

## General

# Fixation Techniques for Scaphoid Fractures: A Narrative Review

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Scaphoid fractures are the most common carpal bone injuries and remain clinically challenging due to retrograde vascular supply and risks of nonunion, malunion, and avascular necrosis. Surgical fixation is often preferred over conservative management for unstable, displaced, or proximal fractures, offering faster union and earlier functional recovery.

This review outlines current fixation techniques, including Herbert and headless compression screws, plate fixation, and newer minimally invasive or hybrid methods. Headless compression screws provide interfragmentary compression, while plate fixation is particularly useful in complex or comminuted cases, though hardware irritation is a common drawback. Arthroscopy-assisted fixation reduces soft-tissue disruption and preserves vascularity, showing promising outcomes but requiring further long-term validation. Adjunctive methods such as bone grafting and emerging biomaterials, including bioabsorbable and allogeneic cortical bone screws, expand treatment options and may reduce complications related to metal hardware.

Across studies, surgical fixation consistently demonstrates higher and faster union rates, improved early grip strength, and accelerated return to activity, particularly in high-demand populations. However, the literature is limited by small sample sizes, heterogeneous outcome measures, and a lack of long-term data. Future high-quality randomized controlled trials are needed to establish clearer evidence-based guidelines for optimal fixation strategies in scaphoid fracture management.

## INTRODUCTION

The scaphoid is the largest of eight carpal bones that connect the distal aspect of the forearm to the metacarpal bones of the hand.<sup>1</sup> It is a boat-shaped bone composed of four distinct regions: the tubercle, the proximal and distal poles separated by the waist.<sup>2</sup> It proximally articulates with the distal radius, distally with the carpal bones – the trapezoid and trapezium – and ulnarly with the capitate.<sup>3</sup> As the most radial structure, it plays an important role in wrist stability and kinematics.<sup>4</sup> The blood supply to the scaphoid mainly follows a retrograde manner. It is supplied primarily by the dorsal carpal branch, which provides blood flow to 70-80% of the proximal bone by an intraosseous retrograde flow with secondary blood supply to the remaining distal 20-30% from the superficial palmar arch, both of which are branches of the radial artery.<sup>5,6</sup>

The scaphoid is the most frequently fractured carpal bone. This is secondary to its positioning relative to the wrist and the mechanism of injury which is typically a fall on an outstretched, pronated, and ulnarly deviated hand.<sup>3</sup> Scaphoid fractures account for 60% of carpal, 11% of hand,

and over 2% of all fractures. There is a high incidence of these fractures in young adults, more males than females, specifically young active males.<sup>7</sup>

Anatomically, the most commonly fractured area is the waist, the part of the scaphoid known to have the thinner and more distributed trabeculae,<sup>2</sup> followed by distal third fractures and lastly proximal third fractures.<sup>7</sup> Majority of scaphoid fractures are known to be stable and quick to heal; however, due to the retrograde blood supply and the common fracture location, there is increased risk of improper bone healing, resulting in nonunion, malunion, avascular necrosis (AVN), or osteoarthritis.<sup>8,9</sup> Malunion occurs when a fractured fragment heals in an incorrect position, usually in a flexed position.<sup>8</sup> Nonunion is not only associated with disturbed blood supply, but may also be caused by inappropriate stability of the proximal fractured fragments. This may cause a flexed appearance of the distal fragments, also known as a 'humpback' deformity.<sup>10</sup> Posttraumatic AVN is typically a result of vascular impairment, more often involving the proximal pole of the scaphoid due to the poor blood flow to the area.<sup>11</sup>

Diagnosis of a scaphoid fracture requires a thorough history, adequate physical exam and imaging. X-rays of the wrist should be taken in posteroanterior and lateral views as well as ulnar deviation and 45-degree semi-pronation to allow proper visualization of the scaphoid.<sup>12</sup> While majority of nondisplaced fractures are treated conservatively by casting, complications associated with improper healing increase the need for early surgical intervention, especially in cases of comminuted, displaced or unstable fractures.<sup>7,13</sup> Many surgical techniques have been noted in the literature depending on the type, location and severity of scaphoid fractures. Accordingly, the objective of the following literature review is to assess the different fixation techniques for scaphoid fractures.

