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ORIGINAL ARTICLE

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Screw fixation to the posterior cortical shell does not influence peak torque and pullout in anterior cervical plating

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Abstract There is no consensus over whether screw fixation for anterior cervical plating should include the posterior cortical shell of the vertebral bodies or not. Thus, the purpose of this study was to investigate the function of the posterior cortical shell with respect to maximal screw torque and pullout force. Twenty-four fresh frozen human cervical vertebrae coming from six spinal segments C4–C7 were used. They were scanned for bone mineral density (BMD) and then assigned to two groups with comparable bone density and segmental distribution. The posterior longitudinal ligament was resected carefully and two parallel burr holes were drilled into each vertebral body. The posterior cortical shell was removed in one burr hole, using a 6-mm steel burr, producing a shallow excavation with a depth of approximately 2 mm. An ABC screw was inserted into each burr hole. The screw to be inserted into the hole with the posterior excavation was called "monocortical". In contrast, the contralateral screw was called "bicortical". Peak torque was measured in one group, while pullout force was analyzed using the specimens of the second group. Mean value and standard deviation were calculated for peak torque and pullout force with respect to the type of fixation. A paired *t*-test was used to determine the effect of fixation type on peak torque and pullout force. Pearson moment correlation coefficients were calculated to determine the effect of BMD on peak torque and pullout force with respect to whether the screw was "mono- or bicortical". A 95% level of significance was used for all tests. No significant differences for peak torque and pullout force could be found comparing monocortical and bicortical screw fixation. However, for both monocortical and bicortical screw fixation, a positive correlation was seen for peak torque versus BMD and for pullout force versus bone mineral density, respectively. The importance of the posterior cortical shell for screw pullout force and screw peak torque seems to be negligible. In constrast, BMD greatly influences both peak torque and pullout force for both types of fixation.

Keywords Cervical spine · Bone · Biomechanics · In vitro · Implant stabilisation · Bone mineral density

Introduction

As a consequence of the results of anterior cervical fusion reported by Cloward [6] and Smith and Robinson [18], additional anterior cervical plating was advocated by Orozco and Llovet [12], Böhler and Gaudernack [1], de Olivera [7], and Caspar and co-workers [3, 4]. Today anterior cervical fusion and plating has become a widely accepted technique in cervical spine stabilization for a variety of indications, including degenerative pathology, trauma, tumour, infectious disease and rheumatoid instability [3, 4, 19]. One of the main points of this technique has been the bicortical fixation of the plate, which has been recommended by Böhler and Gaudernack [1], Caspar and coworkers [3, 4], Orozco and Llovet [12] and de Olivera [7]. However, at the time those papers were published, no biomechanical data from in vitro experiments were available to support these recommendations. In 1992, Maimann et al. [11] published the results of in vitro testing of pullout strength of Caspar screws. The findings suggested that bicortical engagement of the screws does not result in increased pullout strength when compared to subcortical fixation. Ryken et al. [14] found a significantly better screw torque as well as pullout force if the screws were anchored to the posterior cortical shell. To sum up, the importance of the posterior cortical shell for fixation of the cervical spine plate osteosynthesis with respect to screw torque and pullout force is debatable and poorly understood.

Thus, the purpose of this study was to investigate the function of the posterior cortical shell of the cervical spine with regard to torque and pullout force of a screw used for fixation of a cervical spine plate.

Materials and methods

Six human cervical spine segments C4–C7 were explanted during routine autopsies from fresh human cadavers with a mean age of 61.5 years. They were stored in double plastic bags at –20°C. Following careful removal of the attached muscles, bone mineral density (BMD) was determined for each vertebral body by a scan through its mid-third section, using quantitative computed tomography (Stratec XCT – 960 A, Birkenfeld, Germany). Each vertebra was dissected from the segment, resulting in 24 single vertebrae. Steel wires were wrapped around the lamina of each vertebra. The spinous process and the lamina with the attached wires were mounted into polymethylmethacrylate (Technovit 3040, Heräus Kulzer, Wehrheim, Germany), with the anterior surface of each vertebral body placed horizontally and looking upward. Next, the posterior longitudinal ligament was removed carefully without damaging the posterior cortical shell, using a small scalpel and small rongeurs. The specimens were assigned to two groups in which torque and pullout were tested.

