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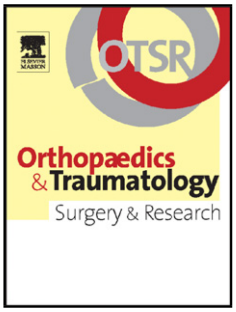

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Scaphoid Screw Fixation Perpendicular to the Fracture Plane: Comparing Volar and Dorsal Approaches

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Abstract

Introduction To percutaneously fixate a midwaist scaphoid fracture, both volar and dorsal approaches are considered valid options although they may have different screw insertion angles relative to the scaphoid fracture plane influencing fixation stability. In this virtual simulation study, we investigated the accessibility of placing a screw perpendicular to the fracture plane in *transverse* and *horizontal oblique* scaphoid midwaist fracture models and compared standard volar and dorsal approaches.

Material and methods Computed tomography scans of 38 healthy wrists were used to obtain virtual 3-dimensional wrist models in flexion and extension. In case the trapezium in volar approach or the distal radius in dorsal approach obstructed the screw axis perpendicular to the fracture plane, an alternative non-obstructed screw axis was chosen as close as possible to the perpendicular axis. The deviation angle between the best possible non-obstructed screw placement and true perpendicular screw placement was quantified.

Results For transverse fractures, the average deviation angle (± standard deviation) was 8° (±5°) in volar approach, and 0° (±0°) in dorsal approach. For horizontal oblique fractures, these angles were 40° (±6°) and 14° (±8°), respectively.

Discussion In our simulations, compared to the volar approach, the dorsal approach provided the most precise screw placement perpendicular to the fracture plane, with the largest differences for horizontal oblique fractures. When taken in addition to screw purchase, thread engagement and protrusion risk, information about screw orientation may help surgeons in deciding between percutaneous approaches in scaphoid surgery on which there is currently no consensus.

Key words: scaphoid fracture, percutaneous, screw fixation, fixation, dorsal approach, volar approach

Original article

1. Introduction

Percutaneous screw fixation is becoming a popular treatment option in the management of acute displaced scaphoid fractures and selected scaphoid nonunions. It has also been advocated in young active individuals with nondisplaced scaphoid fractures as an alternative to conservative treatment, since it shortens the immobilization period and allows for early return of function [1,2].

There is no consensus regarding the optimal approach to percutaneous screw fixation of scaphoid midwaist fractures [3]. In the volar retrograde approach, the trapezium may hinder accessing the distal pole, and the patient may develop scaphotrapeziotrapezoid arthritis; in the dorsal antegrade approach, it may be more difficult to maintain fracture reduction with wrist flexion, and there is a risk for nerve and tendon damage [3-5].

A factor influencing the surgical decision between volar and dorsal approaches is the freedom to place a screw at a certain relevant position and angle. A conventional recommendation is to place a screw along the central axis of the scaphoid, irrespective of the fracture pattern [6,7]. Based on the experience of surgeons and the interpretation of standard 2-D images [1,3,5,8], the dorsal approach allows for precise screw placement down the central scaphoid axis. Recent biomechanical studies [9,10], however, showed that placing a screw perpendicular to the fracture plane provides equivalent strength to one placed down the central axis. A computerized simulation study [11] showed even higher strength for perpendicular placed screws and hypothesized that placing the screw with consideration of the fracture plane and not the scaphoid central axis should achieve better fixation. Previous pathoanatomic studies [12,13] showed that usually scaphoid fractures are *horizontal oblique*, rather than *transverse.* Consequently, due to the obliquity of a fracture plane, the optimal screw entry point may not be centrally located when considering placing a screw perpendicular to the fracture plane. This considerably affects comparing volar and dorsal approaches with regard to the level of accessibility for screw insertion. As the fracture plane and screw axes are 3-D entities, a 3-D imaging technique to assess screw placement is required for a reliable comparison.

