Use of High-Speed X ray and Video to Analyze Distal Radius Fracture Pathomechanics

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KEYWORDS

• Distal radius fracture • High-speed X ray • Video X ray • Fracture biomechanics • Wrist guard

KEY POINTS

- Distal radius fractures are common injuries, especially in the pediatric and elderly populations, that account for significant morbidity and mortality.
- The combination of high-speed x-ray and video imaging has been used in other areas of medicine to investigate physiologic movement, joint kinematics, and fracture propagation. This type of recording system has not been used in the study of distal radius fracture pathomechanics.
- This imaging technique proved feasible with a drop tower apparatus consisting of a potted cadaver forearm, weights dropped to simulate a fall onto an outstretched hand, 2 identical video recorders, an x-ray source, and an image intensifier.
- In the presented pilot study, when impacted, the distal radius was found to shift in a volar direction with respect to the proximal carpal row, with the carpus also hyperextending. In elderly wrists, failure of the distal radius began as compressive failure on the dorsal cortex followed by tensile failure of the volar cortex. In younger wrists, both cortices tended to fail simultaneously.
- As a proof of concept, this study confirms that future studies with larger cadaveric samples can be analyzed with high-speed X ray and video to better understand distal radius fracture pathomechanics.

INTRODUCTION

Distal radius fractures are among the most common injuries treated by orthopedists[1] and the most frequently diagnosed fracture in women.[2] In fact, healthy women who are 60 years of age have a 17% chance of sustaining a fracture of the distal radius.[2] The incidence of this injury has increased significantly over the last several decades, a trend noted both domestically and internationally.[3–5] Distal radius fractures result in considerable pain and loss of productivity, often require surgical treatment, and are an indicator of increased risk of other fractures.[6] A 2011 report estimated that $170 million was paid by Medicare in 2007 toward treatment of distal radius fractures,

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and the future burden to Medicare will approach $240 million if trends in utilization of internal fixation continue as anticipated.[7] These fractures are also a common injury in the pediatric population,[8] accounting for 25% of all fractures in this age group.[9] The estimated cost associated with treating pediatric distal radius fractures is upwards of $2 billion per year in the United States.[10] Given the high incidence of distal radius fractures in the young and old alike, and the significance as both a personal injury and a public health concern, further understanding of the biomechanical mechanism of this fracture is essential. Moreover, improving our understanding of failure mechanisms of the distal radius might enable us to develop both improved treatments and preventative or protective devices.

The failure sequence of the distal radius during a typical fall on an outstretched hand is not well described in the literature. Ulrich and colleagues[11] (1999) used high-resolution images captured by a micro–computed tomography scanner and micro-finite element analysis techniques to calculate stress and strain on areas of the distal radius at the tissue level and quantify load transfer through the trabecular network. However, this in vivo study did not simulate an actual fracture to the distal radius; only subfailure loads were applied to the bone through the scaphoid or lunate. In other anatomic locations, the bony sequence of injury is better understood. In the cervical spine, for example, axial loading has long been considered to be the force behind the mechanism of vertebral burst fracture. Both in vivo and in vitro laboratory experimental studies as well as finite element modeling can subsequently predict areas of the vertebral body where failure is likely to begin and propagate when exposed to a given load.[12] No study exists that investigates the failure mechanism of the distal radius to this extent.

There are several published research studies that have evaluated the effectiveness of wrist guards in protecting against distal radius fractures.[13] They use a variety of test setups to simulate an impact across the wrist by using force-measuring platforms and strain gauges to calculate the force applied to the distal radius. These studies were conducted both with the wrist bare and while wearing a protective guard. Investigations using both cadavers and human subjects suggest that various forms of wrist guards can be helpful in reducing momentum and allowing for a higher impulse to be applied to the wrist/brace construct before distal radius failure.[14–17] Although these biomechanical data points can provide valuable support for wrist guard utilization, they do not provide direct information regarding the biomechanics of force transmission across the wrist and forearm during a fall.

In order to better understand the sequence of events, specifically the relative motion and failure sequence that occurs during a distal radius fracture, the authors think that high-speed imaging techniques, combined x-ray and video imaging, offer promise. These techniques have been used in other fields, although the literature is scarce regarding their use in orthopedic trauma, especially in investigating distal radius fractures. For example, in veterinary medicine, a high-speed x-ray system was described by Snelderwaard and colleagues[18] to analyze the rapid projection of a small animal's tongue to capture prey during a feeding experiment. Techniques of imaging fluid movement[19] and the motion of artificial heart valves[20] have also been described by using high-speed modern video systems.

In orthopedic sports medicine and arthroplasty, dynamic fluoroscopy has been investigated to elucidate joint kinematics in vivo in attempt to understand the weight-bearing forces, shear stresses, and relative motion of the joint.[21,22] To the best of the authors' knowledge, combined high-speed X ray and video has not been used to investigate fracture pathomechanics. The objective of the current report is to serve as a proof-of-concept demonstration, evaluating the feasibility of combined high-speed x-ray and video imaging techniques applied to a fracture model. Specifically, the authors sought to investigate the fracture mechanism of the distal radius from a typical fall on an outstretched hand and the effectiveness of various wrist guard designs.

EXPERIMENTAL DESIGN

Eight fresh-frozen cadaveric arms were thawed at room temperature for 24 hours. The elbow was disarticulated, and all soft tissues were removed from the proximal forearm. The proximal radius and ulna were potted using R1 FastCast (Goldenwest Manufacturing, Grass Valley, CA) urethane casting resin. The forearms were positioned vertically in an impact testing apparatus with the wrist preloaded in extension (**Fig. 1**). The impact force, provided by a 45-kg drop weight, was transferred to the arm via a load transfer plate assembly that restricted motion to the vertical direction using guide shafts. A rigid weight stopper prevented excessive compression of the arm. Weight was dropped on bare cadaver wrists as well as those protected by one of 3 wrist guard designs.

The drop test was photographed with high-speed video and X ray using a mechanical trigger