Imaging and Treatment of Scaphoid Fractures and their Complications

Poster No.: P-0013
Congress: ESSR 2012
Type: Scientific Exhibit
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Keywords: Trauma, Tissue characterisation, Athletic injuries, Imaging sequences, Education, Diagnostic procedure, MR, CT, Conventional radiography, Extremities, Bones

DOI: 10.1594/essr2012/P-0013

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Purpose

- To review normal scaphoid bone anatomy (Slide 1), vascular supply (Slide 2), mechanism of injury, and classification of scaphoid fractures (Slide 3)
- To review current imaging techniques (Slides 4-17) and treatment options (Slides 18-19) of scaphoid fractures and their complications
**Methods and Materials**

- Normal scaphoid anatomy (Slide 1) and blood supply (Slide 2)

- Mechanism of injury and classification of scaphoid fractures (Slide 3) and their complications (nonunion, osteonecrosis, SNAC wrist)

- Imaging of scaphoid fractures including radiography, MRI, CT, ultrasonography, and bone scan

- Treatment options for scaphoid fractures and their complications (non-operative, operative)
Results

Scaphoid Bone/Normal Anatomy/Mechanism of Injury/Imaging

The scaphoid is the most frequently injured carpal bone, accounting for 60% to 70% of all carpal fractures. Patients with scaphoid fractures most often present with wrist pain and with tenderness and fullness in the anatomic snuffbox. These fractures are frequently seen in young adults as a result of fall on outstretched palm of the hand. The mechanism of injury is typically dorsiflexion secondary to fall, with hyperextension with radial deviation.

Often misdiagnosed as a simple wrist sprain, scaphoid fractures are prone to complications such as non-union (Slides 7-10, 15-16, 18), osteonecrosis (Slides 11-12, 17), carpal instability and osteoarthritis (13). Early diagnosis of scaphoid fractures is therefore of great importance to minimize these potential complications.

The proximal pole of the scaphoid is fixed in place by the distal radius proximally, radially and dorsally; by the radioscapohapitate and long radiolunate ligaments volarly; and by the lunate and capitate bones at the ulnar aspect. The distal pole of the scaphoid bone is relatively mobile. The anatomic location of the scaphoid bone makes it prone to trauma (Slide 1).

Perilunate fracture dislocations, although relatively uncommon, may be associated with scaphoid fractures. These occur as a result of high energy trauma with notable disruption of normal carpal arcs, and require prompt reduction and surgical fixation (Slide 14).

Sixty five percent of scaphoid fractures involve the waist, 15% the proximal pole (Slides 6, 11), 10% the distal body (Slide 5), 8% the volar tubercle and 2% the distal articular surface. Several classification systems of scaphoid fractures have been proposed in the literature. The Russe classification divides the fractures on the basis of the orientation of the fracture line into horizontal oblique, transverse and vertical oblique, with the latter considered to be the most unstable. In the Herbert classification, displacement or instability of a scaphoid fracture is defined as displacement of the fracture fragment by at least 1 mm or radiolunate angulation of more than 15° or scapholunate angulation of more than 60°. Scaphoid fractures are divided into type A, stable acute (fracture of the tubercle or incomplete waist), type B, unstable acute (distal oblique, complete waist, proximal pole fracture or trans-scaphoid perilunate dislocation of the carpus), type C, delayed union, and type D established non-union (fibrous union or pseudoarthrosis) (Slide 3). Recently, Ho and Wong proposed an additional classification dividing scaphoid fractures into type A, distal pole fractures (A1- of the scaphoid tubercle, A2- distal articular), type B, body
fractures (B1- distal 1/3, B2- middle 1/3, B3- proximal 1/3, B4- sulcal fracture), type C, proximal pole fractures, and type D, trans-scaphoid perilunate fracture dislocation.

After the clinical exam, 4-view standard radiographs (posteroanterior- PA, 45 degrees external oblique, lateral, and PA with ulnar deviation) should be the initial imaging modality for suspected scaphoid fractures (Slide 4). Dorsal tilting of the proximal pole and palmar tilting of the distal pole with scaphoid waist fractures resulting in dorsal angulation of the fractured scaphoid is described as a humpback deformity which is best seen on sagittal CT and MR images (Slide 8D).

If the radiographs are negative and the fracture is clinically suspected, MRI is the imaging modality of choice for detection of occult fractures, bone contusions and associated soft tissue injuries (Slide 6B-C).

