Comparison of Percutaneous Dorsal Versus Volar Fixation of Scaphoid Waist Fractures Using a Computer Model in Cadavers

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Purpose Percutaneous screw fixation (PSF) is widely used to treat acute nondisplaced scaphoid waist fractures. PSF can be performed through a volar or dorsal approach. The aim of our study was to compare a dorsal versus volar surgical approach for PSF according to the sagittal orientation of the waist fracture (B1 or B2 in Herbert and Fisher's classification scheme, in which B1 and B2 designate, respectively, oblique and transverse nondisplaced scaphoid waist fractures) on computer modeling of cadaver wrists.

Methods We used 12 upper limbs, and for each wrist we performed 3 computed tomography scans in maximal flexion, neutral position, and maximal extension. For each position, a parasagittal slice corresponding to the plane of ideal screw placement was obtained by numerical reconstruction. On each slice, we modeled B1- and B2-type fractures and the placement of the corresponding screws (S1 and S2) inserted through a volar or dorsal approach. Optimal screw orientation was perpendicular to the fracture. For each configuration, we measured the angle between the S1 screw and B1 fracture, which we designated V1 when modeling volar PSF and D1 when modeling dorsal PSF. Similarly, we measured angles V2 and D2.

Results For B2 fractures, virtual screw placement perpendicular to the fracture was achieved equally well with the 2 approaches. For B1 fractures, the virtual screw could not be placed perpendicular to the fracture with either approach, but the dorsal approach with maximal wrist flexion allowed the best screw placement.

Conclusions For B2 fractures, the dorsal and volar approaches allow optimal virtual screw placement, and the choice of the approach depends on the surgeon's preference. For B1 fractures, we recommend the dorsal approach. *(J Hand Surg 2009;34A:1838–1844. Copyright © 2009 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Scaphoid fractures, percutaneous screw fixation.

THE SCAPHOID IS the most frequently fractured carpal bone. The annual incidence of scaphoid fracture has been estimated at 43 fractures per 100,000 people,[1] 8 in 100,000 in women, and 38 in 100,000 in men.[2] Most scaphoid fractures are not displaced and involve the scaphoid waist.[3]

Acute nondisplaced fractures of the scaphoid waist can be treated either with cast immobilization or with

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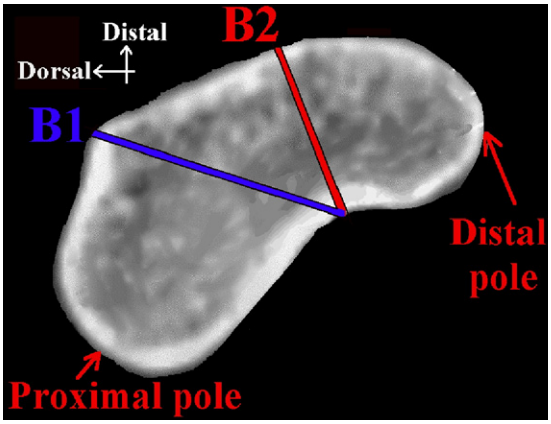

FIGURE 1: Aspect of the scaphoid after reconstruction of the parasagittal slice. Modeling of B1- and B2-type fractures (according to Herbert and Fisher[4]) is shown.

percutaneous screw fixation (PSF). Scaphoid fractures are generally described using Herbert and Fisher's classification scheme,[4,5] in which B1 and B2 designate, respectively, oblique and transverse nondisplaced scaphoid-waist fractures that are good indications for PSF, as explained by Haisman et al.[5] Because of the lack of fracture displacement, no reduction requiring wrist opening is necessary. Moreover, the location of the fracture at the level of the waist allows good fixation of the screw in both the proximal and distal poles. B1 and B2 fractures differ regarding their sagittal orientation (Fig. 1). The screw must be as perpendicular as possible to the fracture to induce maximal compression forces and minimal shearing forces, thereby optimizing the stability of the fixation.[6] Compression loading is an important factor for bone healing.[7–10]

