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Factors affecting the interface of cervical spine facet screws placed in the technique by Roy-Camille et al.

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Abstract The objective of the study was to investigate the influence of bone cement, length of burr hole and bone density on pullout force and insertional screw torque of cervical spine facet screws. Both facets of 24 human cervical vertebrae were scanned for bone mineral density (BMD) and assigned to two groups for measuring of insertional screw torque and pullout strength. Maximal insertional screw torque was measured and removal of the screws was performed in displacement control (0.25 mm/s) without bone cement (PMMA), with 0.1 ml of PMMA and with the burr hole completely filled with PMMA. Screw torque was 59.1 N cm (± 25.7 N cm), pullout force was 382.8 N (± 140.5 N) without PMMA. Injection of 0.1 ml PMMA did not change significantly both screw torque ($p=0.73$) and pullout ($p=0.129$). Filling of the burr holes with PMMA increased significantly both screw torque ($p<0.0001$) and pullout force ($p=0.028$) when

compared with injection of 0.1 ml of PMMA. A positive, moderate correlation was seen between BMD and screw torque before ($r=0.501$; $p=0.097$) and after filling with PMMA ($r=0.514$; $p=0.088$), BMD and pullout force before ($r=0.441$; $p=0.152$) and after complete filling with PMMA ($r=0.673$; $p=0.047$). The PMMA does increase both screw torque ($p<0.0001$) and pullout force ($p=0.028$) of facet screws significantly if the burr hole is filled with PMMA completely when compared with injection of 0.1 ml PMMA. Bone mineral density of the cervical facets moderately correlates with peak insertional torque and pullout force. This is true for a facet without PMMA and for a facet filled with PMMA. The length of the burr hole seems to be less important.

Keywords Cervical spine · Biomechanics · Bone cement · Bone density · Screws

Introduction

Posterior stabilisation of the cervical spine was introduced by Hadra in 1891 [4]. Rogers in 1942 also used wires to fix an unstable spine [21]. Presently, posterior instrumentation is an approved method for fixation in the presence of posterior or combined anterior–posterior instability of the cervical spine [1, 3, 6, 13, 14, 20, 26, 29]. Among the methods for posterior cervical spine fixation, facet stabilisation using screw–rod devices has become a safe,

widespread and stable osteosynthesis [1, 2, 5, 6, 7, 8, 10, 13, 14, 15, 17, 20, 22, 25, 26, 29]. It has been shown that fixation strength and segmental stability of both anterior stabilisation devices and pedicle screws strongly correlate with bone mineral density [9, 16, 19]. Other factors to influence spinal implant fixation are length of the burr hole or bone cement [8, 11, 24, 25, 27]. Moreover, bone cement has been shown to be effective in strengthening the bone–implant interface for pedicle screws or screws within the vertebral body [17, 24, 27, 30]; however, there is paucity of knowledge how these factors

may influence fixation strength of cervical spine facet screws.

Therefore, the objective of the study was to investigate the influence of bone cement, length of burr hole and bone density on both insertional screw torque and pullout force of cervical spine facet screws.

Materials and methods

Preparation of specimens

Six human cervical spine segments C4–C7 were explanted during routine autopsies. They were stored in double plastic bags at -20°C . Following careful removal of the attached muscles, each vertebra was dissected from the segment resulting in 24 single vertebrae. Bone mineral density was determined for both facets using a quantitative computed tomography (Stratec XCT-960 A, Birkenfeld, Germany). The region of interest for measuring bone density was placed into an axial cut through the facets. Measurement was performed within the cancellous bone of the facets (Fig. 1). Commercially available screws were drilled through the anterior part of the vertebral body and steel wires were wrapped around both pedicles of each vertebra. The vertebral body with the screw and the attached wires was mounted into polymethylmetacrylat (Technovit 3040, Heräus Kulzer, Wehrheim, Germany) with both facets oriented upwards. According to bone density and level the specimens were assigned to two groups in which torque and pullout were tested, respectively.

According to Roy-Camille et al.'s method [22, 26], a burr hole was drilled into each facet with a 2-mm drill (Aesculap, Tuttlingen, Germany) and the anterior cortical shell of the facet was perforated in each; therefore, the screws could be fixed bicortically. The length of the burr hole was measured using a caliper.

