Biomechanical Effect of In-line Skating Wrist Guards on the Prevention of Wrist Fracture

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A biomechanical study was conducted in this study to investigate if in-line skating wrist guards can effectively reduce the impact forces so as to protect the wrist from fracture. The forearm specimens with and without wrist guards were dropped using a specially designed sled to simulate the impact on the wrist while falling. A force plate was used to measure the total impact force on the dropping weight whereas a load cell was attached to the proximal end of the specimen and used to quantify the impact transmitted through the wrist joint. From the non-destructive tests, mean peak force measured from a force plate showed no difference between the guarded and unguarded groups whereas mean impulse of the guarded group was significantly greater than that of the unguarded group ($p<0.01$). Comparing the peak force and impulse measured from the load cell, the peak force of the guarded group was significantly less than that of the unguarded group ($p<0.001$), while the impulse values were similar. When the specimens were dropped from a higher position (2.5 ft vs. 1 ft), all unguarded specimens had severe wrist fractures whereas fracture was found in three out of 5 guarded specimens. Comparison of mean peak forces and impulses showed a significant difference between the guarded and unguarded groups only in the mean impulse measured from the force plate. These results suggest that the wrist guard may protect the wrist by attenuating the peak force transmitted to radius and ulnar although it may not be effective when the wrist is subjected to an impact sufficiently large to cause fractures.

Key Words : Wrist Guard, Impact Force, Impulse, Fracture, Wrist Joint

1. Introduction

In-line skating is one of the fastest growing sports in the United States with over 20 million participants. With greater use comes increased incidence of injury. Injuries have increased 180% over the past 2 years (Schieber and Branche-Dorsey, 1995). In 1995, the Centers for Disease Control and Prevention estimated that over 100, 000 in-line skating injuries were evaluated in emergency rooms. The most common area of injury is the wrist (Calle and Eaton, 1993; Schieber and Branche-Dorsey, 1995; US Consumer Satefty Commission Data base).

Approximately two-thirds of the wrist injuries are fractures or dislocations (Calle and Eaton, 1993; Schieber and Branche-Dorsey, 1995). Most upper extremity injuries occur when patients do not wear wrist guards. However, injuries do occur

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even when wearing the wrist guards (Calle and Eaton, 1993; Chong et al. 1995).

In-line skating wrist guards are made of high impact ABS plastic plates and nylon. They are believed to protect the wrist from the biomechanical forces that cause fracture by two mechanisms: 1) diffusion of impact forces across the scapho-radial junction and 2) prevention of wrist hyperextension. However, many skaters do not use wrist guards in part because of a lack of belief in their effectiveness in injury prevention.

While clinical studies have anecdotally suggested the protective value of the wrist guards, little scientific supporting data exist in the literature. The purpose of this study was to investigate if in-line skating wrist guards can effectively reduce the impact forces so as to protect the wrist from fracture.

2. Materials and Methods

Five pairs of forearms obtained from fresh frozen cadavers were used in this study. Plain radiographs of all specimens were taken to rule out the specimens with gross pathology or damages in the wrist. All specimens were sealed in double plastic bags and stored at −20 degC until testing.

Each specimen was thawed at room temperature before testing. Extensor tendons (carpi ulnaris, carpi radialis brevis, and carpi radialis longus) were dissected out through a small incision on the mid-forearm to extend the wrist 30 degrees when testing unguarded specimens. Then, the proximal radial ulna of each specimen was potted into a custom designed cup using PMMA.

