Screw Head Design: An Experimental Study to Assess the Influence of Design on Performance

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Purpose: This experimental study was designed to examine whether screw head design influenced the angle of application of a screwdriver at which failure of engagement or stripping of the screw head occurred.

Materials and Methods: Four different screw head designs (slot, cross, square, star) were tested in a custom-made jig that was designed to enable the screws to be tested over a range of angles of application of the respective screwdrivers, to determine whether the screw head design influenced the torque value at which the screw head stripped or failure of driver engagement occurred.

Results: The results fell clearly into 2 groups: The slot and cross designs gave the highest torque values at all angles, while the torque values for the square and star designs dropped to a low value with increasing angulation between the screw and driver. These differences were significant ($P < .001$).

Conclusions: Although this experimental situation cannot be entirely extrapolated to the clinical situation, it indicates that the slot or cross design may offer an advantage in regions of difficult access where the angulation of the screwdriver to the screw may of necessity be increased.

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Titanium miniplates and screws are widely used in oral and maxillofacial surgery. They are routinely used for fixation of the facial bones in fractures and in orthognathic and reconstructive surgery. The first published account of internal fixation for the treatment of facial fractures was by Jean Baptiste Baudens,[1] who in 1840 used silver thread to treat a mandibular fracture. Bone plates were used as early as the American Civil War (1861 to 1865) and further developed to improve strength and adaptability throughout the early 1900s.[2]

During the late 1960s, compression bone plating for the treatment of mandibular fractures was developed by Luhr and later popularized by Speissl using the AO/ASIF (Arbeitsgemeinschaft für Osteosynthesefragen/Swiss Association for the Study of Internal Fixation) technique.[3] These large bone plates used 2.7-mm bicortical screws and often were applied through transfacial approaches. In 1973, Michelet et al[4] reported the treatment of mandibular fractures with the use of small, easily bendable noncompression bone plates, placed transorally, using monocortical screws. A scientific basis for the application of such miniplates was subsequently developed by Champy et al,[5] who examined stresses created in the mandible by loading at different sites. This work established that miniplates should be placed along well-defined lines of tension, and these principles have subsequently been widely accepted. Many different monocortical miniplate systems are now available, although the principles for their application remain the same.

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Initially, the miniplates and screws were made of stainless steel; however, most of the systems are now manufactured in titanium. The use of miniplates, typically 2.0-mm systems, for the treatment of certain midfacial fractures has been superseded by the development of even smaller (micro) plates, and recently drill-free screws and biodegradable screws and plates have become available for clinical use.

Studies on screw design and performance can be found in both the orthopedic and maxillofacial surgery literature. Prevel et al[6] used fresh frozen human metacarpal bones to compare titanium self-tapping with pretapped screw fixation of spiral fractures and found no difference in shear stress and axial stress between screw designs. Heidemann et al[7] suggested that when screws were inserted into thick cortical bone, a small pilot hole size could result in high torsional stress, leading to screw failure. Using 1.5- and 2.0-mm screws inserted into various materials, these investigators were able to determine the critical pilot hole size above which the holding power of the screw rapidly decreased. Seating and fracturing torque of 2.0- and 2.7-mm diameter tapped and non-tapped titanium screws have been analyzed in different regions of the cadaver mandible.[8] The investigators found that smaller screws required greater seating torque, regardless of whether the holes were tapped, and that the region of the mandible requiring the greatest seating torque was the symphysis. The clinical performance of drill-free screws with specially formed tips and cutting flutes, which can be inserted into the bone without predrilling, was recently reported. It was found that the insertion of the screws was simple. The investigators recommended the use of this screw for fixation in the central midface. Insertion of the screws was difficult but possible in the anterior mandible and in the lateral midface but not possible in the mandibular angle region.[9]

The torsion-axial force characteristics of conventional titanium screws has been investigated[10,11] and compared with the newly developed biodegradable screws.[12] However, the angulation between screwdriver and screw, at which distortion or stripping of the screw head begins to occur, does not appear to have been previously reported or compared for the differing screw head designs.

