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CASE REPORT

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Investigation of an alleged mechanism of finger injury in an automobile crash

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Abstract This investigation centers on the case of an adult male whose finger was allegedly amputated by the steering wheel of his car during a crash. The subject claimed to have been driving with his left index finger inserted through a hole in the spoke of his steering wheel and was subsequently involved in an offset frontal collision with a tree. The finger was found to be cleanly severed at the mid-shaft of the proximal phalanx after the crash. This injury was alleged to have been caused by inertial loading from the rotation of the steering wheel during the crash. To determine whether this injury mechanism was plausible, three laboratory tests representing distinct loading scenarios were carried out with postmortem human surrogates loaded dynamically by the subject's steering wheel. It was found that the inertial loads generated in this loading scenario are insufficient to amputate the finger. Additionally, artificially constraining the finger to force an amputation to occur revealed that a separation at the proximal interphalangeal joint occurs rather than a bony fracture of the proximal phalanx. Based on these biomechanical tests, it can be concluded that the subject's injury did not occur during the automobile crash in question. Furthermore, it can be shown that the injury was self-inflicted to fraudulently claim on an insurance policy.

Keywords Finger injury · Finger tolerance · Amputation · Hand injury · Proximal interphalangeal joint

Introduction

Several cases of self-inflicted hand and finger injuries have been reported, especially among physicians [1]. The motive behind these injuries is for the claimant to receive financial compensation from insurance companies due to their inability to work. This case presented a series of unique challenges such as inconclusive accident reconstruction data, no photographs of the severed finger (and therefore questionable superficial injury morphology), and limited toxicological information. These aspects could not be addressed by traditional medicolegal investigative techniques; therefore, an interdisciplinary approach (in the form of injury biomechanics tests) was utilized to determine the validity of the subject's claim.

Case report

A middle-aged male was involved in a single-vehicle offset frontal crash with a tree. A crash reconstruction was performed by local authorities, which found that he was traveling between approximately 40 km/h on a straight road and struck the tree with the right front corner of his vehicle. The posted speed limit on this road is 70 km/h, and the subject claims to have been driving at approximately 50 km/h. The crash occurred during daylight on a dry, straight road with no adverse weather conditions that could affect visibility.

The subject alleges that he was driving with his left index finger inserted through the left hole in the steering wheel, and that upon impact with the tree, the rotation of the steering wheel severed his finger at the proximal phalanx. The severed finger was found on the floor near the driver's seat, and the driver did not sustain any other injuries. The driver was belted, and an inspection of the vehicle interior revealed trace amounts of blood in the steering wheel hole as well as on the seatbelt and driver's seat. The driver was transported to the local hospital where the examining physician described the injury as "a clear cut wound without any signs of crush or avulsion." It is unclear why his finger was not surgically reattached. While at the hospital, the driver tested positive for lidocaine, which he explained as a result of having visited the dentist earlier that afternoon.

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Fig. 1 Photograph of the case vehicle taken shortly after the collision with the tree. All of the damage to the vehicle is localized in the front passenger side

Fig. 2 Photograph of the interior of the case vehicle at the accident scene. Note the traces of blood near the bottom (*left*) hole in the steering wheel, and that the wheel is rotated approximately 90° counterclockwise

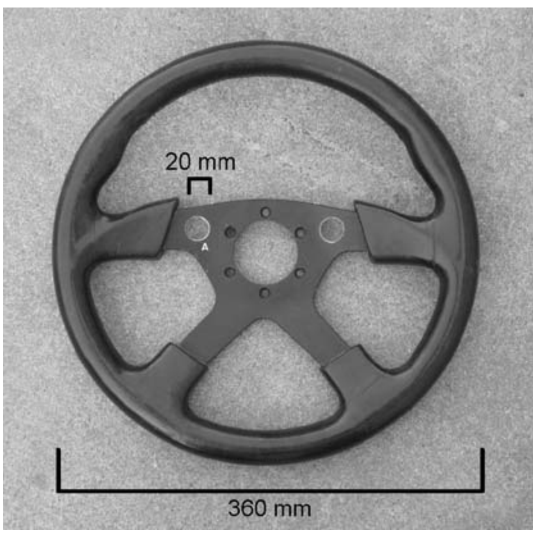

Fig. 3 Photograph of steering wheel showing 20-mm diameter holes in spokes. Note hole in left spoke (labeled *A*), where the subject's finger was allegedly positioned

