One-Screw Fixation Provides Similar Stability to That of Two-Screw Fixation for Type II Dens Fractures

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Abstract

Background Anterior screw fixation has been widely adopted for the treatment of Type II dens fractures. However, there is still controversy regarding whether one- or two-screw fixation is more appropriate.

Questions/Purposes We addressed three questions: (1) Do one- and two-screw fixation techniques differ regarding shear stiffness and rotational stiffness? (2) Can shear stiffness and rotational stiffness after screw fixation

be restored to normal? (3) Does stiffness after screw fixation correlate with bone mineral density (BMD)?

Methods We randomly assigned 14 fresh axes into two groups (seven axes each): one receiving one-screw fixation and another receiving two-screw fixation. Shear and torsional stiffness were measured using a nondestructive low-load test in six directions. A transverse osteotomy then was created at the base of the dens and fixed using one or two screws. Shear and torsional stiffness were tested again under the same testing conditions.

Results Mean stiffness in all directions after screw fixation was similar in both groups. The stiffness after one- and two-screw fixation was not restored to normal: the mean shear stiffness restored ratio was less than 50% and the mean torsional stiffness restored ratio was less than 6% in both groups. BMD did not correlate with mean stiffness after screw fixation in both groups.

Conclusions One- and two-screw fixation for Type II dens fractures provide similar stability but neither restores normal shear or torsional stiffness.

Clinical Relevance One-screw fixation might be used as an alternative to two-screw fixation. Assumed BMD should not influence surgical decision making.

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In accordance with the local ethical committee, all cadavers used in this trial stem were from donors who during their lifetime signed their remains to medical research at the University Lübeck; the study does not require ethical committee approval.

This work was performed at the Laboratory for Biomechanics of the University Hospital Schleswig-Holstein, Lübeck, Germany.

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Introduction

Type II dens fractures are the most common type of dens fracture and account for approximately 60% in the general population and greater than 90% in the elderly [19, 21, 28, 34]. Type II fractures have a weaker tendency for spontaneous union and are associated with lower union rates than Types I and III fractures [8, 47]. Direct anterior screw fixation has been used to internally stabilize Type II dens fractures [1, 4–7, 9, 11–13, 15, 24, 29, 32, 33, 41–43, 46–48] from the early 1980s [5, 36]. It provides immediate rigid stabilization, and therefore early active cervical spine mobilization with minimal postoperative external support is feasible [8, 18, 19, 21, 36, 41, 46, 47]. Direct anterior screw fixation reportedly allows for the best anatomic and functional recovery [1, 7, 13, 24, 26, 32, 41], with high union rates (90%–100%) [1, 4, 11, 13, 15, 24, 26, 27, 33, 41, 48].

Despite direct anterior screw fixation having been used widely for Type II dens fractures, there is still controversy regarding whether the one- or two-screw technique is the most appropriate method of fixation for these fractures. Many surgeons prefer to use two screws [1, 4, 6, 11, 13, 26, 41–43]. From a theoretical biomechanical point of view, two screws can afford better stability for bending and rotation compared with one screw, especially when providing rotational control of the fragment which the two-screw fixation technique can provide. However, it is a formidable challenge for surgeons to insert two screws through the relatively small dens with many vital anatomic structures nearby. Morphologic studies suggest the diametric dimensions of the dens in a large percentage of patients would be insufficient to accommodate the passage of two screws with 3.5-mm diameter or larger and only one screw could be placed successfully [23, 24, 45]. Some clinical studies reported successfully using one-screw fixation for Type II dens fractures [7, 12, 15, 24, 29, 46, 48]. The sample sizes of these clinical studies and other limitations of the study design make a definitive conclusion regarding one- or two-screw fixation impossible.

Bone mineral density (BMD), one of the most important quantitative parameters of bone quality, influences the screw's holding ability in the bone [14, 20, 49]. Some complications after anterior screw fixation for dens fractures attributable to osteopenic bone have been described [1]. The quality of bone is not uniform in the axis. The highest density is found at the tip of the dens, whereas low bone density is seen consistently in the junction area of the dens and the middle part in the corpus of the axis. The anteroinferior area always has good cortical bone [3, 16, 22].