## METHODS

This narrative review was conducted by searching PubMed and Google Scholar for English-language articles published between 1984 and 2025. Keywords included “scaphoid fracture,” “scaphoid fixation techniques,” “headless compression screw,” and “complications of scaphoid fixation.” No formal PRISMA methodology was applied, as this is a narrative, not systematic, review. Studies were selected based on clinical relevance, novelty, and contribution to current surgical practice. Priority was given to randomized controlled trials, systematic reviews, meta-analyses, biomechanical studies, and papers discussing emerging or minimally invasive techniques.

## CLASSIFICATION OF SCAPHOID FRACTURES

Accurately classifying a scaphoid fracture is critical because it directly influences the treatment strategy, forecasts the likelihood of complications, and aids in outcome prediction. The most widely used classification systems concentrate on the degree of displacement, stability, and anatomical location of the fracture.<sup>7</sup>

One important factor influencing the scaphoid’s capacity to heal is the fracture location along its longitudinal axis. According to the Mayo classification, the scaphoid is divided into three sections: the waist, which accounts for 70% of fractures, the proximal pole (10%), and the distal pole (20%). This classification is clinically significant because it takes into consideration the retrograde blood supply of the scaphoid. A fracture at the waist can damage the vessels that supply the proximal pole, whereas a fracture of the proximal pole separates it nearly completely from its blood supply, increasing the risk of AVN and nonunion.<sup>14,15</sup>

On the other hand, the Russe classification is based on the orientation of the fracture line—horizontal oblique (type 1), transverse (type 2), or vertical oblique (type 3)—as visualized on radiographs.<sup>16</sup> Vertical oblique fractures are less stable due to the shearing forces exerted during wrist motion, leading to a higher risk of nonunion.<sup>17</sup> Despite its simplicity, the Russe system offers biomechanical insight and can influence the decision to fixate operatively, especially in unstable patterns.

Herbert and Fisher first described the Herbert classification in 1984, and it is now one of the most extensively used due to its predictive significance and direct link to treatment options. It classifies fractures according to their stability, which reflects their capacity to heal without internal fixation.<sup>18,19</sup> Where in this case, instability is defined by fracture displacement greater than 1 mm, dorsal intercalated segment instability (DISI) scaphoid lunate angle > 60 degrees, lateral intra-scaphoid angle > 35 degrees, comminution of fracture, or scaphoid fracture when part of perilunate injury.<sup>7</sup> Below is a summary table on scaphoid fracture classification systems ([Table 1](#)).

## INDICATIONS FOR SURGICAL FIXATION

The decision to proceed with surgery is complicated, weighing the advantages of early stabilization and return to function against the inherent hazards of an invasive procedure.

### A. PATIENT-RELATED FACTORS

The prolonged immobilization required for non-operative therapy may negatively affect the lives or careers of athletes and those who frequently utilize their wrists. Therefore, even for non-displaced fractures, open reduction and internal fixation (ORIF) or percutaneous reduction is often advised. Reducing time away from work or sports and enabling early mobilization are the main objectives.<sup>20</sup> A systematic review by Goffin et al. (2019) found that surgical treatment of scaphoid fractures in athletes led to a significantly faster return to sport compared to non-operative management.<sup>21</sup> Important factors to take into account include a patient’s wish to avoid extended casting and their capacity to adhere to non-operative treatment guidelines. Patients who are unlikely to follow long-term immobilization instructions or follow-up treatment may benefit from surgical fixing. Similarly, surgery may be required for dominant hand fractures, especially if a quick recovery of fine motor function is required for daily or occupational tasks.<sup>22</sup>

### B. FRACTURE CHARACTERISTICS

Fracture displacement is a crucial factor in choosing a surgical course of treatment. The risk of non-union and deformity is greatly increased by displacement more than 1 mm and angular or rotational malalignment (such a hump-back deformity) shown on CT scan, which usually calls for surgical fixation. Displacement greatly raises the chance of nonunion by forming a gap that is challenging for the bone to fill.<sup>23,24</sup>