Percutaneous screw fixation for scaphoid-waist fractures can be performed through a volar approach[11–16] or through a dorsal approach.[17–19] Final screw placement in the scaphoid is determined by the entry point and orientation of the screw, which in turn depend on the shape of the scaphoid and on the neighboring bones (radius and trapezium). With the dorsal approach, access to the tip of the proximal pole, and, therefore, optimal screw orientation, are impeded by the posterior margin of the distal radius unless the wrist is flexed maximally. With the volar approach, the trapezium hinders access to the tubercle and optimal orientation of the screw,[20,21] requiring either maximal wrist extension[11–13] or the use of finger traps to hold the wrist in neutral position.[14–16] Thus, PSF for acute nondisplaced scaphoid waist fractures can be done via the dorsal approach with the wrist in maximal flexion, via the volar approach with the wrist in neutral position, or via the volar approach with the wrist in maximal extension.

The objective of this cadaver study was to compare a dorsal versus volar surgical approach, in terms of screw placement, according to the sagittal orientation of acute nondisplaced scaphoid-waist fractures on computer modeling of cadaver wrists.

MATERIALS AND METHODS

Materials

We used 12 upper limbs from fresh-frozen cadavers thawed 24 hours before the study. Of the 12 wrists used in this study, 7 were male and 5 were female. The mean age was 75 years (range, 68–89 years). The humerus was cut at the midshaft and all soft tissues were preserved. Each limb was assessed clinically and by anteroposterior and lateral fluoroscopy of the wrist to rule out previous trauma or surgery, as well as anatomic abnormalities.

Methods

Computed tomography (CT) of each wrist was performed in maximal flexion, neutral position (without radial or ulnar inclination), and maximal extension. An external fixator (Hoffman 2; Stryker, Kalamazoo, MI) maintained each position with pins implanted in the index finger metacarpal and radius. Additional pins were placed in the ulna and the humerus to immobilize the forearm in neutral rotation and the elbow at 90° flexion. For each wrist, the angles of maximal flexion and extension were measured using a goniometer placed on the dorsal side of the radius and third metacarpal. We used a 16-multidetector computerized scanner (Sensation 16; Siemens Medical Solutions, Munich, Germany). Three orthopedic surgeons participated in the study. Each surgeon performed reconstructions and measurements for all CT scans.

Reconstruction protocol

We performed multiplanar reconstructions, image analyses, and measurements using Carestream PACS 10.1 software (Kodak Carestream Health, Rochester, NY). The aim was to build a parasagittal slice of the scaphoid in the plane where an optimally placed screw would be located. We used the optimal screw-placement criteria developed by Menapace et al.[22] The parasagittal slice was obtained using a 2-step procedure, as shown in Figure 2. First, a slice parallel to the lunate surface of the scaphoid was built. Second, this slice was rotated to pass through the center of the proximal pole and tubercle of the scaphoid. The Carestream PACS 10.1 software allowed us to perform real-time 2-dimensional reconstruction with interactive windows. We started from the frontal reconstruc-

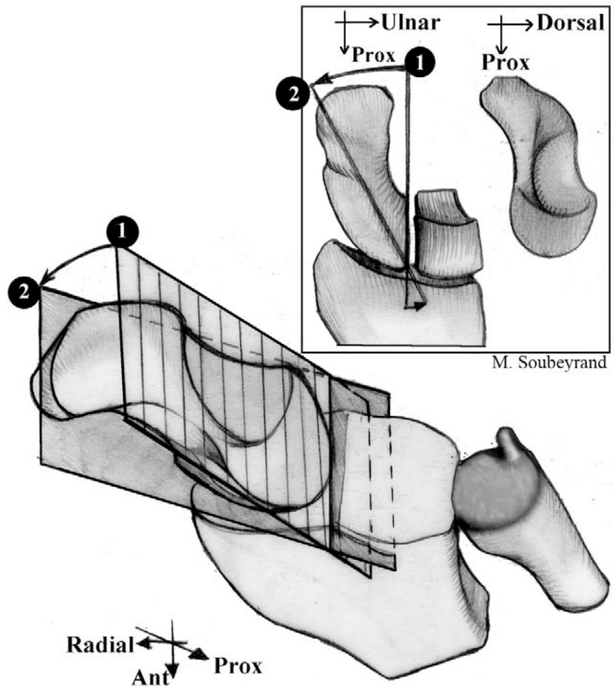

FIGURE 2: Reconstruction protocol for obtaining the parasagittal slice. First, a slice corresponding to the plane parallel to the lunate surface of the scaphoid bone was obtained (1). This slice was rotated to obtain a second slice (2) through the tubercle and middle of the proximal pole.