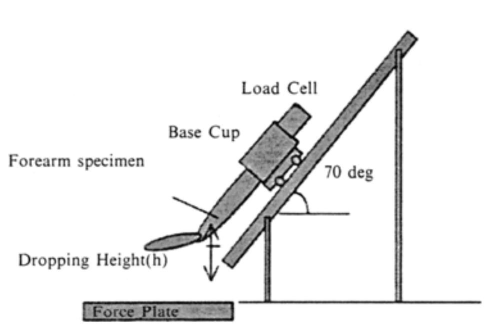


Fig. 1 Schematic diagram of the testing set-up

The prepared specimen was mounted on the sled system as shown in Fig. 1. A force plate was used to measure the total impact force on the dropping weight whereas the load cell was attached to the proximal end of the specimen to quantify the impact transmitted through the wrist joint. Each specimen underwent nondestructive tests followed by destructive impact tests.

2.1 Impact testing procedure

Nondestructive Test : One specimen was dropped from the 1 ft height (h in Fig. 1) with the wrist guard on first, and dropped again from the same position after removing the wrist guard. When the test started with the wrist guard on, the matched specimen from the other side was dropped without using the wrist guard first. While testing the specimen without the wrist guard, 30 degree extension of the hand was made by pulling the extensor tendons and maintained during the impact. After each impact, radiographs were taken to check bony fractures in the specimen.

Destructive Test : Following the nondestructive tests, the specimens were dropped from the 2.5 ft height (h in Fig. 1) for destructive tests. Paired extremities were successively dropped with or without using the wrist guard. Dropping height was determined from repeated drops of a few forearm specimens without the wrist guard until the bony fracture was observed. After impact, radiographs of each wrist were taken and examined by two sports medicine surgeons.

During these impact tests, two force-time curves were obtained from the force plate on the floor and the load cell attached to the proximal end of the specimen. Peak force and impulse (area under the force curve) data were measured from these force-time curves.

3. Results

Typical force-time curves obtained from the destructive and nondestructive tests are shown in Fig. 2.

Nondestructive Test Results : Examination of radiographs taken after nondestructive tests

Table 1 Mean (SD) peak forces and impulses measured during nondestructive tests

Groups	PF_F (N)	IMP_F (Nsec)	PF_L (N)	IMP_L (Nsec)
Guarded	733.3 (201.7)	29.75 (2.55)	17.61 (7.39)	0.204 (0.035)
Unguarded	824.6 (153.3)	23.37 (3.10)	28.81 (9.70)	0.1999 (0.029)

