Journal of Hand Surgery Global Online 6 (2024) 836–841

Contents lists available at ScienceDirect

Journal of Hand Surgery Global Online

journal homepage: www.JHSGO.org

Original Research

Scaphoid Fractures and Nonunion: A Survey-based Review of Hand Surgeon's Practice and the Evidence

Jason A. Strelzow, MD, [*] W. Kelsey Snapp, MD, [†] Aviram M. Giladi, MD, MS, [‡] Robert Wysocki, MD, [§] Charles C. Jehle, MD [‖]

[*] *Department of Orthopaedic Surgery, Washington University, St. Louis, MO*
[†] *Baptist Health Medical Group, Lexington, KY*
[‡] *The Curtis National Hand Center, MedStar Union Memorial Hospital, Baltimore, MD*
[§] *Midwest Orthopaedic at RUSH University Medical Center, Chicago, IL*
[‖] *University of Kansas Medical Center, Department of Plastic, Burn, and Wound Surgery, Kansas City, KS*

ARTICLE INFO

Article history:
Received for publication April 20, 2024
Accepted in revised form June 12, 2024
Available online September 14, 2024

Key words:
Evidence-based practice
Nonunion
Practice patterns
Scaphoid
Scaphoid Fracture

Purpose: The Evidence-Based Practice Committee of the American Society for Surgery of the Hand set out to assess the membership's practice patterns (PPs) and familiarity with evidence-based principles for scaphoid fracture and nonunion management.
Methods: Using a consensus-generated 25-item online survey, all the American Society for Surgery of the Hand members were invited to participate via email in September 2023. Two question types were used including evidence-based practice (EBP) and PPs. The survey was divided into the following subtopics: minimally displaced scaphoid fracture, operative options for scaphoid fixation, and treatment of scaphoid nonunion.
Results: Of 9 EBP questions, only one was answered with the preferred response by >80% of surgeons. The remaining seven EBP questions had greater frequencies of less preferred responses. These questions concerned the current evidence for initial imaging options, optimal nonsurgical immobilization, percutaneous management, and the identification and treatment of nonunion. Of the PP questions, there were substantial differences of opinion on the choice of bone graft for nonunion, revisions, and patients with avascular necrosis. Nearly unanimous agreement was found for the use of headless compression screws for scaphoid fixation; however, the choice of approach for waist fixation was split between dorsal and volar percutaneous techniques and an open dorsal approach.
Conclusions: Scaphoid fracture and nonunion management continues to be an area of expanding evidence. There remain opportunities for our community to improve knowledge and familiarization with current evidence-based data. Many PPs areas demonstrated substantial agreement among the membership; however, there are areas of differences particularly graft choice, optimal approach for waist fixation, and postfixation protocols. Knowledge and familiarity with peer practices may help develop future areas of research and help to optimize patient care through a critically review and interpretation of the evidence.
Type of study/level of evidence: Economic/decision analyses V.

Scaphoid fractures and nonunion are common pathologies encountered by hand surgeons.[1,2] These injuries, despite their frequency, can be diagnostically and technically challenging. This has given rise to a wide breadth of literature that is at times contradictory, leading to both controversy and questions about the optimal strategies for treatment.[3,4] Therefore, it is critical to periodically review the current evidence and relate it to current practice pattern (PP) of hand surgeons.

The Evidence-Based Practice Committee of the American Society for Surgery of the Hand (ASSH) has previously established survey-based questionnaires on topics of interest for membership

Corresponding author: Jason A. Strelzow, MD, The University of Chicago Medicine 5841 S. Maryland Avenue, Chicago, IL, 60653.
E-mail address: jstrelzow@bsd.uchicago.edu (J.A. Strelzow).

https://doi.org/10.1016/j.jhsg.2024.06.013

(reference Dup article).[5] Scaphoid fracture/nonunion was selected as a topic for the committee's survey given the frequency with which these injuries are managed and the established and robust evidence-based literature available to guide clinical decision making. The goal of the survey and this subsequent report was 2-fold. The first was to function as a review of the existing evidence-based literature for survey responders and help them identify and improve knowledge gaps in management. Second, specific to this manuscript, is to summarize current PPs of the ASSH members so readers of the journal can see how their own tendencies in controversial scenarios are similar or different from their peers.

