to the upper lateral of the anterior ridge

Fig. 2 The entry point for the new proposed technique is the medial lower area of the posterior ridge of the lateral mass (dot). Previously described techniques use a more lateral and cranial entry point as we can see in the picture (square)

generated were fully infilled and covered by warm wax, so the used hole was not visualizable. Wire insertion was performed in every case by MAD, the senior author, who has been performing these techniques for more than 25 years. The trajectory length was established by the maximal distance than that can be obtained in the lateral mass (from the entry point to the exit point in the mass) and was confirmed and measured by the two junior authors.

A universal plastic protractor was used to measure the trajectory angles, using fix planes to prevent modification between measurements. Using a cannulated direct measuring device, the length was gauges. The exit point of the trajectory was examined, and potential damage to artery and nerve root was judged according to the theoretical artery and nerve location simulated by previously inserted cables (Fig. 4). By this setting we ascertain the potential risk of a neurovascular injury with each drilling technique, after the bicortical purchase of the lateral mass and checking the exit point in relation to the mock neurovascular structures.

Statistical analysis

For all the data management and statistical analysis, we used the software R-Project software [21].

Measurements were expressed as the average value with the standard deviation.

For comparative purposes and to homogenize different vertebra sizes, length ratio of the new proposed technique with respect to Magerl's Anderson's and An's was considered. This allows to compare the data obtained from each specimen and vertebras using a classical t-test for the mean. In this case, null hypothesis that the mean is equal to 1 versus the alternative that the mean is greater has been tested.

Table 1 Trajectories compared in this study

Trajectory	Entry point	Superior angle	Lateral angle
Magerl	1 mm cranial and 1 mm medial to the center	Parallel to joint surface	25
Anderson	1 mm medial to the center	30°–40°	10°
An	1 mm medial to the center	15°	30°
Ulloa/Ahmaz	Inferomedial corner (posterior ridge)	Superolateral corner (anterior ridge)	

Fig. 3 1.1-mm drill tip guide wire was inserted bicortically into the lateral mass according to the original description of each trajectory and the new proposed one. Using a cannulated direct measuring device, the length was evaluated

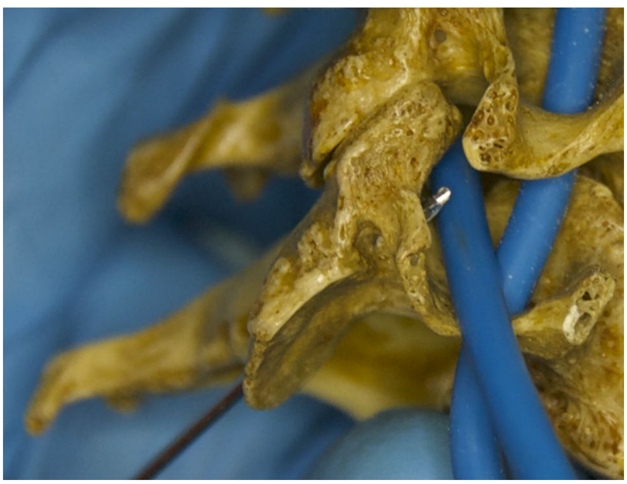

Fig. 4 Exit point was examined and potential damage to artery and nerve root was judged according to the theoretical artery and nerve location simulated by previously inserted cables. See blue cables mimicking both the root (front) and the vertebral artery (bottom)

The number of injuries can be considered that follows a binomial distribution, in order to compare the proportion of injuries for each technique with regard to each other. This was done using the classical for equality of proportions, first considering a 4-sample test and then making all pairwise comparisons.

Results

In total, 320 insertions where performed, 80 for each trajectory. The measurements and estimation of potential nerve or artery damage were compiled for each trajectory.

Trajectory length

When we measured trajectory length, we obtained that the mean length was 14.1 mm using Magerl's technique, 13.5 mm using Anderson's, 12.8 mm using An's and 17.0 mm using the new technique.

In all cases, the null hypothesis was rejected with p values less than 0.00001 being the mean of these ratios 1.24 with respect to Magerl, 1.31 to Anderson and 1.37 to An (Fig. 5).

Nerve and arterial damage

After studying the exit point of the trajectory, we discover that nerve root potential injury occurred 37 times using Magerl's technique, 28 using Anderson's, 13 using An's and twice using the new technique.

Artery potential damage occurred once using Magerl's technique, 8 times using Anderson's and none with either An's or the new proposed technique.

Concerning the potential for a nerve root injury, the proportion test rejects the hypothesis that for the four techniques they are equal ($p < 0.00001$). Then, pairwise comparisons showed significant differences comparing Magerl vs. New Technique ($p < 0.00001$); Anderson vs. New Technique ($p < 0.00001$) and An vs. New Technique ($p = 0.01$).

Regarding artery potential damage, the overall test was also significant (p value $= 0.000136$) and the pairwise comparisons showed significant differences between former trajectories and the new technique (p value < 0.00001).