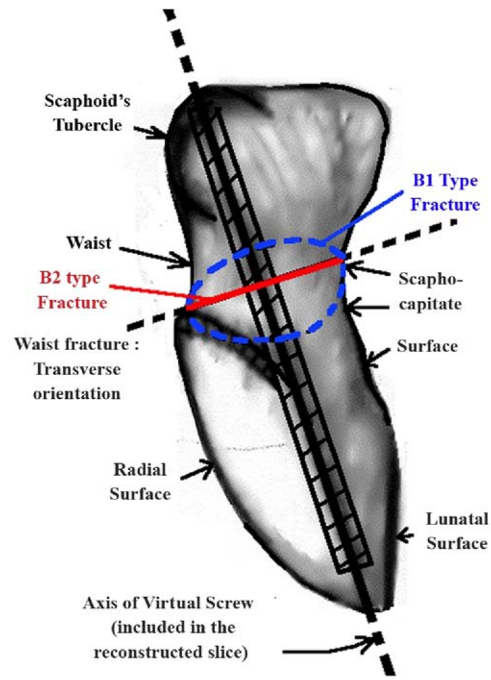

FIGURE 3: View of the model in the coronal plane. The screw passes through the tubercle and middle of the proximal pole. The coronal orientation of the fracture is transverse according to Russe's[3] classification.

tion in the first window. On this window, a line corresponding to a parasagittal plan was moved and rotated with a cursor to pass through the proximal pole and the scaphoid tubercle. During rotation of this line, the corresponding parasagittal slice was reconstructed in real time. We did not measure the rotation angle of the line because it was not the aim of our study. When the parasagittal reconstruction was correct, modeled B1- and B2-type fractures and screw position were drawn with the line tool. Then, the compass tool was used to measure each angle. For each wrist, a slice was built for each of the 3 positions (maximal flexion, neutral, and maximal extension). Measurements were made on each reconstructed slice.

Measurement protocol

On each reconstructed slice, we simulated the placement of a screw 2.2 mm in diameter inserted into the scaphoid. This diameter corresponds to a cannulated screw according to Herbert and Fisher.[4] On each slice, based on the detailed anatomic descriptions of Compson et al,[23,24] we located the edges of the following anatomic landmarks (Fig. 1): scaphoid tubercle, distal pole, waist, proximal pole, and tip of the proximal pole. Then, we modeled B1- and B2-type fractures according to Herbert and Fisher's classification scheme, and we drew them on the slice. The sagittal orientation of the virtual B1-type fracture was orientated proximally and posteriorly, parallel to the scaphoid's sulcus, which corresponds to the most frequent fracture pattern as reported by Compson et al.[25] There is agreement between Herbert and Fisher's classification and anatomical fractures description made by Compson et al[25]: Herbert and Fisher's B2- and B1-type fractures respectively correspond to waist transversal fractures and sulcal oblique fractures, as described by Compson et al. In a series of 91 acute fractures, Compson et al found 24 waist transversal fractures and 39 sulcal oblique fractures. For each fracture type (B1 and B2), the placement of 2 virtual screws (S1 and S2, respectively) was modeled. In the reconstructed slice, the direction of the screw tended toward the line perpendicular to the relevant fracture. We postulated that fracture orientation in the coronal plane was the same throughout the study (Fig. 3)–that is, transverse according to Russe's classification scheme.[3]

Placing a rectilinear screw into the sagitally curved scaphoid bone is challenging (Fig. 1). The curve is largely due to the anterior concavity of the volar aspect of the scaphoid.

