The Vascular Anatomy of the Capitate: New Discoveries Using Micro-Computed Tomography Imaging

Assaf Kadar, MD,*† Mohamed Morsy, MBBCh, MSc,*‡ Yoo-Joon Sur, MD, PhD,*§
Alexis T. Laungani, MD,* Osman Akdag, MD,*|| Steven L. Moran, MD*

Purpose To study the intraosseous 3-dimensional microvasculature of the capitate bone using a novel high-resolution micro-computed tomography (μCT) imaging technology, and to examine the blood supply as it relates to the most common fracture types.

Methods Ten cadaveric wrists were injected with a lead-based contrast agent. The capitates were harvested and imaged using a μCT scanner. The intraosseous vascularity was incorporated into a 3-dimensional image. We measured the vascular pattern as well as the vessels' cross-sectional area, number, and distribution. An average capitate fracture line was calculated using clinical data from 22 patients with capitate fractures. The fracture line was projected on the representative capitate to assess its relation with the nutrient vessels' entry points.

Results The capitate is a well-vascularized carpal supplied by dorsal and volar vascular systems that anastomose in 30% of cases. There was no predominance of one vascular system over the other. Most vessels enter the capitate at the distal half and supply the proximal pole in a retrograde fashion. In addition, most specimens (70%) also had at least one vessel entering the proximal pole through the volar capitate ligaments and supplying the proximal pole directly. The average fracture line had an oblique orientation, and 90% of the specimens had a blood vessel entering proximal to that line.

Conclusions This μCT vascular study further verifies that the capitate receives most of its vasculature in a retrograde fashion, but the study also shows that most capitates have vessels supplying the proximal pole directly. These findings might explain why most capitate waist fractures do not progress to proximal pole avascular necrosis.

Clinical relevance This study characterizes the microvasculature of the capitate and might shed light on processes involved in bone healing and the etiology of capitate avascular necrosis. *(J Hand Surg Am. 2017;42(2):78–86. Copyright © 2017 by the American Society for Surgery of the Hand. All rights reserved.)*

Key words Avascular necrosis, capitate, capitate fracture, μCT, vascular.

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*From the *Division of Plastic Surgery, Mayo Clinic, Rochester, MN; the †Orthopedic Division, Tel Aviv Sourasky Medical Center, Sackler Faculty of Medicine, Tel Aviv University, Tel Aviv, Israel; the ‡Department of Orthopedic Surgery, Assiut University Hospital, Assiut, Egypt; the §Department of Orthopedic Surgery, Uijeongbu St. Mary's Hospital, College of Medicine, Catholic University of Korea, Uijeongbu, Republic of Korea; and the ||Department of Plastic Reconstructive and Aesthetic Surgery, Selcuk University, Konya, Turkey.*

Received for publication April 8, 2016; accepted in revised form December 8, 2016.

S. L. Moran is a consultant for Integra. The rest of the authors declare that they have no relevant conflicts.

Corresponding author: Steven L. Moran, MD, Division of Plastic Surgery, Mayo Clinic, 200 First Street SW, Rochester, MN 55902; e-mail: moran.steven@mayo.edu.

0363-5023/17/4202-0002$36.00/0
http://dx.doi.org/10.1016/j.jhsa.2016.12.002

Avascular necrosis (AVN) can be a debilitating clinical problem; in some of carpals it is thought to be related to their unique blood supply.[1] The carpals most commonly involved in AVN are the lunate, scaphoid, and capitate.[2,3] Although the etiology of AVN of the lunate, commonly known as Kienböck disease,[4] is still a topic of some debate, AVN of the scaphoid usually results from a fracture that disrupts the blood supply to the bone's proximal pole. In addition, AVN of the capitate has been reported to result from a fracture.[4]