This report includes a detailed review of the questions and answers contained in the survey. Additionally, a list of references is included for review and further reading of the current evidence. Practice pattern question analysis is provided to showcase the consistencies and differences present between hand surgeons in their daily practices.

Materials and Methods

Members of the Evidence-Based Practice Committee through consensus and literature review generated a 25-question survey. The survey was distributed to active members of the ASSH through email in September 2023. One week following initial distribution, a single reminder email was sent. The constructed survey included demographical questions followed by two general categories of questions: evidence-based (EBP) and PP.

Initial survey questions established baseline practice characteristics, including location, training, and frequency with which the respondents manage scaphoid fractures. All EBP questions were derived from the literature. Scientific data and specific references for each question were linked to the questions. Except for one question, all EBP questions had multiple scientific reports to support the preferred answer. Questions were assessed by the committee members to ensure adequate evidence supported a single correct response. The goal of these questions was to identify areas or topics on which the ASSH membership did or did not have sound knowledge of the evidence. In the second part of the survey, PP questions were generated to establish the current practice patterns for a variety of clinical scenarios in which the literature has limited evidence or established controversy.

Survey data were collected online through the SurveyMonkey.com© service. All survey data were collected and analyzed by the authors. The percentage of correct answers and the areas of agreement and disagreement were identified. A copy of the complete survey can be found in Appendix 1 (available online on the Journal's website at https://www.jhsgo.org).

Results

The survey was distributed to 2,211 active members. After the survey closure 296 respondents completed the survey (response rate = 13%). Demographic data for all respondents can be found in Table 1. Most respondents were orthopedic board-certified surgeons who completed orthopedic hand fellowships and practiced in private practice. Geographically, no specific region was over or underrepresented. This study was deemed exempt from our institutional review board.

Table 2 summarizes the EBP questions along with the proportion of respondents who selected the preferred responses to each question. Overall, only one of the EBP questions achieved a response rate of over >80% for the preferred answer. This suggested divergence within the community with the existing evidence base.

Table 1
Survey Respondent Self-Reported Demographics

Demographics	No.	Range/Percentages
In practice (y)	19	1–33
No. of scaphoid fractures managed/year	16	0–60
No. of scaphoid nonunions managed/year	7	0–30
Board certification		
Plastic surgeons	29	9.8
General surgeons	9	3.0
Orthopedic surgeons	258	87.2
Type of fellowship		0.0
Plastic surgery hand fellowship	5	1.7
Orthopedic hand fellowship	221	74.7
Combined hand fellowship	68	23.0
General surgery fellowship	1	0.3
No fellowship	1	0.3
Practice setting		
Academic	88	29.7
Private practice	152	51.4
Hospital based	56	18.9
Location of practice		
Pacific	26	8.8
Southeast	55	18.6
Midwest	60	20.3
Northeast	52	17.6
Mid-Atlantic	33	11.1
West	42	14.2
Southwest	28	9.5

Four questions achieved a correct response between 50% and 67%, and four questions had scores below 50%. With over 80% of respondents correctly identifying the risk factors for nonunion, we have elected to focus on the other eight questions in descending order of percentage of correct responses.

Evidence-based questions

EBP question #1 (cost effective diagnostic imaging for initial negative x-rays)

The evaluation of the occult/suspected scaphoid fracture with negative initial plain radiographs presents a diagnostic dilemma. As a common clinical problem encountered frequently in the emergency room and clinic, this question focused on the existing imaging modalities to improve the detection of scaphoid fractures. Empiric immobilization followed by repeat radiographs at 2 weeks has long been the standard treatment; however, only a minority of these patients have a scaphoid fracture. Recent decision analysis models and a clinical trial have demonstrated that empiric immobilization may not be cost effective compared to immediate advanced imaging. Immediate magnetic resonance imaging (MRI), although costly, potentially avoids later direct costs associated with outpatient appointments and further diagnostic tests as well as the indirect costs associated with unnecessary immobilization. In a decision analysis model published by Karl et al.,[6] the cost per a case for a suspected scaphoid fracture was lower for the immediate MRI group ($526) compared to the empiric cast immobilization group ($1,227), whereas the quality-adjusted life years were higher. The Scaphoid Magnetic Resonance Imaging in Trauma (SMaRT) trial demonstrated the short- and medium-term cost savings inherent to early MRI diagnostic testing.[7–9] Over 70% of survey respondents selected 2 weeks of immobilization followed by repeat radiographs as their answer of choice for the most cost effective. Based on the current body of evidence, immediate MRI remains the most cost effective.