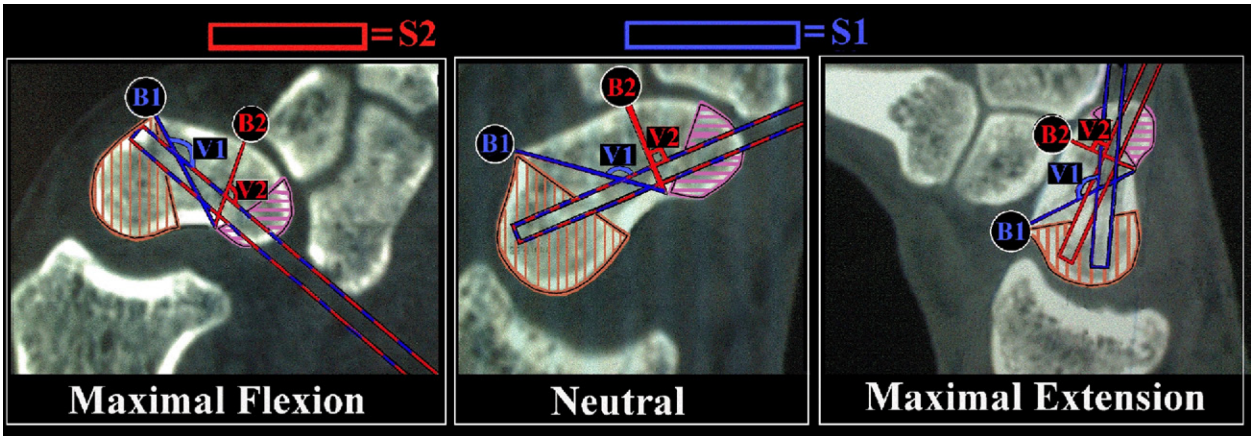

FIGURE 4: Modeling of volar percutaneous screw fixation in maximal flexion, neutral position, and maximal extension. S1, screw 1 corresponding to the B1 fracture; S2, screw 2 corresponding to the B2 fracture; V1, angle between S1 and the B1 fracture; V2, angle between S2 and the B2 fracture.

Modeling volar PSF

The rules for volar placement of each virtual screw were as follows: entry point fully included within the tubercle, screw as perpendicular as possible to the relevant fracture line without penetrating the trapezium or exiting the scaphoid, and screw tip fully included within the proximal pole (Fig. 4). We measured the angles between the virtual screws (S1 and S2) and the corresponding fractures (B1 and B2, respectively). These angles were called V1 and V2, respectively.

Modeling of dorsal PSF

The rules for dorsal placement of each virtual screw were as follows: entry point fully included within the tip of the proximal pole, screw as perpendicular as possible to the relevant fracture line without penetrating the posterior margin of the radius or exiting the scaphoid, and screw tip fully included within the distal pole (Fig. 5). We measured the angles between the virtual screws (S1 and S2) and the corresponding fractures (B1 and B2, respectively). These angles were called D1 and D2, respectively.

Statistical analyses

Quantitative variables are reported as median and interquartile range (IQR) and qualitative variables as counts and proportions. The IQR is the 25th and 75th percentiles. Together with the median, it gives the values that separate the sample into 4 equally populated subgroups. To ensure that the angles measured by the different observers could be compared, we first assessed rater reliability using the intraclass correlation coefficient (ICC)[26]; 2-sided bootstrapped 95% confidence intervals (95% CIs) of ICC were determined. Then, we performed a global test of no effect of wrist position on angles V1 and V2 at the .05 level using analysis of variance. When a significant global effect was found, pairwise within-group comparisons were performed at the .01 level. Finally, angles V1, V2, D1, and D2 were compared using the nonparametric Wilcoxon test for each wrist position with the optimal 90° angle that yielded the best mechanical properties. All analyses were performed using R software (http://CRAN.R-project.org/doc/FAQ/R-FAQ.html; ISBN 3-900051-08-9).[27]

RESULTS

Median maximal flexion was 86° (IQR, 81° to 87°) and median maximal extension was 72° (IQR, 70° to 75°).

Modeling volar PSF

In maximal flexion, the median value of angle V1 was 162° (IQR, 156° to 165°) and the median value of angle V2 was 111.5° (IQR, 110° to 113°; Table 1). In the neutral position, the median value of angle V1 was 143.5° (IQR, 140.5° to 145°) and the median value of angle V2 was 90° (IQR, 90° to 90°). In maximal extension, the median value of angle V1 was 126° (IQR, 122° to 127°) and the median value of angle V2 was 90° (IQR, 90° to 90°).