We therefore addressed three questions: (1) Do one- and two-screw fixation techniques differ regarding shear stiffness and rotational stiffness? (2) Can shear stiffness and rotational stiffness after screw fixation be restored to normal? (3) Does stiffness of a dens screw fixation correlate with BMD?

Materials and Methods

We harvested 14 fresh axes from human cadavers (eight male, six female) with an average age of 77.9 years (range, 60–98 years) at the anatomic department of Lübeck University. We randomly assigned the specimens to two groups (seven specimens each; four males, three females): in Group I, only one fracture compression screw (FCS) was used to fix the Type II dens fracture models, and in Group II, two FCSs were used. After dissection of all soft tissue and cartilage, radiographs were obtained to rule out the possibility of pathologic lesions. BMD was scanned at three levels on each specimen: on the top and base of the dens and on the anteroinferior part of the axis. The BMD of the axis was defined as the mean BMD data of the three levels. There were no differences in the mean donor age and BMD between the two groups. The specimens were sealed in double-layered plastic bags and kept frozen at -20°C . On the testing day, they were fully thawed at room temperature and kept moist by spraying the specimens with 0.9% physiologic saline solution during testing.

The necessary sample size for this study was determined a priori using the software G*Power 3.1.2 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). McBride et al. used six cadavers and found no differences in stiffness with one or two screws [30]. We found no literature to suggest what differences in stiffness might result in clinically important differences in maintenance of fixation or healing and many factors influence the failure of fixation or non-union. We therefore arbitrarily selected an effect size of 0.8. With a level of significance set to 0.05 and a power targeted at 0.8, considering mechanical failure during testing, we estimated a requirement of seven specimens per group.

The FCS used in the study (Königsee Implantate GmbH, Königsee, Germany) (proximal end, 4.0 mm; shank, 3.0 mm) has been used to treat Type II dens fractures in patients at the University Hospital of Schleswig-Holstein. It is a double-threaded, headless, cannulated, self-tapping, and self-drilling titanium screw. The double-threaded structure comes with different gradients and pitches, with the finer pitch at the proximal end and the wider pitch at the distal end. It produces compression between fracture fragments by the distal end passing across the fracture line and the proximal thread entering the proximal bone fragment, drawing the two bone fragments together during insertion of the FCS. As the distal thread has a diameter of 3.0 mm (with a core diameter of 2.0 mm) and the proximal thread has a diameter of 4.0 mm (with a core diameter of 2.9 mm), both threads can cut without interfering with each other during insertion.

We embedded the C2 in an interior columniform metal container with resin (Technovit 4006; Heraeus Kulzer GmbH, Wehrheim, Germany) to provide a firm base of

support. Before embedding, Plasticine[®] (Flair Leisure Products PLC, Cheam, UK) was placed around the anterior, lateral, and anteroinferior surfaces of the C2 to prevent resin-bone and resin-screw head interaction from lending extra stability to the specimen. The pivot axis of the dens was kept perpendicular to the base of the container at the central point under two laser line generators, which were used for monitoring during embedding. Once the resin was tightly cured, the Plasticine[®] was removed and the C2 was reinforced by three screws, two from the superior articular surface and one from the spinous process to the resin. In this way, the C2 achieved enough stabilization for testing without any negative effects from the resin (Fig. 1). The embedded C2 specimens then were mounted on the testing device of the Zwick 14 5670 universal mechanical testing machine (UTM; Zwick International, Ulm, Germany).

One hundred Newtons is reportedly the *in vivo* physiologic load of the cervical spine in a relaxed neutral posture [31] and 1.5 Nm moment is a good approximation to the maximum physiologic rotational load [25, 35, 38–40]. Although direct anterior screw fixation cannot restore the original strength of the intact dens [2, 10, 44], based on the above factors, we established the following parameters for testing. When testing shear stiffness, the maximum load was 40 N and the load speed was 0.1 mm/second. The shear stiffness and torsional stiffness were calculated from the slope of the most linear portion of the load-linear displacement curve under a nondestructive low-load test.

