Bucholz, Robert W., Heckman, James D.
Rockwood & Green's Fractures in Adults, 5th Edition

SURGICAL/APPLIED ANATOMY

Part of "19 - FRACTURES AND DISLOCATIONS OF THE WRIST"

Vascular Supply

The vascular supply to the carpus is rich with multiple anastomoses. Gelberman and colleagues (139,141) have divided it into extraosseous and interosseous contributions. The ulnar and radial arteries as well as the anterior interosseous and posterior interosseous arteries contribute three palmar and three dorsal extraosseous arches (Fig. 19-1). These arches then feed into interosseous vessels that enter into the carpal bones from dorsal and palmar entry sites. The pisiform is the one exception that does not obtain blood supply through dorsal and palmar entry sites (28).

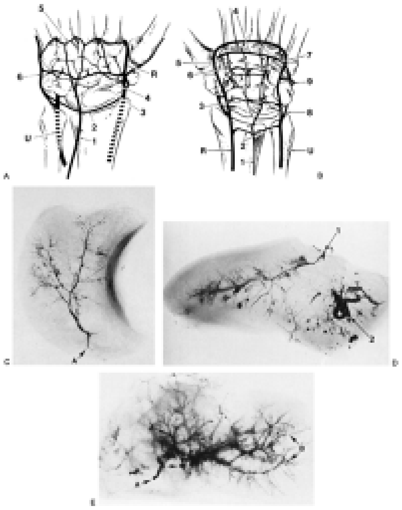


FIGURE 19-1. A: Schematic drawing of the arterial supply of the dorsum of the wrist. R, radial artery; U, ulnar artery; *1,* dorsal branch, anterior interosseous artery; *2,* dorsal radiocarpal arch; *3,* branch to the dorsal ridge of the scaphoid; *4,* dorsal intercarpal arch; *5,* basal metacarpal arch; *6,* medial branch of the ulnar artery. **B:** Schematic drawing of the arterial supply of the palmar aspect of the wrist. R, radial artery; U, ulnar artery; *1,* palmar branch, anterior interosseous artery; *2,* palmar radiocarpal arch; *3,* palmar intercarpal arch; *4,* deep palmar arch; *5,* superficial palmar arch; *6,* radial recurrent artery; *7,* ulnar recurrent artery; *8,* deep branch of ulnar artery; *9,* branch off the ulnar artery contributing to the dorsal intercarpal arch. **C:** Lunate. Lateral view, showing a single large vessel *(A)* entering the lunate off the palmar radial carpal arch and branching within the bone to provide the sole blood supply. This pattern was seen in 20% of specimens. **D:** Photograph of a specimen showing the internal vascularity of the scaphoid (*1,* dorsal branch of the radial artery; *2,* volar scaphoid branch). **E:** Capitate. Dorsal view, following clearing by Spalteholz technique. Nutrient vessels enter the distal third *(A)*, with retrograde course toward the proximal articular surface and *(B)*, terminal vessels enter into the head of the capitate. (**A,B** from Gelberman RH, Taleisnik J, Panagis JS, et al. The arterial anatomy of the human carpus: I. The extraosseous vascularity: II. The intraosseous. *J Hand Surg* 1983;8A:367–375. **C,E** from Gelberman RH, Taleisnik J, Panagis JS, et al. The arterial anatomy of the human carpus: II. The intraosseous vascularity. *J Hand Surg* 1983;8(4):375–382. **D:** From Gelberman RH, Menon J. The vascularity of scaphoid bone. *J Hand Surg* 1980;5A:508–513, with permission.)

Panagis's group (141) describes the interosseous vascularity as occurring in one of three separate patterns. The pattern found in the scaphoid, capitate, and 20% of the lunates had large areas of bone supplied by a single interosseous vessel. This was categorized as group 1 and was felt to explain the higher risk of vascular compromise after fracture. Group 2 has two areas of vessel entry but no interosseous anastomosis. This was found in the trapezoid and hamate. Group 3, which included the trapezium, triquetrum, pisiform, and 80% of the lunates, was found to have nutrient arteries entering through two portals and consistent interosseous anastomoses with no large areas of bone dependent on a single vessel for nutrient blood supply.