Table 2
Topics and the Corresponding Preferred Answer for Each of the Survey Questions

No.	Evidence-Based Question - Topic Addressed	Preferred Answer	% of Respondents
1	Including both direct and indirect costs, which of the following options is the most cost-effective management strategy for acute, suspected scaphoid fracture with negative initial radiographs?	Immediate MRI	24
2	A 45-year-old man presents to the emergency department with a computer tomography confirmed minimally (<1 mm)/nondisplaced scaphoid waist fracture. He is desk based at work and wishes to return to work within the coming week. You review the treatment options and recommend which of the following:	A short-arm cast to immobilize wrist extension and ulnar deviation	67
3	A 33-year-old man presents to clinic with a minimally displaced (≤1 mm) scaphoid waist fracture after a fall from standing. You counsel the patient regarding potential nonsurgical and operative options for fracture management. Which of the following is true regarding operative fixation?	Operative fixation results in faster time to union	57
4	Which of the following is true regarding dorsal percutaneous screw fixation compared to volar percutaneous screw fixation for acute scaphoid waist fractures?	Dorsal fixation allows screw placement more perpendicular to the fracture line	60
5	Fracture gap reduction during scaphoid fixation with fully threaded variable-pitch headless compression screws may be compromised by which of the following?	Backing out of the screw by a single full turn	65
6	Which of the following factors increases the likelihood of nonunion after open reduction and internal fixation of an isolated scaphoid fracture?	Proximal fracture fragment volume of 30%	42
7	Which of the following is true regarding diagnosis of avascular necrosis in the setting of scaphoid nonunion?	The characteristic imaging features of AVN, including sclerosis, fragmentation, or collapse, cannot accurately predict vascularity.	23
8	A 45-year-old man presents with an unstable scaphoid nonunion of his dominant wrist after sustaining a scaphoid waist fracture 9 months prior that was managed nonoperatively. You are considering fixation and bone grafting with either avascular cancellous or corticocancellous autograft. Which of the following is true regarding these two options?	Cancellous graft results in faster time to union	25
9	Which of the following preoperative characteristics is not a risk factor for failure of scaphoid nonunion surgery?	All of the above are risk factors for failure	88

The total percentage of respondents for each question is also reported.

EBP question #2 (nonsurgical versus operative indications for a lower demand patient with minimally displaced scaphoid waist fracture)

This question focused on the ideal treatment for a nondisplaced fracture in a low demand/office worker without risk factors for nonunion. In total, 67% of survey respondents selected the most appropriate answer suggesting a short-arm cast to immobilize wrist extension and deviation. Nonsurgical treatment with cast immobilization is an adequate treatment for this patient who can continue desk work in a cast. Immobilization need only include wrist extension and ulnar deviation to stabilize the scaphoid fracture site. Thumb spica cast and long-arm casting is not required for scaphoid immobilization.[10] Short-arm casting without thumb immobilization also provides enhanced motion/freedom of the thumb and fingers, which may prevent stiffness, improve hand function, and increase patient comfort. Surgery, although an option for this patient, is typically discussed in the context of a potential faster return to work (a few weeks), and the lack of needing a cast.[11,12] Importantly, other techniques including open and percutaneous fixation techniques have been associated with higher rates of complications and long-term findings of osteoarthritis.[13–15]

EBP question #5 (fracture gapping after fixation)