Discussion

Our findings confirm with statistical evidence that under the conditions given (dry bone and trajectory assumed as a 1.1-m wire), our trajectory seems to facilitate longer screws introduction with and exit point in the lateral mass away from neurovascular structures in a higher percentage of cases.

It has been postulated that the ideal lateral mass screw trajectory should provide correct stability and pull-out resistance while keeping complications to a minimum, maximal screw length and bicortical purchase is then a must [5, 18, 19].

Several authors have compared most frequently used techniques. Ebraheim et al. investigated the mean safe lateral mass screw lengths in Roy Camille and Magerl trajectories in fourteen cervical spines. They found that a safe screw length is 14–15 mm in the Roy Camille technique and 15–16 mm in the Magerl technique [2] Hockel et al. [12] performed a retrospective study of a fifty-five patient cohort (284 lateral mass screws) and found a mean screw length of 16 mm using a modified Magerl technique and an 88%

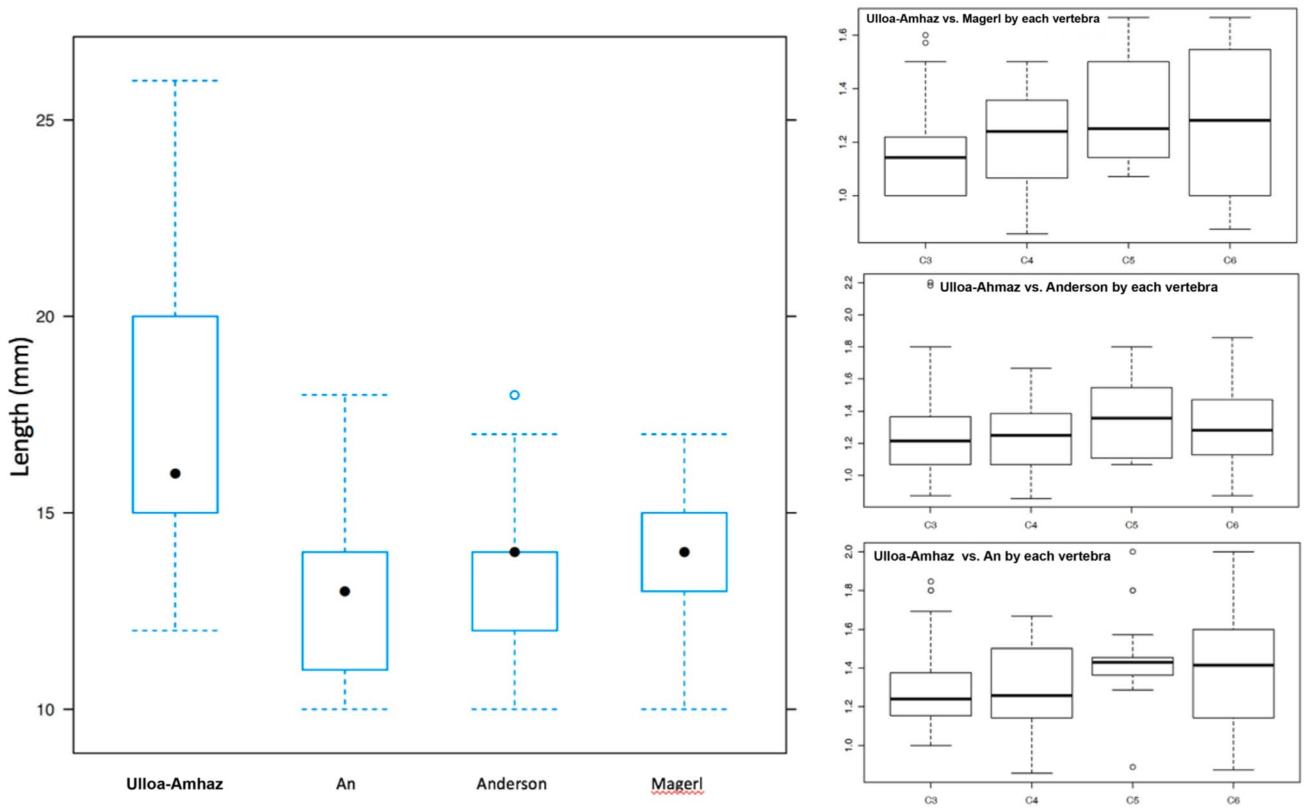

Fig. 5 Left boxplot shows length differences between trajectories. Right boxplots show statistical analysis in regard to the new proposed technique and Magerl (upper), Anderson (middle), and An (lower)

bicortical purchase rate. Stemper et al. studied the theoretical safe screw length using Roy Camille and Magerl techniques in 98 CT scans and concluded 6.3–16.7 for the former and 6.3–20.4 for the latter. They found safe length varied significantly but not regarding anthropometric measurements and recommend preoperative templating [16].