Photographs taken at the scene (Figs. 1 and 2) show damage to the right front quarter panel, hood and bumper, as well as the steering wheel turned 90° to the left (counterclockwise from the driver's position). The steering wheel is a custom wheel with two holes drilled through the aluminum spokes, each approximately 20 mm in diameter (Fig. 3).

Methods

To determine the probability of the subject sustaining an amputation at mid-shaft of the proximal phalanx, a series of three tests involving postmortem human surrogates (PMHS) was developed to simulate the forces a finger would experience during a crash similar to that of the subject. These tests were performed to supplement the existing forensic evidence in this case to more definitively determine the mechanism of injury during loading from a steering wheel. Furthermore, these tests were designed to investigate the injury mechanism and tolerance of a hand loaded in a manner closely representative of the case in question. The ability to impart both rotational and translational motions to the steering wheel was required to duplicate accurately the relevant dynamics. This requirement was necessary to account for the relative motion between the driver and the steering wheel so the inertial environment in a frontal collision could be replicated in the laboratory.

Photographs of the subject vehicle taken shortly after the collision showed that the wheel rotated approximately 90° to the left. This was used to define the range over which the tests would be performed. Acceleration pulses of vehicles striking narrow objects in offset frontal configurations were analyzed to establish a reasonable time duration over which the 90° rotation occurred [2–7]. From the literature, a range of 110- to 170-ms impact duration was identified. Since the subject collision was concentrated generally in the region of the right front wheel, it was assumed that any collision-induced wheel rotation would occur over a time duration similar to the duration of the collision; therefore, a 90° left-hand rotation over approximately 100 ms was chosen as the target design specification for the test fixture.

An occupant (even if belted) will translate forward in the vehicle during a frontal collision, which occurs as the vehicle decelerates due to the impact. As a result of this translation, the occupant moves toward the steering wheel. The inertia of the arm therefore tends to "push" the finger into the hole during the collision. To replicate this phenomenon in the absence of a vehicle acceleration field, the test fixture was designed to move the wheel into the hand, thereby generating this "pushing" motion. The translational acceleration of the test fixture was based on the vehicle acceleration pulses found in the literature so that the inertial forces generated by accelerating the arm would be appropriate in magnitude and timing. This type of coordinate frame transformation is used extensively in biomechanical and crash testing. For example, the common HYGE sled system uses this concept of "reverse acceleration" and is the industry standard for laboratory simulation of crashes [8].

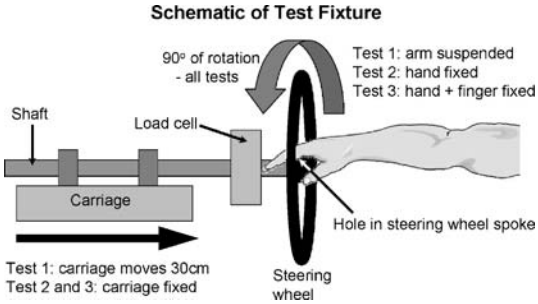

Fig. 4 Schematic drawing of test apparatus showing component parts and conditions for each test. Note that the tests were performed with left arms. The right arm is shown here for clarity of illustration

To investigate the effects of complex loading on the finger and occupant kinematics during the crash event, three distinct test scenarios were developed. For all tests, the target duration of the rotation and translation (if applicable) was 100 ms. The first scenario (test 1) involved 90° of steering wheel rotation (counterclockwise from the driver's point of view) in conjunction with 30 cm of steering wheel translation toward the driver. A human cadaver upper extremity was amputated and suspended at mid-humerus, with the second finger of the left hand inserted through the left hole in the steering wheel to the level of the mid-shaft of the proximal phalanx. This test was designed to simulate relative motion between the driver and the steering wheel with no active muscle tensing from the driver (Fig. 4).