The purpose of this virtual simulation study was to investigate the accessibility of placing a screw perpendicular to the fracture plane in both *transverse* and *horizontal oblique* scaphoid fractures, and to compare volar and dorsal approaches. To this end, virtual three-dimensional (3-D) computed tomography (CT) midwaist scaphoid fracture models were used including 3-D models of the trapezium and distal radius to account for the potential obstruction. Our null-hypothesis is that there is no difference in precision of placing screws perpendicularly to the fracture plane between volar and dorsal approaches for both *transverse* and *horizontal oblique* scaphoid fractures.

2. Materials and methods

2.1. Three-dimensional CT modelling

In order to simulate screw placement, we created virtual 3-D CT scaphoid models accompanied by the trapezium in extended configuration and distal radius in flexed position, relative to the scaphoid. To this end, we used an existing anatomic database including bilateral wrist CT-scans from 20 healthy volunteers (10 men, 10 women; mean age 28 years: range: 21–40), without wrist complaints and history of wrist injury. High-quality scans were taken at 120 kV and 75 mAs with the wrist in neutral position. From these scans, we obtained virtual 3-D surface models of the scaphoid (Fig. 1), trapezium and distal radius based on custom-made 3-D modeling software. Additional low dose scans were taken at 120 kV and 15 mAs with the wrist in full active flexion and extension. The latter scans were used to find the flexed and extended position of respectively the trapezium and radius models with respect to the scaphoid, by registration of the bone models to the low dose images (Fig. 2). In two male wrists, part of the trapezium and/or radius were not captured on CT scan, as they felt out of the scanning volume. These two wrists were therefore excluded from further analyses. The remaining 38 virtual 3-D wrist models were transported to a commercially available 3-D architecture software (Rhinoceros, version 5.0; McNeel North America, Seattle, WA). This study was approved by our institutional review board. Informed consent was obtained from all individual participants included in the study.

2.2. Fracture planes

In each virtual 3-D scaphoid model, we simulated a transverse and horizontal oblique midwaist fracture plane (Fig. 1). To this end, we first determined the scaphoid inertial axes, corresponding to the proximal-to-distal axis, volar-to-dorsal axis, and ulnar-to-radial axis in an automated fashion [14,15]. The transverse fracture plane was set perpendicular to the proximal-to-distal axis at 50% of the scaphoid length. The horizontal oblique fracture plane had a dorsal proximal to volar distal inclination which was obtained by rotating the transverse plane over 34° around the ulnar-to-radial axis (Fig. 1) at 50% of the scaphoid length. This is in agreement with the average fracture plane obliquity as recently demonstrated in a 3-D imaging study of 124 acute scaphoid fractures [13].

2.3. Screw placement simulation

First, we defined *the perpendicular screw axis* as the axis perpendicular to transverse and horizontal oblique fracture planes through the center of the scaphoid in the waist area (Fig. 1). As there is no clear definition of the scaphoid center due to the curved, irregular geometry [16], we calculated the centroids of the proximal and distal poles in transverse cross-sections at 25% and 75% length and defined the scaphoid center as the point halfway these centroids.

To simulate screw placement, we considered a frequently used commercial screw with a 3.2 mm diameter, visualized as a cylinder running along the perpendicular screw axis (Figs. 1 and 2). If this cylinder was obstructed by one of the surrounding bones, an alternative, non-obstructed screw axis was chosen. This axis was placed at half the screw diameter (1.6 mm) away from the surrounding bone and as close to the perpendicular screw axis as possible, by pivoting it around the scaphoid center in 3-D space. In the volar approach, the best possible non-obstructed screw axis approached the scaphoid from the radial-volar aspect of the trapezium; in the dorsal approach this axis approached the scaphoid from the distal-dorsal aspect (i.e. dorsal rim) of the distal radius (Fig. 2). Our primary outcome measure was the angle between the best possible non-obstructed screw axis and the true perpendicular screw axis relative to the fracture plane (i.e. deviation angle), which deviated from zero in suboptimal cases of screw placement (Fig. 2). Simulation of screw placement and subsequent calculation of the deviation angle was repeated by the same observer at a separate occasion to investigate intra-observer agreement.