Currently, there are various designs of 2.0-mm titanium mini-plates with tapped or self-tapping screws. However, there are only 2 basic screw head designs. One uses a slot or cross pattern and requires a holding sleeve on the screwdriver to pick up and hold the screw, and the other uses an internal design such as a square or star to engage the screw, relying on friction to pick up and hold the screw, thus obviating the need for the holding sleeve. Miniplates and screws are usually applied intraorally, which has the advantage of avoiding a facial scar; however, in certain regions, access can be restricted and placement may become difficult. In anatomic regions that are difficult to access, the angulation of the screw and screwdriver to the bone and to each other increases, and problems with either the screwdriver disengaging from the screw or stripping of the screw head become more apparent. This leads to increased operating time and frustration for the operator and may lead either to failure to fully seat the screw into the countersunk plate hole or to failure to seat the plate against the bone, as the screw head may deform or strip before the screw is fully seated. Once the screw head is deformed or stripped, further seating of the screw may not be possible, whereas screw and therefore plate removal is difficult, if not impossible, without drilling the screw out of the plate and bone. A screw head design that allows the screw to be placed with the greatest range in screwdriver angulation will thus have an advantage in these regions.

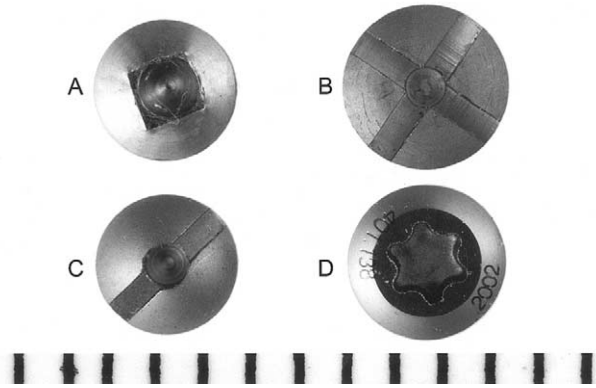

FIGURE 1. The 4 different screw head designs that were tested: *A,* square (Martin; Medizin-Tecknik, Tuttlingen, Germany); *B,* cross (Synthes; Mathys Medical Ltd, Bettlach, Switzerland); *C,* slot (Wurzburg; Howmedica Leibinger Inc, Freiburg, Germany); and *D,* star (Synthes; Mathys Medical Ltd, Switzerland).

Materials and Methods

Titanium 2-mm screws of 4 differing head designs, 7 or 8 mm in length, were tested: A) square (Martin; Medizin-Tecknik, Tuttlingen, Germany), B) cross (Synthes; Mathys Medical Ltd, Bettlach, Switzerland), C) slot (Wurzburg; Howmedica Leibinger Inc, Freiburg, Germany), and D) star (Synthes; Mathys Medical Ltd) (Fig 1).

Testing was undertaken in a materials testing laboratory using a custom-made jig with 500-N and 100-N force transducers (Material Test System Corporation, Eden Prairie, MN), connected to a data acquisition board (AT-MID-16E-2; National Instruments Corp, Austin, TX), which transferred all data to a computer using process control software (LabVIEW 4.0; National Instruments Corp) (Fig 2). Up to 3 screws of

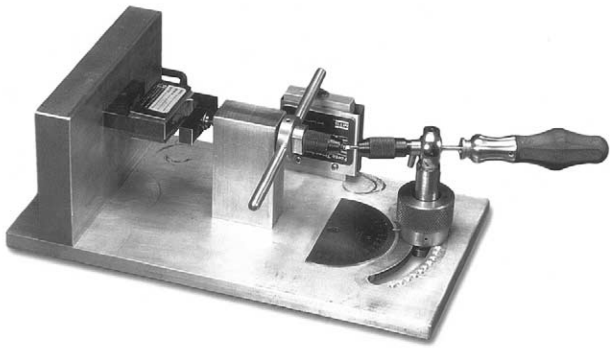

FIGURE 2. Custom-made jig designed to test screws at different angulations.

each design were tested at each angle; a total of 66 screws were tested. The custom-made jig allowed testing between the angles of 0° and 30° in 5° increments. After each screw was immobilized in the jig, the examiner engaged the driver firmly into the head. Care was taken to ensure that each screw from each of the design groups had the same orientation in the jig so that the rotational angle between the screwdriver and screw was constant among the different types of screws that were tested.