The prepared C2 was bolted in the metal container, which was mounted on the testing table of the UTM. The base of the container was set perpendicular to the horizontal plane. The load bar of the UTM acted directly on the upper articular surface of the dens, and the tip of the linear variable incremental-optical displacement transducer's (LDT) guided plunger touched the opposite articular surface. By rotating the resin in the metal container, the shear

load could be applied from the anterior, posterior, left, and right directions to the dens with the load rod. The shear load and linear displacement data were transmitted from the UTM and the LDT to the data-collecting computer where the shear load-linear displacement curve was made (Fig. 2A). When testing torsional stiffness, the maximum torque was 0.75 Nm and the rotational speed was 0.1°/second. The rotational testing device (RTD) and the spring clamp were self-designed and custom-fit devices. We stably fixed the RTD on the testing table of the UTM and attached it to the UTM by connecting the gear wheel to the load bar. Thus, when the load bar of the UTM was moved up and down, the RTD could change the linear load to the left and right of the torsional load. The spring clamp, connected to a Burster Model 8627-5010 torque sensor (Burster Präzisionsmesstechnik, Gernsbach, Germany), was fixed on the circular plate of the RTD in the same pivot axis as the RTD. The dens and the rotational part of the RTD were in the same pivot axis after the dens was held stable by the spring clamp. The resin of the prepared C2 was fixed in the circular metal container, which was mounted on the framework. One marker on the left and right transverse processes of the C2 and one marker on the pivot axis of the RTD were applied. All of them were connected to Megatron[®] MOB 2500-5-BZ-N rotary encoders (Megatron Elektronik AG & Co, Munich, Germany) by threads tied with 100-g plumbs. The direction of the threads was retained at the plumb line by pulleys. The torque sensor and the rotary encoders were connected to the data-collecting computer. When the load bar of the UTM was moved up and down, torsional loads were applied to the left and right of the dens. The torque and angular displacement data were transmitted from the sensors to the data-collecting computer and the torque-angular displacement curve in left and right rotation was recorded (Fig. 2B). The shear load was applied from four directions,

Fig. 1A–C (A) A specimen with Plasticine[®] was embedded in resin. (B) After the resin was cured, the specimen was taken out and the Plasticine[®] was removed. (C) The specimen then was reinforced by three screws.

Fig. 2A–B The photographs show the apparatus setting for testing (A) shear stiffness and (B) torsional stiffness. 1 = dens; 2 = axis; 3 = loading bar; 4 = LDT; 5 = spring clamp; 6 = marker.

namely, from anterior to posterior, from posterior to anterior, from left to right, and from right to left. The torsional load was applied in left rotation and right rotation.

We calculated the stiffness of the intact dens in six directions, namely, shear stiffness loading from anterior (SA), shear stiffness loading from posterior (SP), shear stiffness loading from left (SL), shear stiffness loading from right (SR), torsional stiffness in left rotation (TL), and torsional stiffness in right rotation (TR), from the shear load-linear displacement curves and torque-angular displacement curves, respectively. The mean shear stiffness and mean torsional stiffness of the intact dens were compared between the randomized groups and showed no differences (in all tests, $p > 0.05$).

We then placed guide wires from the anteroinferior edge of the C2 vertebral body to the apex of the dens. In Group I, one guide wire was inserted through the midline of the coronal plane. In Group II, two guide wires were inserted under the tissue-protecting drill apparatus guide (Königsee). According to the tissue-protecting drill apparatus, the distance from the screw entry points to the midline was 4 mm and the angle between the guide wire trajectories and the midline in the coronal plane was 5° in Group II. The appropriate guide wire trajectory in the sagittal plane of Groups I and II was the same as described above. The proper length of the FCS could be measured directly by the gauge over the guide wire. We then removed the guide wires and created an osteotomy at the junction of the dens and vertebra with a thin saw by hand to simulate a Type II dens fracture. The two fracture fragments were reduced anatomically and the guide wires were inserted again through the original trajectory. A clamp held the two fracture fragments tightly with compression between the two fragments. We used the cannulated pilot drill bit to open the bony entry point for the FCS over the guide wires by hand, and no tapping was required for the threads of the FCS. The FCS was introduced by hand over the guide wire and overpenetrated the apex of the dens by one or two

threads to eliminate one variable by ensuring all screws engaged the same amount of bone. The tightening was stopped when the thread of the FCS head totally entered the vertebra. We obtained AP and lateral radiographs to prove satisfactory reduction and fixation.