2.4. Statistical analysis

Statistical analysis was performed using SPSS statistical software, version 22.0 (IBM SPSS Statistics, Armonk, New York). Statistical analyses included determining the mean and standard deviation (SD) based on pooled data from the two readings. We used an independent one-sample T-test to compare deviation angles with zero for each approach and a paired T-test to compare the deviation angles between approaches. As measure of intra-observer agreement we used the 95% normal range (mean ±1.96 SD) of the differences in deviation angles between the two readings. A 5% significance level was used for all analyses.

3. Results

The mean difference (±SD) in deviation angles between the two readings was 0.4° (±0.8°); as a result, 95% of the differences between the two readings fall within 2°.

3.1. Transverse fractures

In the volar approach, the perpendicular screw axis was obstructed by the trapezium in 34 (89%) wrists, resulting in a mean deviation angle (±SD) of 8° (±5°), which was significantly different from zero ($P < 0.001$). In the dorsal approach, there was no obstruction by the distal radius, resulting in deviation angles equal to zero (Table 1).

3.2. Horizontal oblique fractures

In the volar approach, the perpendicular screw axis was obstructed in all wrists resulting in a mean deviation angle (±SD) of 40° (±6°) (Table 1). In 4 wrists, the volar approach resulted in deviation angles larger than 45°, indicating a more parallel than perpendicular placement. In the dorsal approach, there was obstruction in 35 (92%) wrists showing a smaller mean deviation angle (±SD) of 14° (±8°) ($P < 0.001$). Both angles were different from zero ($P < 0.001$).

4.1. Discussion

In conventional percutaneous screw fixation of midwaist scaphoid fractures, the screw is directed down the central axis of the scaphoid, irrespective of the fracture pattern [6,7], in either a dorsal and volar approach [17]. The increasing interest to insert screws perpendicular to the fracture plane may require a different screw insertion angle and a different approach [9-11]. We evaluated the feasibility of inserting a fixation screw perpendicular to the fracture plane for transverse and horizontal oblique fractures, in dorsal and volar approaches, by simulating surgery in 3-D virtual space. Based on our simulations, the dorsal approach was unobstructed for transverse fractures and required deviating slightly (mean: 13°) from perpendicular screw placement for most horizontal oblique fractures. In the standard volar approach, the deviation from perpendicular placement was much higher for horizontal oblique fractures (mean: 39°) than for transverse fractures (mean: 8°).

In a previous experimental scaphoid study, Chan et al. [17] found a better central screw placement in the dorsal approach, than in the volar approach, but they did not make any distinction between transverse or horizontal oblique fractures. Soubeyrand et al. [18] also investigated accessibility for scaphoid screw insertion based on virtual simulations using CT images from twelve cadaveric wrists. The dorsal approach allowed for the best virtual screw placement perpendicular to the fracture plane, which is in agreement with our findings. Soubeyrand et al. [18], however, used a single parasagittal slice to perform simulations in, instead of using a full 3-D approach. As previously stated, we deem a 3-D approach necessary as the fracture plane and screw axis are 3-D entities.

In actual scaphoid fractures, the fracture plane is not as flat as in the case of our simulation study which may be considered a limitation. Nevertheless, the use of flat fracture planes is well-accepted in scaphoid research including cadaver studies [6,7,19]. We further evaluated screw insertion for the most-frequently occurring scaphoid fracture types and therefore excluded rare fracture types such as a vertical oblique fracture plane in the waist area [20,21]. Another limitation is that our volunteers actively kept their wrist in flexion or extension while in patient cases, the wrist is moved passively, sometimes using traction assistance or techniques to lever the trapezium, with a possible higher range of motion. Still, many surgeons use a simple volar technique with the wrist in hyperextension over a towel roll [4,22-24], which is comparable to the hyperextended wrists of our volunteers. An advantage of our simulation study compared to a clinical study is the retrieval of a large sample size in a short time span in a standardized fashion.