Modeling dorsal PSF

In maximal flexion, the median value of angle D1 was 106° (IQR, 104° to 109°) and the median value of angle D2 was 90° (IQR, 90° to 90°; Table 1). In neutral position and maximal extension, we were unable to place the virtual screw because the tip of the proximal pole was covered by the posterior margin of the distal radius.

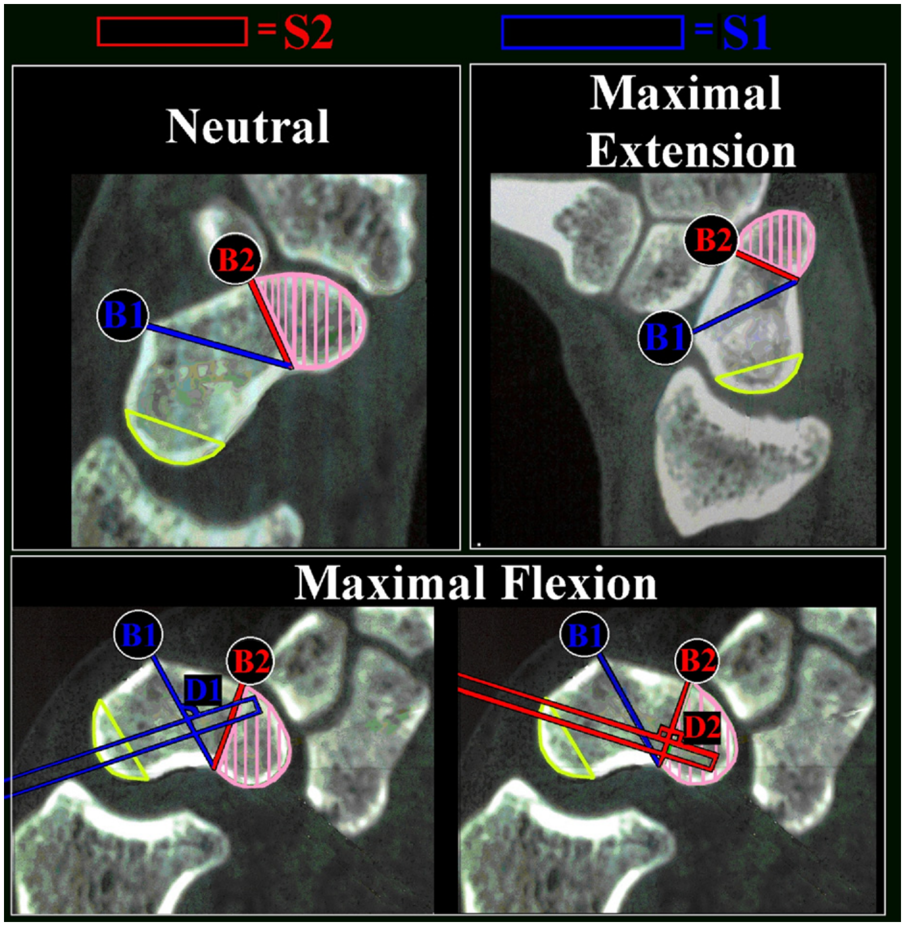

FIGURE 5: Modeling of dorsal percutaneous screw fixation in maximal flexion, neutral position, and maximal extension. S1, screw 1 corresponding to the B1 fracture; S2, screw 2 corresponding to the B2 fracture; D1, angle between S1 and the B1 fracture; D2, angle between S2 and the B2 fracture. The tip of the proximal pole is covered by the radius when the wrist is in neutral position or maximal extension, precluding percutaneous screw fixation.