The scaphoid's blood supply has been detailed by Gelberman and Menon (139) and Taleisnik and Kelly (327). The blood supply enters dorsally and then courses proximally, supplying the proximal 70% of the scaphoid itself. The tubercle is supplied with the distal 30% by several small vessels. There is no interosseous anastomosis, this explains the high incidence of avascular necrosis (AVN) after scaphoid waist fractures (Fig. 19-1).

One anatomic variation worth noting when considering the surgical treatment of fractures and fracture dislocations of the carpus is that of the persistent median artery. One should be prepared to encounter a variably sized persistent median artery upon exploration of the carpal canal for reconstruction of palmar dislocations. The artery itself is usually quite evident and does not represent a surgical challenge, but may be the source of bleeding. It is important to know that accompanying the persistent median artery is often a bifid median nerve. The surgeon should be aware of this fact and be diligent in protecting both its branches, thus ensuring that one branch is not inadvertently injured while it is assumed that the retracted branch represents the nerve in its entirety.

Neural Anatomy

The ulnar and median nerves constitute the major neural structures at the wrist. Only these two nerves contribute to the intrinsic motor supply of the hand. Direct trauma to these two nerves is uncommon in carpal fractures and dislocations, unless the trauma is caused by a penetrating injury. Indirect injury from the swelling associated with the injury can cause compression of these structures, which more commonly occurs within the carpal canal, causing an acute carpal tunnel syndrome. Acute carpal tunnel is more common after dislocations or fracture-dislocations in comparison to isolated carpal fractures.

The remaining neural structures at the wrist are sensory, either cutaneous or articular. These structures are usually involved through direct trauma with fractures and dislocations about the wrist. Their locations are important, however, when considering surgical approaches to the carpal anatomy. The radial sensory branch is invariably encountered when surgically approaching the radial side of the wrist. Particularly sensitive to traction, injury during surgery can result in a painful neuropraxia or neuroma. Recent studies also recommend that percutaneous pinning at the snuffbox be done through a limited open approach to avoid injury to the nerve (166,320). Palmar dissection should be done with careful attention paid to the palmar cutaneous nerve (224). Some authors have also advocated wrist denervation as the sole treatment of painful posttraumatic wrists or in combination with other reconstructions (146,271).

General Anatomy

The bones of the carpus do not serve as origins or insertions for any muscle-tendon units. The pisiform is a sesamoid bone encased within the flexor carpi ulnaris (FCU) tendon and therefore gives biomechanical advantage to the FCU tendon itself. Rather than serving as a set of attachments or origin, the carpus serves as a conduit for passage of the wrist and digital motors. The wrist motors insert at the periphery of the hand base, providing more mechanical advantage to move the hand on the wrist. The digital motors are more centrally located, offsetting their influence on wrist position during digital motion (210).

The fact that the double row of carpal bones does not collapse into a static position is an indication of the complexity and interaction of the carpal ligaments. The transverse carpal ligament, also known as the flexor retinaculum, which is firmly anchored to the trapezial tuberosity, scaphoid tubercle, pisiform, and hook of the hamate, serves as an origin for both the thenar and hypothenar musculature. It is felt that the transverse carpal ligament serves as a pulley for the digital flexor system; it does not appear to contribute significantly to carpal stability.

Skeletal and Ligamentous Anatomy

Understanding fractures and fracture dislocations of the wrist can only be accomplished with complementary understanding of the osseous anatomy and the ligamentous contributions to stability and motion.

There are eight carpal bones in the wrist. The proximal row starting at the radial side contains the scaphoid, lunate, triquetrum, and pisiform. The pisiform is a sesamoid that is contained within the FCU tendon, and although it is part of the carpus is not usually significantly involved with injuries about the wrist. The distal row contains (radial to ulnar) the trapezium, trapezoid, capitate, and hamate. Traditionally, the carpus has been divided into a proximal and distal row, with the scaphoid serving as a link between the two rows. The carpus has also been divided into three columns by different authors (28,210). Studies have demonstrated the kinematics to be more consistent with the concepts of carpal rows (89,292).

