Scaphoid fractures: anatomy, diagnosis and treatment

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Citation for published version (APA):
Osseous and ligamentous scaphoid anatomy: Part I
A systematic literature review highlighting controversies

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Abstract

Purpose The interpretation of scaphoid anatomy and kinematics is confusing and controversial. This results from a lack of consensus on the anatomy of the ligaments attaching to the scaphoid and an overwhelming variety of substantially different anatomic descriptions and classification systems of the wrist joint in the literature. The present study systemically reviews the consistencies or inconsistencies of the various scaphoid ligament descriptions and aims to clarify and unify different concepts and classification systems.

Methods We performed a systematic search of the medical literature from 1950 to 2010. We included all descriptive reports of the anatomy or morphology of the scaphoid, ligaments, or both. With the aim to describe the best available evidence, we considered all anatomical descriptions but emphasized a selection of the most frequently cited articles.

Results The literature search resulted in 555 potentially eligible descriptive reports, 58 of which met the inclusion criteria and were included in the review. Variations in the anatomic descriptions appear to be mostly due to the difficulty of identifying individual interdigitating ligaments or bundles by macroscopic dissections, as well as the interindividual variability in ligament anatomy. The most important areas of controversy in the scaphoid ligament attachments include the radial collateral ligament, dorsal radiocarpal ligament, dorsal intercarpal ligament, volar scaphotriquetral ligament, and scaphotrapezium-trapezoid ligament.

Conclusions None of the scaphoid ligaments other than the scaphocapitate ligament have been described consistently. Future research is required to verify the ligament attachments that currently have the most controversial descriptions, while addressing the interindividual variability of ligament insertions and morphology.

Clinical relevance Thorough knowledge of the anatomy will enhance our understanding of the kinematics of the scaphoid.
Introduction

In the scaphoid has characteristic anatomical features. The ligaments that attach to the scaphoid have an essential role in carpal stability of both normal and injured wrists. To understand the kinematics of the scaphoid, a thorough knowledge of its anatomy is required. For instance, a comprehensive explanation of carpal instability can be found by assessing the carpal anatomy. However, the literature provides a variety of substantially different anatomic descriptions and classification systems of the scaphoid ligaments, creating controversy and confusion.

Vesalius was the first to describe the osseous anatomy of the carpus in 1543, when he referred to the scaphoid as the first carpal (os carpi primum). The first detailed description of the carpal ligament anatomy was not until 2 centuries later. In 1742, Weitbrecht provided an illustrated description of the anatomy of all human ligaments including those of the wrist (Fig. 1). In the 18th and 19th centuries, a greater variety of descriptions and classifications by European anatomists followed. The late 20th century was characterized by an exponential increase in anatomic and kinematic studies of the wrist, and the number of studies is still expanding.

No consensus has been reached on the anatomic description of the ligaments that have scaphoid attachments and their function in normal kinematics. Controversy...
increases when the discussion focuses on fractures or ligament pathologies such as scapholunate dissociation.

This study systematically reviews anatomical studies on the ligaments of the wrist with a specific focus on the scaphoid. We performed a literature search to collect all available articles and book chapters on carpal ligaments. With the aim to describe the best available evidence, we emphasized a selection of the most highly cited literature. The purposes of this study were to clarify and try to unify different concepts and classifications of the wrist ligaments, and to describe the ligaments related to the scaphoid, according to the available literature.

Materials and Methods

Literature search

We conducted a 2-step systematic literature search: an online search for articles and a manual search for book chapters. The search for articles was performed in MEDLINE from the inception of the database in 1950 to December 15, 2010, with the following terms: *ligament*[Title] AND (*carp* [Title] OR *scaph* [Title] OR *wrist* [Title]). We retrieved the abstracts and assessed them for eligibility. Inclusion criteria for the selection of manuscripts were: (1) original description of the anatomy or morphology of the scaphoid and/or ligaments, and (2) availability of the full-text copy of the manuscript. Exclusion criteria were: (1) personal communications, letters, or meeting proceedings; and (2) languages other than English, French, Italian, Dutch, German, and Spanish. We performed the manual search for book chapters by screening the reference lists for all selected articles using the same inclusion and exclusion criteria.