The ideal screw direction is controversial, and vertebral artery and nerve root injury remain a major concern in lateral mass screw fixation. Xu et al. compared Magerl, Anderson and An techniques in six cadavers and analyzed screw relations to spinal nerves. The overall percentage of nerve injury was 95% with Magerl, 90% with Anderson and 60% with An. They recommended that the screw should be directed as superior and lateral as possible to exit at the anterolateral corner of the upper portion of the superior articular process if the Magerl or Anderson technique is preferred. Ebraheim et al. [1] concluded in a 43 cervical spines evaluation that, regarding posterior midpoint of the lateral mass, screw insertion is safe if it is directed 10° laterally. We fully agree that the trajectory should be directed up and lateral as possible to maintain our exit point as far as possible from the neurovascular structures. To achieve this direction, it is not always easy because the spinous process is in the way, and our screw insertion may be difficult, especially in those situations with anatomical variations. Partial spinous process resection/fracture is an alternative in theses situations.

Freehand screw insertion accuracy is unclear, and some angle estimation mismatch is expected [15, 20]. Merola et al. tried to stablish a safe angulation range by comparing Roy Camille, Magerl and Anderson trajectories as well as 0°–30° modifications in ten human spine specimens. They concluded a higher risk of neurovascular damage using Roy Camille technique (specially below C3). The same applied to all techniques when the lateral angulation decreased [17].

Posterior subaxial cervical spine stabilization with bars and lateral mass screws is a safe technique. Coe et al. performed a systematic review of the safety profile and effectiveness of lateral mass screw fixation and found that the risk of complications is low although the fusion rate is high. Nerve root injury occurs in 1% of the procedures. Screw complications such as pull-out or loosening accounted less than 1% [3].

Inoue et al. examined the risk factors for complications associated with screw insertion in a cohort of ninety-four patients (457 lateral mass screws) and found a 2.8% facet violation rate. Joint violation was related to a poor screw trajectory angle in the sagittal plane [22] In another retrospective study of a cohort of 117 patients, they found a 4.7% incidence of lateral mass fracture during screw insertion [23].

Katonis et al. [24] studied lateral mass screw complications in a 225-patient cohort and found lateral mass fracture in 27 screws and nerve irritation in 3 bicortical screws and 3 pull-out cases.

Ra et al. retrospectively examined a cohort of 26 patients treated with lateral mass screws freehand inserted. They found 13.5% rate of transverse foramen involvement and a 6% rate of joint violation [25].

The use of tridimensional angle-based references to establish the correct screw path can lead to errors, especially when anatomy is distorted; hence, the interest in finding more accurate ways. Bayley et al. [20] studied ipsilateral lamina as a theoretical reference plane for lateral mass screw insertion based on CT studies, but as far as the authors know, they did not carry on any further investigation.

From the best of our knowledge, this is the first lateral mass screw trajectory description not based on angles, but on on-site spatial references that has proved to be effective and safe in spine specimens.

According to our study, the mean screw lengths for Magerl, Anderson and An are similar to those previously published. The new proposed trajectory mean length was 17.0 mm, allowing longer screws that may lead to a better purchase, and a better pull-out resistance and stability. The theoretical complication rate, assumed by the exit point of the trajectory in relation to the neurovascular structures, was also lower regarding potential nerve and artery damage. We would like to emphasize that in this work clinical neurovascular risk was not assessed, because we measured if the exit point with the trajectory may impact the root, the artery or both. This does not mean that all potential injuries would correlate with an unequivocal true injury as clinical studies have previously confirmed and should be performed with our trajectory.

By using a 1.1-mm K-wire with full retrieval after each trajectory measurement, we allowed neither for any hindrance in the next text nor for a lateral mass burst (Fig. 2)

The new trajectory entry point is more caudal, so it is closer to the joint, but facet articular penetration is avoided with a steeper cranial angle.

Impingement in a real surgery or difficulties to perform a decompression if needed may be a concern, but we find that as shearing forces are the main in subaxial cervical spine joints and that there is some distance between the entry point and the rod connector, it is unlikely to happen.

Our study has some limitations: The anatomic nature of the study using dry vertebras or the use of drill tip guide wires instead of screws. We used dry specimens as it allows for the better analysis of the trajectory and drilled length. It allows as well for a better examination of entry and exit points and its relationship with danger zones. The inventor of the technique performed all of the trajectories, and therefore, there could have been bias, since the inventor has a vested interest in describing his technique.

Further studies in cadaver using lateral mass screws insertion with axial tomography confirmation should be done, and clinical trials to confirm that our new trajectory is not inferior to previously described, and in future research demonstrate that is superior.

Conclusion

We have proposed a new technique that seems to facilitate the insertion of longer screws, maximizing theoretically purchase and stability in our constructions. It also seems that this new trajectory exit point in the lateral mass moves away from the neurovascular structures, with the theoretical advantage of minimizing their damage. It is an easy technique, with the benefit of eliminating the need for angle estimation, and avoiding distorted anatomical landmarks, by using on site spatial references instead.

This is the start point of a new trajectory technique that should be validated in cadaveric studies prior to its use in clinical practice.

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Compliance with ethical standards

Conflict of interest The authors declare they have no conflict of interest.

Ethical approval The study and procedures were approved by the institutional review board and ethics committee.

Informed consent Informed generic consent was obtained from all the donors while still alive to use their bodies in studies as the one presented by the authors.

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