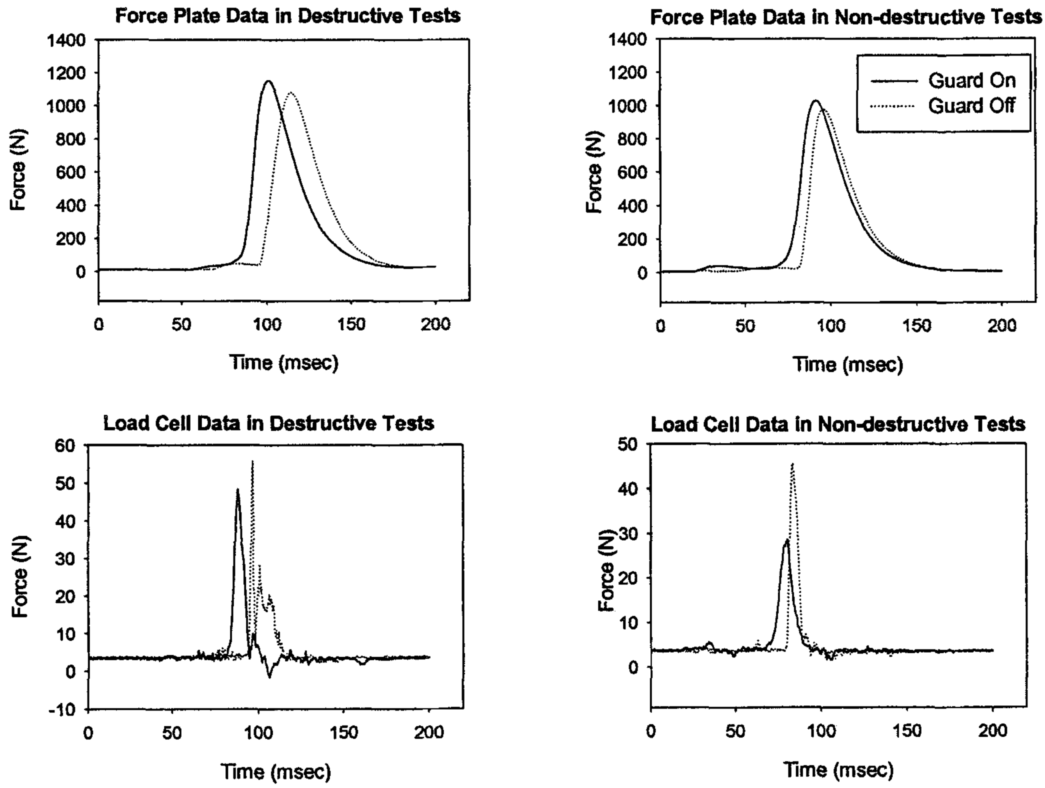


Fig. 2 Typical force-time curves obtained during destructive and non-destructive tests

showed that 9 out of 10 specimens had no bony fracture whereas one seemed to have a radius fracture. Mean peak forces and impulses measured from the force plate (PFF and IMPF) and the load cell (PFL and IMPL) are listed in Table 1.

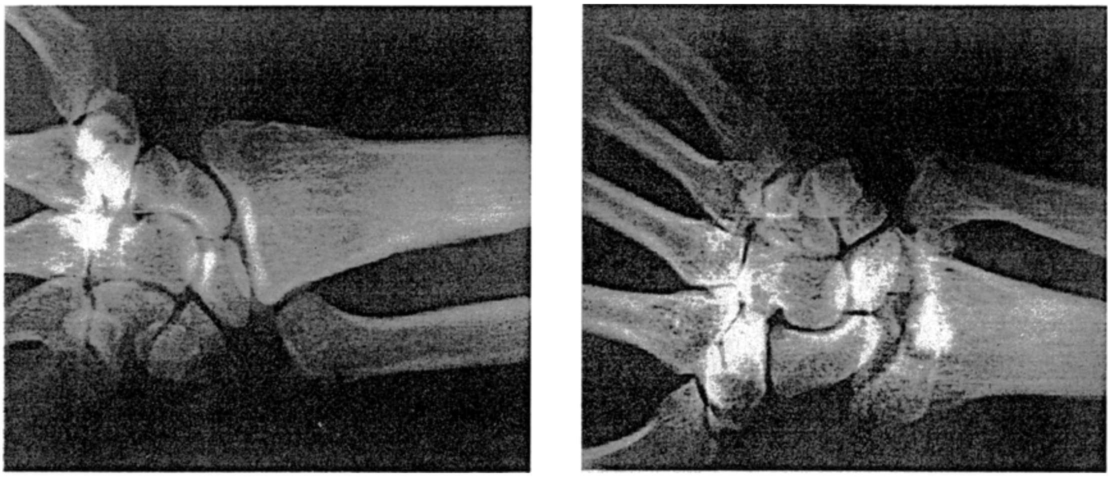
Mean PFF showed no difference between the guarded and unguarded groups. Mean IMPF of the guarded group was significantly greater than that of the unguarded group ($p<0.01$). By contrast, mean PFL of the guarded group was significantly less than that of the guarded group (17.6 vs. 28.8 N, $p<0.001$), while almost same mean IMPL values were measured in both groups.

Destructive Test Results : Examination of radiographs taken after nondestructive tests showed that all unguarded specimens had severe wrist fracture. Observed fractures in the unguarded group were distal radius fracture in three, radius and ulna fracture in one, and scaphoid fracture in one. The observation of guarded specimens showed no fracture in two, whereas ulna condyle fracture in one and radius fracture in the other two specimens. However, these fractures were less severe than fractures observed in the unguarded specimens. Figure 3 illustrates the radiographs of one matched pair of specimens, one with radius fracture without using wrist guard and the other with no fracture when using wrist guard.