Technetium bone scans show increased uptake at the fracture site and can potentially show decreased uptake over a proximal scaphoid fragment with decreased vascularity and possible osteonecrosis. However, scintigraphy does not provide information regarding fracture fragment displacement or angulation. Additionally, scintigraphy cannot help distinguish bone marrow edema or bone contusion, both of which may be associated with increased osteoblastic activity due to trabecular microfractures, from a fracture.

A few studies have been published on ultrasonographic assessment of acute scaphoid fractures with variable results. The key imaging findings of the occult acute scaphoid fractures were related to cortical discontinuity and/or periosteal elevation. In the first author’s institution, ultrasonography of the scaphoid bone is not routinely utilized for evaluation of occult fractures, but is occasionally performed as a part of routine wrist ultrasonography. Further limitations of ultrasonography are its operator dependent nature and difficulty appreciating full fracture extent.

In healing fractures, CT imaging is more accurate in assessing the crossing bone trabeculae (mineralization of immature osteoid) than radiography, which lacks a high degree of sensitivity and specificity. MRI was shown to detect early bony union in 45% of patients who were not considered to have a healed fracture both clinically and radiographically. Healed fractures and healed nonunions after bone grafting show obliteration of the fracture line with normal trabeculae bridging the fracture or nonunion (Slide 15C). MRI is the most sensitive imaging modality (Slide 15D-E). The MRI criterion for the presence of bony union on T1W images is normal high signal intensity bone marrow crossing the previous fracture line (Slide 15D).

Complications of Scaphoid Fractures/Imaging
Scaphoid Fracture Healing and Nonunion

The reported incidence of scaphoid fracture nonunion is 5-15%. The time required for healing of scaphoid fractures depends on the location. Fractures of the scaphoid waist may require 6 to 8 weeks or longer to heal, and the nonunion is diagnosed if the fracture does not unite in 6 months. Delayed unions and fracture nonunions are most common with proximal pole fractures, vertical oblique fractures of the middle third, and with displacement of the fracture fragments. Unstable nonunions are associated with displacement of the fracture fragments, DISI deformity, osteoarthritis and scaphoid nonunion advanced collapse (SNAC wrist) (Slide 13).

Radiographic (Slides 7, 8A, 10A, 15A) and CT abnormalities (Slides 8B-D) of nonunited scaphoid fractures include sclerosis of the fracture margins, cyst formation (Slides 8B-D, 10A), widening of the scapholunate interval, bone resorption (Slide 13A) and, subsequently, osteoarthritis (Slide 13). Multislice CT with sagittal oblique reformatted images parallel to the long axis of the scaphoid bone (Slides 8C-D) and coronal (Slide 8B) and sagittal reformats is frequently valuable for the evaluation of delayed union and nonunion sites; metal reduction artifact allows good evaluation of the fracture sites transfixed by orthopaedic hardware (screws). MRI shows a persistent intermediate signal intensity fracture line without continuity of the bony trabeculae (Slide 10B-C, 15B). Increased signal at the fracture site on the fluid sensitive sequences is consistent with instability (Slides 9, 12B, 16B, 17B). MRI may also show injury of the adjacent tendons or ligaments (radioscaphocapitate, long radiolunate).

Scaphoid Fracture Malunion

The scaphoid bone may heal in an abnormal position and this malunion is usually in flexion resulting in foreshortening; fractures of the distal part are of primary concern. Scaphoid malunion may result in alteration of carpal mechanics with resultant osteoarthritis, causing pain and decreased motion or strength. If symptomatic, the malunion may be surgically corrected.

Scaphoid Osteonecrosis

The reported incidence of scaphoid osteonecrosis is 10-15% which rises to 30-40% with scaphoid nonunions. The proximal pole is most frequently involved secondary to absence of a separate vascular supply (Slide 11). On radiographs, osteonecrosis most frequently becomes apparent 3 to 6 months after the injury when the involved fragment shows increased density. CT is more sensitive in depiction of subtle findings of increased density/sclerosis in the affected fragment.
At the present time, MRI without and with contrast is the imaging modality of choice to evaluate for occult osteonecrosis (Slide 12). Low signal intensity on all sequences is consistent with osteonecrosis/nonviable marrow in the chronic phase. Lack of increased signal on the fluid sensitive sequences (Slide 12B) and lack of enhancement on the T1W fat suppressed sequences post intravenous administration of Gadolinium-based contrast agents (Slide 12C) is indicative of ischemia/osteonecrosis. "Normal" signal intensity on the T1W images without fat suppression (Slide 12A) with lack of increased signal on fluid sensitive sequences (Slide 12B) and lack of enhancement on the post-contrast sequences (Slide 12C) indicates the presence of mummified fat/early osteonecrosis. Contrast-enhanced sequences show better correlation with surgical findings and postoperative results. Diffuse marrow hyperintensity may represent proximal pole ischemia with reactive edema in the distal pole. Additionally, osteonecrosis may demonstrate normal or increased signal intensity on the T2W sequences and usually has a patchy pattern (Slide 17B). Low signal intensity on the T1W sequences does not necessarily mean osteonecrosis; this appearance may reflect ischemia and potentially viable tissue (Slide 16B).