Fracture compression is a critical tenet for bony healing. This question focused on the factors associated with fracture gapping after placement of a headless compression screw. In total, 65% of survey respondents selected the preferred response identifying the action of backing the screw out by a single turn is associated with compromise of the fracture reduction. Fully threaded variable-pitch headless compression screws are widely used in scaphoid fracture fixation given their low profile and ability to compress across the fracture site. Several biomechanical studies have demonstrated that the degree of compression may be compromised by several factors. These include derotational wires placed >30° oblique to the screw guide wire, a preexisting fracture gap >1.5 mm, failure to drill 4 mm past the fracture site, small screw diameter (2.8 mm) and backing the screw out even a single full turn after initial placement.[16–18]

EBP question #4 (volar vs dorsal percutaneous screw fixation)

Surgical technique for screw placement is a frequently discussed area of interest in the hand community. Although there are inherent strengths and weaknesses in both techniques, 60% of respondents selected the correct answer reporting that dorsal fixation allows a more perpendicular screw placement relative to the fracture site when compared to volar percutaneous techniques. The dorsal approach has been demonstrated to allow screw placement both more central to the scaphoid axis and more perpendicular to the fracture line in both cadaveric and clinical studies; however, there is no difference in rate of nonunion despite these findings. Furthermore, there is no clinical difference in secondary outcomes such as range of motion, Mayo Wrist score or rates of complications between the two techniques.[19–21]

EBP question #3 (advantages of operative versus nonsurgical treatment of minimally displaced scaphoid waist fractures)

Operative and nonsurgical treatment of scaphoid waist fractures continue to require careful discussion and education of patients to optimally select the most appropriate treatment for each patient. There have been several studies evaluating nonsurgical and operative treatment of scaphoid waist fractures; however, interpretation of these results is difficult because of heterogeneity between fracture characteristics, treatment type, and reported outcomes. Dias et al[22] published the results of the SWIFFT study comparing nonsurgical and operative management of minimally displaced scaphoid waist fractures in 2020 that demonstrated no difference in rate of union, wrist range of motion, or grip strength at 1-year

follow-up. In the study, the incidence of surgery-related complications in the operative group was similar to the incidence of cast-related complications in the nonsurgical group. Although it was not a primary or secondary outcome in this study, time to union has been shown to decrease with operative fixation in prior meta-analyses by Alnaeem and Ibrahim et al.[22–25] In total, 57% of survey respondents correctly selected a faster time to union in those patients who undergo surgically managed scaphoid waist fractures.

EBP question # 6 (risk factors for nonunion after scaphoid fixation)

Minimizing nonunion after scaphoid fixation is critical. Multiple studies have evaluated the potential variables associated with nonunion following nonsurgical and operative modalities of treatment. The established risk factors for nonunion following nonsurgical treatment are more clearly defined; however, Prabhakar et al[26] established a series of risk factors for operatively treated scaphoid fractures. In this question, only 42% of respondents correctly identified proximal fragment volume of 30% as an established risk factor for nonunion based on established literature. The 2020 case-control study by Prabhakar et al[26] examined factors associated with scaphoid nonunion following open reduction and internal fixation. Factors associated with increased risk of nonunion include delay in surgery greater than 31 days after the initial injury and proximal fracture fragment volume less than 38%. Body mass index, sex, mechanism of trauma, angle of the screw to the scaphoid axis, or the angle of screw to the fracture plane were not identified as potential risk factors for nonunion.[26]

EBP question #8 (cancellous vs corticocancellous autograft for scaphoid fracture avascular necrosis)

Graft options for nonunion are broadly categorized as corticocancellous or cancellous options. Both prospective and retrospective studies have demonstrated that there is no difference between the union rate or complication profile after scaphoid nonunion fixation with either structural (corticocancellous) or nonstructural (cancellous only) bone graft; however, each option does have its advantages. The only prospective, randomized trial comparing cancellous versus corticocancellous grafting by Hegazy et al[27] found that cancellous-only bone graft resulted in earlier union, whereas corticocancellous bone graft resulted in higher Quick Disabilities of the Arm, Shoulder, and Hand scores and better deformity correction for patients with a greater preoperative scaphoid deformity (lateral intrascaphoid angle >70°). In total, 25% of survey respondents selected cancellous grafting, whereas nearly 50% (49.1%) selected the option that deformity correction was similar between these two techniques. Results from Hegazy et al[27] corroborate the results from an earlier systematic review by Sayegh et al.[28] A retrospective study by Kim et al[29] did demonstrate similar functional outcomes after fixation with cancellous or corticocancellous bone graft; however, the preoperative lateral intrascaphoid angle was ≤70° for all patients.[27–29]

