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Design Parameters of Hand Surgery Screws: Measurement Discrepancies and Clinical Implications



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Purpose: The use of self-tapping cortical screws is indicated in patients with metacarpal and phalangeal fractures requiring formal stabilization. The aim of this study was to systematically compare and evaluate the design parameters of 4 commercially available self-tapping screw systems.

Methods: We measured various design parameters of self-tapping cortical screws of different lengths from several manufactures using scanning electron microscopy. Screws were obtained in 8, 12, 16, and 20 mm lengths. The measured parameters included screw length, head height, pitch, outer diameter, inner diameter, terminal thread diameter, terminal thread-to-tip distance, thread-to-tip distance of 1 full revolution, and crest width. Data were assessed statistically using 1- and 2-way analysis of variance (ANOVA) tests, and the significance level was set at a P value $< .05$.

Results: There was variability in advertised screw lengths compared with measured screw lengths with 2 manufacturers. There was a statistically significant difference between the thread-to-tip distance and head height between screws while controlling for diameter.

Conclusions: Screw sizes and dimensions are critical in order to avoid complications such as prominent hardware and postoperative stiffness. Knowledge of the design parameters presented for each of the different manufacturers may prove useful to hand surgeons when selecting screws for fixation of metacarpal and phalangeal fractures.

Clinical relevance: Specific design characteristics of commonly used screws in hand surgery vary slightly by manufacturer and may have clinically relevant implications in fixation of metacarpal and phalangeal fractures.

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Currently, mini-screw/plate fixation is indicated in patients with metacarpal and phalangeal fractures that require formal stabilization. In long oblique fractures of the metacarpals and phalanges, rigid fixation can be achieved with a minimum of 2 lag screws.¹ The goal of lag screw fixation is to achieve interfragmentary compression to prevent micromotion across fracture lines and guide the healing process.²

A crucial parameter in screw fixation is screw length. The most common complication following articular and phalangeal fractures of the hand after fixation is residual finger stiffness.³ Fambrough

and Green⁴ reported flexor tendon rupture due to irritation from a protruding screw tip as a postoperative complication risk in the treatment of an oblique intra-articular fracture. According to the Arbeitsgemeinschaft für Osteosynthesefragen Foundation, if the length of the screw is too short, there will not be enough threads to engage the cortex adequately and achieve required interfragmentary compression. Conversely, if the screw is too long in length, the protruding tip can damage the soft tissues such as tendons and neurovascular structures.² This is of particular interest in the proximal phalanx, as the proximal phalanx has a volar concavity that intimately associates with the flexor tendon, putting it at increased risk of damage from a protruding screw tip.⁵ Because of this, there is a narrow margin for error when treating fractures of the hand using mini-screw/plate fixation.

Despite the high number of patients undergoing treatment of hand fractures and the acknowledgment of the importance of the screw length and design in preventing postoperative

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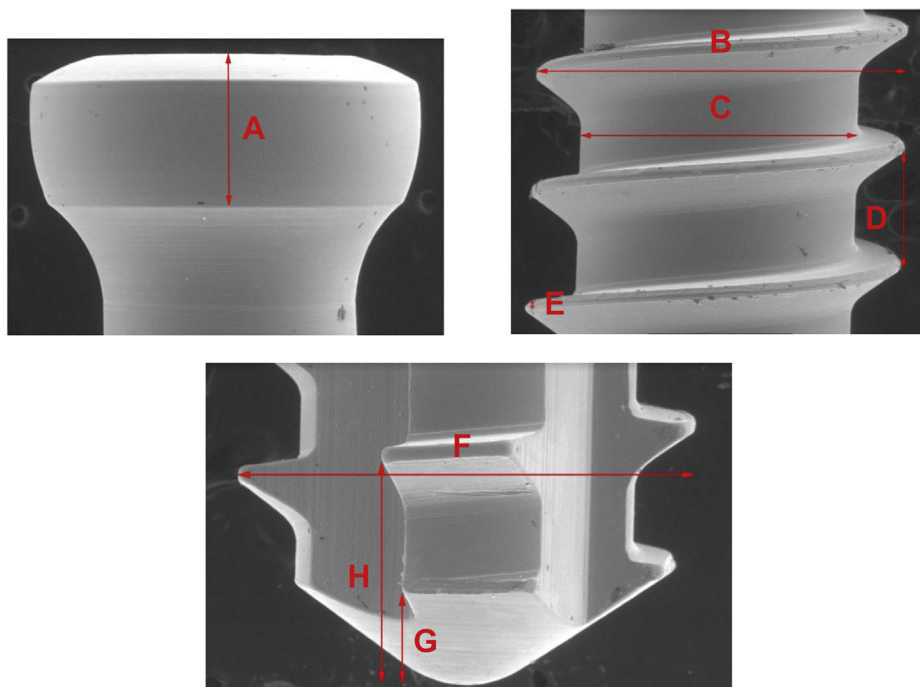