TABLE 1. Median Values of Angles V1, V2, D1, and D2 According to Wrist Position

Modeled Procedure	Angle	Wrist Maximal Flexion	Wrist Neutral Position	Wrist Maximal Extension
Volar PSF	V1	162° (IQR:156°–165°)	143.5° (IQR:140.5°–145°)	126° (IQR:122°–127°)
	V2	111.5° (IQR:110°–113°)	90° (IQR:90°–90°)	90° (IQR:90°–90°)
Dorsal PSF	D1	106° (IQR:104°–109°)	*x*	*x*
	D2	90° (IQR:90°–90°)	*x*	*x*

The *x* value means that placement of the virtual screw was impossible because the tip of the proximal pole was covered by the posterior margin of the distal radius.

Interrater agreement was excellent for angles V1 (ICC, 98.9%; 95% CI, 98.4% to 99.2%), V2 (ICC, 99.2%; 95% CI, 98.8% to 99.6%), D1 (ICC, 80%; 95% CI, 47.6% to 87.2%), and D2 (perfect correlation; ICC not applicable).

For V1 angles, statistically significant differences were found between flexion and neutral position ($p < .001$), flexion and extension ($p < .001$) and extension and neutral position ($p < .001$).

For V2 angles, statistically significant differences were found between flexion and neutral position ($p < .001$) and between flexion and extension ($p < .001$). V2 values measured with the wrist in extension and neutral position were not significantly different.

When we compared the angles modeled on the CT image with the ideal 90° angle, only B2-type fractures with the volar approach in neutral position or extension, or with the dorsal approach with flexion, led to the screw being perpendicular to the fracture ($p < .005$). Screw placement perpendicular to the fracture could not be achieved with any other fracture type, approach, or wrist position configuration.

DISCUSSION

Scaphoid fractures are common,[1,2] usually nondisplaced, and usually located in the waist of the bone.[3] PSF of B1- and B2-type fractures[4,5] requires precise screw placement, ideally perpendicular to the fracture. However, surrounding anatomical structures hinder optimal screw placement. In this cadaver study, we found that the screw could be placed perpendicularly to B2-type fractures (transverse) using either the volar or the dorsal approach. With B1-type fractures (oblique), in contrast, screw placement perpendicular to the fracture could not be achieved with either approach.

Dorsal PSF requires flexion of the wrist and insertion of the screw between the extensor tendons, then through the dorsal aspect of the capsule. The screw is then inserted through the cartilage at the tip of the proximal pole and buried deep in the subchondral bone. However, numerous neighboring structures may be damaged. An experimental study of dorsal PSF in 12 cadavers showed that the extensor digitorum communis, extensor indicis proprius, and posterior interosseous nerve were at risk for injury; in addition, the screw protruded into the scaphoradial joint in 2 cases.[17] In a case-series study of combined distal radius and scaphoid fractures treated by arthroscopic and percutaneous fixation, iatrogenic rupture of the extensor pollicis longus tendon occurred in 1 of 7 patients.[28] Complications recorded during a retrospective review of 24 scaphoid fractures treated with dorsal PSF included failure of a screw to capture the distal fragment, requiring reoperation; and intraoperative breakage of a guidewire because of failure to maintain the wrist flexed during manipulation.[19]

Volar PSF can be performed with the wrist either in maximal extension or held in neutral position with finger traps. The incision is located at the level of the scaphotrapezial joint and the screw is inserted in the distal tubercle of the scaphoid. The main difficulty with this approach is that the trapezium hinders guidewire insertion and orientation.[20] The scaphotrapezial joint may be damaged by the drill or by protrusion of the screw. In a prospective, randomized study of 83 patients, the prevalence of scaphotrapezial osteoarthritis was significantly higher with a Herbert and Fisher–type screw than with a cast.[29] Degenerative changes in the scaphotrapezial joint after volar screw insertion have been found in other studies.[30–32] Of 25 patients randomly allocated to conservative or percutaneous treatment of nondisplaced scaphoid fractures, 1 experienced pain from a prominent screw in the distal scaphoid, which had to be removed.[13] A transtrapezial volar approach that abolishes obstruction by the trapezium and allows more central screw placement has been described.[21] However, this approach does not eliminate concerns about the development of scaphotrapezial osteoarthritis.