Study selection

There are many different systems to describe and classify ligaments related to the scaphoid; each has its own characteristics and limitations. To our knowledge, no guidelines have yet been developed to assess the quality of anatomical studies. With the aim of describing the best available evidence, we considered all anatomical descriptions that resulted from the search, emphasizing a selection of the most frequently cited articles. We investigated this using the database from the Institute for Scientific Information (ISI) Web of Knowledge. For each of the included studies, we recorded the number of citations using the option of “cited reference search” in the ISI Web of Knowledge.\(^\text{16}\)
Results

Literature search
The online search resulted in 555 potentially eligible articles, 45 of which met our inclusion criteria (Fig. 2). The manual search resulted in an additional 13 anatomical descriptions in book chapters. We included a total of 58 anatomical reports in the review.

Osseous anatomy of the scaphoid
The scaphoid has a characteristic and irregular form that is complex. A substantial variety in shapes has been described and classified in detail. The scaphoid is the largest bone in the proximal carpal row. Its long axis is on an oblique plane. Approximately 75% of the surface of the scaphoid is covered with cartilage, forming articulations with adjacent bones. It articulates proximally with the distal radius (scaphoid fossa) through a biconvex dorsally sloped articular surface (Fig. 3A).
The dorsoradial ridge separates the dorsal and proximal articular surfaces from the distal volar aspect (Fig. 3B). The ridge is a narrow and non-articulating area with several vascular perforations allowing important perfusion of the scaphoid. About 70% to 80% of the intraosseous vascularity and the entire proximal pole is supplied from branches of the radial artery entering through this ridge.23 The convex articular surface distal to the dorsoradial ridge articulates ulnodorsally with the trapezoid and radiovolarly with the trapezium.24–26

The surface on the ulnar side is almost entirely articular. Proximally on the ulnar side, a flat and semi-lunar area articulates with the lunate; distally, a large, concave surface articulates with the radial, proximal part of the capitate (Fig. 3C).24,25

The volar surface is mostly nonarticular (Fig. 3D). It is composed of a proximal depressed irregular zone and a prominent distal tubercle. The proximal depression has a large vascular foramen. In the region of the tubercle, 20% to 30% of the bone receives its blood supply from the volar radial artery branches entering these vascular foramina.23 The tubercle, which points radiovolarly, serves as an attachment for several ligaments and is also almost entirely covered by the crossing flexor carpi radialis tendon.24–26

Carpal ligament classifications

The carpal capsule is reinforced by a series of dorsal and volar ligaments. Characteristically, the volar ligaments are stiffer than the dorsal ones.15,27,28 Most classic anatomical reports distinguished the dorsal and volar ligamentary complex4,5,7,9,11–15; however, more detailed descriptions currently subdivide these into more subgroups. According to the registration of the ISI Web of Knowledge, the most highly cited descriptions and classification systems in the contemporary era are from the following authors: Taleisnik12 (1976, cited 180 times), Mayfield et al13 (1976, cited 133 times), Berger and Landsmeer29–32 (1997, cited 186 times), and Viegas et al33,34 and Nanno et al35 (1999, cited 76 times). Frequently cited book chapters are those from Fahrer10 (1981), Kaplan and Taleisnik26 (1984), and Bogumill36 (1988). To date, the detailed carpal ligament nomenclature and classification by Berger is the most commonly cited and the most detailed of all; we therefore used it in this review as the core guideline for the comparison with other descriptions. The classification is based mainly on the localization of the ligaments within the carpus and their organization within the joint capsule.29–32 In terms of nomenclature, the name of each ligament stems from the major bones where it attaches. The proximal attachment is recognized as the ligament origin and the distal as insertion. For ligaments that have more than 2 attachments, adjectives such as “short” and “long” are added.
Figure 3: Radial A, dorsal B, ulnar C, and volar D views of the scaphoid and its articular surfaces color coded for contact with the distal radius (green), trapezium (yellow), trapezoid (orange), capitate (blue), and lunate (red). The bottom of each image represents proximal and the top represents distal. Note the vascular foramina in the regions of the radiodorsal ridge and the tubercle.

Ligament anatomy of the scaphoid

Radioscaphocapitate (RSC) ligament: The RSC ligament is the most radiovolar ligament (Fig. 4). It originates on the radial styloid at the level of the scaphoid fossa. From its origin, it passes ulnarly toward the scaphoid and capitate, with bundles of fibers inserting in the radial aspect of the scaphoid waist, the proximal edge of the scaphoid tubercle, and the volar surface of the capitate head. Fibers from this ligament interdigitate with surrounding ligaments: mainly, the ulnolunate, triquetrocaptate, and volar scaphotriquetral ligaments. This interdigititation is referred to as the

There are several controversies regarding the RSC (Table 1). Although most authors concur regarding interdigitation of the ligament with surrounding ligaments, some describe the presence of a separate (noninterdigitating) volar scaphotriquetral ligament. Others describe the presence of a separate volar radioscapophid ligament, which was inconsistently visualized (radial adjacent to the RSL) in 33 of 50
wrist on magnetic resonance imaging (MRI). Some authors did not report on an attachment on the scaphoid.

