As I complete this project, I think about the people who influenced me at critical stages of my career:

Steve Gunther, who was responsible for my decision to pursue orthopedics;
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They are all responsible, in part, for where I am today.

***

I have forever had the unequivocal, loving support from my parents Burt and Lorraine Greenberg.

***

Most importantly, I dedicate this to Nancy, my best friend and partner since college, who has been by my side and supported me in everything I do and who has given me two great daughters, Ryann and Sawyer, who are simply the best.
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Foreword

Early hand surgery writings, such as Dr. Sterling Bunnell's *Surgery of the Hand: Volumes 1–5*, lack any significant information dealing with the anatomy of or conditions involving the ulnar aspect of the wrist. Such was also my experience during my hand fellowship under the late Drs. Jim Dobyns and Ronald Linscheid, where I do not recall ever seeing a patient with ulnar-sided wrist pain despite a major focus of the fellowship being on the wrist. So, when I first went into practice, I was greatly challenged when I encountered a patient previously operated on for ulnar wrist pain with intolerable pain and “wrist locking.” (His condition eventually turned out to be a central tear of the triangular fibrocartilage complex that responded to open resection of the flap tear.)

This paucity of information on ulnar wrist pathology led to SUNY Upstate Medical University’s laboratory and subsequent clinical work on ulnar wrist conditions. Our original study of the anatomy and biomechanics of this area was awarded the Emanuel B. Kaplan Award at the annual meeting of the American Society for Surgery of the Hand (ASSH) in 1980. In 1984, the ASSH sponsored a Members’ Day Symposium dealing with the distal radioulnar joint (DRUJ). In 1987, when we suggested an instructional course on the DRUJ, initially there was skepticism that such a course could attract enough registrants to justify its being held. However, within 3 weeks of being posted, the course was sold out as have been subsequent courses on ulnar wrist problems.

Such enthusiasm for the ulnar aspect of the wrist continues to this day in response to the outstanding work of many investigators throughout the world. Dr. Jeffrey Greenberg's interest in this area began many years ago when he was an orthopedic resident in Syracuse, NY, and then grew during his hand fellowship and subsequent practice of hand surgery in Indianapolis. With this text, Dr. Greenberg has assembled the world’s experts to share with us the state of the art of *Ulnar-Sided Wrist Pain*. The book covers a topic that is one of the most complex and fascinating areas of all of hand surgery—an area that has been dubbed the *low back pain* of the upper extremity.

—Andrew K. Palmer, MD
Preface

In the first edition of David P. Green's *Operative Hand Surgery*, little (if any) attention was devoted to ailments on the ulnar side of the wrist, let alone the distal radioulnar joint. We have come a long way since then.

We, as contemporary surgeons interested in treating disorders that cause ulnar-sided wrist pain, are indebted to the clinicians, scientists, and patients who have contributed to our detailed understanding of this previously ignored anatomic region. *Ulnar-Sided Wrist Pain* is the latest addition to the Master Skills Series published and presented by the ASSH. It is the first publication devoted solely to addressing—in detail—problems and solutions related to ulnar wrist pain.

This text is divided into 30 chapters and will take the reader through the entire spectrum of disorders and dysfunction. The early chapters on development, anatomy, and biomechanics lay the foundation in formulating a diagnosis and treatment plan. These previously poorly understood aspects of the distal radioulnar joint are presented by experts who elucidate nuances and details in a fashion that is appropriate for students of all levels: from those in the early phases of their training to experienced surgeons. The authors of subsequent chapters present their topics in a similar fashion, and they have highlighted contemporary literature pertinent to their individual topics in their bibliographies. I am sure that the student, at any level, will find this book educational, innovative, and informative, and it will be a welcome addition to their print or e-library.

In the course of editing this text, I have reviewed chapters written by multiple experts all who have special interest in treating disorders of the wrist. It has become clear to me, based on the inconsistent use of terminology and abbreviations, that significant confusion exists regarding the terms triangular fibrocartilage (TFC) and triangular fibrocartilage complex (TFCC). In this text, in order to maintain consistency and standardize nomenclature, the term TFC will refer to the articular disc and the superficial (distal) and deep (proximal) components of the palmar and dorsal radioulnar ligaments (PRUL and DRUL). The TFCC refers to the TFC in conjunction with other elements that comprise the TFCC, namely the meniscal homologue, extensor carpi ulnaris subsheath, and disc-carpal ligaments, frequently referred to as ulnolunate (UL) and ulnotriquetral (UT) ligaments.

Personally, I am deeply indebted to all of the authors who volunteered to contribute to this textbook. They have devoted countless hours of their time and expertise in an
effort to assimilate contemporary scientific information, evidence-based information, and their own experience into chapters that allow the reader to formulate a diagnostic and treatment plan for their own practices.