Surgical fixation is nearly always advised if the fracture is in the proximal pole, even if it is not displaced, due to the high rates of AVN (up to 100% in some series) and nonunion linked to proximal pole fractures.<sup>7</sup> Fixation of scaphoid fractures presents two main biomechanical challenges — achieving sufficient bone contact and maintaining interfragmentary compression.<sup>25</sup> Scaphoid fractures heal primarily through direct bone union rather than callus for-

**Table 1. Scaphoid Fracture Classification Systems**

Classification System	Basis / Criteria	Types / Subtypes	Clinical Use / Relevance
Herbert & Fisher	Stability and chronicity	A1: Tubercle (stable), A2: Incomplete waist B1–B5: Unstable acute C: Delayed union D1–D2: Nonunion types	Surgical decision-making Incorporates mechanical stability and healing potential
Russe	Orientation of fracture line (radiograph)	Horizontal oblique Transverse Vertical oblique	Biomechanical relevance Vertical oblique = high instability
Mayo	Location of fracture line	Middle, distal, proximal	Guides management
Anatomic Location	Location in scaphoid bone	Proximal pole Waist Distal pole	Predicts vascular risk Guides imaging and monitoring

mation due to its nearly circumferential articular surface that does not accommodate callus. Compression enhances bone contact, construct rigidity, and overall stability.<sup>26</sup> In order to increase the likelihood of revascularization and union in proximal pole fractures, fixation offers the compression and stability required.<sup>7</sup>

Comminution is another indication for surgery, because numerous little fracture fragments are linked to a higher risk of non-union and are challenging to stabilize with a cast alone. Better realignment and mechanical stability are made possible by internal fixation, especially when intrinsic stability is compromised by the fracture pattern.<sup>27</sup> The choice to have surgery is also influenced by radiological signs of carpal instability, such as flexed scaphoid, scapholunate widening, or DISI.<sup>23</sup>

A flexion deformity of the scaphoid, also known as a “humpback” deformity, is indicated by signs of carpal instability, such as an elevated radiolunate angle (> 15 degrees) or an intrascaphoid angle larger than 35 degrees. If this abnormality is not surgically addressed, it changes the kinematics of the wrist and causes arthritis.<sup>28</sup> Additionally, scaphoid fractures linked to oblique and vertical fractures as well as perilunate dislocation make the fracture unstable and warrant surgical fixation.<sup>7</sup> Furthermore, a fracture with delayed presentation more than two weeks after the injury is linked to a higher risk of non-union and frequently requires surgical treatment, even in cases that were initially thought to be stable. This results from the gradual loss of hematoma-driven healing potential and early alterations in fracture biology.<sup>27</sup>

## OVERVIEW OF FIXATION TECHNIQUES

### A. HEADLESS COMPRESSION SCREWS

#### HERBERT SCREW FIXATION

A Herbert screw is a headless, cannulated screw primarily used for the management of small bone fractures including unstable scaphoid fractures. The screw is formed in two halves to create a differential pitch, causing compression of fractures.<sup>29</sup> Herbert screws have been utilized for the man-

agement of acute non-displaced and minimally displaced scaphoid fractures.<sup>50</sup>

Different techniques for screw insertion have been noted in literature depending on the level of displacement or comminution of the fracture. Open reduction and internal fixation (ORIF) is more often reserved for displaced or comminuted fractures or failure of percutaneous screw management.<sup>31</sup> Percutaneous screw fixation of scaphoid fractures is more commonly used, as it prevents usual complications associated with surgical intervention of the carpal bone, namely the division of the carpal ligament and devascularization of the scaphoid.<sup>32</sup>

Minimally invasive percutaneous screw fixation of scaphoid fractures type A2, B1 or B2 with minimal to no displacement has presented satisfactory results. It has shown a shorter fracture union time and, more importantly, quicker return to normal function at work or sports while avoiding stiffness and muscle weakness in comparison with conservative treatment.<sup>31</sup> Much like any other fixation technique, complications of percutaneous screw fixation include malunion, non-union and mechanical complications from inappropriate placement or length of the screw.<sup>33</sup>

#### NEWER GENERATION COMPRESSION SCREWS (ACUTRAK, SYNTHES)

New generation headless compression screws are designed to have threads in place of the head with a finer pitch to allow compression of the fracture line.<sup>34</sup> In comparison to Herbert screws, the newer headless models demonstrated higher compression forces, with Acutrak screws generating the greatest compression force.<sup>35</sup> Studies that compare the newer headless compression screw models, Acutrak and Synthes screws, showed that both screws had similar mean compression of fragments; however, Acutrak screws generated a higher interfragmentary compression.<sup>36</sup>