Figure. SEM images of the Acumed lag screw indicating how various measurements were made: **A** head height, **B** outer diameter, **C** inner diameter, **D** pitch, **E** crest width, **F** terminal thread diameter, **G** terminal thread-to-tip distance, and **H** terminal thread-to-tip distance of 1 full revolution.

complications, there remains a paucity of studies comparing the design features of commercially available screws for use in hand fractures between different manufacturers. The aims of this study were to systematically compare and evaluate the design parameters of 4 commercially available self-tapping screws and determine whether any discrepancies could have clinical relevance or implications. We hypothesized that there would be discrepancies between advertised and measured screw parameters.

Materials and Methods

Self-tapping cortical screws from 4 different manufacturers were selected: 1.5-mm and 2.5-mm nonlocking cortical screws from Zimmer Biomet, 1.5-mm and 2.3-mm Hexalobe lag screws from Acumed, 1.5-mm and 2.4-mm nonlocking cortical screws from Synthes, and 1.7-mm and 2.3-mm cortical screws from Stryker. Screws were obtained in 8, 12, 16, and 20 mm lengths. Three screws of each type were used. Screw length, defined as the distance from the tip of the screw to the top of the head, was obtained using a digital caliper. All screw types were cross-referenced with the manufacturer-provided depth gauge to assess whether the screw length accurately reflected the depth gauge. Images of the screws were also taken using Environmental Scanning Electron Microscopy (FEI Quanta 200 Field Emission Gun; FEI), and all other measurements of the screws were obtained through the ImageJ image processing program (National Institutes of Health). Standard techniques were used for acquisition of the scanning electron microscope (SEM) images. Each screw was affixed to the stage with double-sided carbon tape. The stage was tilted appropriately to ensure the screw was imaged directly in profile without obliquity. Images were obtained at $\times 20$, $\times 50$, and $\times 100$ magnification. Each image was analyzed on ImageJ. The scale was set on ImageJ using the scale provided on each SEM image to calibrate pixels to millimeters. All measurements were made from these images through ImageJ by the lead author (A.C.P.), experienced in SEM techniques and ImageJ. The measured parameters included screw length, head

height, head width, pitch, outer diameter, inner diameter, terminal thread diameter, terminal thread-to-tip distance, thread-to-tip distance of 1 full revolution, and crest width. The Figure indicates how the measurements were made using SEM images.

Means and SDs were calculated for screw length, head height, head width, pitch, outer and inner diameter, terminal thread-to-tip distance, terminal thread diameter, and crest width. A 1-way ANOVA was used to determine whether there was a significant difference between design parameters of different lengths made by the same manufacturer, with an overall significance level of .05. A 2-way ANOVA was conducted with the post hoc Tukey honest significance test to determine whether there was a statistically significant interaction between the effects of screw size and manufacturer on design parameters, with a significance level of .05.

Results

Screw length

The screw lengths as reported by the manufacturers included the head height in addition to the length of the screw shaft. However, there was some variability among the advertised screw length and the measured screw length for 2 of the manufacturers. Zimmer Biomet screws consistently had an actual measured length that was consistently 2 mm shorter than the labeled length of the screw. For example, the 1.5-mm diameter Zimmer Biomet screw, labeled as having a length of 8 mm, was measured to be 6.06 ± 0.09 mm. Synthes screws were also consistently 0.2 to 0.3 mm longer than the labeled length of the screw. Additionally, we found inconsistencies when cross-referencing the screw length with the manufacturer-provided depth gauges. For Synthes and Acumed, the length measured by the depth gauge accounted for only the shaft length. The head height was not included in this measurement; thus, the total length of the screw, including the head height, was longer than that measured by the depth gauge. For Stryker and