For test 2, the hand was rigidly constrained at the wrist, and the steering wheel was rotated through 90° without any linear translation. This test simulated the "worst-case" condition, wherein the driver generates enough force to keep his hand stationary while the steering wheel rotates. This condition would produce the greatest inertial force in response to the hand resisting the rotation of the steering wheel.

The goal of test 3 was to force an injury to occur to compare the resulting injury pattern to the case subject. A similar setup to test 2 was utilized (wrist rigidly constrained, 90° of rotation, no linear translation). Due to the fact that the same specimen was used for tests 2 and 3, the fourth finger was used for test 3 to be able to discern between injuries caused during tests 2 and 3. Although the case involves the subject's second finger, the geometrical and anatomical similarities between the second and fourth digits allow the results to be compared directly. To assure that an injury occurred, the fourth finger was inserted through the hole in the steering wheel, and the distal portion of the finger was rigidly secured. With the wrist and distal portion of the finger both constrained, an injury resulting from the rotation of the steering wheel was assured. See Table 1 for a summary of loading conditions and injury outcomes.

For each test, data were recorded from a load cell mounted in series with the steering wheel, angular rate sensors mounted to the wheel, and accelerometers mounted to the wheel and carriage. The shear force on the finger from the rotation of the steering wheel was calculated by subtracting the inertial moment of the steering wheel (due to the wheel's rotational acceleration) from the moment measured by the load cell and dividing by the distance from the center of the wheel to the finger: $M_x = I_x\alpha + Fd$ where M_x is the moment measured by load cell about x-axis, I_x is the moment of inertia of steering wheel, α is the angular acceleration of steering wheel, F is the shear force on finger, and d is the distance from finger to center of steering wheel.

To represent more accurately the subject's interaction with the steering wheel, all cadaveric specimens were selected using anthropometric measurements that closely matched the subject, who was a small male. After each test, the specimen was dissected to identify injuries to the skin, tendons, and bones of the finger.

All cadaveric specimens were prescreened for HIV, hepatitis A, B, and C, as well as preexisting injury and pathologic anomalies. Pretest CT scans were performed to screen for preexisting fractures or other injuries. All cadaver testing and handling procedures were approved by the University of Virginia Institutional Review Board.

Results

Figure 5 summarizes the shear force experienced by the finger for each of the three loading scenarios. For comparison, the angular rate of rotation and linear velocity (for test 1 only) are shown in Fig. 6. Note that the more rigidly the finger was constrained, the greater the peak shear force on the finger and the greater the risk of amputation or disarticulation.

Test 1 resulted in the skin being partially torn at the loading site, and the flexor and extensor tendons were both intact along with the proximal phalanx. Test 2 also produced a partial tear in the skin at the loading site, but no tendonous or bony injuries were found. No bony fractures or avulsions were evident for either test. For test 3, the skin was completely torn at loading site, the extensor tendon was torn, and the flexor tendon was partially torn. The

Table 1 Summary of loading location and condition as well as observed injuries for each of the tests

Test	Subject	Loading location	Loading condition	Boundary condition	Observed injury
1	A	Left hand, second finger	90° rotation and 30-cm translation	Suspended at mid-humerus	Superficial skin laceration
2	B	Left hand, second finger	90° rotation	Rigidly constrained at wrist	1-cm superficial skin laceration
3	B	Left hand, fourth finger	90° rotation	Rigidly constrained at wrist, finger rigidly fixed	Disarticulation at proximal interphalangeal joint