Two burr holes were drilled into the mid section of each vertebral body with a 2.7-mm tapper (Aesculap AG + CoKG, Tuttlingen, Germany), and the posterior cortical shell was perforated in each. The posterior cortical shell around one burr hole was removed with a 6-mm burr in such a way that the burr was centred at the hole and the bone was removed until the rod of the burr touched the posterior cortical shell. This resulted in a shallow, 2-mm-deep excavation around the hole (Fig. 1). As a consequence, the screw could not be fixed within the posterior cortical shell. This is called “monocortical fixation”. The cortical shell was not affected around the contralateral hole. Thus, this screw could be fixed within the posterior cortical shell surrounding that hole (“bicortical fixation”). The condition of the posterior cortical shell was checked in each vertebra using a rigid endoscope and a cold-light source (Axel 180, Aesculap Ag+CoKG, Tuttlingen, Germany). Complete removal of the posterior cortical shell was seen for each of the burr holes used for monocortical fixation.

For determination of the peak torque, a 4-mm ABC bicortical screw (Aesculap AG+CoKG, Tuttlingen, Germany), 20–25 mm in length, depending on the diameter of the vertebral body, was inserted in each burr hole through the corresponding holes of a 22-mm ABC plate (Aesculap Ag+CoKG, Tuttlingen, Germany). For each vertebra, the length of the screws was identical. The primary design feature of the plate is an oval screw-hole in the plate that allows sliding of the screw head within the plate, resulting in a shortening of the effective height of the plate in the case of bone graft settling. The screw is a non self-tapping screw with an outer diameter of 4.0 mm and a conical core diameter of 2.7 mm at the tip, increasing to 3.2 mm at the head. It is made of titanium alloy with a corrundum-blasted surface of the thread. In the first specimen, the monocortical screw was inserted first, in the second the bicortical screw, and so on. Torque was measured with an electronic, custom-modified torque wrench (ITW 10 N, Staiger Mohilo, Lorch, Germany) during insertion. The accuracy of the wrench exceeds 0.5%. Data were recorded on a computer. Peak torque was defined as the highest value of torque measured during insertion (Fig. 2).

Fig. 1 Photograph of the posterior wall of a cervical vertebra with two screws inserted. A shallow excavation has been performed around the burr hole on the right side to remove the posterior cortical shell, and the cortical shell is intact around the contralateral burr hole

For investigation of pullout forces, a 4-mm ABC screw, 25–28 mm in length, depending on the diameter of the vertebral body, was inserted into the burr holes. For each vertebra, the length of the two inserted screws was identical. There was a distance of at least 1 cm between the two burr holes. The heads of the screws were fixed into a metal cylinder to avoid any kind of coupled motion during the pullout test and to allow a distractive force along the axis of the screw. The metal cylinder was made with a central perforation, through which the screw was inserted into the vertebral body. The area at the bottom of the cylinder was machined precisely to match the shape of the head of the screw. The perforation in the cylinder below the area to take the head of the screw was 8 mm in length and 4 mm in diameter, thus enabling the axis of the box to be aligned with the axis of the screw. The cylinder was then aligned with the axis of the machine. A material testing machine (Zwick 1485, Ulm, Germany) was used for that part of

