Establishing a central zone in scaphoid surgery: a computational approach

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Abstract

Purpose Scaphoid fractures are commonly fixed with headless cannulated screws positioned centrally in the scaphoid. Judgement of central placement of the screw may be difficult. We generated a central zone using computer analysis of 3D reconstructions of computed tomography (CT) images. As long as the screw axis is completely contained within this central zone, the screw would be considered as centrally placed.

Methods Thirty cases of 3D CT reconstructions of normal scaphoids in a computerised operation planning and simulation system (Vxwork software) were obtained. The central zone was established after some distance shrinkage of the original scaphoid surface reconstruction model using the function “erode” in the software. The shape of the central zone was evaluated, and the width of the central zone in the proximal pole, waist portion and distal pole was measured. We also established the long axis of the scaphoid to see whether it stays in the central zone.

Results All central zones could be divided into distal, waist and proximal portions according to the corresponding irregular shape of the scaphoid. As the geometry of the central zone was so irregular and its width very narrow, it was possible to completely contain the screw axis either in the proximal portion alone, waist alone or distal central zone alone.

Conclusions Establishing the central zone of scaphoid 3D CT images provided a baseline for discussion of central placement of a scaphoid screw. The geometry of the scaphoid central

zone determined that the screw could hardly be inserted through entire scaphoid central area during surgery.

Keywords Computed tomography · Spiral · Central · Screw · Scaphoid bone · Image processing · Computer-assisted

Introduction

Screw fixation of an acute scaphoid fracture or nonunion is a popular technique due to its well-known mechanical advantages. The optimal position of this screw has been discussed frequently in recent years [3, 9]. Central placement, as supported by biomechanical studies that have examined scaphoid fractures in a cadaveric model, is accepted as one of the preferred methods of internal fixation [10, 18]. Central placement of the screw could be determined either by Trumble et al.’s [18] central one-third proximal-pole criterion on anteroposterior (AP) and lateral X-rays or roughly follow the overall scaphoid central axis as reported by some authors [11, 16]. Both of these concepts were based on 2D plain films. As the concept of central may be different between the proximal or distal part of the scaphoid due to its twisted shape, it is necessary that the entire central area other than the proximal pole be defined and considered.

During the last decade, the continued developments in computed tomography (CT) and computer technology has enabled a generation of 3D models allowing a more accurate demonstration of scaphoid geometry [5, 7]. We borrowed the concept of a central one third of the scaphoid and developed a computer programme to establish an entire central third zone within the entire scaphoid reconstruction model. To simplify the discussion, we further established a central zone 1.5 mm inside the central-one-third-zone model. As long as the screw axis is completely contained within this central zone, the position of the screw can be considered to be in the central one third, or the so-called central zone, inside the scaphoid.

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Materials and methods

CT scans of 30 wrists (22 men, eight women; average age of 36 years) were randomly selected from the existing CT Digital Imaging and Communications in Medicine (DICOM) database [16]. The hospital management and the ethics committee gave written permission to perform this study. The clinical diagnoses comprised 18 patients with a distal radial fracture, eight with a carpal bone fracture apart from that of the scaphoid and four with ulnar impingement syndrome. CT data were obtained from a 64-row spiral CT scan (Aqualin, Toshiba Corporation Medical Systems Company, Otawara, Japan) (120 kV, 100 mA, 0.5 s scan time, field of view ~300.0 mm, and 0.5-mm slices, 256×256). Data was saved in the DICOM format. A 3D reconstruction of the scaphoid bone was extracted with an interval of 0.3 mm using a commercially available simulation and surgical planning system (Zhouge Vxwork, Beijing, China). The scaphoid was separated semimanually based on the volume and surface reconstruction model in magnified images in the software. The volume reconstruction threshold was set at 116 for bone tissue reconstruction. A 3D region within the scaphoid—termed the central zone—was computed to delineate when a screw axis was completely placed within this zone, and the screw would therefore be considered centrally placed in the scaphoid. The following steps generated the central zone:

1. In step 1, we shrank the scaphoid surface model in a uniform manner using the function “erode” in the software (Fig. 1). One pixel space (d) was allowed by one shrinkage in the programme. The CT scan matrix and field of view determined the value of the pixel space (d).
2. Step 1 was repeated, and the surface model became smaller until the scaphoid waist portion disappeared. Repeat times were documented as (T). Thus, the distance

Fig. 1 Shrinkage of the reconstructed scaphoid surface was obtained using the erode function in the software until the waist portion disappeared

between the innermost surface model and the original scaphoid was calculated: $L=d \times T$ (Fig. 2).