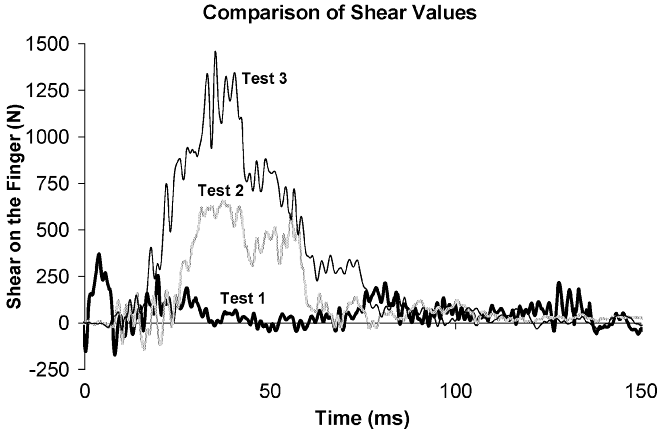

Fig. 5 Comparison of the shear force experienced by the finger for each of the three test conditions

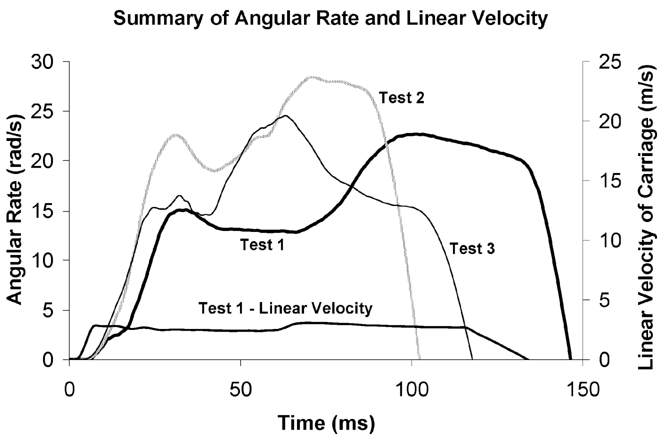

Fig. 6 Graphical representation of the angular rate for each of the three tests, as well as linear carriage velocity for test 1

finger was disarticulated at the proximal interphalangeal joint, with the flexor tendon being the only remaining attachment between the finger and the metacarpal (Fig. 7). A tuft fracture at the proximal end of the middle phalanx was noted. There was no bony fracture of the proximal phalanx, no "clean-cut" amputation, nor any other visible injury to the proximal phalanx.

Discussion

This study evaluated three scenarios for generating a bony amputation similar to the subject's injury. All three scenarios involved dynamic loading from the subject steering wheel. In the first scenario, the dynamics of the collision were reproduced as realistically as possible according to standard and accepted techniques for estimating the wheel motion during the crash and its alleged interaction with the subject's upper extremity. The rotational motion of the wheel, as well as the relative translation between the wheel and the subject's body, was simulated. In test 1, the finger rotated with the wheel, remaining within the hole and attached to the rest of the upper extremity. The finger was exposed to a peak shear load of less than 400 N and sustained only minor skin injuries.

Fig. 7 Photograph taken after tests 2 and 3. Note skin laceration and absence of bony injury to the second digit, and disarticulation of the fourth digit at the proximal interphalangeal joint

In the second scenario, the hand was fixed to increase the force generated on the finger when the wheel rotated. This condition was identified as a reasonable representation of a "worst-case" loading situation since it simulates the case where the inertial forces "push" the finger into the hole, and an external force (such as active muscle tensing) resists motion of the hand. Yet even this excessive loading condition did not generate a significant injury to the finger. When the impact loading was applied to the finger, the rotating wheel pulled the hole laterally relative to the axis of the finger, and the finger was able to escape from the hole. As the finger was being pulled from the hole, just over 600 N of shear force was exerted on the finger. This force was sufficient to cause some superficial injuries, but the underlying bones and tendons were undamaged.