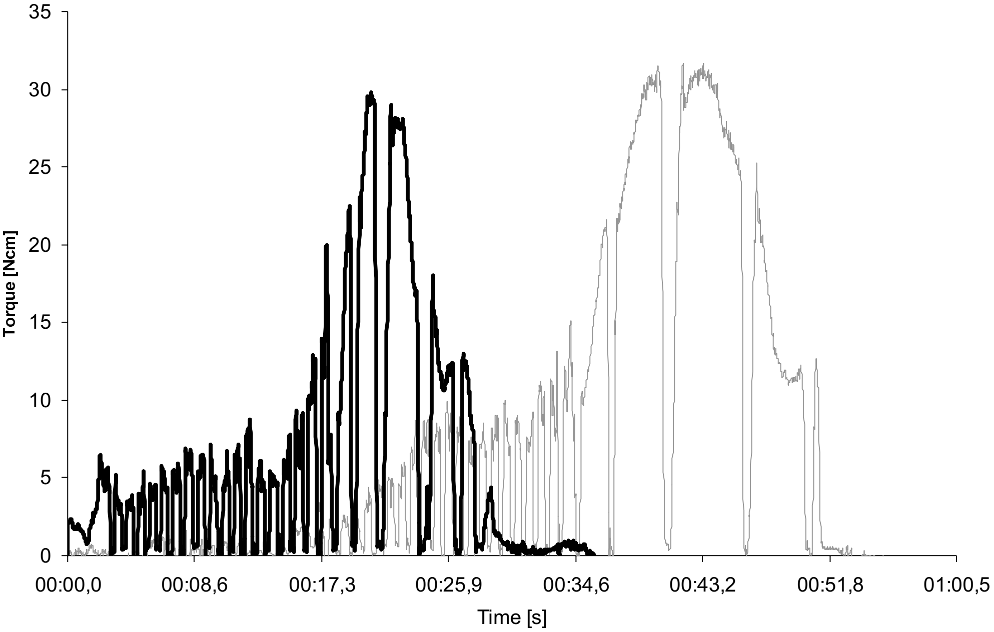

Fig. 2 Comparison of typical screw torque during insertion of the mono- and bicortical screw in one specimen. Note that there is no relevant difference in peak torque (*thin line* monocortical fixation, *thick line* bicortical fixation)

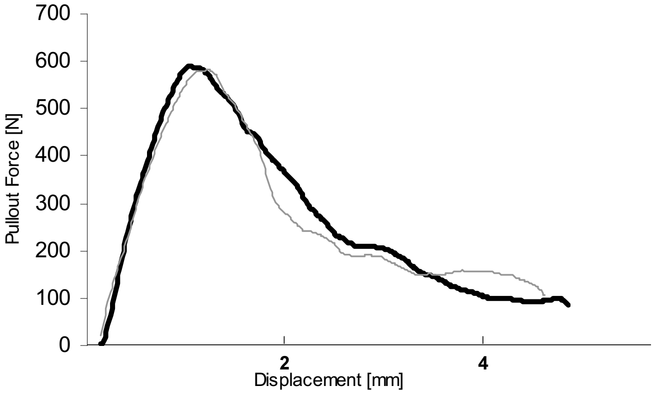

Fig. 3 Comparison of typical pullout forces of the mono- and bicortical screw in one specimen. Note that there is no relevant difference in pullout force *(thin line* monocortical fixation, *thick line* bicortical fixation)

the study. A preforce of 5 N was applied and a pullout test was performed, with displacement set at a constant speed of 0.25 mm/s. In the first specimen, the monocortical screw was removed first; in the second, the bicortical, and so on. Data were recorded on a computer, using the software TestXpert (Zwick, Ulm, Germany). Pullout force was defined as the highest value found during the test (Fig. 3).

Mean value and standard deviation were calculated for peak torque and pullout force with respect to the type of fixation. A paired *t*-test was used to determine the effect of fixation type on peak torque and pullout force. Pearson moment correlation coefficients were calculated to determine the effect of BMD on peak torque and pullout force with respect to the type of fixation (mono- or bicortical). A 95% level of significance was used for all tests.

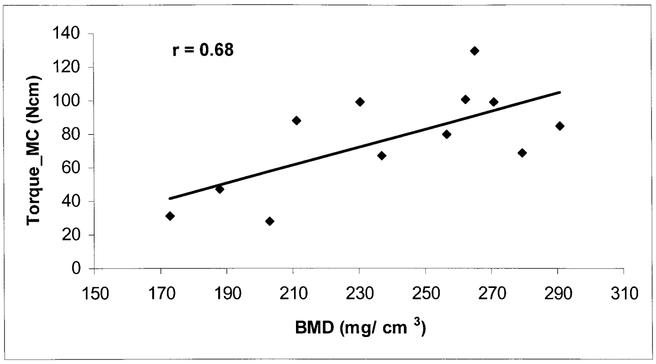

Fig. 4 Correlation of torque versus bone mineral density (BMD) for monocortical fixation

Results

Mean BMD was 238.9 mg/cm^3 (±38.1 mg/cm^3) for the group in which torque was measured, and 241.15 mg/cm^3 (±40.7 mg/cm^3) for the group in which pullout was measured.

Mean peak torque was 77 Ncm (±30.3 Ncm) for monocortical fixation and 74.8 Ncm (±45.2 Ncm) for bicortical fixation. No statistical difference was found between the two types of fixation for peak torque (P=0.864).

Mean pullout force was 544.18 N (±198.4 N) for monocortical fixation and 551.1 N (±230.7 N) for bicortical fixation. No statistical difference was noted between the two types of fixation (P=0.885).