Analysis of peak torque

For determination of the peak insertional torque, a 3.5-mm facet screw of 14-mm length (Spine System Evolution Cervical, Aesculap, Tuttlingen, Germany) was inserted into each burr hole. Torque was measured with a electronic, custom modified torque wrench (ITW 10 N, Staiger Mohilo, Germany) during insertion. The accuracy of the wrench exceeded 0.5%. Data were collected on a computer. Peak torque was defined as the highest value of torque measured during insertion.

Analysis of pullout forces

For investigation of pullout forces, a 3.5-mm facet screw of 19-mm length (Spine System Evolution Cervical, Aesculap, Tuttlingen, Germany) was inserted into the burr holes. The heads of the screws were fixed into a metal fork to allow distractive force along the axis of the screw. A material testing machine (Zwick 1485, Ulm, Germany) was used for that part of the study. A pre-force of 5 N was applied and a pullout test was performed displacement controlled with a constant speed of 0.25 mm/s. Data were collected on a computer using the software TestXpert, Zwick, Ulm, Germany. Pullout force was defined as the highest value found during the test.

Testing conditions

These measurements were first done in each specimen without bone cement. Following determination of peak insertional torque and

Fig. 1 Axial cut of a quantitative computed tomography of a specimen. Measurement of bone mineral density was performed within the cancellous bone. Note the region of interest marked by rectangles placed within both facets

pullout force, respectively, the screw was removed. Bone fragments within the burr hole were removed, specimens which had been severely destroyed were excluded from further investigation. Bone cement [0.1 ml; a low-viscosity cement, i.e. Polymethylmetacrylat (PMMA) Osteopal, Merk, Germany] was injected into the burr hole using a syringe. Note that the anterior aperture of the hole was closed using plastine to avoid loosening of the injected cement. The screw was inserted again. Measurements were then repeated as described above after hardening of the cement. Again, screw and bone fragments were removed from the burr holes, and destroyed specimens were excluded from further investigation. The burr holes of the remaining specimens were widened to a diameter of 5 mm. The burr hole was then filled completely with PMMA, and the screws were inserted. Measurements were repeated after hardening of the cement.

Statistical analysis

Mean value and standard deviation were calculated for peak torque and pullout force for each configuration of the burr hole (i.e. without PMMA, after injection of 0.1 ml PMMA and after complete filling with PMMA). A two-factor analysis of variance and post hoc Scheffé test were used to detect statistically significant differences. Linear regression was used to determine the effect of bone density and length of the burr hole on peak torque and pullout force. In case of the correlation coefficient being between 0.4 and 0.7, the correlation was called moderate correlation. A 95% level of significance was used for all tests.

Results

Bone density of facets and length of burr holes

The mean bone density of the facets used for analysis of screw torque was 365 mg/cm^3 ($\pm 104.2 \text{ mg/cm}^3$) and the mean length of burr holes placed in these specimens was 10.1 mm ($\pm 1.2 \text{ mm}$). The mean bone density of the facets used for analysis of pullout force was 384.2 mg/cm^3 ($\pm 126.4 \text{ mg/cm}^3$) and the mean length of burr holes placed in these specimens was 9.1 mm ($\pm 1.5 \text{ mm}$).

Screw torque

Peak screw torque was 59.1 N cm ($\pm 25.7 \text{ N cm}$) without PMMA. Following injection of 0.1 ml PMMA, torque was 53.5 N cm ($\pm 18.8 \text{ N cm}$). After complete filling of the burr holes with PMMA, torque was 107.2 N cm ($\pm 22.5 \text{ N cm}$). Injection of 0.1 ml PMMA did not influence significantly screw torque when compared with the configuration without PMMA ($p=0.73$). Filling of the burr holes with PMMA increased significantly screw torque when compared with

Fig. 2 Mean value and standard deviation of insertional peak torque for the facet without PMMA, with 0.1 ml PMMA and after filling of the burr hole with PMMA. A significant effect was seen for “filling with PMMA” vs “ 0.1 ml PMMA” ($p<0.0001$) and vs “without PMMA” ($p<0.0001$)

Fig. 3 Mean value and standard deviation of pullout force for the facet without PMMA, with 0.1 ml PMMA and after filling of the burr hole with PMMA. A significant effect was seen for “filling with PMMA” vs “ 0.1 ml PMMA” ($p=0.028$)

injection of 0.1 ml of PMMA ($p<0.0001$) and significantly when compared with the configuration without PMMA ($p<0.0001$; Fig. 2).