After the classic description of traumatic instability of the wrist by Linscheid et al. (213), there was a significant increase in the interest of the specific anatomy of the ligaments of the wrist. Taleisnik and Kelly's (327) report is a classic study of the specific ligaments of the wrist. They divided the ligaments into extrinsic and intrinsic. The intrinsic ligaments are the intercarpal ligaments and the extrinsic ligaments the radiocarpal and carpometacarpal. Since their report in 1966, there have been tremendous advances in the understanding of the ligaments about the wrist (28,30). Unfortunately, one of the byproducts of the significant amount of study has been the proliferation of alternative names for ligaments as well as alternative classification schemes. The use of eponyms has also clouded the organization of the wrist ligaments.

Although a complete treatise on the anatomy is beyond the scope of this text, an understanding of the ligaments and their role in wrist stability is paramount in comprehending the fractures and dislocations about the wrist.

The capsular ligaments are synonymous with Taleisnik's extrinsic ligaments (Fig. 19-2, Fig. 19-3, Fig. 19-4, Fig. 19-5, Fig. 19-6 and Fig. 19-7) (30). The volar radiocarpal ligaments of the wrist are stronger than the dorsal ligaments. Four ligaments make up the volar radiocarpal ligaments: the radioscaphocapitate (RSC), long radiolunate (LRL), radioscapholunate (RSL), and short radiolunate (SRL). The radioscaphocapitate ligament (Fig. 19-5) restrains the wrist against radiocarpal pronation and ulnocarpal translation. It also is believed to stabilize the distal pole of the scaphoid.

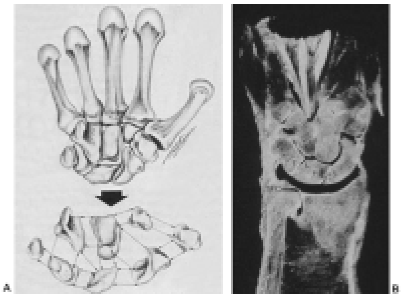


FIGURE 19-2. A: Exploded view of the carpal bones. The wrist is composed of two rows of bones that provide motion and transfer of forces. The distal row (trapezium, trapezoid, capitate, and hamate) is quite stable and moves as a unit. The proximal row (scaphoid, lunate, and triquetrum) is potentially unstable. The carpal bones are supported by extrinsic ligaments attached to roughened areas on the dorsal and volar surfaces, and by intrinsic ligaments attaching intraarticular components, particularly between the scaphoid, lunate, and triquetrum. The radial side of the wrist, exemplified by the scaphoid, provides flexion-extension control of the lunate and distal carpal row. The ulnar side of the wrist exerts rotational control and stability. **B:** Cross-sectional anatomy of the wrist demonstrating the intrinsic scapholunate *(SL)* and lunatotriquetral *(LT)* ligaments and the triangular fibrocartilage *(TFC)*. Full visualization of these structures can be achieved by arthroscopic examination of the wrist. (**A** modified from Taleisnik J, Kelly PJ. Extraosseous and intraosseous blood supply of th scaphoid bone. *J Bone Joint Surg* 1966;48A:1125–1137.)

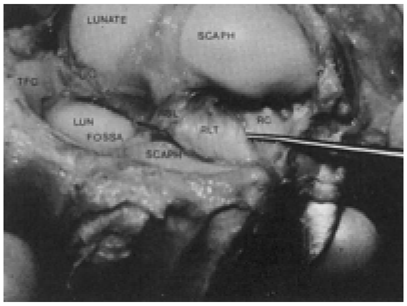
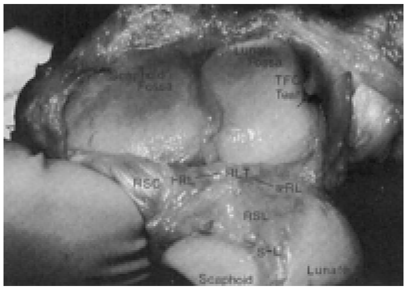


FIGURE 19-3. Intraarticular proximal-to-distal view. Intracapsular ligaments of the wrist include the radiocapitate *(RC)*, radiolunatotriquetral *(RLT)*, radioscapholunate *(RSL)*, and ulnocarpal *(UC)* ligaments. These ligaments originate from the volar flare of the distal radius (scaphoid and lunate fossae), and insert on the volar aspects of the proximal carpal row. The triangular fibrocartilage *(TFC)* extends from the ulnar aspect of the distal radius and inserts at the base of the ulnar styloid.