**Radial collateral ligament (RCL):** The RCL is the most radial carpal structure and is a controversial ligament because many surgeons deny its existence. The greatest controversy is whether it is a separate ligament or the most radial bundle of the RSC ligament (Fig. 4). Insertions of the RCL are described inconsistently. Most proponents of a separate RCL describe a radiovolar origin, although a radiodorsal origin has been described as well. It is also thought that the RCL has no distinct function in the wrist because the radiocarpal joint is not a hinged flexion-extension joint with collateral ligaments.

**Volar scaphotriquetral (vScTq) ligament:** The presence of this controversial ligament was described in only 2 studies: 1 on MRI and 1 on dissected wrists. On magnetic resonance images of 50 wrists, the vScTq ligament definitely had an insertion on the capitate in 19 wrists, it probably had an insertion in 28 wrists, and it was completely separate in 3 wrists. According to the other study, it should be considered a separate entity because its presence was documented in each of the 15 dissected specimens and was visible on MRI in some cases. Berger stated that most wrists do possess such a band, but he considered it an integral part of the midcarpal arcuate ligament formed by the RSC and ulnocapitate ligaments.
Long radiolunate (LRL) ligament: There is consensus among authors that the LRL ligament, which originates ulnar to the RSC ligament on the volar rim, courses anterior to the proximal pole of the scaphoid (without attaching) and inserts on the lunate and triquetrum. The LRL ligament is sometimes also called the (palmar) radiolunotriquetral ligament.

Radioscapholunate (RSL) ligament: The ligament located ulnar to the LRL ligament on the volar rim of the distal radius is the RSL ligament. Cruveilhier was the first to describe this ligament in 1837, but later it became known as the ligament of Testut (or Testut-Keuntz), after the detailed description by Testut’s student in his thesis “Les géodes du semilunaire”. It originates on the volar rim of the radius at the interfossal ridge and inserts on the proximal aspects of the scaphoid and lunate. The location of the attachment areas of the RSL ligament have been described consistently (Fig. 4). There is consensus regarding the fact that the RSL ligament is relatively weak; material property studies have confirmed this and have found a significantly higher compliance compared with other ligaments.

As opposed to many investigators, some authors do not consider the RSL ligament a true ligament or substantial mechanical structure, but rather a mesocapsular structure, because it lacks organized fascicular collagen bundles. In contrast to other ligaments, this poorly organized collagenous structure supports an abundant network of vascular and neural structures. Studies on microdissections revealed that these blood vessels did not penetrate the cortex of the scaphoid or lunate. When observed arthroscopically, the ligament has a relatively amorphous appearance. The biomechanical properties of the different portions are unclear. According to some authors, most fibers pass to the proximal pole of the scaphoid and function as a reinforcement of the volar component of the scapholunate interosseous (SLIO) ligament. Rupture of this ligament is associated with SLIO ligament injury.

SLIO ligament: This is a C-shaped ligament spanning the perimeter of the scapholunate joint. It was described in the 19th through the mid-20th century as 2 independent ligaments (dorsal and volar). In the late 20th century, the ligaments were considered to be 2 portions of a single ligament. In 1996, the first gross and histologic anatomical study reported the SLIO ligament as 1 stiff ligament consisting of 3 portions (dorsal, proximal, and volar), of which the proximal is membranous. Since then, there has been consensus among authors about the presence of these 3 interconnecting bundles. There are minor inconsistencies regarding the dimensions of each bundle. The dorsal portion courses from the dorsal horn of the lunate to the corresponding ulnar-dorsal region of the proximal pole of the scaphoid. Distally, it merges with the dorsal intercarpal ligament. Proximally, it merges with the membranous region of the
dorsal carpal capsule. It is regarded as the thickest, strongest, and most crucial portion of the SLIO ligament.\textsuperscript{54} This dorsal portion of the SLIO ligament is on average 2 to 4 mm thick, 3 to 5 mm long, and 5 to 6 mm wide.\textsuperscript{32,44,52,53} The most proximal portion is grossly anisotropic (composed of fibrocartilage with few collagen bundles without neurovascular bundles). It is approximately 1 mm thick, 4 mm long, and 11 mm wide.\textsuperscript{44} It is the widest and weakest portion of the SLIO ligament.\textsuperscript{54} The volar portion courses obliquely and distally between the proximal pole of the scaphoid and the lunate. This portion is thinner but is histologically comparable to the dorsal portion in terms of structure. Its dimensions vary between 1 and 2 mm in thickness, 3 and 5 mm in length, and 4 and 7 mm in width.\textsuperscript{32,44,52,53} Although it is less stiff than the dorsal portion, the volar and proximal portions make important contributions to the rotational stability of the scapholunate joint.\textsuperscript{54}