Table 1
Means (SDs) of Measured Screw Length of Orthopedic Screws*

Labeled Screw Length	Biomet 1.5	Biomet 2.5	Acumed 1.5	Acumed 2.3	Synthes 1.5	Synthes 2.4	Stryker 1.7	Stryker 2.3
8-mm screws	6.06 (0.09)	6.11 (0.02)	7.98 (0.01)	7.99 (0.03)	8.28 (0.02)	8.25 (0.02)	8.04 (0.04)	8.05 (0.04)
12-mm screws	10.05 (0.04)	10.07 (0.01)	12.00 (0.01)	12.00 (0.01)	12.27 (0.03)	12.24 (0.03)	12.04 (0.02)	11.98 (0.02)
16-mm screws	13.95 (0.01)	14.04 (0.01)	15.96 (0.03)	15.97 (0.02)	16.24 (0.04)	16.24 (0.01)	16.02 (0.01)	15.99 (0.01)
20-mm screws	17.95 (0.01)	18.06 (0.06)	20.00 (0.03)	19.98 (0.02)	20.29 (0.02)	20.23 (0.03)	20.02 (0.04)	19.98 (0.03)

* Values for screw length are based on the mean of 3 screws.

Table 2
Means (SDs) of Design Parameters of the Orthopedic Screws*

Screw Design Parameter	Biomet 1.5	Biomet 2.5	Acumed 1.5	Acumed 2.3	Synthes 1.5	Synthes 2.4	Stryker 1.7	Stryker 2.3
Head height, mm	1.35 (0.03)	0.54 (0.07)	1.11 (0.04)	1.09 (0.02)	1.18 (0.03)	1.44 (0.08)	0.87 (0.02)	0.95 (0.01)
Pitch, mm	0.64 (0.01)	1.01 (0.05)	0.50 (0.02)	0.69 (0.01)	0.51 (0.01)	1.01 (0.01)	0.60 (0.01)	0.78 (0.01)
Minor diameter, mm	1.09 (0.03)	1.85 (0.04)	1.06 (0.04)	1.76 (0.07)	1.07 (0.02)	1.69 (0.02)	1.18 (0.01)	1.53 (0.01)
Major diameter, mm	1.52 (0.05)	2.49 (0.07)	1.47 (0.06)	2.29 (0.04)	1.49 (0.03)	2.40 (0.03)	1.65 (0.01)	2.19 (0.01)
Terminal thread diameter, mm	1.37 (0.03)	2.37 (0.04)	1.41 (0.07)	2.22 (0.04)	1.39 (0.01)	2.27 (0.02)	1.63 (0.02)	2.15 (0.01)
Terminal thread-to-tip distance, mm	0.29 (0.03)	0.54 (0.05)	0.35 (0.04)	0.46 (0.06)	0.51 (0.05)	0.83 (0.06)	0.58 (0.03)	0.80 (0.05)
One full revolution of terminal thread-to-tip distance, mm	0.78 (0.04)	1.40 (0.08)	0.77 (0.06)	1.08 (0.09)	0.92 (0.05)	1.79 (0.19)	1.11 (0.05)	1.11 (0.05)
Crest width, mm	0.05 (0.01)	0.06 (0.01)	0.05 (0.01)	0.08 (0.01)	0.07 (0.01)	0.07 (0.01)	0.05 (0.01)	0.05 (0.01)

* Values are based on the mean of 12 screws.

Zimmer Biomet screws, the depth gauge included the head heights. All screw lengths are recorded in [Table 1](#).

Thread-to-tip distance

One-way ANOVAs of the terminal thread-to-tip distance did not reveal a statistically significant difference between screws of different lengths from the same manufacturer ($F_{2,3} = 2.08$; $P = .18$). However, a 2-way ANOVA of the terminal thread-to-tip distance found statistically significant differences among the means based on screw manufacturer and size ($F_{3,88} = 19.3$; $P < .001$). Tukey studentized range (honesty significance difference) test showed a significant difference at $P < .05$ between 2.4-mm Synthes screws (0.83 ± 0.06 mm) and 2.3-mm Stryker screws (0.80 ± 0.05 mm) compared with the 2.3-mm Acumed screws (0.46 ± 0.06 mm) and 2.5-mm Zimmer Biomet screws (0.54 ± 0.05 mm). Similar results were obtained for the smaller diameter screws. There was a significant difference at $P < .05$ between the thread-to-tip distances of the 1.7-mm Stryker screws (0.58 ± 0.03 mm) and the 1.5-mm Synthes screws (0.51 ± 0.05 mm) compared to the 1.5-mm Zimmer Biomet (0.29 ± 0.03 mm) and Acumed screws (0.35 ± 0.04 mm).