Pullout force

Pullout force was 382.8 N ($\pm 140.5 \text{ N}$) without PMMA. Following injection of 0.1 ml PMMA, pullout force was 278 N ($\pm 111.2 \text{ N}$). After complete filling of the burr holes with PMMA, pullout force was 433.5 N ($\pm 119.8 \text{ N}$). Injection of 0.1 ml PMMA did not change significantly pullout force when compared with the configuration without PMMA ($p=0.129$). Complete filling of the burr holes with PMMA increased significantly pullout force when compared with injection of 0.1 ml of PMMA ($p=0.028$) and did not influence significantly pullout force when compared with the configuration without PMMA ($p=0.605$; Fig. 3).

Screw torque vs bone density

A positive, moderate correlation was seen between bone density and screw torque before ($r=0.501$; $p=0.097$) and after filling with PMMA ($r=0.514$; $p=0.088$).

Screw torque vs length of burr hole

No correlation was seen between length of burr hole and screw torque before ($r=0.166$; $p=0.607$) and after filling with PMMA ($r=0.386$; $p=0.216$).

Pullout force vs bone density

A positive, moderate correlation was seen between bone density and pullout force before ($r=0.441$; $p=0.152$). A positive, moderate and significant correlation was seen between bone density and pullout force after complete filling with PMMA ($r=0.673$; $p=0.047$; Fig. 4).

Fig. 4 A positive, moderate correlation was found between bone mineral density and pullout force with PMMA ($r=0.673$; $p=0.047$)

Pullout force vs length of burr hole

A positive, moderate correlation was seen between length of burr holes and pullout force before injection of PMMA ($r=0.451$; $p=0.142$). No correlation was seen after filling with PMMA ($r=0.369$; $p=0.329$).

Discussion

Aim and results of the study

The aim of the study was to investigate the influence of PMMA, bone density and length of burr hole on both insertional screw torque and pullout force of cervical spine facet screws. The PMMA does increase both screw torque and pullout force of facet screws for cervical spine fixation significantly, however, just in case the burr hole has been filled with PMMA completely; therefore, the efficacy of PMMA seems to depend on the amount. Bone mineral density of the cervical facets moderately correlates with both peak insertional torque and pullout force of facet screws. This is true for a facet without PMMA and for a facet filled with PMMA. The length of burr hole, however, seems to be less important.

Comparison with former studies

Mean pullout force of cervical spine facet screws has been investigated previously: Montesano found that pullout force of facet screws placed in the technique by Roy-Camille et al. [22] was about 152 N, whereas it was 585 N if the screws were paced according to Magerl [15]. Errico, in a study using bovine spinal specimens, found comparable results: the mean pullout force of a screw placed in the technique by Magerl was 471 N [2]. Jones placed screws according to An, which resulted in a mean pullout force of 355 N [8]. Seybold found a mean pullout force of 519 N if screws were fixed unicortically and 562 N of screws were fixed bicortically according to the Magerl technique [25]. The mean pullout force for a cervical spine facet screw of 3.5-mm diameter, which was placed bicortically without PMMA, was found to be 382.8 N (± 140.5 N) in the current study. These results are in major agreement with the studies mentioned previously: the mean pullout force of cervical spine facet screws is about 400 N.