A project like this cannot be completed without significant administrative guidance and assistance. Kim Mackey from the central ASSH office has worked tirelessly to bring this work to fruition. She is the true taskmaster who kept this project rolling along, coordinating all aspects of its production from start to finish. She is an invaluable resource and is to be congratulated.

Finally, I would like to acknowledge the assistance of Beth Bush, my administrative assistant at the Indiana Hand to Shoulder Center. She manages to juggle care of our fellows, all aspects of our fellowship, my calendar, and my clinical and academic practice while being able to be the liaison between the central office and myself during the course of this project.

—Jeffrey A. Greenberg, MD, MS
PART I

Introduction

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CHAPTER 1

The Evolution of the Distal Radioulnar Joint

Charity S. Burke, MD • Jeffrey A. Greenberg, MD, MS

For such a small joint, the distal radioulnar joint (DRUJ) functions by supporting an extreme amount of load while still providing a stable platform for forearm rotation and functional use of the upper extremity. The average articular surface area of this synovial joint is less than 0.8 cm$^2$.\textsuperscript{1} Loads across the joint are tremendous, as it serves as the fulcrum for the forearm unit, withstanding axial, shear, and compressive loads. Not only does it support such force, but the DRUJ also allows for a nearly 180° supination/pronation arc of motion at the wrist, which is arguably more important to the function of the hand unit than the opposable thumb. The DRUJ construct is not intuitive and seems to be of questionable biomechanical design. The joint relies on a small surface area for weight bearing while enabling a large arc of rotational motion with joint stability relying largely upon the triangular fibrocartilage complex and not bony architecture. It has been stated that the modern human wrist (including the DRUJ) is not constructed as a mechanical engineer might have designed it.\textsuperscript{2} The modern wrist is a mosaic of ancient and modern elements showing some shared features with other animals that are capable of manipulative activities. It also demonstrates features that are shared with other animals that constrain these activities and lead to wrist abnormalities. Finally, the modern wrist has features that are unique to humans. To best understand a joint’s form, function, and dysfunction, evolution is an ideal place to start.

Regardless of a person’s belief about creation versus evolution or some integration of the two schools of thought, anthropologists have tried to study Homo sapiens, our history, our behavior, and our societies as a science. The evolution of the DRUJ is extrapolated mainly from sets of fossils estimated by their position in the rock strata, radiometric dating, and some molecular biological studies of DNA and RNA. There is a requirement of logic and reason when studying religion and also when extrapolating information from bits and pieces of fossils and minute acid sequences. This chapter’s aim is not to make a philosophical statement, but rather to utilize available information to help explain the development of this unique and complex joint.
Darwin’s phyletic evolution was described as a linear process with one species evolving into the next influenced by selective advantage. Most anthropologists currently profess a more complex evolutionary dogma that is more tree-like in its shape, incorporating the theory that one species could have led to multiple lineages. Cladism describes the variety of alterations that can develop in a primitive line, creating branching hierarchies. A second process called punctuated equilibrium relies on random mutation to create a small group of morphologically distinct organisms. Most small groups become extinct, but through a true evolutionary advantage alone or paired with an environmental stress or change, a small group can emerge as dominant. This theory of cladism and punctuated equilibrium is strongly epitomized by the fact that although the DRUJ of a gorilla is most human-like, the chimpanzee is seemingly a much closer relative to *Homo sapiens* in other aspects although their DRUJ is not as similar. If evolution was a linear process, then the species with one characteristic so similar to humans, such as the DRUJ, should mirror humans in all other characteristics.

**Primitive Fish**

When the word evolution is mentioned, the idea of apes and monkeys immediately comes to mind, but for the dawn of the wrist and DRUJ, the archaeological path leads even farther back to 416 million years ago, which corresponds to the era of the primitive fish. The development of the pectoral fin represented the localization of appendages and was the first sign of evolution of the wrist. This occurred in the Devonian period in the primitive fish known as the Crossopterygia or Sarcopterygii (Fig. 1-1). Their fringed pectoral fin possessed carpal bones. Neil Shubin, an author, anatomy professor at the University of Chicago, and paleontologist, helped unearth “Tiktaalik,” a fossil in the Canadian arctic in 2004, which confirmed the existence of this type of fish. The modern day coelacanth, *Latimeria chalumnae*, is a descendent of this subclass and still demonstrates a primitive carpus in its fins (Fig. 1-2).
**Figure 1-1** A diagrammatic representation of the primitive fish Crossopterygii showing the earliest evidence of a bony pectoral fin that contains the early elements of the modern carpus. (Based on Almquist E. Evolution of the distal radioulnar joint. *Clin Orthop Relat Res.* 1992;(275):P5-P13.)

**Figure 1-2** Photograph of a fossilized modern day coelacanth *Latimeria chalumnae*, which is a descendant of the earliest primitive fringed-finned fishes (Photograph taken at Field Museum of Natural History, Chicago, IL.)