A significant correlation was found between torque and BMD for both monocortical (r=0.68, P<0.05) (Fig. 4) and bicortical (r=0.635, P<0.05) (Fig. 5) type of fixation

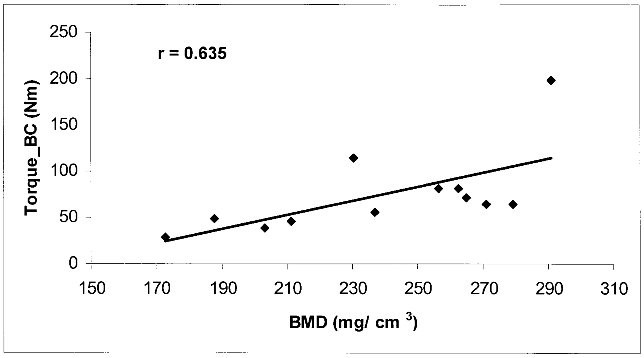

Fig. 5 Correlation of torque versus BMD for bicortical fixation

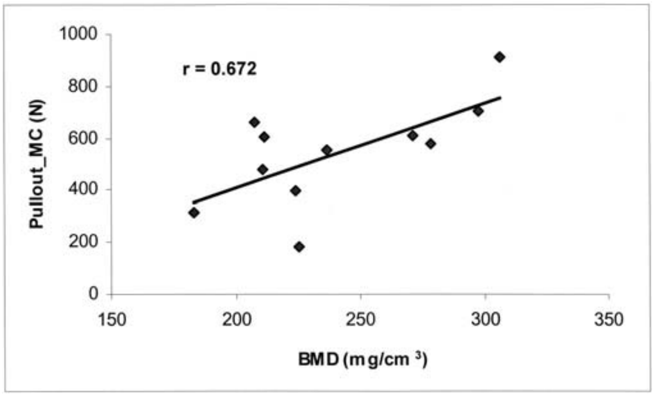

Fig. 6 Correlation of pullout force versus BMD for monocortical fixation

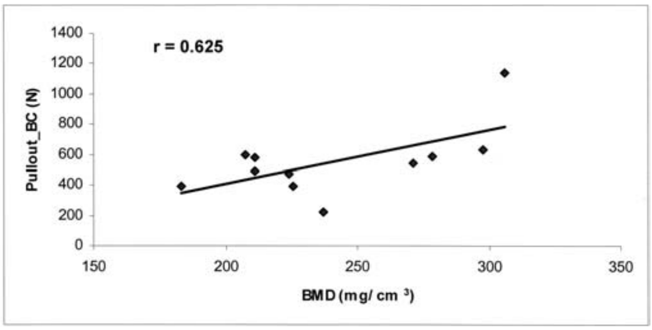

Fig. 7 Correlation of pullout force versus BMD for bicortical fixation

and also between pullout force and BMD for both monocortical (r=0.672, P<0.05) (Fig. 6) and bicortical (r=0.625, P<0.05,) (Fig. 7) fixation.

Discussion

The purpose of this study was to investigate the importance of the posterior cortical shell of the vertebral bodies with respect to peak torque and pullout force of screws in anterior cervical plate fixation. The results suggest that including the posterior cortical shell in the screw fixation influences neither peak torque nor pullout force, and that BMD of the vertebral bodies is much more important for torque and pullout force of the screws.