FIGURE 19-4. Intraarticular distal-to-proximal view. The volar radioscapholunate *(RSL)* and radiolunatotriquetral *(RLT)* ligaments blend with the volar aspect of the



scapholunate *(SL)* interosseous ligaments (*s-RL*, short radiolunate, and *l-RL*, long radiolunate are subdivisions of the radiolunatotriquetral ligament, *RLT*).

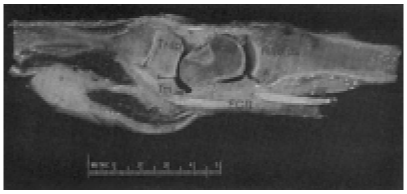
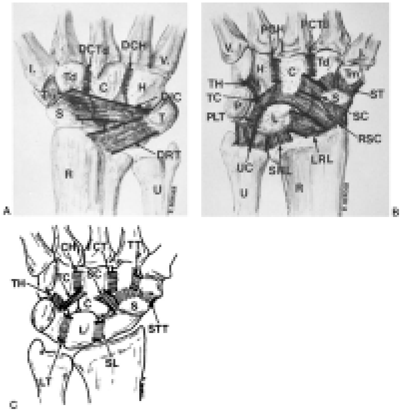


FIGURE 19-5. Sagittal view through the radius, scaphoid, and trapeziotrapezoidal joints. Note joint configuration, the volar ligaments, and the bow-stringing of the FCR tendon around the scaphoid tuberosity (*Trap*, trapezoid; Tz, trapezium; *Scap*, scaphoid; *FCR*, flexor carpi radials).

FIGURE 19-6. Cross-section anatomy (coronal view) demonstrates the intraosseous ligaments *(small arrows)* that imperceptibly blend the scaphoid *(Scap)*, lunate *(Lun)*, and triquetrum *(Tri)* to each other and separate the radiocarpal joint *(RC)* from the midcarpal joint *(MC)*. The triangular fibrocartilage *(TFC)* is an ulnar extension of the articular surface of the distal radius, and separates the radiocarpal from the distal radioulnar joint *(DRUJ)*. It is the main stabilizer of the distal radioulnar joint.

FIGURE 19-7. A: Dorsal extrinsic ligaments of the wrist: dorsal intercarpal ligaments *(DIC)*; dorsal radiotriquetral ligament *(DRT)*; trapezium *(Tm)*; trapezoid *(Td)*; capitate *(C)*; hamate *(H)*; scaphoid *(S)*; triquetrum *(T)*. **B:** Volar extrinsic ligaments of the wrist: scaphotrapezial *(ST)*; radioscaphocapitate *(RSC)*; scaphocapitate *(SC)*; long radiolunate *(LRL)*; short radiolunate *(SRL)*; ulnocarpal



(UC); palmar lunatotriquetral *(PLT)*; triquetral-capitate *(TC)*; triquetral-hamate *(TH)*; lunate *(L)*; scaphoid *(S)*; pisiform *(P)*. **C:** Intrinsic ligaments of the wrist: scapholunate *(SL)*; lunatotriquetral *(LT)*; scaphotrapeziotrapezoidal *(STT)*; scaphocapitate *(SC)*; triquetral capitate *(TC)*; triquetral-hamate *(TH)*; capitohamate *(CH)*; capitotrapezoidal *(CT)*; trapeziotrapezoidal *(TT)*. *C*, capitate; *S*, scaphoid; *L*, lunate.

Between the radioscaphocapitate ligament and the long radiolunate ligament (Fig. 19-2, Fig. 19-3, Fig. 19-4, Fig. 19-5, Fig. 19-6 and Fig. 19-7) is a cleft known as the interligamentous sulcus. This biomechanically weaker area (the space of Poirier) becomes the focal point of disruption in a perilunate dislocation.

The long radiolunate ligament (Fig. 19-4) has also been called the palmar radiolunotriquetral ligament and the palmar radiotriquetral ligament. This ligament appears to share some function with the radioscaphocapitate ligament in constraint against ulnar and distal translation of the lunate.

The radioscapholunate ligament, also called the ligament of Testut, is not truly a ligament, but rather a composition of nervous tissue, and arterioles and venules. These structures have a poorly organized collagen sleeve around them, which is covered by synovial tissue. It is thought that this ligament may have a more important role as a mechanoreceptor of the wrist. According to Berger it is also a likely source for synovial filtration.