For assessment of scaphoid non-unions and proximal pole viability, in addition to static contrast enhanced sequences, perfusion/dynamic contrast enhanced imaging may also be used utilized (Slides 16C-D, 17C-D). Fat suppressed FSE T1-weighted imaging is performed in the coronal (Slides 16C, 17C) or sagittal-oblique plane depending on the best visualized longitudinal mid-axis of the scaphoid, with dynamic imaging after intravenous injection of a contrast medium bolus. Time-intensity curves in the proximal and distal scaphoid poles are then compared, with a viable proximal pole usually demonstrating similar enhancement to the distal pole (Slide 16D), but a non-viable proximal pole demonstrating poor enhancement compared to the viable distal pole (Slide 17D). As a reference standard, an area in the radial styloid or capitate may also be used. Some authors advocate dynamic contrast enhancement for evaluation of possible proximal pole osteonecrosis, and others reported less promising results.

MRI was reported to be useful to determine whether vascularized bone graft incorporation and revascularization of the proximal scaphoid pole has occurred in the setting of avascular scaphoid nonunion.

Scaphoid Nonunion Advanced Collapse (SNAC Wrist)

SNAC wrist comprises osteoarthritis of the radiocarpal joint between the distal pole of the fractured scaphoid and distal radius which may be accompanied by osteoarthritis of the midcarpal joint. SNAC wrist occurs with the greater arc injury. Fragmentation and collapse of the proximal pole occur in the late stages (Slide 13).

Treatment Options for Scaphoid Fractures and their Complications
Nondisplaced, uncomplicated fractures may be treated conservatively with immobilization and casting with the union rate up to 95% (Slide 5B). Displaced fractures are treated surgically with an interfragmentary screw fixation with a success rate of approximately 92%. Symptomatic scaphoid nonunions are treated surgically with conventional or vascularized bone graft and interfragmentary screw fixation (Slide 10E, 18C). Nonunions associated with osteonecrosis of the proximal pole are treated with vascularized bone graft and interfragmentary screw fixation. Reasons cited for poor results include the size of the proximal fragment, degree of displacement, bone grafting method, surgical techniques, and the presence of osteonecrosis of the proximal fragment, which is the most important factor in predicting the likelihood of success or failure. The treatment algorithm of scaphoid fractures and their complications that is used in the first author’s institution is shown on slide 19.
Images for this section:

**Fig. 1:** Scaphoid Bone- Normal Anatomy.

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Fig. 2: 2A-B. Artist drawing of the dorsal (A) and volar (B) branches of the radial artery (arrows) that provide the blood supply to scaphoid bone in retrograde fashion.

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Fig. 3: Herbert classification of scaphoid fractures.

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**Fig. 4:** 4A-D. 18 year old male patient with an acute scaphoid waist fracture. PA (A), PA oblique (B), Lateral (C) and PA ulnar deviation (D) radiographs of the left wrist show a minimally displaced scaphoid waist fracture (arrows) which is best seen in the PA ulnar deviation projection.

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**Fig. 5:** 5A-B. Comminuted right scaphoid distal pole fracture in a 20 year old male patient that was treated conservatively with a spica cast. PA ulnar deviation radiograph of the right wrist (A) shows a comminuted fracture of the distal scaphoid pole (arrow). PA radiograph of the right wrist obtained 8 weeks later (B) shows that the fracture is healed (arrow). Note generalized osteopenia secondary to disuse.

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Fig. 6: 6A-D. Sixteen year old male patient with a non-displaced fracture of the proximal pole of the right scaphoid treated with ORIF. PA radiograph of the right wrist (A) shows a subtle fracture of the proximal scaphoid pole (arrow). The fracture line is better seen on the coronal T1W (B) and STIR (C) MR images (arrows). Note bone marrow edema of intermediate signal intensity in (B) and high signal intensity in (C) involving the near entire scaphoid bone. PA radiograph of the radial side of the right wrist obtained 8 weeks after ORIF (D) shows a dorsally placed variable pitch cannulated fixation screw transfixing a healed scaphoid fracture.