Placing a fixation screw perpendicularly to the fracture plane may have biomechanical advantages in terms of fracture healing, although this requires future evaluation in clinical setting. To recommend one approach over another, besides screw orientation, the surgeon should also consider screw length, number of screw threads across the fracture site, screw purchase and risk of protrusion.

In percutaneous scaphoid screw fixation, usually, first a guide wire is inserted under fluoroscopic guidance. In scaphoid surgery, precise control upon first pass of the guide wire is of utmost importance as each passing makes the next attempt more difficult [25]. To precisely insert the guide wire the first time, studies have investigated the use of navigation systems based on preoperative planning [26]. A precise insertion, however, may be hampered due to the complex 3-D shape of the scaphoid and the inability to show more than one view simultaneously when using standard fluoroscopy. To improve verification of the guide wire position, additional intraoperative 3-D imaging modalities including 3-D imaging fluoroscopes may be used, although artifacts caused by the wire may be a limiting factor [25]. Currently, these systems are still in their early stages, being time- and resource intensive due the complex workflow, limiting utilization in standard clinical practice [27]. In efforts to improve guide wire insertion precision, knowledge about the degree of screw orientation becomes increasingly relevant. The current simulation study quantified the benefit of the dorsal approach in precisely placing a screw perpendicular to the fracture plane, especially in horizontal oblique scaphoid fractures.

Level of evidence

N/A

Disclosure of interest

G.M. certifies that he has received payments or benefits during the study period from Depuy and Johnson and Johnson for consultancy work. The other authors (P.W.T.B; J.G.D.; M.E.B., S.D.S.; F.V.; G.J.S.) declare that they have no conflict of interest.

Ethical review committee statement

Approval of project MEC 2013_242 (use of volunteer data). All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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Tables

Table 1

Mean values of screw placement after simulated scaphoid screw insertion in 38 wrist models

	Transverse fractures		**Horizontal Oblique fractures**	
	Approaches*		**Approaches***	
	Volar	**Dorsal**	**Volar**	**Dorsal**
Deviation angle α (SD)	8º (5)†	0□ (0)	40º (6)†	14º (8)†

Percentage wrists with obstructed perpendicular screw axis	89%	0%	100%	92%

α: angle between best possible non-obstructed screw placement and true perpendicular screw placement. *Angles of volar and dorsal approaches were significantly different (both $P <$ 0.001); †Angles significantly different from zero (all P <0.001)