Fractures of the capitate bone comprise about 1% to 2% of all carpal fractures.[5] Most fractures occur in conjunction with other carpal fractures, most notably with perilunate fracture patterns and the scaphocapitate syndrome.[6–8] Commonly cited complications of capitate fractures are nonunion and AVN of the proximal pole.[7,9,10] Both of these complications have been traditionally attributed to a retrograde blood supply to the proximal capitate, which renders the proximal pole avascular in cases of capitate body fracture.[4] Avascular necrosis of the capitate has been compared with the much more common scaphoid fracture and AVN of the scaphoid proximal pole.[11] Panagis et al[3] found that the capitate and scaphoid and some lunates contain a single intraosseous vessel that supplies a large area of bone. Such group 1 bones, as defined by those authors, are considered to be at greater risk for developing AVN after fracture. Indeed, several earlier studies demonstrated that nonunion and AVN were common complications if the fracture was initially missed.[4,7]

Recently, we have questioned the paradigm of retrograde vascularity to the capitate. In a group of 23 patients with capitate waist fracture, we found only one case of nonunion and none of AVN.[12] In addition, we found no cases of AVN in patients with scaphocapitate syndrome and fractures involving displacement of the capitate proximal pole. Furthermore, the incidence of AVN in reported series of capitate shortening for Kienböck disease is low.[13] This procedure,[14] which includes cutting a wafer of bone from the capitate waist, has not been associated with iatrogenic AVN of the proximal pole. These findings suggest that there may be additional sources of blood flow into the proximal pole of the capitate.

Previous studies examining the vascularity of the capitate used the classical modified Spalteholz bone clearing technique to identify bone blood supply.[3,4,15] Recent advances in computed tomography (CT) imaging allow for more precise study of bone blood flow. Three-dimensional micro-CT (μCT) provides the ability to image the bone specimen and its vascular supply up to the smallest capillaries with no need for dissection, debridement, or decalcification. It also enables accurate localization of the smallest blood vessels in the complex 3-dimensional structure of the carpal.[16] Whereas conventional CT scanners provide image resolution of 100 μm, μCT is capable of resolution to 1 μm.

The purpose of this study was to use μCT technology to better define the intraosseous vascularity of the capitate and to evaluate the theory that capitate blood supply is entirely retrograde in nature.

MATERIALS AND METHODS

Preparation of the specimen

After we obtained institutional review board approval of the study design by the Biospecimen Subcommittee (ID 15-006129), we obtained 10 unembalmed cadaveric wrists from the Department of Anatomy at Mayo Clinic, Rochester, MN. None of the extremities had a known history of disease, trauma, or surgery. Radial and ulnar arteries were identified and cannulated with a 20-gauge catheter (BD Insyte; Becton, Dickinson and Co, Franklin Lakes, NJ). The arteries were flushed with 50 mL heparinized saline followed by 50 mL formalin, and then with 50 mL heparinized saline, until clear retrograde effluent was observed. Injection of a lead-based contrast agent (Microfil MV-117; Flow Tech, Carver, MA) was observed by a pressure monitor (Protocol Systems, Inc, Beaverton, OR) to reach a physiologic pressure of 140 mm Hg. Leaks were sealed with clamps and the Microfil was allowed to cool for 24 hours in a 4°C refrigerator. The capitates were removed from the wrist with inclusion of as much of the surrounding tissue and interosseous ligaments as possible to trace vessels entry points.

Specimen scanning

Capitate specimens were scanned at a resolution of 20-μm/voxel resolution using a bench-top scanner (Physiological Imaging Research Lab, Mayo Clinic, MN).[16] The μCT scanner generates 3-dimensional images consisting of up to a billion cubic voxels, each 5 to 25 μm on a side, and has isotropic spatial resolution. Tomographic reconstruction algorithms applied to these recorded images were used to generate 3-dimensional images of the specimens. The intraosseous vascularity was assessed and incorporated into 3-dimensional rendering. All nutrient vessels entering the capitate were measured for vessel diameter and entry point distance from the tangent to the proximal pole. The capitate length was measured