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Fig. 7: Non-united displaced scaphoid fracture in a 30 year old male patient. PA radiograph of the left wrist shows a displaced non-united scaphoid fracture at the junction of the waist and proximal pole (arrow).

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Fig. 8: 8A-D. Non-united scaphoid waist fracture in a 44 year old male patient 13 years after trauma. PA radiograph of the left wrist (A) shows a non-united scaphoid waist fracture (arrow). Coronal reformatted (B) and sagittal oblique reformatted (C) CT images of the left wrist better demonstrate sclerosis and cystic changes about the fracture line (arrows). On the sagittal oblique reformatted CT image (D), note humpback deformity at the dorsal aspect of the scaphoid (arrow) and measurements of the scaphoid height (double black arrow) and length (double white arrow).

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**Fig. 9:** 18 year old male patient with scaphoid waist fracture delayed union. Coronal T2W fat suppressed MR image of the left wrist shows a non-united scaphoid waist fracture with high signal intensity at the fracture line (arrow) suggestive of instability along with bone marrow edema in both proximal and distal poles.

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Fig. 10: 10A-E. 43 year old female patient with a non-united scaphoid waist fracture. PA ulnar deviation radiograph of the left wrist (A) shows a non-united scaphoid waist fracture (solid head arrow). Note cystic change about the fracture site indicative of instability/motion and sclerotic proximal pole (arrow) that appeared viable at surgery. T1W coronal MR image (B) shows low signal intensity fracture line (solid head arrow) with cystic change and intermediate signal intensity in the proximal pole (arrow). Coronal STIR MR image (C) shows low signal intensity fracture line with adjacent cystic change (arrow) and high signal intensity in the proximal and distal scaphoid poles and in the lunate, with enhancement on the T1W fat suppressed coronal MR image (D). High signal intensity and enhancement in the lunate are probably related to carpal instability. The fracture was treated with ORIF and bone grafting after debridement of non-union (E); note variable pitch volarly placed cannulated screw transfixing the fracture site with bone graft material at the fracture site that was harvested from the distal radius. The bone graft donor side was filled with the radiodense bone graft substitute.
Fig. 11: 40 year old male patient with scaphoid fracture non-union and proximal pole osteonecrosis. PA radiograph of the left wrist shows a non-united fracture of the proximal scaphoid pole associated with moderate volume loss of the proximal pole(arrow). Courtesy of Winnie Mar MD, Chicago, IL

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Fig. 12: 12A-C. 23 year old male patient with non-united scaphoid waist fracture and early osteonecrosis of the proximal pole. T1W coronal MR image of the left wrist (A) shows a non-united scaphoid waist fracture (solid head arrow), mildly decreased signal intensity in the distal pole (white arrow) and relatively normal signal in the proximal pole (open arrow) consistent with mummified fat (early osteonecrosis) of the proximal pole. Coronal PDW fat suppressed MR image of the left wrist (B) shows high signal intensity at the fracture site (solid head arrow), high signal in the distal pole (white arrow) and low signal in the proximal pole (open arrow). Coronal contrast enhanced T1W fat suppressed MR image of the left wrist (C) shows enhancement at the fracture site (solid head arrow) and in the distal scaphoid pole (white arrow) with no enhancement of the necrotic proximal pole (open arrow).

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Fig. 13: 13A-B. Scaphoid nonunion advanced collapse in a 56 year old man twenty years after scaphoid fracture. PA radiograph of the left wrist (A) shows advanced osteoarthritis of the radiscaphoid joint between the distal scaphoid fracture fragment and the radial styloid with near complete resorption of the proximal scaphoid pole (arrow) and additional narrowing of the scaphocapitate and capitolunate joints and of the basal joints of the thumb. Lateral radiograph (B) shows dorsal tilt of the lunate consistent with DISI (dorsal intercalated segment instability) deformity (arrow).