The importance of bone mineral density for fixation of spinal implants has been investigated previously [9, 16, 19]; however, little is known about the importance of bone mineral density for fixation strength of facet screws or the initial stability of a segment fixed with facet screw-rod instrumentation. Jones et al. did not see a significant correlation between bone density and pullout strength [8]. Richter et al. found a negative correlation between bone mineral density and range of motion of a segment fixed

with facet screw-rod stabilisation [20]. These authors, however, had measured the bone density within the vertebral bodies of the specimen, which received facet screws. The current study therefore gives important information about the importance of bone density for facet screw fixation: a positive, albeit moderate, correlation was found for both torque and pullout vs bone mineral density of the facets for the configuration without cement and after complete filling with cement. It is possible that the results reflect more the effect of bicortical fixation rather than the importance of bone density; however, Seybold et al. showed that engaging the anterior cortical shell did not increase pullout forces when compared with monocortical fixation [25]. Additionally, a study dealing with this topic in anterior spine fixation has recently been published. To check the importance of the posterior cortical shell for insertional screw torque and pullout forces we compared insertional screw torque and pullout force for mono- and bicortical screws for plate fixation [19]. No difference for insertional screw torque or pullout force was found; therefore, we consider the influence of anterior cortical shell to be negligible also for insertional torque and pullout for facet screws, and we recommend monocortical screw fixation from a mechanical point of view.

The length of the burr hole also was found to be less important for both screw torque and pullout in the current study. This is in major agreement with the results by Seybold and co-workers, who did not see any influence of the length of the burr hole on pullout force [25]. Jones et al. also did not see a significant correlation between length of the burr hole and pullout force [8].

Limitations of the study

The current study describes the results of in vitro testing of cervical spine facet screws in which, for example, factors such as three-dimensional stability of an instrumented segment, influence of muscular envelope, and orthosis is completely neglected. Also, cyclic loading of the screws was not performed. It may be expected that investigation of both pullout force and peak torque following cyclic loading would have shown a difference in pullout force or peak torque. The effect of cyclic loading on screws in the lumbar and sacral regions has been analysed recently. Displacement of pedicle screws following cyclic loading was described by Lill et al. [11]. It is, however, debatable whether cyclic loading may be used to simulate repeated movements in daily activity, because the biological process of bony fusion is completely neglected using an in vitro model [18]. Moreover, the model is a lot more artificial than any in vivo condition: it is a worst-case scenario. Due to the small area available for screw fixation in the facet process of the cervical spine, widening of the burr hole to 5 mm resulted in a destruction of these structures in more than 30% of the specimens. This situation will

probably not occur during surgery to that extent, thus probably limiting the clinical relevance of the current study. Conversely, this extensive destruction has been accepted to look at the effectiveness of bone cement *especially* in case of a worst-case condition during surgery (i.e. facet destruction, malpositioning of the burr hole, etc.). Nevertheless, the biomechanical setup used here limits conclusions towards clinical application; however, in these cases, although it might be possible that cement is extruded anteriorly, the first author used PMMA several times to repair bony defects within the facet process during surgery.

Long-term effects of PMMA on bone biology cannot be investigated here. There is no clinical study dealing with long-term effects of cemented pedicle or cervical spine facet screws; however, relevant data do exist for cemented and non-cemented hip prosthesis: Weise et al. in a prospective study compared the long-term survival of cemented vs uncemented total hip prosthesis [28]. Identical results were found for follow-up rate and long-term survival rate after 11 years. Conversely, the long-term effects of bone remodelling, including osteoporosis and osteolysis leading to implant loosening at the bone–cement interface, are well known following insertion of cemented hip prosthesis [12].

Clinical relevance

In case of poor bone quality, fixation of spinal implants may be difficult and challenging; however, strong fixation

of the implants is necessary to get acceptable primary stability of a spinal segment. The PMMA has been shown to be effective in strengthening the bone–implant interface for pedicle screws or screws within the vertebral body [24, 27, 30]. Comparable data, however, did not exist for the cervical spine facets; therefore, the data presented here may be of some clinical relevance: the PMMA seems to be an effective means to strengthen the interface between a cervical spine facet screw and the cervical spine facet; however, if PMMA is used, the diameter of the burr hole should be enlarged and the burr hole filled with bone cement completely.

Conclusion

The efficacy of PMMA for increasing peak insertional torque and pullout force of cervical spine facet screws placed in the technique by Roy-Camille et al. [22] depends on the amount: a small amount is not sufficient, but filling the burr hole completely seems to be useful. Bone mineral density of the cervical facets correlates moderately with both peak insertional torque and pullout force of facet screws. This is true for a facet without PMMA and for a facet filled with PMMA. The length of burr hole, however, seems to be less important.

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