The *axial force* (the amount of force applied to each screw along its axis) was recorded by one of the force transducers and digitally displayed. This indicated to the examiner how much force was being applied to the screw head. However, if the examiner had attempted to keep this force reading at a constant, the true amount of force applied to the screw head would have actually been greater with increasing angulation. This is because a higher amount of force would have had to be applied in an oblique direction to register the same force in an axial direction. Therefore, a conversion table was devised so the examiner could use the digital display of the axial force to calculate the amount of force to apply to the screw head to keep the *radial force* (actual amount of force at the screw head) at a constant. The examiner then attempted to turn the driver against the immobilized screw until the screw head stripped. The other force transducer recorded the maximum torque achieved before stripping occurred.

Only one screwdriver was available for each type of screw head design. With the possibility that, at low angulation, the stripping torque may have been high enough to cause distortion or breakage of the driver, it was decided to start testing at 30° (where low torque values would be expected), and to then decrease the angulation. After each test the driver was visually checked by stereomicroscopy (×10 magnification) to ensure that it had not broken or distorted. The screws were also studied by stereomicroscopy (×10 magnification) to reveal patterns of distortion or stripping at the failure angulation. Descriptive statistics for the maximum torque values and radial force were calculated (Tables 1 and 2).

Table 1. DESCRIPTIVE STATISTICS FOR TORQUE (N-cm)

Design	Degree	No. of Samples	Mean	Median	SD	Minimum	Maximum
Cross	15	1	59.0	59.0	*	59.0	59.0
Cross	20	3	30.5	30.8	0.8	29.6	31.0
Cross	25	3	23.5	22.4	3.2	21.1	27.1
Cross	30	3	17.7	16.9	1.5	16.8	19.4
Slot	10	2	54.0	54.0	7.9	48.4	59.6
Slot	15	3	35.5	34.5	2.5	33.7	38.4
Slot	20	3	27.4	28.3	1.6	25.6	28.3
Slot	25	3	25.1	24.5	1.6	23.8	26.9
Slot	30	3	22.7	22.4	0.6	22.2	23.4
Square	0	3	42.5	43.2	2.2	40.1	44.3
Square	5	3	36.3	33.7	4.6	33.5	41.6
Square	10	3	15.3	15.8	3.3	11.8	18.3
Square	15	3	9.9	6.3	6.8	5.7	17.8
Square	20	3	3.7	4.1	0.6	3.0	4.1
Square	25	3	4.4	4.6	1.2	3.1	5.5
Square	30	3	2.8	2.6	1.7	1.3	4.6
Star	0	3	52.4	49.5	9.9	44.2	63.4
Star	5	3	30.2	30.6	5.1	24.9	35.1
Star	10	3	13.5	12.2	3.9	10.4	17.8
Star	15	3	6.2	5.6	2.0	4.6	8.5
Star	20	3	2.4	2.5	0.5	1.9	2.8
Star	25	3	2.3	2.5	0.6	1.6	2.8
Star	30	3	3.2	2.5	1.5	2.2	4.9

*Indicates that SD could not be determined because only 1 screw was tested.

Table 2. DESCRIPTIVE STATISTICS FOR RADIAL FORCE (N)