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Fig. 14: 14A-C. Trans-scaphoid trans-ulnar styloid perilunate fracture dislocation in a 19 year old male patient treated with closed reduction and subsequent ORIF. PA radiograph of the left wrist (A) shows displaced comminuted scaphoid waist fracture (arrow), mildly displaced ulnar styloid fracture (solid head arrow) with disruption of normal carpal arcs. Lateral radiograph of the left wrist (B) shows dorsal displacement of the capitate (solid head arrow) in respect to lunate (open white arrow) that articulates with the distal radius, distal pole of a displaced scaphoid fracture (open black arrow), and completely volarly displaced and rotated proximal scaphoid pole that partially overlies the distal pole. The triquetrum is dorsipositioned (arrow). Small bone fragments proximal to the triquetrum originate from the ulnar styloid and possibly from the dorsal radial articular surface. Postoperative PA radiograph (C) of the left wrist shows a variable pitch volarly placed screw transfixing the comminuted scaphoid waist fracture (arrow) and 3 K wires transfixing the scapholunate, lunotriquetral, and scaphocapitate joints. Note ulnar styloid fracture (solid head arrow) and skin staples.

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Fig. 15: 15A-E. A 28-year-old male patient with a history of scaphoid fracture 2 years earlier and persistent pain and functional limitation of the wrist. The preoperative radiograph (A) and coronal T1W MR image (B), show pseudarthrosis in the waist of the scaphoid bone with sclerosis in the bony surfaces on both sides (arrows). The 3-month postoperative radiograph (C) shows diffuse ostopenia due to immobilization and bone bridging on both sides of the graft (open arrows). The corresponding postoperative coronal T1W (D) and coronal fat suppressed contrast enhanced T1W MR image (E) show fusion of the bone marrow between the proximal and distal poles and the bone graft (open arrows). The enhancement throughout the scaphoid bone is suggesting normal bone graft incorporation. Enhancing bone marrow edema is seen in the lunate, secondary to previous surgical manipulations.

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Fig. 16: 16A-D. Scaphoid nonunion with good proximal pole perfusion in 28-year-old man. Coronal T1W MR image of the left wrist (A) shows a non-united fracture of the proximal scaphoid pole (arrow) with sclerosis of the fracture margins, and low signal intensity in the proximal pole and proximal aspect of the distal pole. Increased signal intensity is seen at the fracture site (arrow) and in the proximal and distal scaphoid poles on the coronal STIR image (B). The region of interest in the proximal scaphoid pole is outlined with a red line and the reference area in the distal pole with a dashed yellow line on coronal T1W fat suppressed perfusion MR image (C). The time-signal intensity curve of proximal scaphoid pole (red curve) shows a good perfusion similar to the distal pole (yellow dashed curve).

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**Fig. 17:** 17A-D. Scaphoid nonunion with poor proximal pole perfusion in 25-year-old male. Coronal T1W MR image of the right wrist (A) shows a non-united fracture of the proximal scaphoid pole (arrow) with sclerosis of the fracture margins, and mild intermediate signal intensity in the proximal and distal poles about the fracture line. Increased signal intensity is seen at the fracture site (arrow), in the distal aspect of the proximal pole and in the distal scaphoid pole on the coronal STIR image (B). The region of interest in the proximal scaphoid pole is outlined with a yellow dashed line and the reference area in the distal pole with a red line on coronal T1W fat suppressed perfusion MR image (C). The time-signal intensity curve of the proximal scaphoid pole (yellow dashed curve) shows poor perfusion when compared to the distal pole (red curve).

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**Fig. 18:** 18A-C. Scaphoid fracture non-union in a 15 year old male patient. Intraoperative photograph of the right wrist (A) shows the nonunion site in the region of the scaphoid waist (arrow) adjacent to the flexor carpi radialis tendon (solid head arrow). In (B) note debrided scaphoid nonunion site (arrow) and bone graft donor site in the distal radius (solid head arrow). Postoperative PA radiograph of the right wrist obtained 2 weeks after surgery (C) shows a volarly placed variable pitch cannulated screw transfixing the scaphoid waist fracture and bone graft donor site in the distal radial metaphysis (arrow).
Fig. 19: Treatment algorithm of scaphoid fractures and their complications that is used in the first author’s institution. DJD = degenerative joint disease, ORIF = operative reduction and internal fixation, SNAC = scaphoid non-union advanced collapse, PRC = proximal row carpectomy, PCF = partial carpal fusion, TWA = total wrist arthroplasty, AVN = osteonecrosis, ‘Vascular’ = vascularized bone graft

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Conclusion

Imaging should start with radiographs; CT better demonstrates displacement and angulation of the scaphoid fracture; MRI is the study of choice for radiographically occult fractures; contrast enhanced MRI aids in evaluation of nonunions including osteonecrosis; surgical treatment is indicated for unstable and complicated fractures.
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