EBP questions # 7 (avascular necrosis diagnosis)

Several studies investigating the diagnosis of avascular necrosis (AVN) have come to use the "characteristic imaging features" of sclerosis, fragmentation and collapse as the defining attributes when reporting scaphoid nonunion (SNU) and AVN treatment outcomes. Even these characteristic features of AVN do not accurately predict histologic vascularity. In total, 23% of survey respondents correctly identified these factors do not adequately predict avascularity. Additionally, the most selected response, the presence or absence of punctate bleeding, often disagrees with histologic presence of viable osteocytes. Moreover, current diagnostic tools do not accurately reflect proximal pole vascular status as defined by punctate bleeding and may blur outcome comparisons between vascularized and nonvascularized bone grafting. Gunal et al[30] compared T1-weighted and T2-weighted magnetic resonance (MR) signal intensity with punctate bleeding and found that the two parameters agreed in only 19 out of 32 SNUs. Fox et al[31] also compared unenhanced T1-weighted MR signal intensity with punctate bleeding in 29 SNUs and reported 55% sensitivity, 94% specificity, and 79% accuracy. Even among MRI modalities there are conflicting results as to what correlates best with AVN as defined by punctate bleeding. Donati et al[32] reported that unenhanced MR was diagnostically superior to gadolinium-enhanced MR in 28 patients. There was no correlation between contrast enhancement and proximal pole trabecular composition on histology in their study ($P > .05$). In contrast, Schmitt et al[33] compared unenhanced T1-weighted and T2- weighted MR signal intensity with contrast uptake against punctate bleeding in 88 SNUs. They concluded that contrast MRI had significantly improved sensitivity (76.5% vs 6.3%) and accuracy (94.3% vs 82.9%) compared with unenhanced MRI for proximal pole AVN ($P < .001$).[32–37]

PP questions

The PP questions were designed to allow survey respondents to select their preferred management techniques for a variety of controversial topics that do not currently have an abundance of evidence to suggest a single answer. Table 3 contains a summary of the practice questions and mostly commonly selected answers. A full list of all survey questions and answers are available in the Appendix (available online on the Journal's website at https://www.jhsgo.org).

Considerable variation was noted across a myriad of clinical vignettes. Only one question generated nearly unanimous agreement between all survey respondents. Below we outline a several findings of interest.

- In the diagnostic setting of negative initial imaging, 50% of respondents reported they used MRI in the emergency department compared to 41% who immobilized patients and repeated plain films in 1–2 weeks. Determining displacement was defined as more than 1 mm on computed tomography CT by 50% of the responding surgeons with 14% reporting any visualized displacement on either x-ray or computed tomography determining displacement.
- Surgical approach of choice in the setting of a minimally displaced scaphoid waist fractures was selected in roughly equal proportions, dorsal percutaneous (27%), volar percutaneous (23%), and by slightly more using dorsal open/mini-open (49%).
- Nearly all respondents chose a headless compression screw as their fixation method of choice. This was the only question to achieve any substantial agreement between respondents with nearly all respondents selecting compression screws (one or two) as their preferred surgical fixation. Interestingly, although the fixation method of choice was nearly unanimous among respondents, the graft choices for nonunions across the spectrum of pathology showed significantly less cohesion of results.
- In the setting of middle or proximal third fractures without AVN or humpback deformity, avascular nonstructural cancellous autograft was the preferred graft (34% and 47%, respectively). In the setting of waist fractures with humpback deformity, corticocancellous grafts were selected as the preferred graft choice by 49% of respondents. A minority of respondents selected vascular grafts in the setting of nonunion without AVN (less than 10%) except for those in the proximal pole, in which 16% of those surveyed chose a pedicled corticocancellous autograft.
- The choice of postoperative protocols varied based on the level of displacement in waist fractures. In the setting of minimally/