3. Next, the central one third of the scaphoid was determined by generating a surface model located two thirds of L inside the original cortical bone surface model (Fig. 2).
4. The central zone was computed as a surface model 1.5-mm (screw radius inside the central one third of the scaphoid (Fig. 2). A straight line was introduced into the programme as the screw axis. As long as this line could be completely placed into this central zone, the Herbert screw (Zimmer) would be considered as being within the central one third of the scaphoid. We also measured the widest part of the central zone in the distal and proximal poles and waist portion of the AP and radial ulnar direction, documented as W1, W2, W3 and H1, H2, H3, as shown in Fig. 3 (results in Table 1). We did not do a statistical analysis to compare values between men and women, because the number of study scaphoids was limited.

We also established the long axis of the scaphoid by the method described in our previous paper [5] to determine whether the long axis stays in the central zone.

Results

All central scaphoid zones could be divided into distal, waist and proximal portions according to the corresponding geometry. As the contour of the central zone was so irregular and the width very narrow in the AP direction (Table 1), it was difficult in every surface model to draw a straight screw axis completely through the entire central zone region—from proximal pole to distal pole. It is much easier to put the screw axis into the proximal central zone alone, waist portion alone or distal central zone alone. These results indicate that a straight screw could not be completely contained through the entire central one third of the scaphoid. A screw axis placed along the distal central zone would pierce the distal cortex at the trapezial facet. If the axis is contained in the proximal central zone, the exit point of this line on the distal scaphoid cortex would be at the centre of the scaphoid tubercle, very close to the distal point of the long axis we calculated earlier (Fig. 4).

Regarding the long axis, our results show that most of the long axis stayed outside the central zone. That is to say, the long axis might not be an optimal option (Fig. 5).

Discussion

This is not the first time that investigators have attempted to use radiographic images to identify the central position for scaphoid screw placement [7–9, 18]. The purpose of this study

Fig. 2 After the waist portion disappeared, we created the central one-third zone and central zone of the scaphoid

was to identify the criterion of central placement for a scaphoid screw using tools with greater accuracy, as earlier described by us. We borrowed the concept of the central one third zone from Trumble et al.'s theory [18] and used the central zone established from 3D images to replace the central one third of the scaphoid in order to simplify the discussion.

It has been shown in biomechanical and clinical study that central placement of a scaphoid screw improves the healing rate and reduces the immobilisation period of a scaphoid fracture [10, 13, 18]. Trumble et al. [18] reported that the scaphoid screw located in the central scaphoid was associated with shorter union time based on their clinical data of 34 patients. McCallister et al. [10] later confirmed this theory with biomechanical testing, directly comparing central versus eccentric screw placement in cadaver scaphoids. Both studies showed that for central screw placement criteria to be determined, the screw needed to be placed in the central one third of the proximal pole of the scaphoid in AP and lateral X-rays. In our opinion, the width of the scaphoid on AP X-ray is subject to projection position, especially the part adjacent to the capitate. On lateral X-rays, because of the overlapping carpal bones, the central one third of the proximal pole is also difficult to identify. Therefore, in this study, we used 3D image analysis to replace a two dimensional evaluation. Moreover, the central one third of the scaphoid bone, other than the proximal pole, was not mentioned in previous papers. Our study showed it is impossible to insert a screw guidewire contained completely within the distal pole of the central zone to the proximal pole of the central zone due to the very narrow and irregular curvature of the central zone. In fact, the fracture line may run transversely, horizontally or vertically from the waist portion to the distal or proximal third of the scaphoid [1, 12, 16, 17]. When the fracture line runs in the proximal half, screw-axis placement in the proximal central zone should undoubtedly be considered central; however, when the fracture line runs distally, the question becomes: Should the screw axis in the proximal central zone be considered central or not? Our study suggests that the answer is “no”. Because there is no