**Dorsal radiocarpal (DRC) ligament:** The DRC ligament was classically known as the dorsal radiotriquetral or dorsal radioluontriquetral ligament\textsuperscript{15,24,32,41}; numerous descriptions regarding its distal insertions are available.\textsuperscript{10,12,15,26,32,34,36,41} As the previous names suggest, most authors agree on an origin on the distal radius and insertions onto the lunate and triquetrum, but there are several controversies. First, there is controversy about the location of the origin on the distal radius. Most authors describe a dorsal ulnar origin spanning between the sigmoid notch and the Lister tubercle, but according to some it can originate dorsoradially as well.\textsuperscript{12,34,41,55,56} Second, there is controversy about the attachment on the dorsal area of the scaphoid. Some report on a bundle that inserts on the dorsoradial ridge of the scaphoid, named the dorsal radioscapoid ligament (Fig. 5).\textsuperscript{10,12,24,57,58} Most reports deny a scaphoid insertion.\textsuperscript{13,15,32,34,35,38,40–42} Instead some fibers of the ligament run across the scaphoid, providing some dorsal stability without inserting onto it.\textsuperscript{33,34,41} Owing to the high variation found in different descriptions, classification systems were generated that allow for characterization of the different DRC ligament insertion patterns that can be present in the general population.\textsuperscript{33,41} There are 4 different patterns, 2 of which have thin fiber coverage of the proximal scaphoid without any insertion (giving the ligament a deltoid shape); the other 2 have neither coverage nor insertion.

**Dorsal intercarpal (DIC) ligament:** The DIC ligament forms a lateral V configuration with the DRC ligament. Classically, these ligaments were described as the dorsal V ligament.\textsuperscript{37} There is consensus on the finding that the DIC ligament originates from the radial part of the dorsal aspect of the triquetrum and is orientated transversely. The controversy regards the insertions on the radial side of the midcarpus. Many descriptions about insertions have been proposed; all of them differ to some extent.\textsuperscript{12–15,32,33,41,42,55,56,59–61} The most consistently described insertion is the one on the dorsoradial ridge of the scaphoid, which seems to be present in all wrists. The
exceptions are 1 series reporting that the ligament contours the radial side of the scaphoid to insert in the distal tubercle on the volar side,\textsuperscript{41} and 1 series reporting no insertion to the scaphoid.\textsuperscript{15} The additional insertion(s) on the lunate, trapezium, trapezoid, and/or capitate vary greatly between series.\textsuperscript{32,44,55,61} The largest series reported in the literature presented a classification of the different type of patterns in 90 embalmed cadavers, which may explain the variations between smaller series.\textsuperscript{33} There were insertions in the lunate and scaphoid in nearly all specimens (90\% and 97\%, respectively). The ligament continued to insert in the proximal rim of either the trapezoid or trapezium in roughly one-half of the specimens (42\% and 50\%, respectively). In a few cases (7\%), there was an additional insertion to the capitate. These findings are mostly consistent with a classification based on MRI.\textsuperscript{60}

**Scaphotrapezium-trapezoid (STT) ligament:** The STT ligament consists of 2 or more bundles originating on the ulnar, volar, and radial cortices of the distal pole of the scaphoid, just distal to the attachment of the RSC ligament. Most recent studies mention either 2 distinguishable STT ligament bundles or 2 separate ligaments, the scaphotrapezium (ScTm) and the scaphotrapezoid (ScTd) ligaments.\textsuperscript{1,32,35,40} Each courses distally, forming the volar STT capsule, and inserts in the proximal volar edges of the trapezium and trapezoid, respectively. The precise function of the STT ligament is not clear, but it would seem to be an important stabilizer of the scaphoid and STT joint that minimizes excessive scaphoid flexion.\textsuperscript{32,62,63} There is consensus on the consistent presence of a stout radiovolar ScTm ligament, forming a V shape with the apex on the scaphoid.\textsuperscript{12,35,40,62,64,65} Some describe the presence of 2 or more bundles diverging from the scaphoid to form this shape.\textsuperscript{35,40,64} The controversial entity is the ScTd bundle or ligament, because several authors who described the STT ligament did not report on this part.\textsuperscript{12,62,64,65} According to some, any connections between the scaphoid and trapezoid are merely in the form of a thin STT capsule.\textsuperscript{62} Others did describe an ScTd ligament, which they found to be much thinner than the ScTm ligament.\textsuperscript{35} Berger\textsuperscript{32} described both bundles and reported that the volar capsule of the STT joint has sparse ligamentous stability.