Design	Degree	No. of Samples	Mean	Median	SD	Minimum	Maximum
Cross	15	1	53.1	53.1	*	53.1	53.1
Cross	20	3	47.6	44.4	8.9	40.8	57.7
Cross	25	3	46.2	44.4	6.6	40.7	53.6
Cross	30	3	40.0	42.3	5.2	34.1	43.7
Slot	10	2	63.3	63.3	11.2	55.3	71.2
Slot	15	3	54.4	55.6	3.7	50.3	57.4
Slot	20	3	49.1	49.1	4.4	44.7	53.5
Slot	25	3	44.3	46.3	7.7	35.8	50.9
Slot	30	3	51.5	55.3	7.3	43.1	56.1
Square	0	3	39.1	38.8	0.8	38.6	40.0
Square	5	3	45.3	45.3	3.7	41.6	48.9
Square	10	3	45.2	44.4	2.6	43	48.1
Square	15	3	32.3	33.1	1.9	30.1	33.7
Square	20	3	34.3	33.8	1.9	32.8	36.4
Square	25	3	31.7	31.3	1.5	30.4	33.4
Square	30	3	30.0	29.6	1.7	28.5	31.9
Star	0	3	59.6	61.0	9.6	49.3	68.4
Star	5	3	50.7	47.1	11.2	41.7	63.2
Star	10	3	48.6	46.6	6.0	43.9	55.3
Star	15	3	44.7	42.0	7.9	38.5	53.6
Star	20	3	33.3	33.0	3.9	29.6	37.4
Star	25	3	40.1	37.4	11.4	30.2	52.6
Star	30	3	30.3	29.0	2.6	28.5	33.3

*Indicates that SD could not be determined because only 1 screw was tested.

STATISTICAL ANALYSIS

Analysis of covariance was performed on the raw torque values. However, the results of this analysis were not valid as the distribution of the data was skewed, and the variances of each of the 4 screw designs were different (these are 2 assumptions behind the analysis of covariance). A standard method of handling such data is to apply a transformation to the data; in this case, a natural logarithm was used. Analysis of covariance was carried out on the transformed data, comparing the mean adjusted torque value of each screw at a constant radial force.

Results

A plot of the raw data showed a clear difference in the value of the maximum torque values for each screw design at each angle, with the results clearly falling into 2 groups (Fig 3). Torque values ranged from 1.3 to 63.4 N-cm, and the radial force ranged from 28.5 to 71.2 N. There was a pattern in the amount of radial force applied with higher forces being registered for the slot and cross designs. The examiner must therefore have inadvertently applied a greater force to these 2 designs during testing. As some of the differences in mean torque values between the designs could have been influenced by differences in the radial force, this value was made a constant, and the torque value of each of the screws was adjusted to allow a fairer comparison of torque values between designs.

As expected, there were significant differences in the torque between angles ($P < .001$). More important, there were significant differences between designs ($P < .001$), with the results falling clearly into 2 defined groups. The cross and slot screws achieved similar mean torque, significantly different ($P < .001$) from the square and star screws. From a practical viewpoint, once the driver was at an angle of greater

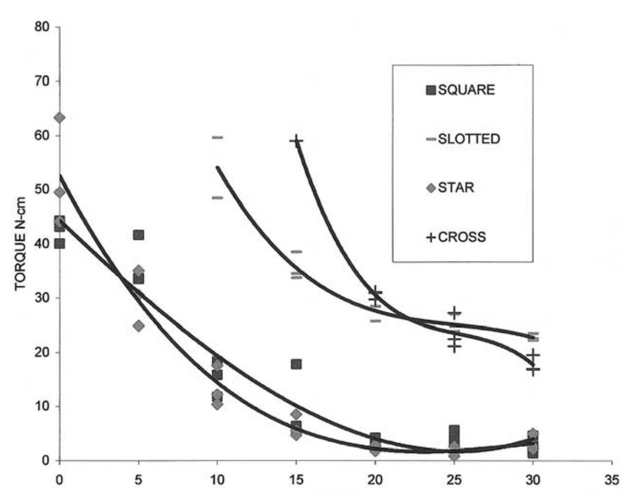

FIGURE 3. Comparison between screw types of maximum torque values at each angle.