A retrospective study conducted by Oduwole et al. (2012) compared the efficiency of Acutrak and Herbert screws for scaphoid non-union and delayed union. While both screws had a similar time-to-union, Acutrak screws demonstrated higher union rates, more accurate axial placement, and

overall higher Modified Mayo Wrist Scores (MMWS) when compared to Herbert screws.<sup>37</sup>

## B. PLATE FIXATION

Plate fixation of scaphoid fractures is recommended in cases of comminuted fractures, unstable fractures, and in cases of non-union as a salvage procedure. The scaphoid plate has a buttress effect by offering structural support and stability, while also ensuring effective rotational control of both the proximal and distal poles.<sup>38</sup> It eliminates the rotational instability found with headless screws and prevents further fragment displacement.<sup>39</sup>

Lemke et al, in their retrospective case series of 28 patients, found a 96% union rate of which all previous nonunions achieved successful union after plate fixation.<sup>39</sup> One major drawback is plate impingement resulting in irritation and wrist clicking, and requiring another surgery for removal.<sup>39</sup> Liao et al yielded a 100% union rate in their case series of 9 patients with complex fractures treated with volar plate osteosynthesis.<sup>38</sup> Their results of wrist flexion-extension arc and QuickDASH score indicated mild residual disability at 1 year postoperatively.<sup>38</sup> Similar to the study by Lemke et al, their only reported complication was plate impingement.<sup>38</sup>

Biomechanical studies have shown that volar plating of the scaphoid offers superior rigidity and stability—outperforming single compression screws and matching dual-screw constructs—provides stronger hold in osteoporotic bone models, serves as a buttress to correct humpback deformity, and enhances resistance to rotational forces.<sup>38,39</sup> Locking plates are particularly effective in complex scaphoid fractures, especially in osteopenic bone, due to their higher load-to-failure strength compared to screws.<sup>38</sup> Across multiple series, volar scaphoid plating consistently achieved high union rates—ranging from 87% to 100%—even in cases of prior screw-fixation failure, though hardware complications (plate impingement, breakage, or screw back-out) often necessitated removal in 37–67% of patients.<sup>39</sup> Additionally, plates can help retain cortico-cancellous bone grafts in nonunion cases, which is difficult to achieve with screws alone.<sup>38</sup>

Munk and Larsen, covering 75 years of data, highlighted the diversity of techniques but emphasized the lack of randomized controlled trials (RCTs) to establish comparative efficacy. Volar plating has been investigated in a limited number of studies, with early work focusing on the Ender plating system, which provides rotational stability and dynamic compression.<sup>40</sup> More recently, anatomically precontoured locking plates, such as the Medartis TriLock system, have been introduced, offering multiple points of fixation, torsional stability, and the ability to buttress bone grafts.<sup>40</sup> While headless compression screws remain the preferred fixation in most cases, anatomic locking plates may serve as a valuable alternative when screw fixation is insufficient to achieve stable union.<sup>40</sup>

## C. OTHER OR HYBRID TECHNIQUES

### *ARTHROSCOPIC-ASSISTED FIXATION*

ORIF reliably restores scaphoid alignment but involves extensive soft-tissue disruption, which can hinder healing and function. Arthroscopy-assisted fixation (AAF), by contrast, limits tissue damage, preserves blood flow, and speeds recovery.<sup>41</sup> It is also advantageous in treating non-union of scaphoid fractures as it has the benefit of preserving the blood supply and preserving carpal ligament proprioception.<sup>42</sup>

Du et al. (2025) conducted a retrospective cohort study to evaluate the clinical effectiveness of wrist AAF compared to traditional ORIF for acute scaphoid fractures. Patients treated with the arthroscopy-assisted technique showed significantly improved outcomes across multiple domains. Wrist AAF offers minimally invasive access, faster recovery, better functional outcomes, reduced complications, and higher patient satisfaction.<sup>41</sup> Since first described by Ho in 1988, the first systematic review investigating the benefits of arthroscopically treated scaphoid fractures was done by Basso et al in 2023. This review demonstrated that arthroscopic management of scaphoid nonunion is a safe and effective technique, achieving high union rates (over 90%), good functional outcomes, and minimal complications.<sup>42</sup>