Again, the specimens were mounted and tested for stiffness in six directions in the same positions and orientations on the testing device of the UTM as in intact specimens.

We performed data collection and processing with DIAdem™ 11.0 software (National Instruments Corp, Austin, TX, USA). The data-collecting computer collected load and displacement data continuously throughout the study at a frequency of 100 Hz. Data were expressed as mean $\pm$ SD. ANOVA was used for statistical analysis of the differences in the stiffness loading from the same direction between and within groups. Independent-samples t-test was used to detect differences in the stiffness restored ratio in the same loading direction between Groups I and Group II. Bivariate analysis (Pearson correlation coefficients) was used to correlate BMD and stiffness. We performed the statistical analyses using SPSS® 17.0 (SPSS Inc, Chicago, IL, USA).

Results

We found no differences in mean stiffness of the dens after FCS fixation in six directions between specimens with one- and two-screw fixation (Table 1).

In Groups I and II, we found decreases in the mean stiffness of the dens between intact specimens and after FCS with either one- or two- screw fixation in six directions, especially in rotational stiffness (Table 2). The mean shear stiffness restore ratio of the fracture dens after screw fixation in the two groups was less than 50% and the mean torsional stiffness was less than 6% (Table 3).

BMD did not correlate with mean stiffness after screw fixation in both groups (Table 4).

Table 1. Shear stiffness and torsional stiffness of the dens after screw fixation in the two groups

Loading direction	Group I	Group II	p value
SA (N/mm)	317.3 ± 253.2	227.8 ± 122.3	0.44
SP (N/mm)	264.3 ± 219.9	193.9 ± 101.2	0.97
SL (N/mm)	278.7 ± 227.2	355.7 ± 209.8	0.64
SR (N/mm)	270.3 ± 247.8	290.0 ± 165.2	0.94
TL (Nm/°)	0.03 ± 0.04	0.07 ± 0.06	0.88
TR (Nm/°)	0.03 ± 0.03	0.08 ± 0.10	0.87

Values are expressed as mean ± SD; Group I = one-screw fixation; Group II = two-screw fixation; SA = shear stiffness loading from anterior; SP = shear stiffness loading from posterior; SL = shear stiffness loading from left; SR = shear stiffness loading from right; TL = torsional stiffness in left rotation; TR = torsional stiffness in right rotation.

Table 2. Shear stiffness and torsional stiffness in the intact dens and after screw fixation in the two groups

Group	Loading direction	Intact	After screw fixation	p value
I	SA (N/mm)	640.1 ± 245.3	317.3 ± 253.2	0.01
	SP (N/mm)	682.8 ± 445.8	264.3 ± 219.9	0.01
	SL (N/mm)	1153.6 ± 287.8	278.7 ± 227.2	0.00
	SR (N/mm)	1310.6 ± 768.3	270.3 ± 247.8	0.00
	TL (Nm/°)	1.7 ± 0.6	0.03 ± 0.04	0.00
	TR (Nm/°)	1.6 ± 0.6	0.03 ± 0.03	0.00
II	SA (N/mm)	544.5 ± 205.3	227.8 ± 122.3	0.01
	SP (N/mm)	503.2 ± 210.3	193.9 ± 101.2	0.05
	SL (N/mm)	967.1 ± 383.7	355.7 ± 209.8	0.00
	SR (N/mm)	877.8 ± 272.9	290.0 ± 165.2	0.02
	TL (Nm/°)	1.5 ± 0.2	0.07 ± 0.06	0.00
	TR (Nm/°)	1.7 ± 0.6	0.08 ± 0.10	0.00

Values are expressed as mean ± SD; Group I = one-screw fixation; Group II = two-screw fixation; SA = shear stiffness loading from anterior; SP = shear stiffness loading from posterior; SL = shear stiffness loading from left; SR = shear stiffness loading from right; TL = torsional stiffness in left rotation; TR = torsional stiffness in right rotation.