Head height

A 2-way ANOVA revealed a statistically significant difference among the means of the head height based on the screw manufacturer and size ($F_{3,88} = 698$; $P < .05$). Among the larger diameter screws, the 2.5-mm Zimmer Biomet screws had the smallest average head height (0.54 ± 0.07 mm) and the 2.4-mm Synthes screws had the largest average head height (1.44 ± 0.08 mm). Among the smaller diameter screws, the 1.7-mm Stryker screws had the smallest average head height (0.87 ± 0.02 mm) and the 1.5-mm Zimmer Biomet screws had the largest average head height (1.35 ± 0.03 mm). All remaining screw measurements are recorded in [Table 2](#).

Discussion

There was discrepancy between the manufacturers' reported screw length and the measured screw length for the Zimmer Biomet screws and the Synthes screws. The Zimmer Biomet screws

were 2 mm shorter than reported across all screw lengths. The consistent 0.2 to 0.3 mm discrepancy seen with the Synthes screws regarding screw length is due the difference in the definition of screw length used by the manufacturer. Synthes defines the screw length as the length from the tip of the screw to the undersurface of the screw head. It does not take into account the dome-shaped portion of the head of the screw (the 0.2–0.3 mm discrepancy may not be clinically relevant). All the Acumed and Stryker screws were within 0.04 mm of their labeled length.

It is important to consider that these length discrepancies, while interesting, have little clinical significance without discussing their relation to the manufacturer-provided depth gauge. The Zimmer Biomet screws, while 2 mm shorter than that described by the manufacturer, aligned correctly with their depth gauge. Thus, screw length, especially for the Zimmer Biomet screws, should be chosen based on depth gauge measurements and without the consideration of absolute measurements of the bone from preoperative radiographs. All 4 of the screw systems correctly correlated their lengths with the depth gauge; nevertheless, there were discrepancies when considering the head height. Synthes and Acumed only included the shaft of the screw, without the head height in the depth gauge measurement, whereas Stryker and Zimmer Biomet did include the head height in the depth gauge measurement.

The head height is an important consideration when countersinking, a technique used to increase compression and avoid the dome-shaped screw heads interacting with the surrounding soft tissues, a consideration of particular importance in small bones such as the phalanges. Countersinking is primarily performed in diaphyseal bone and not in the metaphysis, as its cortex is thin. According to the Arbeitsgemeinschaft für Osteosynthesefragen Foundation, eccentric loading caused by improper countersinking could compromise the amount of compression obtained within the bone, and lead to displacement of fragments in a thin cortex.² It is critical for the surgeon to consider these discrepancies in inclusion of head height in depth gauge measurements when selecting screws. If countersinking is to be performed and the depth gauge does not include the head height, there may be a problem with screw prominence. Similarly, if countersinking is not to be performed and the depth gauge does include head height, adequate purchase may not be obtained on the far cortex.

The terminal thread-to-tip distance, defined as the distance from the tip of the screw to the start of the terminal thread, has not

been previously characterized in literature for bone screws. For both the small and large diameter screws, this value was significantly greater for the Synthes and Stryker screws compared to the Zimmer Biomet and Acumed screws. This part of the screw gains no purchase in bone. Therefore, the ideal screw design would minimize this distance, while maintaining the ability to self-tap. In small bone fixation, where prominent hardware may play an important role in development of postoperative stiffness or other soft tissue irritation, screws that minimize the terminal thread-to-tip distance may be preferable.

There are several limitations to this study, including a small sample of 3 screws of each type as well as little existing literature on the topic. Future studies should be performed using a larger sample size of screws to assess for significant measurement differences. Additionally, there is the potential for error in measurements obtained using ImageJ software. We are unaware of published error values for measurements obtained through this software, though it is widely used to measure images obtained in scientific research. In this study, only 1 author experienced in ImageJ made all measurements in order to minimize variation in measurements across samples.

This investigation provides interesting data on small screw design characteristics and discrepancies among screws of different manufacturers. As described, these discrepancies can have important clinical implications with regards to screw selection with or without countersinking or when absolute screw length is considered by the surgeon. Depending on the clinical application or fracture pattern encountered, this information may allow the surgeon to tailor screw selection based on these differences to optimize outcomes of metacarpal and phalangeal fractures managed with screw fixation.

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