Mean peak forces and impulses measured from the force plate (PFF and IMPF) and the load cell

Table 2 Mean (SD) peak forces and impulses measured during destructive tests

Groups	PF_F (N)	IMP_F (Nsec)	PF_L (N)	IMP_L (Nsec)
Guarded	1082 (168)	42.50 (3.86)	26.05 (6.36)	0.294 (0.026)
Unguarded	1104 (119)	38.96 (2.71)	30.70 (8.08)	0.301 (0.015)



(a) (b)

Fig. 3 Radiographs of paired specimens taken after destructive tests: (a) Right wrist with no fracture after testing with the wrist guard; and (b) Left wrist with radius fractures after testing with no wrist guard

(PFL and IMPL) are listed in Table 2. Significant difference between the guarded and unguarded groups was found only in the mean impulse measured from the force plate (IMPF).

4. Discussion

In-line skating has become popular in recent years, and the incidence of injuries is likely to increase. The use of protective gear, including wrist guards, has been encouraged although there have been little scientific investigations of the efficacy of in-line skating wrist guards in preventing wrist injuries. In fact, Giacobetti et al. (1997) concluded that the in-line skating wrist guards were not effective in preventing wrist injuries under the experimental conditions of their study in which the forearms were subjected to a fast compressive load until failure. The limitation of this was that the testing conditions might not adequately simulate the dynamic variables involved in a fall onto an outstretched hand.

In this study, a new method for testing the wrist injury due to a fall was developed and used to investigate the efficacy of in-line skating wrist guards in the prevention of wrist fracture. In contrast to the methods used in previous studies in which the forearm specimens were fixed and loaded by an impactor, we dropped the forearm specimen using a specially designed sled to simulate the impact on the wrist while falling. Using our testing method, it was possible to create the wrist fractures similar to in-line skating injuries.

The force plate was used to measure the total impact on the dropping weight whereas the load cell was attached to the proximal end of the specimen was used to quantify the impact transmitted to the forearm through the wrist joint. Since the mass of each specimen was constant in tests of each specimen, force variation with time measured from the load cell represents the acceleration change along the sled direction during impact. In this way, it was possible to measure more objective measurement of force on the wrist joint as compared with previous methods.

Similar PFF in both destructive and nondestructive tests indicate that similar impact force was applied on the specimens in both groups. This was expected because objects of similar weights were dropped on the force plate. On the other hand, our results showed smaller peak force (PFL) and larger impulse on the force plate (IMPF) in the guarded group. A significantly larger impulse (IMPF) in the guarded group was likely to result from a longer contact time taken by the deformation of the wrist guard. Such a deformation of the wrist guard seemed to attenuate the peak force transmitted to radius and ulnar as shown in significantly smaller peak force (PFL) in the guarded group in nondestructive tests. However, similar peak force data were observed in destructive tests, although the severity of injuries seemed to be reduced due to the use of wrist guards. These suggest that the protection provided by a wrist guard may be effective only within a certain range of load while being ineffective when an impact sufficiently large to cause wrist fractures is applied on the wrist joint. Unfortunately, we were not able to determine the critical impact range for effective protection of wrist guards in this study. Further studies using a high speed cameras and accelerometers attached to the radius and ulna are required to investigate this protection mechanism in more detail and thereby to improve the wrist guard design for better protection.

5. Conclusion

Results of this study showed that in-line skating wrist guards may not be effective in preventing wrist fractures, particularly when the load on wrist during fall is large enough to produce the fractures. However, our results also demonstrate that the wrist guards may provide effective protection within a certain range of loads, although not determined in this study, by attenuating the peak force transmitted to the forearm. Such a protection mechanism should be helpful in reducing at least the soft tissue injuries and possibly the fracture severity, even though not effective in preventing the wrist fractures.

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