McCallister et al demonstrated that central screw placement is an important goal because it offers the optimum biomechanical stability of screw fixation.[33] In a cadaveric study, Chan and McAdams compared screw placement when performing PSF through a volar and a dorsal approach.[34] They showed that both techniques allowed surgeons to perform central screw placement in the proximal pole and waist region, but a dorsal approach allows more central placement in the distal pole. In this study, we showed that the entry point and orientation of the screw depend on wrist position in maximal extension and flexion. Values of wrist maximal extension and flexion depend on the mobility of each wrist. The latter was within the normal range for all 12 wrists. Range of wrist motion should be assessed before choosing the surgical approach, as joint stiffness may impede PSF. Lateral radiographs in maximal flexion and extension are useful for planning the procedure. B2-type fractures can be managed using either the volar approach with the wrist in maximal extension or neutral position or the dorsal approach. There is no evidence in the literature suggesting that one of these approaches is associated with fewer complications. For B1-type fractures, our study suggests that the dorsal approach allows better screw placement than the volar approach.

Our study has several limitations. First, our findings in cadavers may not be entirely applicable to living patients. However, wrist positions were obtained passively by external handling to simulate *in vivo* manipulation of the upper limb of the anesthetized patient. Moreover, we used fresh-frozen cadavers that were thawed 24 hours before the study, and each preparation included the elbow and all the soft tissues to avoid modifying passive wrist kinematics. Second, the fracture types analyzed in this study may constitute an oversimplification of the range of scaphoid waist fractures seen in clinical practice. Nonetheless, these types are the most frequently encountered scaphoid waist fractures.[3,25]

To perform correct PSF, the screw must be centrally placed into the scaphoid and perpendicular to the fracture line. Screw placement depends on the location of the entry point and the direction of the screw. Both these parameters are directly influenced by the position of the trapezium or radius when performing retrograde or antegrade PSF. In this study, we found that in case of B2-type fracture, correct placement could be achieved by using either a dorsal or volar approach. In the case of B1-type fracture, the dorsal approach allows better placement than volar.