Discussion

Although the anterior screw fixation technique has been used widely for treatment of Type II dens fractures, whether one- or two-screw fixation is the most appropriate option is still a subject of debate. There are strong advocates for both options based on small clinical studies [1, 4, 6, 11, 13, 26, 41–43]. Some authors found two-screw fixation frequently was impossible owing to a small dens and therefore used one-screw fixation [23, 37, 45]. Numerous authors reported one-screw fixation also could achieve stable fixation and bone union [7, 12, 15, 24, 29, 46, 48].

Table 3. Shear stiffness and torsional stiffness restored ratio after screw fixation in the two groups

Loading direction	Group I	Group II	p value
SA	48.7 ± 30.4 %	46.1 ± 34.6 %	0.88
SP	34.1 ± 27.5 %	40.6 ± 23.9 %	0.65
SL	20.9 ± 22.7 %	37.7 ± 24.8 %	0.21
SR	19.2 ± 20.6 %	33.8 ± 22.6 %	0.23
TL	1.4 ± 1.7 %	3.8 ± 4.8 %	0.24
TR	5.1 ± 7.4 %	1.6 ± 1.8 %	0.25

Values are expressed as mean ± SD; Group I = one-screw fixation; Group II = two-screw fixation; SA = shear stiffness loading from anterior; SP = shear stiffness loading from posterior; SL = shear stiffness loading from left; SR = shear stiffness loading from right; TL = torsional stiffness in left rotation; TR = torsional stiffness in right rotation.

Table 4. Correlation analysis between BMD and stiffness after screw fixation in the two groups

Group	BMD (mg/cm ²)*	Loading direction	Pearson correlation	p value
I	477.3 ± 255.6	SA	0.32	0.48
		SP	0.32	0.53
		SL	0.25	0.64
		SR	0.11	0.84
		TL	0.68	0.13
		TR	0.15	0.78
II	343.7 ± 239.0	SA	0.44	0.32
		SP	0.48	0.28
		SL	0.21	0.65
		SR	0.11	0.81
		TL	−0.01	0.99
		TR	−0.19	0.72

Values are expressed as mean ± SD; p values for independent-samples t-test comparison of BMD were 0.333; BMD = bone mineral density; Group I = one-screw fixation; Group II = two-screw fixation; SA = shear stiffness loading from anterior; SP = shear stiffness loading from posterior; SL = shear stiffness loading from left; SR = shear stiffness loading from right; TL = torsional stiffness in left rotation; TR = torsional stiffness in right rotation.

However, two-screw fixation presumably can afford better stability and rotational control compared with one-screw fixation. Clinical therapeutic decisions should be based on the conclusions of clinical observations and basic theoretical research. BMD influences the screw's holding ability in the bone [14, 20, 49]. This important quantitative parameter of bone quality should be considered because many patients are elderly. Therefore, we questioned whether after one- and two-screw fixation for Type II dens fractures (1) shear and rotational stiffness differ, (2) shear and rotational stiffness are restored to normal, and (3) BMD correlates with stiffness after screw fixation.