Table 3
The Practice Pattern Questions Asked During the Survey With the Corresponding Most Common Response

PP Questions	Most Common Response	Respondents (%)
For a patient presenting to the ED following a fall off a skateboard with wrist pain, swelling, anatomic snuffbox tenderness, and pain with pinch and initial negative plain films what is your ideal next step in diagnostic work-up?	MRI of scaphoid in ED	50
What degree of displacement of a minimally comminuted scaphoid waist fracture would you consider strongly indicated for surgical management to avoid nonunion?	Displacement more than 1 mm on CT	50
A 19-year-old college basketball player presents with a minimally displaced scaphoid waist fracture. He would like to pursue operative fixation to allow potential earlier return to play. What is your preferred approach?	Dorsal mini-open/open	49
For the same patient, what is your preferred method of fixation?	1 headless compression screw	93
In the setting of a minimally(<1 mm)/nondisplaced waist fracture of the scaphoid in a 31-year-old nonsmoker patient you elect to move forward with percutaneous headless compression screw fixation. What is your preferred postoperative strategy?	Splint immobilization and gentle range of motion starting within 2 weeks post-op	50
What is your postoperative immobilization protocol after open reduction internal fixation of a displaced flexed waist fracture with a headless compression screw?	Cast immobilization and no range of motion until union based on x-ray, typically 6 weeks	35
For a patient presenting with scaphoid nonunion (middle third with humpback but no AVN) without previous surgery and with no arthritic changes, what procedure do you prefer?	Revision ORIF with structural corticocancellous autograft (avascular) as inlay or interposition	49
For a patient presenting with scaphoid nonunion (middle third without AVN or humpback) after attempted internal fixation and no arthritic changes, what procedure do you prefer?	Revision ORIF with nonstructural cancellous autograft (avascular)	34
For a patient presenting with scaphoid proximal pole fracture nonunion (without clear evidence of AVN or fragmentation) with no previous surgery and no arthritis, what is your preferred procedure?	ORIF with nonstructural cancellous autograft (avascular)	47

Additional precentages responding to each question is also reported.

nondisplaced fractures (<1 mm), 50% of respondents reported starting gentle range of motion within 2 weeks after surgery and splint immobilization with only 23% selecting cast immobilization until the x-ray defined union. In the setting of a displaced waist fracture these values changed slightly with 35% immobilizing until union on x-ray and only 27% permitting motion within 2 weeks.

Discussion

In conclusion, although there are mixed levels of evidence and variability in study quality within the existing literature on scaphoid fractures and nonunions, this literature can provide reasonably good guidance for many areas discussed within this survey. It remains important for providers to be familiar with the evidence and to help it guide treatment and diagnostic choices. Overall, only one question obtained >80% of surveyed physicians answering with the preferred answer. The remaining eight questions were answered with a wider distribution of erroneous or less preferred responses. It remains unclear why many of these items were less familiar to the survey respondents; however, it behooves hand surgeons to familiarize themselves with the existing evidence to optimize their patient management decisions and treatment approaches.

Within the PP questions there was consensus only as it pertained to using cannulated compression screws for internal fixation, which was nearly unanimous. Conversely, there was considerable disagreement among respondents related to surgical approach and graft choice. It remains vital that we continue to understand and appreciate common PPs among hand surgeons and also remain knowledgeable regarding what literature supports how best to navigate those differences.

Conflicts of Interest

No benefits in any form have been received or will be received related directly to this article.