### *USE OF BONE GRAFTS WITH FIXATION*

Bone grafting is commonly used for scaphoid nonunions, with reported union rates of 88% to 92%. Traditionally, iliac crest autografts are preferred due to their superior properties, but they come with significant morbidity. Bone grafting is also used to correct deformities and malalignments, which can lead to pain and arthritis if untreated. Non-vascularized bone grafts (NVBGs), typically harvested from the iliac crest or distal radius, remain the standard option for uncomplicated scaphoid nonunions with adequate blood supply. They rely on surrounding vascularity for bone regeneration but carry a 5–10% donor-site morbidity risk (pain, hematoma, infection) and a 2–5% graft failure rate due to poor revascularization. Less common donor sites include the rib and tibia.<sup>43</sup>

A study by DalCortivo et al. in 2024 comparing distal radius and iliac crest grafts found no significant difference in union rates, with distal radius grafts achieving a 97% union rate and iliac crest grafts achieving 80%.<sup>44</sup> The research highlighted that both graft sources resulted in similar complication rates, including avascular necrosis and hardware issues, with no significant variation in the need for secondary surgeries.<sup>44</sup> While the median time to union was slightly shorter for iliac crest grafts (2.8 months) compared to distal radius grafts (3.2 months), this difference was not statistically significant. The postoperative scapholunate angle was also marginally higher in the iliac crest group.<sup>44</sup> Given the higher morbidity associated with iliac crest grafts, including risks of hernia, infection, and sensory loss, the study suggests that distal radius grafts should be considered a viable alternative, offering similar union outcomes with lower donor site complications.<sup>44</sup>

Vascularized bone grafts (VBGs), such as those from the distal radius or medial femoral condyle, provide their own blood supply and offer superior healing in cases with compromised vascularity. However, they are technically demanding, require specialized facilities, and are associated with higher complication rates, such as wound issues, infection, or vascular pedicle compromise.<sup>43</sup> The medial femoral condyle (MFC) graft is a corticoperiosteal graft with vascularity derived from the descending genicular artery and associated veins. This technique has gained popularity due to its rich blood supply, making it a reliable option for enhancing scaphoid union rates and improving scapholunate angles when used in scaphoid repairs.<sup>45</sup> In a study of 16 patients with persistent scaphoid nonunions following failed surgeries, MFC grafting achieved an 82% union rate; the patients experienced significant pain relief and functional improvement, reflected by an increase in MMWS.<sup>45</sup> Despite some complications (nonunion, saphenous nerve paresthesia, and donor site pain), the results were positive, particularly for cases with avascular necrosis or carpal collapse.<sup>45</sup>

A recent systematic review and meta-analysis by Karimnazhand et al. has reported superior outcomes of healing rate, time to union, range of motion, MMWS, and grip strength, in patients treated with VBGs as compared to NVBGs for scaphoid fracture non-unions.<sup>45</sup> Baamir et al. (2024) conducted an umbrella review showing that VBGs and NVBGs yield comparable outcomes in terms of union rates, functional recovery, and reoperation frequency. The authors emphasized that the choice of technique should depend on multiple individual factors.<sup>46</sup>

#### USE OF BIOMATERIALS AND EMERGING METHODS

Recent advancements in bioabsorbable materials, including Poly-L-Lactic acid (PLLA) derivatives magnesium and polyglycolide, have prompted research into alternatives to conventional metal screws, which are associated with complications like stress shielding, the need for hardware removal, and poor imaging quality.<sup>47</sup> A systematic review by Feeley et al. showed that bioabsorbable materials generally provided comparable outcomes to traditional metallic screws in terms of union rates, although some studies noted mixed findings.<sup>47</sup> Union rates ranged from 60% to 100%, and functional outcomes, including grip strength and pain relief, were also positive, though there was variability.<sup>47</sup> However, complications such as delayed wound healing, hardware issues, and infections were reported in some cases; and larger standardized studies are needed to confirm their efficacy, especially in chronic non-unions and long-term outcomes.<sup>47</sup>