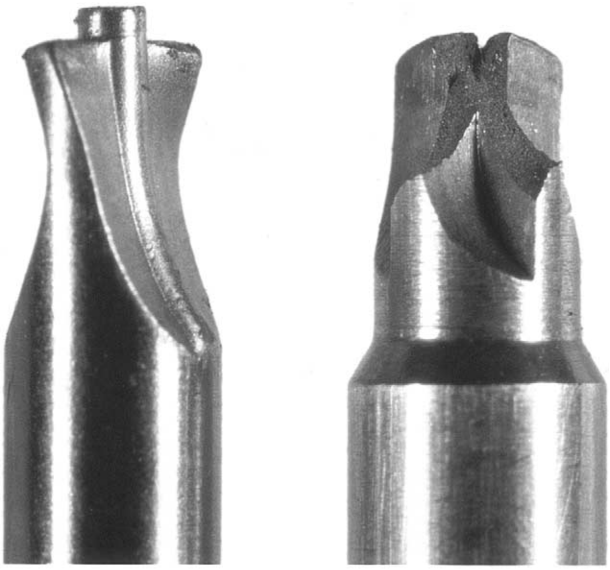

FIGURE 4. Distortion of slot screwdriver *(left)* and fracture of cross screwdriver *(right)*.

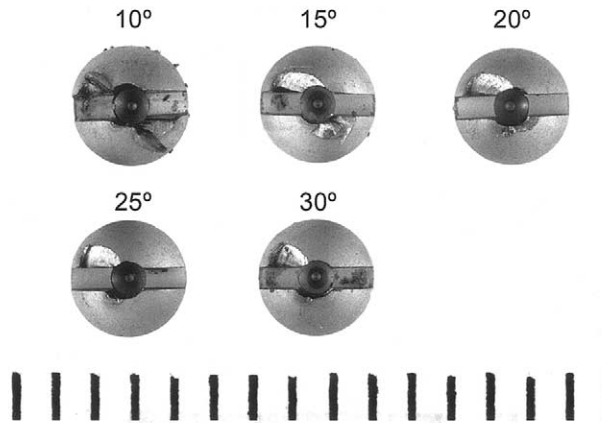

FIGURE 6. "Shaving"-type stripping of slotted design from 10° to 30°. At lower angulations, both walls of the slot are stripped (the driver distorted at 10°).

than 10°, it became much more difficult to engage the screw head of the square and star designs, due to the precise fit of these screws required for the friction pick-up mechanism. Consequently, the torque values for these 2 designs dropped to a low value from this angle. The square and star designs could be stripped at 0°, whereas the slot and cross designs reached such high torque values at 10° and 15°, respectively, that the drivers either distorted or fractured before the screw head stripped (Fig 4).

Typical patterns of deformation for each of the screw heads were observed under stereomicroscopy. The square and star designs "barreled out" to the point where the driver could rotate freely in the head (Fig 5). The slot and cross designs stripped when the driver shaved off a strip from one of the slot walls, leaving the screw head otherwise intact. At low angles the drivers failed, because they were too deeply engaged to shave a strip off a screw head that was mechanically stronger (Fig 6).

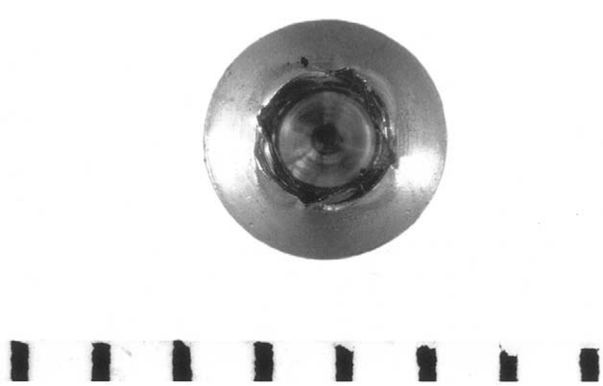

FIGURE 5. "Barrelled-out"–type stripping of internal square design screw.

Discussion

The results of this study show that the slot or cross designs of screw heads perform better in an experimental situation than the internal square or star designs. Although this situation cannot be entirely extrapolated to the clinical situation, it nevertheless suggests that the slot or cross design may offer an advantage in regions of difficult access where the angulation of the screwdriver to the screw may be increased.

The pattern of stripping is also important because it determines how easy it is to remove the screw. The internal star and square designs stripped in such a way that removal would be difficult, if not impossible. The slot and cross designs, on the other hand, retained their basic shape once stripped and would therefore be easier to both place and remove. Even if stripping of these designs occurred during insertion, the side of the slots required for removal would still be intact.

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