The short radiolunate ligament is another stout, strong ligament of the volar portion of the wrist. Both the short and long radiolunate ligaments remain intact during a perilunate dislocation of the wrist, indicative of their strength.

At the ulnar side of the wrist there are three major ligaments. The ulnolunate and ulnotriquetral ligament both arise from the palmar radioulnar ligament, providing increased tension during supination and pronation. The ulnocapitate ligament is firmly anchored at its origin in the ulnar head, forming a ligament arcade in combination with the radioscaphocapitate ligament converging toward the center of the wrist.

The dorsal anatomy of the wrist is as complex as the volar anatomy, but is weaker than the volar ligaments. The dorsal radiocarpal joint is constrained by only one ligament. The dorsal radiocarpal ligament originates proximally at the ulnar portion of the distal radius and inserts on the triquetrum and on the lunate (Fig. 19-7).

The midcarpal joint is constrained by multiple interosseous ligaments (173). These ligaments are considered in Taleisnik's classification scheme to be intrinsic ligaments

(173). The palmar carpal ligaments consist of the scaphotrapezium trapezoid (STT), scaphocapitate (SC), triquetral capitate (TC), and triquetral hamate (TH), while a fifth palmar midcarpal ligament has been described as the scaphotriquetral ligament.

The dorsal midcarpal joint is constrained by two ligaments, which span several bones. By Taleisnik's convention these are still considered intrinsic ligaments. The dorsal intercarpal ligament

attaches on the triquetrum and crosses the midcarpal joint, attaching to the scaphoid waste and the dorsal trapezoid. Coursing in a similar path, the dorsal scaphotriquetral ligament has attachments on the triquetrum and into the scaphoid. This ligament extends just distal to the scapholunate and lunotriquetral ligaments and may add stability to these two intraosseous ligaments.

The proximal row of carpal bones is held together by two important interosseous ligaments that are described as intrinsic ligaments in Taleisnik's system. These are both **C** shaped, and proximally span the dorsal and palmar margins of the lunotriquetral and scapholunate spaces. The **C** shape leaves the distal portion of the joint open for communication of the articulations with the midcarpal space. This is important to recognize when interpreting arthrogram studies of the midcarpal joint.

The scapholunate ligament has been described extensively by Berger (29). The ligament is thickest dorsally. The proximal portion has a histologic appearance, which resembles the knee meniscus, being composed of fibrocartilage. The palmar region is similarly constructed but thinner and has less strength. Integrity of both the dorsal and palmar regions of the scapholunate ligament is needed for normal function of this joint.

The distal row interosseous ligaments consist of the trapeziotrapezoid ligament (TT), trapezial capitate ligament (TC), and capitohamate ligament (CH).

The distal radioulnar joint (DRUJ) has its primary constraint in the dorsoradioulnar ligament. The palmar radioulnar ligament is an important insertion site for the ulnolunate and ulnotriquetral ligaments, which helps keep these ligaments more isometrically tensioned during supination and pronation of the wrist.

The basic tenets of the ligamentous anatomy of the wrist must be understood to more readily appreciate the pathology associated with fractures and dislocations about the wrist. While it may not be necessary to fully understand this anatomy simply for diagnosis of wrist problems, it is paramount that the surgeons treating the full spectrum of wrist pathology have a firm understanding of it.

Biomechanics/Kinematics

Similar to the ligamentous anatomy, the biomechanics and kinematics of the wrist are complex and can be intimidating to understand. More refined experimental data have challenged older dogma, and a better understanding of the subtleties of wrist mechanics has been obtained, while further research is needed to clarify some of the existing confusion and inconsistencies. The basic biomechanics of the wrist pertaining to fractures is presented herein (28,210,358).

The wrist, consisting of its eight carpal bones can be divided into either columns or rows. Proponents of column organizational schemes have categorized the wrist as having three such columns, but have varied in their descriptions of the definition of the columns (28). Studies have demonstrated the kinematics to be more consistent with the concepts of carpal rows (Fig. 19-8) (89,294).