The human allogeneic cortical bone screw (Shark Screw®) has emerged as an effective alternative to traditional metal screws and autologous bone grafts for scaphoid fracture fixation. Unlike metal screws, it avoids the need for removal and donor site morbidity.<sup>48</sup> A multicentric retrospective study in 2023 revealed high union rates, ranging from 94% to 96%. The procedure demonstrated similar or superior outcomes compared to other fixation methods, offering a less invasive surgical approach

and eliminating the need for hardware removal; and resulted in minimal complications.<sup>48</sup> In particular, the pseudarthrosis group benefited from this technique, with higher union rates compared to those reported in previous studies using vascularized or non-vascularized grafts.<sup>48</sup>

Currently, bioabsorbable magnesium-based implants are gaining interest as fixation devices that avoid permanent metal hardware. A recent systematic review shows promising safety profiles for magnesium implants in bone surgery generally, though a recent series in scaphoid fractures reported a higher non-union rate with magnesium screws, indicating caution in small-bone, high-stress settings.<sup>49,50</sup>

Recent technological advances have enabled patient-specific 3D-printed guides for scaphoid fracture fixation. In 2024, Rong et al. reported 100% union in 10 delayed-presentation scaphoid waist fractures treated percutaneously with a 3D-printed guide system.<sup>51</sup> In 2025, Wirth et al. reported similar favorable outcomes in both primary and revision scaphoid fixations using 3D-printed guides.<sup>52</sup> Collectively, these emerging techniques reflect a shift toward more personalized, less invasive, and biologically friendly fixation strategies; however larger comparative studies and long-term outcomes remain limited.

## DISCUSSION

### A. COMPARATIVE OUTCOMES AND EVIDENCE SYNTHESIS

#### A. UNION RATES, TIME TO UNION

A substantial body of evidence has examined the relative efficacy of surgical versus conservative management for scaphoid fractures, particularly regarding union rates and time to union. Across multiple RCTs and meta-analyses, surgical fixation especially using percutaneous screw fixation or ORIF has demonstrated higher union rates and significantly reduced healing time compared to immobilization. Al-Ajmi et al. reported a union rate of 95.6% in the surgical group compared to 88.4% in those treated non-operatively, with time to union reduced from an average of 10–12 weeks with casting to 7–9 weeks in surgically managed patients.<sup>49</sup> Almgidat et al. (2024) reported that delayed unions treated with internal fixation combined with bone grafting achieved union in over 95% of patients, with particularly favorable outcomes when surgery was performed within 6 months of injury.<sup>50</sup> Cheng et al. (2023) evaluated arthroscopic double-screw fixation combined with cancellous bone grafts in established nonunions and observed union rates exceeding 97%, with minimal complications such as avascular necrosis or hardware failure.<sup>51</sup> Similarly, Li et al. corroborated these findings, showing a 96.5% union rate in the operative group versus 89.1% in the conservative cohort, with a mean healing time of 7 versus 12 weeks.<sup>52</sup> Pfeiffer et al., in a prospective multicenter study, also observed that while union rates between surgical and conservative approaches were similar, surgical patients consistently healed faster, within 6–8 weeks versus 10–14 weeks for casted individuals.<sup>53</sup> Furthermore,

Ibrahim et al. synthesized results from multiple RCTs, finding that surgical fixation led to union in 95.2% of patients versus 89.5% in those managed conservatively, with healing achieved at 7.1 weeks compared to 11.4 weeks.<sup>54</sup> Du et al. (2025) further demonstrated that arthroscopy-assisted screw placement improved screw accuracy in revision cases, leading to more reliable compression and potentially better healing in nonunion scenarios.<sup>41</sup> These consistent findings support the superiority of surgical fixation in achieving both quicker and more reliable union, particularly important in younger or more active patients, and in cases of proximal pole fractures which naturally heal slower due to compromised vascularity.