References

1. Hove LM. Epidemiology of scaphoid fractures in Bergen, Norway. *Scand J Plast Reconstr Surg Hand Surg*. 1999;33(4):423–426.
2. Larsen CF, Brøndum V, Skov O. Epidemiology of scaphoid fractures in Odense, Denmark. *Acta Orthop Scand*. 1992;63(2):216–218.
3. Stirling PHC, Strelzow JA, Doornberg JN, White TO, McQueen MM, Duckworth AD. Diagnosis of suspected scaphoid fractures. *JBJS Rev*. 2021;9(12):e20.00247.
4. Li NY, Dennison DG, Shin AY, Pulos NA. Update to management of acute scaphoid fractures. *J Am Acad Orthop Surg*. 2023;31(15):e550–e560.
5. Ahmad F, Raizman N, Giladi AM, Akoon A, Wongworawat MD. Report on the evidence-based practice committee's survey on Dupuytren disease. *J Hand Surg Global Online*. 2021;3(6):317–321.
6. Karl JW, Swart E, Strauch RJ. Diagnosis of occult scaphoid fractures: a cost-effectiveness analysis. *J Bone Joint Surg Am*. 2015;97:1860–1868.
7. Rua T, Malhotra B, Vijayanathan S, et al. Clinical and cost implications of using immediate MRI in the management of patients with a suspected scaphoid fracture and negative radiographs results from the SMaRT trial. *Bone Joint J*. 2019;101-B(8):984–994.
8. Rua T, Parkin D, Goh V, McCrone P, Gidwani S. The economic evidence for advanced imaging in the diagnosis of suspected scaphoid fractures: systematic review of evidence. *J Hand Surg Eur Vol*. 2017;43(6):642–651.
9. Yin Z-G, Zhang J-B, Kan S-L, Wang X-G. Diagnosing suspected scaphoid fractures: A systematic review and meta-analysis. *Clin Orthop Relat Res*. 2010;468(3):723–734.
10. Kawanishi Y, Oka K, Tanaka H, Sugamoto K, Murase T. In vivo scaphoid motion during thumb and forearm motion in casts for scaphoid fractures. *J Hand Surg Am*. 2017;42(6):475.e1–475.e7.
11. Geoghegan JM, Woodruff MJ, Bhatia R, et al. Undisplaced scaphoid waist fractures: is 4 weeks' immobilisation in a below-elbow cast sufficient if a week 4 CT scan suggests fracture union? *J Hand Surg Eur Volume*. 2009;34(5):631–637.
12. Grewal R, King G. Percutaneous screw fixation led to faster recovery and return to work than immobilization for fractures of the waist of the scaphoid. *J Bone Joint Surg Am*. 2008;90(8):1793.
13. Clementson M, Jørgsholm P, Besjakov J, Thomsen N, Björkman A. Conservative treatment versus arthroscopic-assisted screw fixation of scaphoid waist fractures–a randomized trial with minimum 4-year follow-up. *J Hand Surg Am*. 2015;40(7):1341–1348.
14. Clementson M, Jørgsholm P, Besjakov J, Thomsen N, Björkman A. Union of scaphoid waist fractures assessed by CT scan. *J Wrist Surg*. 2015;04(01):049–055.
15. Clementson M, Björkman A, Thomsen NOB. Acute scaphoid fractures: guidelines for diagnosis and treatment. *EFORT Open Rev*. 2020;5(2):96–103.
16. Roebke AJ, Roebke LJ, Goyal KS. Fracture gap reduction with variable-pitch headless screws. *J Hand Surg Am*. 2018;43(4):385.e1–385.e8.
17. Lynch D, Mickley JP, Gordon A, Roebke AJ, Goyal KS. The effect of derotational Kirschner wires on fracture gap reduction with variable-pitch headless screws. *J Hand Surg Am*. 2023;48(1):86.e1–86.e7.