Figure legends

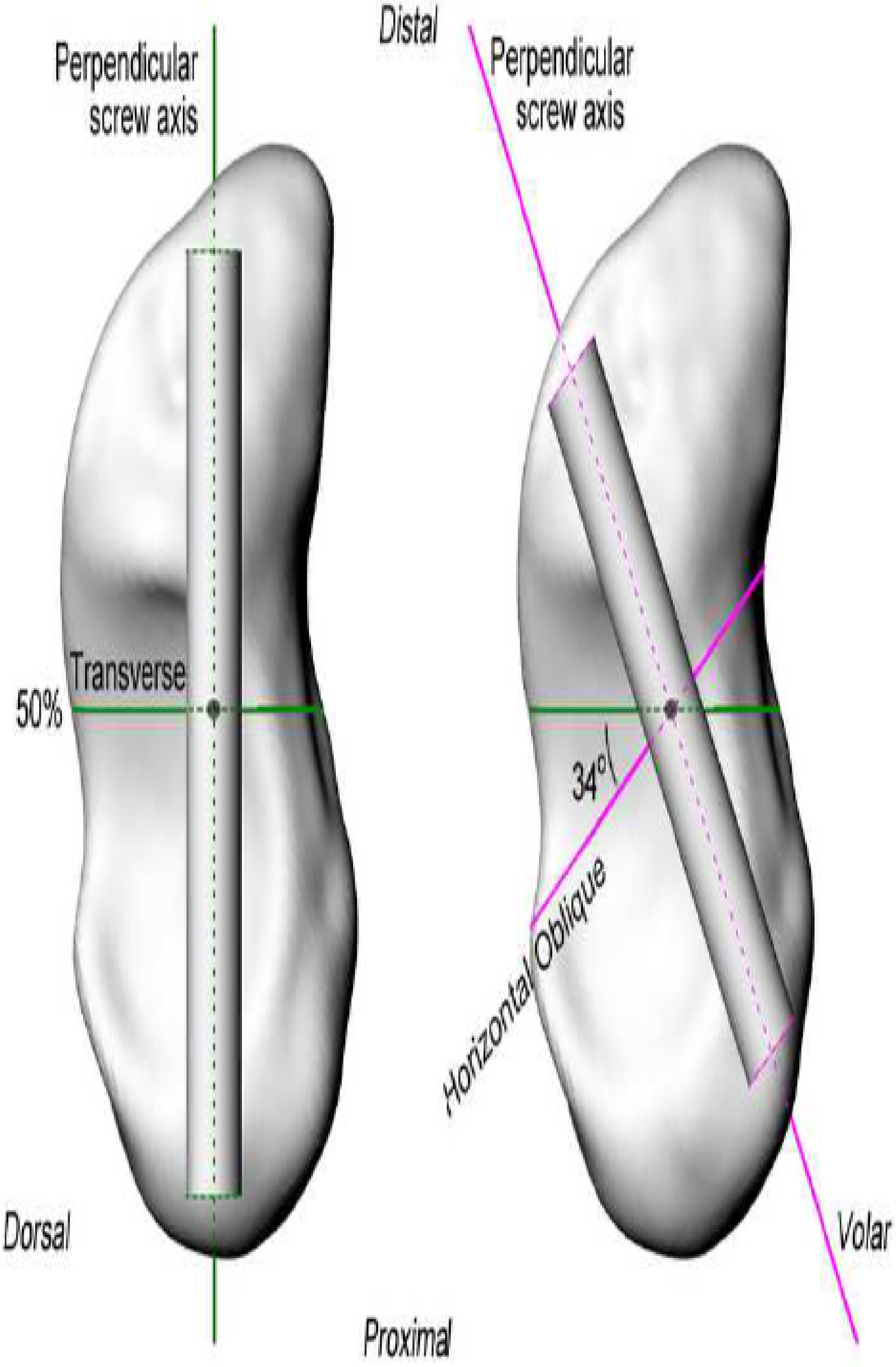
Distal
Perpendicular screw axis
Perpendicular screw axis
Transverse
50%
34°
Horizontal Oblique
Dorsal
Volar
Proximal

Fig. 1. Ulnoradial view showing 3-D CT scaphoid models with a screw axis perpendicular to a transverse fracture plane (left) and horizontal oblique fracture plane (right), running through the scaphoid center (black dot). The transverse plane was set at 90° to the proximal-to-distal axis (not shown) at 50% scaphoid length; the oblique plane was obtained by rotating the transverse plane 34° around the ulnoradial axis (perpendicular to the viewing plane). The cylinders in the models represent a standard screw with a 3.2 mm diameter. For visibility the cylinders are placed in front of the scaphoid.