## B. FUNCTIONAL OUTCOMES

Functional recovery is a critical endpoint in scaphoid fracture management, especially for individuals requiring rapid return to occupational or athletic function. Key performance indicators such as grip strength, wrist range of motion (ROM), and return to activity timelines have been shown to improve more rapidly with surgical management. Al-Ajmi et al. reported significantly improved grip strength across all measured time points (up to and beyond one year) in surgically treated patients, although ROM remained comparable between surgical and conservative cohorts.<sup>49</sup> The early grip strength recovery contributed to earlier functional milestones, with return to activity achieved within 6–8 weeks postoperatively, compared to 10–12 weeks for casted patients.<sup>49</sup> Li et al. echoed this trend, with surgically managed patients regaining strength and returning to work more quickly.<sup>52</sup> Focusing on high-demand individuals, Goffin et al. found that athletes treated surgically returned to sport approximately 4.2 weeks earlier than their conservatively managed counterparts.<sup>21</sup> These patients also demonstrated better early upper-limb function, with lower DASH scores and more rapid grip strength recovery within 12 weeks. Long-term follow-up across studies suggests that while both groups may converge functionally after one year, surgical patients consistently show superior short- to medium-term outcomes particularly in active or professional populations.

## B. COMPLICATIONS

Complications following treatment of scaphoid fractures remain a significant concern, particularly in cases involving the proximal pole, delayed diagnosis, or surgical hardware. Nonunion is a major complication, particularly in conservatively managed fractures or when surgical fixation is delayed. Johnson et al. reported nonunion rates of 4.1% in conservatively treated patients compared to just 1.6% in those who underwent surgical fixation, with reoperation rates slightly elevated in the surgical group due to hardware irritation.<sup>55</sup> Goffin et al. supported this, finding nonunion rates of 8%–10% in non-operative management versus 3%–5% in operative cohorts, especially among high-demand populations.<sup>21</sup> Li et al. observed that nonunion was more likely in waist and proximal pole fractures managed conservatively, and often necessitated secondary surgical

intervention, further prolonging recovery and increasing healthcare burden.<sup>52</sup>

One of the most feared complications is AVN, owing to the unique retrograde vascular supply of the scaphoid. Proximal pole fractures are especially prone to this complication due to their poor blood flow. Al-Ajmi et al noted that AVN was more commonly associated with non-operative management of proximal fractures, especially when diagnosis was delayed, and emphasized the importance of early surgical fixation in preserving vascular integrity.<sup>49</sup> Similarly, Li et al found that the nonunion rate was significantly higher in conservatively treated proximal fractures, with AVN developing in a minority of patients, particularly those with delayed presentation or inadequate immobilization.<sup>52</sup>

Cheng et al., in a study focused on arthroscopic dual-screw fixation with bone grafting, reported an AVN incidence of just 1.2%, demonstrating that modern minimally invasive techniques can significantly reduce the vascular compromise traditionally associated with open procedures.<sup>51</sup> Du et al. also showed that arthroscopy-assisted fixation minimized intraoperative manipulation and malpositioning, which may indirectly lower AVN risk by avoiding repeated hardware insertion and excessive bone disruption.<sup>41</sup> While these advanced techniques show promise, Ibrahim et al cautioned that even with surgical intervention, AVN cannot be completely eliminated, particularly in high-risk fracture types or patients with poor vascular supply.<sup>54</sup>

Hardware-related complications, though relatively infrequent, are not negligible. Almgad et al. reported hardware failure including screw back-out and breakage in approximately 3%–7% of surgically treated patients, primarily in those with insufficient screw length or misalignment.<sup>50</sup> Cheng et al. emphasized the need for meticulous screw placement and adequate compression, particularly in nonunion cases, to prevent loosening or migration.<sup>51</sup> Du et al. highlighted the advantage of arthroscopic assistance in reducing hardware malposition, with significantly fewer technical errors compared to conventional techniques.<sup>41</sup> Despite these improvements, some patients may still require reoperation due to hardware-related irritation or failure, a risk particularly relevant in thinner wrists or young, active individuals with limited soft tissue coverage.<sup>55</sup>

## C. SPECIAL CONSIDERATIONS

### A. PEDIATRIC SCAPHOID FRACTURES

Pediatric scaphoid fractures are relatively rare but clinically important due to the potential for misdiagnosis and growth-related implications. Although most pediatric fractures are non-displaced and heal reliably with cast immobilization, surgical fixation is increasingly considered in specific scenarios. Lin et al. (2022) emphasized that undisplaced fractures in adolescents typically respond well to conservative care, with union rates exceeding 95%, but they also noted that the healing timeline may be prolonged in some cases, particularly if diagnosis is delayed.<sup>56</sup> Goffin et al. (2019) noted that adolescents involved in competitive

sports may benefit from surgical fixation to expedite return to play.<sup>21</sup> Moreover, Almgad et al. (2024) identified that surgical fixation in skeletally immature patients can be performed safely, though the risk of physeal injury must be carefully weighed.<sup>50</sup>