REFERENCES

1. Hove LM. Epidemiology of scaphoid fractures in Bergen, Norway. Scand J Plast Reconstr Surg Hand 1999;33:423–426.
2. Larsen CF, Brondum V, Skov O. Epidemiology of scaphoid fractures in Odense, Denmark. Acta Orthop Scand 1992;63:216–218.
3. Russe O. Fracture of the carpal navicular: diagnosis, non-operative treatment, and operative treatment. J Bone Joint Surg 1960;42A:759–768.
4. Herbert TJ, Fisher WE. Management of the fractured scaphoid using a new bone screw. J Bone Joint Surg 1984;66B:114–123.
5. Haisman JM, Rohde RS, Weiland AJ, American Academy of Orthopaedic Surgeons. Acute fractures of the scaphoid. J Bone Joint Surg 2006;88A:2750–2758.
6. Ezquerro F, Jiménez S, Pérez A, Prado M, de Diego G, Simón A. The influence of wire positioning upon the initial stability of scaphoid fractures fixed using Kirschner wires: a finite element study. Med Eng Phys 2007;29:652–660.
7. Egger EL, Gottsauner-Wolf F, Palmer J, Aro HT, Chao EY. Effects of axial dynamization on bone healing. J Trauma 1993;34:185–192.
8. Sarmiento A, McKellop HA, Llinas A, Park SH, Lu B, Stetson W, et al. Effect of loading and fracture motions on diaphyseal tibial fractures. J Orthop Res 1996;14:80–84.
9. Kenwright J, Richardson JB, Goodship AE, Evans M, Kelly DJ, Spriggins AJ, et al. Effect of controlled axial micromovement on healing of tibial fractures. Lancet 1986;8517:1185–1187.
10. Aro HT, Kelly PJ, Lewallen DG, Chao EY. The effects of physiologic dynamic compression on bone healing under external fixation. Clin Orthop Relat Res 1990;256:260–273.
11. Shin AY, Hofmeister EP. Percutaneous fixation of stable scaphoid fractures. Tech Hand Up Extrem Surg 2004;8:87–94.
12. Gourret JP, Guillot O, Liverneaux P. Dynamic mesh of carpal scaphoid. Chir Main 2006;25:81–88.
13. Bond CD, Shin AY, McBride MT, Dao KD. Percutaneous screw fixation or cast immobilization for nondisplaced scaphoid fractures. J Bone Joint Surg 2001;83A:483–488.
14. Haddad FS, Goddard NJ. Acutrak percutaneous scaphoid fixation. Tech Hand Up Extrem Surg 2000;4:78–80.
15. Adolfsson L, Lindau T, Arner M. Acutrak screw fixation versus cast immobilisation for undisplaced scaphoid waist fractures. J Hand Surg 2001;26B:192–195.
16. Shih JT, Lee HM, Hou YT, Tan CM. Results of arthroscopic reduction and percutaneous fixation for acute displaced scaphoid fractures. Arthroscopy 2005;21:620–626.
17. Adamany DC, Mikola EA, Fraser BJ. Percutaneous fixation of the scaphoid through a dorsal approach: an anatomic study. J Hand Surg 2008;33A:327–331.
18. Caloia MF, Gallino RN, Caloia H, Rivarola H. Incidence of ligamentous and other injuries associated with scaphoid fractures during arthroscopically assisted reduction and percutaneous fixation. Arthroscopy 2008;24:754–759.
19. Bushnell BD, McWilliams AD, Messer TM. Complications in dorsal percutaneous cannulated screw fixation of nondisplaced scaphoid waist fractures. J Hand Surg 2007;32A:827–833.
20. Levitz S, Ring D. Retrograde (volar) scaphoid screw insertion: a quantitative computed tomographic analysis. J Hand Surg 2005;30A:543–548.
21. Meermans G, Verstreken F. Percutaneous transtrapezial fixation of acute scaphoid fractures. J Hand Surg 2008;33B:791–796.
22. Menapace KA, Larabee L, Arnoczky SP, Neginhal VS, Dass AG, Ross LM. Anatomic placement of the Herbert-Whipple screw in scaphoid fractures: a cadaver study. J Hand Surg 2001;26A:883–892.
23. Compson JP, Waterman JK, Heatley FW. The radiological anatomy of the scaphoid. Part 1: Osteology. J Hand Surg 1994;19B:183–187.
24. Compson JP, Waterman JK, Heatley FW. The radiological anatomy of the scaphoid. Part 2: Radiology. J Hand Surg 1997;22B:8–15.
25. Compson JP. The anatomy of acute scaphoid fractures: a three-dimensional analysis of patterns. J Bone Joint Surg 1998;80B:218–224.
26. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. Psychol Bull 1979;86:420–428.
27. R Development Core Team. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria, 2006. Available: http://www.R-project.org; accessed August 5, 2008.
28. Slade JF III, Taksali S, Safanda J. Combined fractures of the scaphoid and distal radius: a revised treatment rationale using percutaneous and arthroscopic techniques. Hand Clin 2005;21:427–441.
29. Vinnars B, Pietreanu M, Bodestedt A, Ekenstam F, Gerdin B. Nonoperative compared with operative treatment of acute scaphoid fractures: a randomized clinical trial. J Bone Joint Surg 2008;90A:1176–1185.
30. Kehoe NJ, Hackney RG, Barton NJ. Incidence of osteoarthritis in the scapho-trapezial joint after Herbert screw fixation of the scaphoid. J Hand Surg 2003;28B:496–499.
31. Nicholl JE, Buckland-Wright JC. Degenerative changes at the scaphotrapezial joint following Herbert screw insertion: a radiographic study comparing patients with scaphoid fracture and primary hand arthritis. J Hand Surg 2000;25B:422–426.
32. Saedén B, Törnkvist H, Ponzer S, Höglund M. Fracture of the carpal scaphoid: a prospective, randomised 12-year follow-up comparing operative and conservative treatment. J Bone Joint Surg 2001;83B:230–234.
33. McCallister WV, Knight J, Kaliappan R, Trumble TE. Central placement of the screw in simulated fractures of the scaphoid waist: a biomechanical study. J Bone Joint Surg 2003;85A:72–77.
34. Chan KW, McAdams TR. Central screw placement in percutaneous screw scaphoid fixation: a cadaveric comparison of proximal and distal techniques. J Hand Surg 2004;29A:74–79.