18. Tan ES, Jais ISM, Rahim SA, Tay SC. Effect of interfragmentary gap on compression force in a headless compression screw used for scaphoid fixation. *J Hand Surg Eur Vol*. 2017;43(1):93–96.
19. Jeon I-H, Micic ID, Oh C-W, Park B-C, Kim P-T. Percutaneous screw fixation for scaphoid fracture: a comparison between the dorsal and the volar approaches. *J Hand Surg Am*. 2009;34(2):228–236.e1.
20. Chan KW, McAdams TR. Central screw placement in percutaneous screw scaphoid fixation: a cadaveric comparison of proximal and distal techniques. *J Hand Surg Am*. 2004;29(1):74–79.
21. Lucenti L, Lutsky K, Jones C, Kazarian E, Fletcher D, Beredjiklian P. Antegrade versus retrograde technique for fixation of scaphoid waist fractures: a comparison of screw placement. *J Wrist Surg*. 2019;09(01):034–038.
22. Dias JJ, Brealey SD, Fairhurst C, et al. Surgery versus cast immobilisation for adults with a bicortical fracture of the scaphoid waist (SWIFFT): a pragmatic, multicentre, open-label, randomised superiority trial. *Lancet*. 2020;396(10248):390–401.
23. Ibrahim T, Qureshi A, Sutton AJ, Dias JJ. Surgical versus nonsurgical treatment of acute minimally displaced and undisplaced scaphoid waist fractures: pairwise and network meta-analyses of randomized controlled trials. *J Hand Surg Am*. 2011;36(11):1759–1768.e1.
24. McQueen MM, Gelbke MK, Wakefield A, Will EM, Gaebler C. Percutaneous screw fixation versus conservative treatment for fractures of the waist of the scaphoid: a prospective randomised study. *J Bone Joint Surg Br*. 2008;90(1):66–71.
25. Alnaeem H, Aldekhayel S, Kanevsky J, Neel OF. A systematic review and meta-analysis examining the differences between nonsurgical management and percutaneous fixation of minimally and nondisplaced scaphoid fractures. *J Hand Surg Am*. 2016;41(12):1135–1144.e1.
26. Prabhakar P, Wessel L, Nguyen J, Stepan J, Carlson M, Fufa D. Factors associated with scaphoid nonunion following early open reduction and internal fixation. *J Wrist Surg*. 2020;9(2):141–149.
27. Hegazy G, Massoud A-H, Seddik M, et al. Structural versus nonstructural bone grafting for the treatment of unstable scaphoid waist nonunion without avascular necrosis: a randomized clinical trial. *J Hand Surg Am*. 2021;46(6):462–470.
28. Sayegh ET, Strauch RJ. Graft choice in the management of unstable scaphoid nonunion: a systematic review. *J Hand Surg Am*. 2014;39(8):1500–1506.e7.
29. Kim JK, Yoon JO, Baek H. Corticocancellous bone graft vs cancellous bone graft for the management of unstable scaphoid nonunion. *Orthop Traumatol: Surg Res*. 2018;104(1):115–120.
30. Günal I, Özçelik A, Göktürk E, Ada S, Demirtaş M. Correlation of magnetic resonance imaging and intraoperative punctuate bleeding to assess the vascularity of scaphoid nonunion. *Arch Orthop Trauma Surg*. 1999;119:285–287.
31. Fox MG, Gaskin CM, Chhabra AB, Anderson MW. Assessment of scaphoid viability with MRI: a reassessment of findings on unenhanced MR images. *AJR Am J Roentgenol*. 2010;195(4):W281–W286.
32. Donati OF, Zanetti M, Nagy L, Bode B, Schweizer A, Pfirrmann CWA. Is dynamic gadolinium enhancement needed in MR imaging for the preoperative assessment of scaphoidal viability in patients with scaphoid nonunion? *Radiology*. 2011;260(3):808–816.
33. Schmitt R, Christopoulos G, Wagner M, et al. Avascular necrosis (AVN) of the proximal fragment in scaphoid nonunion: is intravenous contrast agent necessary in MRI? *Eur J Radiol*. 2011;77(2):222–227.
34. Jones DB, Rhee PC, Shin AY. Vascularized bone grafts for scaphoid nonunions. *J Hand Surg Am*. 2012;37(5):1090–1094.
35. Dailiana ZH, Zachos V, Varitimidis S, Papanagiotou P, Karantanas A, Malizos KN. Scaphoid nonunions treated with vascularised bone grafts: MRI assessment. *Eur J Radiol*. 2004;50(3):217–224.
36. Green DP. The effect of avascular necrosis on Russe bone grafting for scaphoid nonunion. *J Hand Surg Am*. 1985;10(5):597–605.
37. Günal I, Özçelik A, Göktürk E, Ada S, Demirtaş M. Correlation of magnetic resonance imaging and intraoperative punctate bleeding to assess the vascularity of scaphoid nonunion. *Arch Orthop Trauma Surg*. 1999;119(5-6):285–287.