**INTRODUCTION** Wrist guards are worn by snowboarders and in-line skaters to reduce the risk of serious fall-related wrist injury. Still, distal radius fractures are among the most common injuries in these athletes.

Accordingly, wrist guard efficacy has been debated in the recent clinical and basic science orthopaedic literature. In *vitro* biomechanical studies have shown that wrist guards are capable of increasing the force to fracture during dynamic loading (though not if loading is applied quasi-statically), reducing impact energy, and decreasing fracture severity. Clinically, the risk of injury appears to be lower, and injuries are less severe, if guards are worn.

It has been hypothesized that wrist guards function by: preventing extreme dorsiflexion, absorbing energy and reducing impact forces. A recent publication suggests that wrist guards also function, in part, via load sharing; they were found to significantly reduce bone strain in the distal radius during quasi-static loading. It is unknown, however, whether wrist guards can similarly reduce strains during dynamic loading, or whether the protective effect diminishes as fall energy increases.

The purposes of this study, therefore, were to determine whether wrist guards reduce distal radius bone strain under dynamic impact loading conditions, and whether bone strain changes as impact energy is varied.

**METHODS** Eight upper extremities were harvested en bloc from four unembalmed cadavers (2 M, 2 F, 60.8 ± 8.2 years). Prior to inclusion in the study all specimens were screened with plane radiographs. The specimens were dissected at the elbow and all soft tissue was dissected from the proximal 10 cm of the radius and ulna. The forearms were then pronated, positioned in 75° of dorsiflexion (no varus or valgus tilt), and the elbows were embedded to the level of soft tissue in epoxy resin (MAS #718 Epoxy Resin, Phoenix Resins, Inc., Phoenix, AZ). A one-half inch diameter bolt was cast into the base of the potting material to facilitate attachment to the testing apparatus.

Uniaxial strain gauges (CEA-13-125UN-120, Measurements Group, Inc. Raleigh, NC) were affixed to the dorsal and volar distal radius (DDR and VDR), and to the volar radial midshaft (VRM). The gauges at the distal radius and ulna were positioned one centimeter proximal to the radiocarpal joint, while the gauge at the volar midshaft was placed approximately one centimeter proximal to the upper margin of the wrist guard. All the gauges were oriented parallel to the long axis of the radius. The strain signals were conditioned and amplified prior to sampling (model 2120/AD, Measurements Group, Inc., Raleigh, NC).

**Impact Testing** The experimental protocol involved repeated drop testing of each specimen from heights that increased in three-inch increments until fracture (i.e. 3 in., 6 in., 9 in, etc.). At each drop height the specimens were first tested guarded (Bone Shieldz, Litchfield, IL), and then again with the guard removed. The average mass of the combined drop weight device and guard was 6.0 ± 1.2 lbs. The specimen was dropped onto a one-degree-of-freedom load cell (Model MC6-6-4000 Advanced Mechanical Technology, Inc., Watertown, MA) covered with a foam rubber pad designed to simulate packed powder snow. After each drop test, anteroposterior and lateral radiographs were taken with a fluoroscope. The specimens were then dissected from the proximal 10 cm of the radius and ulna. The forearms were then pronated, positioned in 75° of dorsiflexion (no varus or valgus tilt), and the elbows were embedded to the level of soft tissue in epoxy resin (MAS #718 Epoxy Resin, Phoenix Resins, Inc., Phoenix, AZ). A one-half inch diameter bolt was cast into the base of the potting material to facilitate attachment to the testing apparatus.

**Data Analysis** Relationships between the outcome (bone strain, contact force) and independent variables (drop height, use of wrist guard) were determined with a two-way analysis of variance (ANOVA), while the relationships between contact force and bone strain (DDR, VDR, VRM) were explored with correlation analysis (SAS, SAS Institute, Cary, NC). Linear regression was used to examine the significance of the reduction in bone strain with increasing drop height.

**RESULTS** All of the specimens were tested successfully. Strains on the dorsal side of the forearm were compressive (DDR), while strains on the volar surface were tensile (VDR, VRM).

The specimens fractured at an average drop height of 13.1 ± 6.2 in (0.3 ± 0.2 m), which corresponded to an estimated energy of 3.1 ± 1.5 N-m. In all cases, fractures occurred when the wrists were dropped unguarded. As expected, contact force (Fz) increased with drop height (p < 0.001). Contact force was reduced when the specimens were guarded (p < 0.001).

Bone strain in all three sites, (DDR, VDR and VRM), increased as drop height increased (p < 0.001). Of the three, however, only DDR strain was significantly attenuated by the application of wrist guards (p < 0.001). Wrist guards decreased DDR strain at each drop height, by an average of 38 percent (Fig. 1). The effect of wrist guards on VDR strain varied as a function of drop height (height*guard, p = 0.015). Wrist guards had no effect on VRM strain (p = 0.99).

The effectiveness of wrist guards decreased as fall energy (drop height) increased. While the magnitude of the reduction in DDR strain was relatively constant across all drop heights (Fig. 1), when viewed as a percentage of unguarded bone strain (Fig. 2) the relative reduction decreased as drop height increased (p < 0.001). At a drop height of eighteen inches, wrist guards decreased DDR strain by only ~ 20 %, down from ~ 65 % at three inches.

**DISCUSSION** The first goal of this study was to determine whether wrist guards reduce impact-generated bone strains in the distal radius. We found that they do, but that the magnitude of the effect depends on anatomic location (DDR vs. VDR and impact energy (VDR)). The difference may be attributable, in part, to variations in loading at the two locations.

The second goal was to determine whether wrist guard effectiveness decreases as fall-related energy increases. It appears to, as the percentage of DDR strain reduced in guarded wrists decreased with drop height. In fact, while wrist guards may be effective in most (low energy) falls, there may be a threshold above which they can not protect against fracture.

Previous studies have suggested that wrist guards may increase the risk of midshaft forearm fractures, negating somewhat any beneficial effect they might have. Consistent with our previous study, we found no increase in strain in the volar radial midshaft when the wrists were guarded. At least in the orientation we tested—designed to simulate a fall onto an outstretched hand—wrist guards do not appear to increase the risk of forearm fracture.

Despite it's limitation (*in vitro*, one loading orientation) our findings provide further insight into how wrist guard function. The results of our study should provide data for the rational design of future wrist protective equipment.