From the results of tests 1 and 2, it can be concluded that the dynamics of the subject's collision were not appropriate to cause sufficient loading to amputate the finger, even if the finger was in the hole at the start of the collision. The inertial loading of the finger due to the collision forces, even if the subject was exerting maximum muscle force to keep the finger in the hole and resist the rotational motion, was inadequate to generate anything more serious than superficial injury.

The final test condition was intended to force an injury to occur to examine the nature of an injury caused by the interface between the steering wheel hole and a finger. In this scenario, both the hand and the finger were fixed, and the wheel was rotated so that an amputation would occur. When impact loading was applied to the wheel in this test, a finger amputation did, indeed, occur. However, the nature of the injury was unlike the injury sustained by the subject. In the test, the amputation occurred at the proximal interphalangeal joint. This indicates that the joint, not the bone, is the "weak link" in a finger loaded in this manner. This is consistent with the bulk of biomechanical literature, which shows that joints are typically much weaker than the bones adjacent to them. The finger loading from the steering wheel is similar in that the joint would be expected to fail before the bone. This would be equally true for both the second digit (index finger) and the fourth digit (ring finger). Furthermore, the ragged nature of the injury generated in test 3 is not consistent with the "clean-cut" injury sustained by the subject (see Figs. 7, 8, 9 for comparison). The steering wheel material is approximately 5 mm thick at the location of the hole and does not have a sharp edge. As a result, it does not load the finger in a "knife-like" manner. Instead, the mechanism of injury is a complex combined loading that "tears" rather than "cuts" the finger (Fig. 10). In this "tearing" situation, the joint is a weaker link than the bone and therefore sustains the injury.

In addition to the engineering tests that were performed, there are other circumstances surrounding the case that could explain the driver's injury. It is possible that the driver amputated his own finger and staged the crash to collect insurance payments and/or compensation due to his incapacity to work. As mentioned previously, the driver tested positive for lidocaine (a local anesthetic), which he claims was from a dental appointment earlier that afternoon. The driver himself is a dentist, which would provide access to surgical tools and anesthetics; however, none were found at the crash scene. Additionally, the presence of blood on the back of the steering wheel might indicate that the car had been driven after his finger had been amputated, an interesting finding considering the driver claims to have lost consciousness immediately after the crash.

Typical medicolegal and accident reconstruction methods could not definitively determine how this injury was caused, which necessitated a nontraditional approach to investigating the plausibility of the driver's claimed mechanism of injury. The length of time between when the injury occurred and the investigation precludes the use of many advanced forensic investigative techniques. For instance, electron microscopy and mass spectroscopy have been used to detect minute metallic particles in wounds [9], but the driver was unavailable for these technologies to be utilized. In this case, the driver's motives can only be speculated upon, but the analysis of the biomechanics test data provides a reasonable basis for the possibility that the driver's injury was not sustained during the crash and was, in fact, self-inflicted.

Fig. 8 Radiograph of case subject's left hand taken shortly after the injury, showing a clean amputation of the second finger at the mid-shaft of the proximal phalanx

Fig. 9 Radiograph taken after test 1. No bony injuries are evident on X-ray, and none were found upon dissection

Fig. 10 Radiograph taken after tests 2 and 3. Note absence of bony injury to second digit, and complete disarticulation of fourth digit at the proximal interphalangeal joint

Conclusion

Based on these findings, it can be concluded that the subject's injury was not sustained as a result of loading from the hole in the steering wheel during the collision in question. This conclusion is supported by the fact that the inertial forces generated in the crash were insufficient to generate a significant injury when the wheel rotated. Our tests found that a shear force of approximately 1,400 N is required to amputate a finger under these conditions, and when both the hand and the finger are constrained so that the wheel must cause an amputation, the nature of the amputation is unlike the injury sustained by the case subject. When the blunt edge of the wheel amputates the finger, the mechanism is best described as a "tearing" mechanism rather than a "cutting" mechanism. As a result, the joint fails rather than the bone, and the sustained injury is neither "clean cut" nor a bony fracture through the shaft of the phalanx.

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