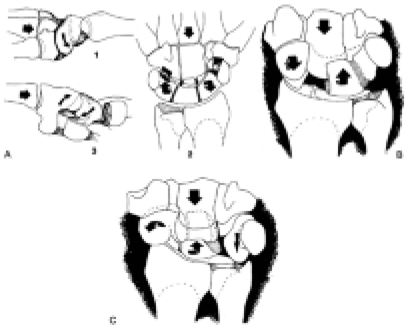
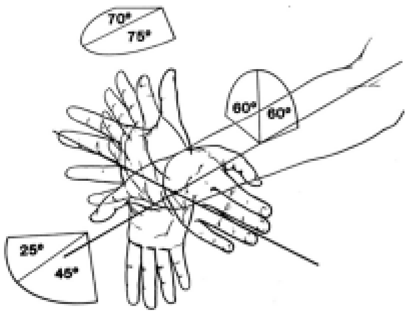


FIGURE 19-8. A: Relative motion of the proximal carpal row under axial compression. The scaphoid tends to palmar flex (*1* and *2*), while the triquetrum extends under the influence of the hamate (*2* and *3*). **B:** With scapholunate dissociation (viewing the carpus from the palmar aspect), the scaphoid rotates into a more vertical position while the lunate extends, creating a scapholunate gap and dorsal intercalated segmental instability (DISI) deformity. **C:** With lunatotriquetral dissociation, the scaphoid forces the unconstrained lunate into palmar flexion, and the triquetrum extends and translates proximally. (From Garcia-Elias M, An KN, Cooney WP, et al. Stability of the transverse carpal arch: an experimental study. *J Hand Surg* 1989;14A:277–282.)

Normal wrist motion has been studied by various authors, and while the exact numbers may vary to some degree, the ranges of motion are approximately 145 degrees of flexion/extension, 40 degrees of radial/ulnar deviation, and 5–10 degrees of pronation and supination (Fig. 19-9) (28). Variations have been documented for the contribution to motion that each articulation provides. Berger (28) states that when measured through the capitate-lunate-radius axis, the midcarpal and radiocarpal joints contribute equally to both flexion and extension. When measured in the plane of the radioscaphoid-scaphotrapeziotrapezoid joint, greater than two-thirds of the motion occurs at the radioscaphoid joint. This is in some conflict with the work of Sarrafian and Breihan (297), who describe 60% of flexion motion and 33.5% of extension at the midcarpal joint. While the conflicting data may add confusion, it does not alter the fact that both the radiocarpal and midcarpal joints each contribute between one-third and one-half of the motion to the wrist. Berger also states that the midcarpal joint contributes 1.5 times the motion of the radiocarpal joint in radial and ulnar deviation.

FIGURE 19-9. Global motion of the wrist and forearm. The wrist has three degrees of freedom through a complex mechanical arrangement that allows approximately 145 degrees of flexion-extension movement (FEM), 70 degrees of radioulnar deviation (RUD), and 120 degrees of pronosupination through the forearm radioulnar joints. The last provides the torque to accomplish twisting motions.



Early work placed the center of rotation within the head of the capitate for both flexion/extension and radial/ulnar deviation (358). It is now recognized that this concept is an approximation, summarizing the carpal bones' individual motions into one global motion (210). Functional use of the wrist requires a range of motion of 40 degrees of both extension and flexion, as well as a combined total of 40 degrees of forearm pronosupination.

The primary motions at the radiocarpal and midcarpal joints are in the coronal and sagittal plane. Axial motion at the wrist (forearm supination and pronation) come almost entirely from the DRUJ, although small amounts of intercarpal and radiocarpal pronation/supination do occur (Fig. 19-10). As described by Linscheid (210), the wrist is a compound joint. Elimination of one of three degrees of freedom (supination/pronation) from the radiocarpal joint allows flexion/extension and radial/ulnar deviation to occur while still permitting torque to be transmitted to the hand through the supination and pronation of the DRUJ. If all three motions (degrees of freedom) were allowed to occur at the radiocarpal and midcarpal joints, the wrist would represent an unconstrained joint and much more extensive ligamentous and muscular attachments would be needed to control it, especially when under torque.