#### B. ATHLETES AND RETURN-TO-PLAY TIMELINES

For athletes and high-demand individuals, expedited recovery and return to performance are paramount. The literature consistently supports surgical fixation in this group due to its ability to facilitate early mobilization and return to activity. Goffin et al. (2019) found that athletes undergoing surgical treatment returned to sport approximately 4.2 weeks earlier than those treated conservatively, with union achieved in 95% of surgical patients versus 85–92% in the non-operative group.<sup>21</sup> Al-Ajmi et al. (2018) and Li et al. (2018) both noted that earlier grip strength recovery and shorter time to radiographic union in the surgical cohort contributed to accelerated return-to-play decisions.<sup>49</sup> Athletes, in particular, benefit from this timeline, as prolonged immobilization associated with casting often results in deconditioning, joint stiffness, and missed competition. Almgad et al. (2024) emphasized that functional recovery, measured via DASH scores and ROM, was significantly better in surgical patients during the first three months, a critical period for competitive return.<sup>50</sup> Consequently, in the context of athletic performance and career preservation, surgical fixation offers tangible advantages in recovery speed, functional return, and predictability.

#### D. LIMITATIONS IN CURRENT LITERATURE

Despite the significant body of research surrounding fixation techniques for scaphoid fractures, there are several limitations in the current literature that must be addressed. One of the primary limitations is the lack of high-quality RCTs directly comparing different fixation methods. Moreover, there is considerable heterogeneity in outcome reporting across studies. Another significant limitation is the small sample sizes in many studies, which reduces the statistical power of findings and increases the likelihood of type I or type II errors. In some cases, sample sizes are further limited by the rarity of certain fracture types (e.g., proximal pole fractures), resulting in studies with limited generalizability. Additionally, while surgical fixation techniques such as percutaneous screw fixation, headless compression screws, and plate fixation demonstrate promising short- and medium-term outcomes, long-term functional data is often lacking. Finally, while newer techniques, such as arthroscopic-assisted fixation and the use of bioabsorbable materials, show potential, these approaches are still relatively novel, and further research is required to confirm their efficacy, long-term outcomes, and safety profiles.

## CONCLUSION

In conclusion, scaphoid fractures remain a significant clinical challenge due to their complex anatomical location, risk of nonunion, and potential for long-term complications such as osteoarthritis. Surgical fixation techniques have evolved, and modern techniques such as arthroscopy-assisted fixation and bioabsorbable implants demonstrate promising outcomes, but long-term comparative studies remain limited. Surgical fixation has been shown to result in faster healing and better functional outcomes compared to conservative management, particularly for unstable fractures and in high-demand patients such as athletes. However, each technique carries the risk of complications, including malunion, nonunion, hardware failure, and avascular necrosis, particularly in proximal pole fractures.

Based on the current evidence, management of scaphoid fractures should be individualized according to fracture characteristics, vascularity, and patient-specific factors such as occupation and functional demand. Early surgical fixation is recommended for proximal pole, displaced, or comminuted fractures to reduce the risk of complications. Whenever feasible, minimally invasive approaches, such as percutaneous or arthroscopy-assisted fixation, should be favored to preserve soft tissue integrity, maintain vascular supply, and allow earlier rehabilitation. In cases involving bone loss, nonunion, or compromised vascularity, the adjunctive use of bone grafting, particularly vascularized grafts, remains essential; while emerging materials such as bioabsorbable or allogeneic implants warrant further evaluation. Future research should adopt standardized fracture classifications and outcome measures to enhance comparability across studies. Large, multicenter RCTs with long-term follow-up are needed to determine the most effective fixation methods and grafting options. Finally, structured rehabilitation protocols promoting early mobilization and the establishment of long-term outcome registries are recommended to optimize recovery and monitor complications over time.

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#### AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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