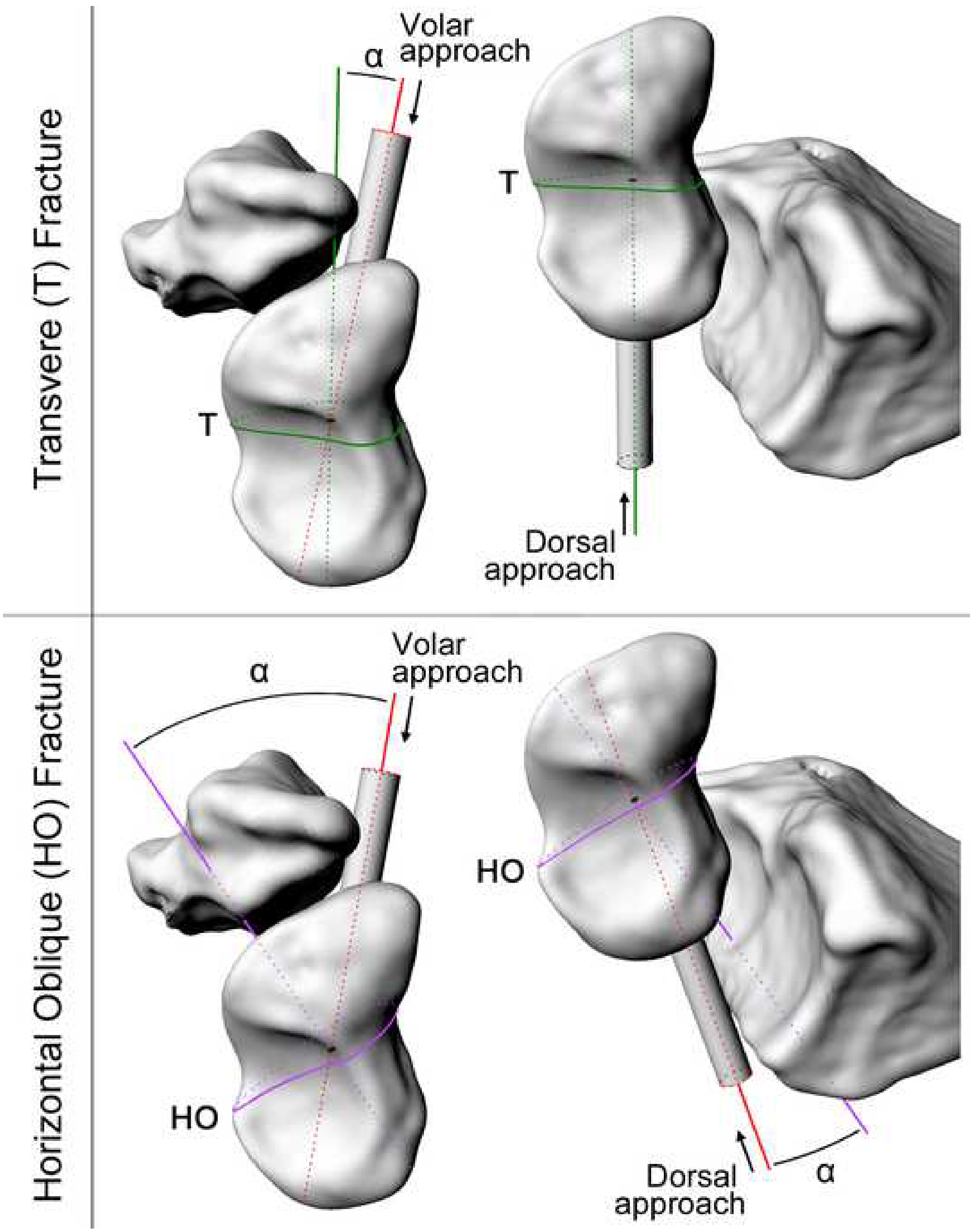

Fig. 2. Three-dimensional CT images showing screw placement simulation in volar and the dorsal approaches. The green and purple axes are perpendicular to the transverse (T) and horizontal oblique (HO) fracture planes, respectively. In case the surrounding bone obstructed the perpendicular screw axis with a 3.2 mm diameter cylinder, an alternative, non-obstructed screw axis (red) was chosen at half the screw diameter (1.6 mm) away from the surrounding bone using the scaphoid center as pivot point. In case of no obstruction, screw axes were

placed along the perpendicular screw (top right image). α: deviation angle between the best possible non-obstructed screw placement and true perpendicular screw placement.