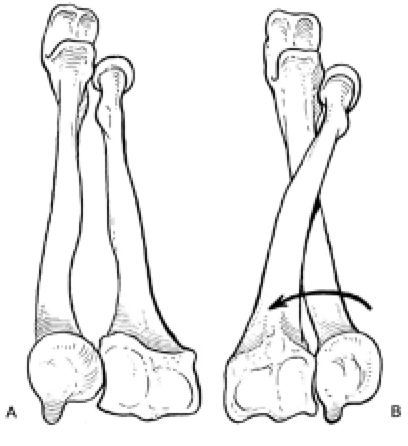


FIGURE 19-10. A: In supination, the ulnar head rests against the volar rim of the sigmoid notch. **B:** In pronation, the ulnar head rests against the dorsal lip of the sigmoid notch.

The distal row of carpal bones is securely fixed to the proximal aspect of the metacarpals. The proximal row is able to move independent of the distal row and the distal radius.

Linscheid (210) has compared the proximal row to a precoiled spring because of the flexion forces on the scaphoid and extension forces on the triquetrum. The proximal row is truly an intercalated segment and will “unwind” (i.e., collapse) if ligamentous support is lost. During flexion and extension, the distal carpal row moves under the influence of the metacarpals, which are controlled by the extrinsic flexors and extensors of the wrist. The scaphoid undergoes the most angular displacement during flexion and extension, while the lunate undergoes the least. The scaphoid also supinates during extension, causing tightening of the scapholunate interosseous ligament. The proximal carpal row flexes with radial deviation and extends with ulnar deviation. The scaphoid also supinates in ulnar deviation and pronates in radial deviation. The lunate undergoes the least displacement of the proximal row carpal bones (Fig. 19-11).

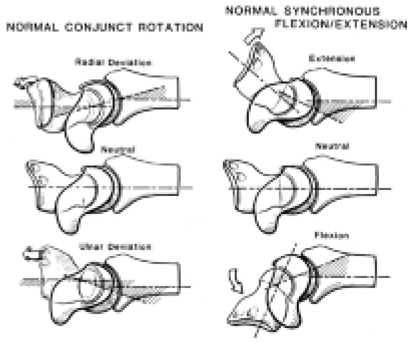
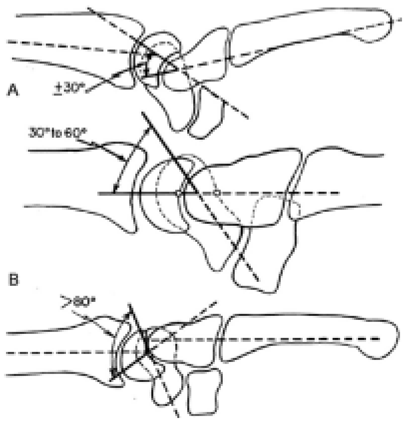


FIGURE 19-11. Conjunct rotation of the entire proximal carpal row occurs in flexion during radial deviation *(upper left)*. The axes of the radius and carpal rows are collinear in neutral *(middle left)*, and the proximal row extends with ulnar deviation *(lower left)*. Angulatory excursions of the proximal and distal rows are essentially equal in amplitude and direction during flexion *(lower right)* and extension *(upper right)*. This may be described as synchronous angulation.

While the scaphoid normally has flexion forces acting on it, the triquetrum has an extension moment acting on it. The lunate is situated between the two opposing forces, connected to both in a state of relative equilibrium. If either of the intercarpal connections is broken, the lunate will assume the position of lowest energy, and move with the carpal bone to which it is still attached. If the scapholunate interosseus ligament is disrupted, the scaphoid will flex, and the lunate will extend with the triquetrum. This will increase the scapholunate angle and result in a DISI deformity of the wrist. Loss of integrity of the ligamentous support between the lunate and the triquetrum will cause a VISI deformity consisting of a flexed scaphoid and lunate and an extended triquetrum (Fig. 19-12).

FIGURE 19-12. A: Abnormal palmar flexion of the lunate and scaphoid with ±30 degrees volar tilt, diagnostic of a volar dorsal intercalated segmental instability (VISI) deformity. **B:** Normal carpal alignment with lunate and capitate collinear and scaphoid angled 45 degrees (normal, 30 to 60 degrees), ±15 degrees to the sagittal plane of forearm. **C:** Abnormal dorsiflexion of the lunate with a vertical scaphoid; scapholunate angle >80 degrees (normal, 45 to 60 degrees), typical DISI deformity.


A
±30°
30° to 60°
B
>60°