Among all spine injuries, approximately 60% affect the cervical spine and up to 20% are fractures of C-2. In geriatric patients, C-2 fractures frequently occur as an isolated injury to the cervical spine.\textsuperscript{3,4,14,15,21,26,27} The classification proposed by Anderson and D’Alonzo\textsuperscript{4} divides dens fractures into 3 types, of which Type II fractures are most often diagnosed and can lead to atlantoaxial instability.\textsuperscript{7}

Treatment of Type II fractures with conservative therapy is associated with a high rate of pseudarthrosis.\textsuperscript{14,20} Denaro et al.\textsuperscript{10} examined 16 retrospective studies regarding the treatment of dens fractures; surgical intervention had been performed for 92.1% of cases. Anterior screw fixation was first proposed in 1982 by Böhler,\textsuperscript{4} and since then it has become established as a common surgical procedure in many centers.\textsuperscript{9} In many cases, anterior screw fixation involves using 2 lag screws. However, Sasso et al.\textsuperscript{25} demonstrated that, at least in vitro, ventral fixation does not restore the original degree of vertebral stability. In a biomechanical study by Magee et al.,\textsuperscript{23} the screws broke out of all the vertebral bodies at the anterior portion of the body of the axis. Heggeness and Doherty\textsuperscript{17} investigated the trabecular structure of the dens and concluded that a higher insertion point could result in screw breakage because the bone quality there is poorer than that at the caudal endplate of the C-2 vertebral body. Our objective was to determine whether the insertion point of the screw affects biomechanical stability of the treated vertebral body.

### Methods
In a cadaver study, screw fixation was performed on 16 formalin-fixed C-2 vertebral bodies with an intact axis. The specimens were randomly assigned to 1 of 2 groups. To ensure comparability of the groups, before randomization the preparations were matched according to length (matched pairs). In Group 1, the screws were inserted directly at the anterior lower endplates; in Group 2, they were inserted 2 mm dorsal to the anterior wall of the vertebral body (Fig. 1). According to bone density measurements taken before the study, all vertebral bodies

### Key Words
- dens axis
- cadaver
- loading
- fracture
- osteoporosis
- trauma
used in this study were osteoporotic; differences between groups were not significant (T-scores $-7.388 \pm 0.3980$ for Group 1 and $-7.750 \pm 0.4567$ for Group 2; $p = 0.2191$).

The vertebral bodies had been completely freed from soft tissues and were first embedded in Technovit 3040 (Heraeus Kulzer GmbH), a cold-curing resin for surface testing and impressions, in such a way that the dens was aligned parallel to the ground. We isolated the second vertebral body completely and removed the axis. To achieve standardization, we used an oscillating saw at an angle of 90° at the base of the dens to create a Type II fracture in each vertebral body, according to the Anderson and D’Alonzo classification (Type A subclassification according to Eysel and Roosen)\(^4\). Subsequently, 2 K-wires were placed across the fracture into the apex of the dens through the cranial cortex. After removal of the K-wires, two 3.5-mm partially threaded lag screws with washers were placed over the boreholes and the fracture was reduced and fixated in this way (Fig. 2). All steps were documented with C-arm images. All operations were performed by the same surgeon.

Subsequently, the individual vertebral bodies were continuously subjected to loading on an Instron 5566 Universal Testing Machine at 1 mm per minute, according to a standardized protocol. The pressure point was the middle of the dens body (Fig. 3). Loading was stopped when the force changed from a positive to a negative value in the load-displacement curve.

After loading was stopped, the resulting radiological findings were documented by using an image converter. The measured values were statistically compared using a 2-tailed t-test (GraphPad Prism 5.03, GraphPad Software, Inc.).

**Results**

All fixations were performed without complications or technical problems. In Group 1, in which the screw was inserted directly at the anterior lower endplate, screw breakage occurred directly at the point of application (Fig. 4). The pressure at which the screws broke (mean load failure) for this group was 290.5 ± 106 N. In Group 2, in which the screw was inserted dorsal to the anterior lower endplate, no screw breakage occurred anteriorly and only a deformation of the screws occurred in the area of the dens (Fig. 4). The mean load failure for this group was 574.2 ± 170.5 N. According to a 2-tailed t-test, the results were significant ($p < 0.05$) (Fig. 5).

**Discussion**

According to the Anderson and D’Alonzo classification,\(^4\) Type II dens fractures can show different fracture line patterns. Eysel and Roosen\(^3\) recognized that these different fracture line patterns were an important factor for selecting the proper treatment strategy, and thus, they additionally classified the fracture line patterns found in Type II fractures of the axis into 3 subtypes. In Type A fractures, the fracture line is horizontal. In Type B fractures, the break runs in a ventral-cranial to dorsal-caudal direction. Type B fractures are best suited for ventral screw fixation because the screws can be placed almost orthogonally to the fracture line and thus can exert the greatest compression on the fracture gap. In Type C fractures, the break runs in a dorsal-cranial to ventral-caudal direction. Also in Type C fractures, the angle to the screw axis is more acute, and placement of the screws can result in parallel displacement of the cranial part of the dens of the C-2 vertebra in a ventral-caudal direction. Therefore, we decided to perform a standardized screw fixation orthogonal to the base of the dens, corresponding to the fracture line pattern seen in Eysel-Roosen classification Type A fractures.