No consensus exists concerning the importance of bicortical screw fixation in anterior cervical plating. Including the posterior cortical shell in the screw fixation has been recommended since anterior cervical plate fixation was first introduced in spinal surgery [1, 3, 4, 7, 12]. However, at that time, no biomechanical data were given to support these authors' recommendations. In 1992, Maimann et al. [11] published the results of an in vitro study using human cervical vertebrae for investigation of pullout strength of Caspar screws. Pullout forces were 375±53 N for the monocortical group and 411±70 N for the bicortical group. There was no significant difference in pullout force between bicortical and monocortical fixation. Using a human in vitro approach, Seybold et al. [16] found that bicortical fixation of facet screws for posterior stabilisation did not result in significantly higher pullout forces (565.2±306 N) when compared to monocortical screw placement (519.9±286.9 N). The findings of our current study support these results, and small differences between these studies concerning the mean pullout force may be due to differences in BMD and anatomical regions. However, bone density was not determined by Maimann et al. [11]. Ryken and co-workers [14] reported on an increase in both pullout force and peak torque using bicortical fixation when compared to monocortical fixation. However, the screws used for monocortical fixation were 16 mm in length, whereas the screws used for bicortical fixation were longer, with a length of 21–28 mm. Therefore, their results may – at least partially – have been influenced by the differences in screw length. To overcome this bias, screws of identical length were used in our study. Another important finding reported by many researchers [2, 8, 10, 14, 17] is supported by our data: BMD is an important factor for increasing both screw torque and screw pullout force. Initial stability was not significantly affected by bicortical screw fixation of anterior plates when compared to monocortical fixation [5, 13, 15], but bicortical screw fixation resulted in higher segmental stability following cyclic loading [5, 15]. Therefore, it may be expected that investigation of both pullout force and peak torque following cyclic loading using bending moments or cyclic transverse force would have shown a difference in pullout force or peak torque (or both) with respect to the type of fixation. The effect of cyclic loading on screws in the lumbar and sacral region has been analysed recently. Displacement of pedicle screws following cyclic loading was described by Lill et al. [9]. Lu and co-workers [10] found that bicortical fixation of sacral screws after cyclic loading was stronger than monocortical fixation. 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. Cyclic loading was, therefore, not performed in the study presented. This does, on the other hand, represent a limitation of the study, which has to be kept in mind with respect to evaluating clinical applicability.

Using human thoracic and lumbar spine segments, Breeze et al. [2] looked for differences between mono- and bicortical screw fixation on the pullout force of screws of 6.5 mm diameter. Bicortical screw fixation resulted in significantly higher pullout force. This finding is in contrast to the results of the current study, but may be explained by different anatomy of the cortical shell in the cervical and lumbar region and by differences in the diameter and type of screws used.

There are some limitations of the current study. We did not find a significant influence of the posterior cortical shell of the cervical vertebra on peak torque or pullout force of plate fixation screws. This, however, does not mean that such a difference does not exist. It is possible that we did not have enough statistical power to detect a difference. For the sample size used in the study and the variability in peak torque and pullout force, the critical effect size equals 63.8 Nm for torque and 324.8 N for pullout force, at a statistical power level of 80%. Another limitation is that pure uniaxial distraction forces were applied along the axis of the screws inserted to remove them. Certainly, this loading scenario is somewhat unphysiological, and thus does not reflect the whole clinical situation, and transfer of these biomechanical in vitro results to clinical application may therefore be problematic. Yet the loading conditions used in this test are accepted in spinal biomechanics, and comparable to the aforementioned studies dealing with this issue. This makes comparison of our results with other in vitro experiments – at least partially – feasible [11, 14]. It has already been mentioned that cyclic loading was not performed. Therefore, the results do not represent the situation following repetitive motion in daily life. Another limitation is that we used each vertebral body as its own control to compare mono- and bicortical screw fixation within the same specimen. This may – especially for pullout testing – result in traumatic changes of the bony micro-architecture, which could influence the results. To control for this, we removed the screws alternately, i.e. in the first specimen we removed the monocortical before the bicortical screw, in the second specimen we did the other way round and so on. In addition, there was a distance of approximately 1 cm between the two screws, and no major damage could be seen after pullout testing. Another possible problem is the thickness of the posterior cortical shell of the human cervical spine. No anatomical data could be found describing the thickness of the cortical shell of the cervical spine. Thus, it is difficult to judge, by radiograph or computed tomogrphy scan, whether the posterior cortical shell was perforated or not. In the present study, the perforation site was therefore checked endoscopically in each specimen. Removal of the posterior cortical shell as described above and checking the result by endoscopic visualisation can be considered sufficient to provide acceptable certainty to this investigation into the influence of the posterior cortical shell on screw torque and pullout.

Thus, transfer of biomechanical in vitro results to clinical application is difficult. However, in vitro testing is performed to get recommendations for clinical application. From the results of the current study and other in vitro investigations, it may be asserted that the role of the posterior cortical shell of the cervical spine vertebral bodies in determining pullout force and peak torque of screws is, at least, debatable, and has probably been overemphasized in the past. Its importance for screw torque and pullout is less than the importance of BMD.

Conclusion

Fixation of the screws used in the current study within the posterior cortical shell of the cervical vertebral bodies does not result in higher screw torque or screw pullout force when compared to monocortical fixation of the same type and length of screws. A significant correlation was found for peak torque and BMD and pullout force and BMD for both monocortical and bicortical screw fixation, thus emphasizing the greater importance of BMD for screw torque and pullout force compared to the posterior cortical shell in cervical spine surgery.

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