There are some limitations to our study. First, the mechanical parameter and loading regimens are surrogates for relevant biological behavior. The mechanical parameters and loading were established according to published biomechanical studies [25, 31, 35, 38–40] on the upper cervical spine. Some authors have reported that anterior screw fixation cannot restore the original strength of the intact dens [2, 10, 44]. To maintain the specimens well during the entire study, we selected a nondestructive low-load test under approximately half of the physiologic load. It was enough to obtain the load-linear displacement curve and calculate stiffness respectively. Second, to establish a fully reproducible fracture model, an osteotomy with a thin saw at the junction of the dens and vertebra was performed to simulate a Type II fracture pattern. By this, a worst-case fracture type with a plane horizontal fracture line was created that does not occur in daily practice. Third, there is no generally accepted standard of screw for Type II dens fractures. Many types of screws have been used in studies of Type II dens fractures, including cortical [11, 26] or cancellous bone screws [1, 12]; Herbert screws [7, 12, 29] or Knoeringer double-threaded screws [6]; fully [11, 26] or partially threaded screws [7, 12, 24, 46] or lag screws [4, 12, 26, 48]; cannulated screws [1, 12, 13, 15, 29, 41, 46]; and self-tapping [11, 13, 24] or nonself-tapping screws [26, 46, 48]. The screws are stainless steel or titanium [11, 46, 48] with diameters of 2.7 mm [11], 3.0 mm [7], 3.5 mm [12, 13, 24, 26, 42], 4.0 mm [1, 46], or 4.5 mm [1, 7, 12, 24, 29]. Different kinds of screws may have different biomechanical properties.

We found no differences in mean stiffness of the dens after FCS fixation in all six loading directions between Groups I and II. One FCS can offer the same stability as two FCSs for Type II dens fractures, supporting the clinical use of the one-screw fixation technique for these fractures. Graziano et al. [17] divided eight fresh C1-C2 specimens into two groups and simulated Type II fractures by osteotomy. All specimens were fixed using one or two 3.5-mm cannulated bone screws. To account for possible variations in specimen quality as related to BMD and fracture configuration, the torsional and bending stiffnesses obtained for each specimen were divided by the corresponding stiffness obtained for wire fixation of that specimen. They concluded one- and two-screw fixation offer similar stability for dens fracture fixation. C1-C2 specimens were used for their experiments. It meant the alar ligaments, which mainly transmit torque on the dens, had been cut out. In this condition, the torque load on C1 was transmitted to neither the dens nor the screws. Sasso et al. [44] used 13 fresh C2 vertebrae and divided the specimens into three groups. Stiffness and failure load were used to compare the stability of Type II dens fractures fixed with one or two

screws. They reported no difference in the extension loading and load-to-failure tests between the two fixation methods. However, they did not test torsional stiffness. Testing shear and torsional stiffness in different directions should show differences in stabilization between two screw constructs and whether they limit rotation between fracture fragments. McBride et al. [30] used 12 specimens (10 embalmed and two fresh C2) to determine the stability of two- versus one-screw fixation for Type II dens fractures. Six specimens were stabilized with two 3.5-mm cannulated AO screws, and the others were stabilized with one 4.5-mm cannulated Herbert screw. The one 4.5-mm cannulated Herbert screw fixation provided superior fixation of Type II dens fractures. However, two different types of screws with different diameters were used in their study and these might have affected the findings.

We found decreases in the mean stiffness of the six loading directions, especially the torsional stiffness, between intact specimens and after FCS fixation in both groups. The mean shear stiffness restore ratio was less than 50% and the mean torsional stiffness restore ratio was less than 6% in both groups. Sasso et al. [44] reported internal fixation of Type II dens fractures could not restore the original stability of the intact specimen and one or two 3.5-mm AO cortical screw fixation provided 50% of the unfractured stability. They showed that the FCS primarily provides a reduction mechanism instead of a stabilization mechanism like most of the other fixation methods for fractures.

The quality of the bone affects the holding strength of the screw in the bone [14, 20, 49]. McBride et al. [30] and Sasso et al. [44] did not consider the quality of the bone in their research. To account for possible variations in specimen quality in relation to BMD, the stiffness of the specimen fixed with screws was divided by the stiffness of the same specimen fixed with wire, as also was performed in the study by Graziano et al. [17]. However, we did not find BMD correlated with the stiffness of the dens before and after FCS fixation.

We evaluated shear and torsional stiffnesses gained by one- and two-screw fixation for simulated Type II dens fractures. One- and two-screw fixation offer similar stability. Neither one- nor two-screw fixation for Type II dens fractures can restore normal shear stiffness and torsional stiffness. The stiffness of the dens after one- or two-FCS fixation is markedly reduced compared with the intact dens. We found no relationship between BMD of the C2 and stiffness after one- and two-screw fixation.

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