Treatment of dens fractures remains controversial. Besides conservative treatment using a halo fixator or a cervical collar,\(^1,6,28\) surgical procedures are also available. Surgical options include anterior screw fixation of the dens\(^6,18\) as well as dorsal fusion of C-1 and C-2, for example, using the Magerl technique.\(^11,16\) However, dorsal fusion results in limited mobility, especially axial rotation, and can lead to accelerated degeneration of the neighboring vertebral bodies.\(^19,23\) By contrast, screw fixation of the dens permits rotational movement\(^6,19\) and achieves a fusion rate of 83% to 100%.\(^1,6,24\)

A number of techniques have been described for ventral screw fixation of the C-2 dens. Keeping in mind that surgical treatment frequently results in pseudarthrosis, attempts were made to provide compression to the fracture site, similar to the treatment of scaphoid fractures. To accomplish this, the atlas orthogonal technique involves
drilling over the caudal portion of the screw canal with a 3.5-mm drill and using a fully threaded screw. Other options include use of partially threaded screws or screws with variable screw pitch (Herbert screws), which allow the fracture gap to be brought under pressure when the screw is tightened. In addition, conically configured screws with increasing screw pitch have been used. The question whether to use 1 or 2 screws has not been resolved. Analogous to the treatment of other kinds of fractures, a pair of screws provides rotational protection and additional stability. However, depending on anatomical conditions, placement of 2 screws can be technically difficult or impossible. When designing our study, we opted to use a pair of 3.5-mm partially threaded screws. The length of the screws was chosen in such a way that at least 1 turn of the screw would perforate the cranial cortex of the dens of the axial vertebra to achieve better compression on the fracture site. In addition, we opted to use a washer to help prevent damage to the osteoporotic bone around the insertion point.

To compare insertion points, we selected 1 point at the transition between the anterior lower endplate and the base plate of the axis (and thus the ventral-caudal peak) and selected the other point 2 mm dorsal to the anterior lower endplate in the area of the endplate. These 2 techniques, performed on axis specimens free of soft tissues, were successfully compared without any difficulties. In clinical practice, reaching the first insertion point is significantly easier from a technical point of view, which is why this insertion point is used much more often. To reach the insertion point 2 mm deeper, it might be necessary to incise the anterior longitudinal ligament along with a transdiscal introduction of the screw.

Without exception, all cadaveric specimens were osteoporotic. One limitation with regard to the validity of the T-scores is that they were not measured in the intact cadavers but were measured in isolated axis vertebral bodies by use of dual-energy x-ray absorptiometry. To simulate a soft-tissue mantle, the vertebral bodies were measured together with a water pool of a defined height. We assume that T-scores obtained in this way are likely to err on the side of being too low. Had the real T-score been larger in the single-group comparison, that finding would ultimately not affect the comparability between groups. Remarkably, during surgical treatment of all specimens, the bones were quite soft and their clinical quality was very poor.

Especially when treating osteoporotic bones, it seems that increased primary stability would be desirable. For this reason, we avoided cyclic loading of the surgically treated vertebral bodies; instead, we performed a 1-time breakage. In Group 1, in which the screw insertion point was directly at the anterior lower endplate, the screws broke loose right at their point of entry (Fig. 4). In Group 2, in which the screw insertion point was dorsal to the anterior lower endplate, there were no instances of the anterior screws breaking loose and only a deformation of the screws occurred in the area of the dens (Fig. 4). According to a 2-tailed t-test, the difference between the groups was significant (p < 0.05) (Fig. 5). On the basis of these results, we successfully demonstrated that the primary stability of the screw fixation was nearly twice as great when we located the point of insertion about 2 mm
further in a dorsal direction. By means of this small modification, screw fixation can be made significantly more stable. Especially in osteoporotic bones with poor bone quality, it would seem useful, independent of the specific type of screw used, to strive for an insertion point that is 2 mm deeper, to thereby achieve the highest possible level of primary stability.

To our knowledge, bone quality is much weaker at the anterior wall than below the cortical ring at the endplate, and the main goal when stabilizing fractures of the odontoid in patients with osteoporosis is to achieve primary stability and avoid neurologic symptoms. The function and importance of the discs in older patients differ from that in younger patients. Destroying the disc in young patients might lead to clinical symptoms. In older patients, the function of the disc is often limited, and for most, disc degeneration has occurred. For older patients, we weigh primary stability against potential functional problems. Our results indicate that higher stability can be achieved when the screw insertion point is behind the anterior wall.

In this biomechanical study that used dissected second vertebral bodies, placing the K-wires at the intended position was quite easy. On the basis of the results, the surgeon might aim for a position behind the anterior wall. In a clinical setting, it might be difficult to place the screws at this position. Reasons why this position is not reached include reduced mobility of the cervical spine, positioning of the head to get a closed reduction of the fracture, and body volume (with the chest being in the way of drilling and the trajectory of the screws). Nevertheless, the surgeon should be aware of the results of this study and should aim for the screw position we described.

One study limitation might be that the testing was conducted on C-2 specimens completely isolated from the rest of the spine. We believe that fracture of the C-2 dens is a symptom of atlantoaxial instability. The translational forces of moving the atlas posterior to the axis often lead to a typical dorsal dislocation of the tip of the dens with a fracture line extending anterocaudially to posterocaudally. We presume that in a clinical setting, the stability might be higher because ligaments and muscles can support the spine. In our study, we decided to reduce other influences as much as possible. That is why we isolated the axis and performed horizontal osteotomies in all specimens. Other fracture patterns and stabilization by soft tissues might influence the primary stability in the clinical setting as well. Another study limitation might be that we did not simulate the complex motion of the cervical spine and tested stability in dorsal translation only (comparable to extension). In our setting we wanted to test primary stability for the main vector that can be found in the clinical setting.

Conclusions

In the cadaveric model, for double screw fixation of Type II dens fractures according to the Anderson and D’Alonzo classification, inserting the screws dorsal to the anterior lower endplate, to the extent possible, seems to be advantageous for load capacity. In day-to-day clinical practice, when introducing the screws, care should be taken to avoid injuring the ventral wall of the vertebral body of the axis.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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