**Amphibians**

The development of shallow seas on the planet saw the emergence of primitive amphibians. Now-extinct progenitors of amphibians demonstrated multi-rayed fins. These initial seven-rayed fins that evolved into pentadactyl fins were used to hold onto the ocean floor in swift, shallow currents. The extinct Eryops is an example of this type of creature. Entire skeletons and fossils have been found in Texas, New Mexico, and West Virginia. They are thought to be from approximately 295 million years ago (Fig. 1-3).
Figure 1-3 A. A photograph of the primitive amphibian Eryops (photograph taken at Field Museum of Natural History, Chicago, IL). B. One of the first amphibians to demonstrate a pentadactyl extremity. (Based on Russell GV Jr, Stern PJ. The phylogeny of the wrist. *Am J Orthop.* 1998;27(7):494-498.)

Footprints fossilized in carboniferous rocks have helped characterize the locomotion of these creatures. The adaptations of the Eryops from aquatic to terrestrial life led to the development of limbs that were not attached to the skull and had osseous structures reminiscent of a scapula with a glenoid, a humerus, a radius, a weight-bearing ulna, 13 carpal bones and five phalanges (Fig. 1-3b). This configuration led to an inefficient broad-based, strenuous gait.

**Reptiles**
This limb configuration underwent many prudent adaptive changes for the evolving reptiles that spent more time on land than their predecessors, the amphibians. To be better positioned for weight bearing, selective advantage led to the emergence of pectoral limbs that were more internally rotated and pronated placing them more under the body for weight bearing. The humerus was still held in an abducted position with the elbow flexed demanding little supination in the reptile wrist (Fig. 1-4).
**Mammals**

During the Triassic period, approximately 230 million years ago, small mammals began to appear. They continued to show adaptation of their limbs with the pectoral limb continuing to internally rotate and pronate, while the pelvic extremities did the opposite. These small mammals were mostly nocturnal creatures and demonstrated a syndesmotic DRUJ in association with the positional changes in their extremities. In these early wrists the ulna articulated with the triquetrum (Tq) and pisiform (p), and ligaments such as the palmar-ulnar (PUCL) and palmar-radial (PRCL) collateral ligaments were identifiable (Fig. 1-5). With their insertions onto the lunate, these ligaments were felt to be a checkrein to wrist extension that facilitated weight bearing.
Primates
The cretaceous extinction has been estimated to have occurred approximately 65 million years ago. The earliest primates, evident approximately 58 million years ago, can be traced back to the prosimians or pre-monkeys, which include lemurs, tarsiers, and bushbabies. Lemurs, found populous in Madagascar today, are felt to be an extant mammal that closely resembles these early primates. Some fossils of now-extinct lemurs demonstrate enlarged ulnar heads that increased rotation at the DRUJ. The theme for wrist development favored mobility and demonstrated proximal retreat of the ulna and development of a synovium-lined DRUJ (Fig. 1-6). They also possessed an extended articular surface on the hamate that facilitates increased rotation at the midcarpal joint.⁹
Mammals dominated the earth after the Cretaceous extinction. During this time, the order of primates flourished. The forests that emerged made arboreal or tree-living very advantageous. Brachiation, the ability to swing from branch to branch, was most easily accomplished through increasing pronation and supination at the wrist. The pisiform, which had functioned much like a calcaneus in axial weight bearing previously, decreased in size, and the ulna retracted proximally in many hominoid species including the tailless primates such as apes. These changes at the DRUJ made accommodations for the increasing range of motion, especially rotation. Some early primates, and even primates
today, use a knuckle-walking gait in which the wrist is held in neutral and the phalanges weight bear. It is postulated that the strong flexors used in brachiation are unable to be overpowered by the weak extensors to hyperextend the wrist to place it plantigrade. Brachiation otherwise was a great segue into bipedal locomotion, serving much like training wheels on a bicycle for these early species. With the shift in ambulation to the pelvic limbs alone, the pectoral limbs, wrists, and hands were free to interact with the surrounding world.

In the primate group, the monkey wrist is most similar to the prosimians (Fig. 1-7). The DRUJ is partially diarthrodial with a further retracted ulna demonstrating only a partial carpal articulation. Septal retraction persists as the PUCL and the radioulnar ligament expand distally. Progressive changes seen in the gibbon (Fig. 1-8) are a synovium—lined DRUJ with a large triangular disc merging with the PUCL. A meniscus is seen between the ulna and pisiform and triquetrum as well as a bony lunula (os Daubentonii). The evolutionary changes seen in the gibbon's wrist enabled a prono-supinatory arc of 150°–180° compared to the 90° arc seen in the monkey. The chimpanzee's wrist demonstrates a meniscal homologue that is incorporated into the triangular disc, a cartilage-covered ulnar styloid, and a synovium-lined DRUJ.