Fig. 3 Measurement of the width of the proximal central zone, distal central zone and waist portion of the central zone. **a** Dorsal palmar view. **b** Side view

Table 1 Average measurements (millimetres) of central zone widths of male and female patients

L, W1, W2, W3, H1, H2, H3

	L	W1	W2	W3	H1	H2	H3
Male	0.62±0.03	1.12±0.15	0.93±0.08	2.11±0.23	3.15±0.35	1.08±0.15	2.23±0.28
Female	0.48±0.04	1.05±0.98	0.85±0.09	1.53±0.17	2.28±0.32	0.86±0.12	2.02±0.19

such universal “central zone” for all fractures, surgeons must clarify which part of the scaphoid should be considered as “central” when determining the screw’s “central placement.” Furthermore, hand surgeons must decide which part of the central zone to follow when they insert the guidewire. For example, for a transverse oblique fracture in the narrowest part, the waist region, the surgeon could insert the screw along the central zone of the waist region in order to ensure it enters sufficient bone mass on both sides of the fracture plane. When the fracture extends to the proximal part of the waist region, placing the screw along the proximal central zone is more appropriate. After one part of the central zone is selected, then insertion angle and entry and exit points can be calculated on this preoperative planning system.

Some authors report using the concept of a central axis and emphasise that the guidewire should follow this axis to ensure central placement of the screw. As the exact position of this axis has never described in detail, judging whether or not a screw is centrally placed in the scaphoid is somewhat arbitrary and imaginary. As the scaphoid bone has an irregular geometry, common sense is that one central axis, if it exists, is not a straight line. Therefore, to insert the guidewire 100 % along the central axis may not be possible; no author has reported how much deviation of the guidewire away from the central axis is permitted under the concept of central placement. Our study shows it is impossible to draw a straight line through the

entire, very narrow, central zone to use as a screw axis. We established the central zone to be 1.5-mm inside the central one third of the scaphoid surface model, because the heading-thread diameter of the current Herbert screw was 3.0 mm. The thinner the diameter of the screw, e.g. Herbert mini (heading thread 2.5 mm), the wider the central zone and the easier it becomes to determine the central axis for screw-placement axis. Average width of the central zone in the waist region in the AP direction in our study was around two millimetres, showing that a two millimetre deviation of the guidewire may make it appear peripheral in the waist region. Considering the diameter of the guidewire is one millimetre, it is not easy to surgically insert a guidewire completely into such a narrow central zone.

The necessity of partial trapeziectomy has been questioned when the volar approach is taken during scaphoid surgery [4, 15]. Some authors suggest that the trapezium resection could not be avoided when attempting to insert the screw centrally. Opponents claim this would increase the chance of degenerative change in the scaphotrapezial joint [6, 14]. Our study suggests such results are partly due to different determinations of “central” placement of a screw. Our study shows the entry point on the distal surface of the scaphoid was different if attempting to insert the screw in a different part of the central zone. The entry point moved away from the radial edge of the trapezium to the centre region of the scaphoid tubercle, whereas the insertion of a guide moved from along the distal central zone to along the proximal central zone. The average distance from the centre of the scaphoid tubercle to the radial edge of

Fig. 4 The screw axis could be located centrally in one part of the central zone (1 proximal pole, 2 waist portion, 3 distal pole) but could not be contained in the entire central zone. When the screw axis is contained in the proximal central zone, the entry point using the palmar approach would be at centre of the scaphoid tubercle (1), when screw axis is contained in the distal central zone, the entry point would be inside the trapezial–scaphoid joint (3). Tm trapezium, C capitate, L lunate, R radius

Fig. 5 The largest part of the long axis of the scaphoid is located outside the central zone

the trapezium was around 1.5 mm, as calculated in our previous study [5], with the wrist in the neutral position. Based on these findings, if a screw axis is contained within the proximal central zone, there will be some space between the entrance point on the scaphoid and the trapezium.

Using a larger number of patients might possibly yield different results. Different scaphoid shapes have been reported, so it is possible that this variability could affect the shape of the central zone and the positional relationship of the long axis and the central zone [2, 19, 20].

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