**Scaphocapitate (ScC) ligament:** The ScC ligament is a large and stout capsular ligament that originates from the distal pole of the scaphoid, adjacent to the STT and RSC ligaments, coursing immediately distal and parallel to the latter. It passes distally and obliquely to insert on the radial half of the volar capitate surface, just proximal to the insertion of the volar trapeziocapitate ligament. The attachment area on the scaphoid is many times larger than that on the capitate, and it covers a large area on the volar and ulnar surface of the distal scaphoid.\textsuperscript{35,66} In an anatomic and biomechanical study, the ScC ligament consistently formed part of the scaphotrapezial ligament complex and
Anatomy of the Scaphoid: Controversial Literature

Chapter 2

was considered to be an important stabilizer of the midcarpal joint. No controversial findings are reported in the literature.

Transverse carpal ligament (TCL): The TCL is an extra-articular structure that originates along the ulnar side of the wrist from the hook of hamate and pisiform and inserts onto the entire volar trapezial ridge and the scaphoid. It forms the roof of the flexor carpi radialis tunnel. There is consensus among most authors on these 4 attachments of the TCL. Although the TCL attachment area on the scaphoid is only minor compared with the attachment areas on the hamate and trapezium, TCL disruption has a meaningful impact on scaphoid kinematics.

The main controversy regarding the TCL relates to its terminology, because the terms “TCL” and “flexor (or volar) retinaculum” have often been used interchangeably. Recent anatomical and histological studies have shown that these should be considered 2 different entities. The flexor retinaculum consists of 3 portions (proximal, mid, and distal), of which the mid portion is the TCL. The proximal portion is continuous with the deep investing fascia of the forearm; the mid portion (TCL) runs between the ridges of the trapezium, the scaphoid tubercle, the pisiform, and the hook of hamate; and the distal portion runs between the bases of the thenar and hypothenar eminences, deep to the proximal apex of the palmar aponeurosis. Recently, Stecco et al propose abandoning the term “flexor retinaculum” because in a histological study it did not correspond to any specific autonomous structure.

Discussion

The present study systematically summarized the consistencies and inconsistencies of the various descriptions and classification systems of scaphoid ligaments. None of the scaphoid ligaments other than the ScC ligament have been described consistently. These variations appear to be based in part on differences in defining related ligaments as either independent ligaments or separate bundles of a continuous ligament. Berger’s classification has the most detailed subdivision of ligaments and identification of the most independent ligaments of all classifications. This may be the reason why its classification and nomenclature are most commonly used in the current literature. One plausible reason for these different definitions of related ligaments may be the difficulty of accurately studying such complex soft tissue anatomy macroscopically when dissecting cadavers. These controversial descriptions are not limited to the wrist. With the exception of 1 arthroscopic study and 2 MRI studies, all descriptive reports of the carpal ligaments are based on macroscopic dissections, some of which were augmented with additional histological analysis. Important limitations of dissecting this complex soft tissue are the difficulty of appreciating ligament...
delineation by inspection and the need for disrupting ligaments to visualize or improve visualization of other ligaments. In a dissection study of 65 formalin-fixed cadaveric wrists, most scaphoid ligaments were graded as “not clearly delineated,” which is consistent with our theory of the complexity of defining these ligaments.42

Another reason for descriptive variations of ligaments is the interindividual variability of ligament insertions and morphology. This can only be determined by studying large numbers of cadaveric specimens. Such studies are difficult and have been performed only for some of the dorsal carpal ligaments. Both studies reported large variations between individuals.33,41

Most controversies regarding scaphoid attachments include the RCL, DRC ligament, DIC ligament, vScTq ligament, and STT ligament. The main reasons for the inconsistency in anatomical descriptions seem to be the difficulty of identifying individual interdigitating ligaments or bundles by macroscopic dissections, and the variability in ligament patterns among individuals. Future research is required to verify the ligament attachments that currently have the most controversial descriptions while addressing the inter-individual variability of ligament attachments and morphology. In Part II of this study, we will address these issues using 3-dimensional anatomical imaging.

Acknowledgements

The authors appreciate the Francis A. Countway Library of Medicine and Harvard College Library Imaging Services for providing access to and scans of historical publications.
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