SB3C2016
Summer Biomechanics, Bioengineering and Biotransport Conference
June 29 –July 2, National Harbor, MD, USA
SB³C2016-1092

AN INVESTIGATION OF HUMAN LONG BONE FRACTURE PATTERNS DURING TRAUMATIC AMPUTATIONS FROM MOVING RAILROAD EQUIPEMNT

Brian T. Weaver (1,2), Mark Davison (1), Steve Rundell (1), Eric Meyer (3)

(1) Explico Engineering Co.
Novi, MI, USA

(2) Orthopaedic Biomechanics Laboratory
Michigan State University
East Lansing, MI, USA

(3) Biomedical Engineering
Lawrence Technological University
Southfield, MI, USA

INTRODUCTION

The Federal Railroad Administration (FRA) reported that 1,844 trespassing pedestrians (non-railroad employees) were struck and injured by moving railroad equipment between the years of 2012 and 2014 [1]. A common injury associated with these types of accidents is Traumatic amputation [2]. Specifically, these injuries occur as a result of interaction between a pedestrian's limb, the rail equipment, and the rail [3]. The circumstances surrounding the injury are often in question. Determining the exact manner and circumstances of the injuries can be challenging when no eyewitness or video evidence is available. In these circumstances, the injury pattern may provide key information in determining what the pedestrian was doing moments before the incident. This information is essential in the implementation of best practices regarding pedestrian safety around moving rail equipment.

Emergency Room nurses and/or physicians assess the injuries and document the findings in the medical records. These often include x-rays of the amputated limb. Currently, there is no research available that document the mechanism of injury associated with contact from a railroad wheel. In the absence of carefully controlled experiments that associate specific fracture patterns with limb position, these x-rays provide very little useful information beyond the location of the amputation. The fracture pattern of the amputated limb might provide details regarding the orientation of the limb at the moment of the incident. This information could assist the investigator in determining the sequence of events that led to the injury.

The current study investigated the mechanism associated with traumatic amputations to human femurs caused by contact with a moving railroad wheel. The objective of the current study was to carefully characterize long bone fracture patterns during a variety of relative positions to moving rail equipment. The current study hypothesized that distinct positioning of a pedestrian's limb would result in distinct and specific bony fracture patterns.

METHODS

Testing was performed at the Henry Ford DT&M Roundhouse in Dearborn, MI. A section of track was blue flagged for safety. Twelve 4th-generation composite femur bones (Sawbones®, Vashon island, WA, USA) were utilized to simulate human femur bones. The proximal and distal ends of each femur were potted into 4-inch and 3-inch schedule 40 PVC couplings, respectively, using room temperature curing epoxy resin (Fiber Strand™, Martin Senior Corp., Cleveland, OH, USA). Approximately 12 inches of composite bone was exposed between each pot. The exposed portion of each bone was covered with ordnance/ballistic gelatin (Gelatin Innovations, Shiller Park, IL, USA) to simulate soft tissue.

Each leg was secured on top of, and perpendicular to, the rail by fastening each pot to wooden blocks located on either side of the rail (Figure 1). These blocks were rigidly fixed to a railroad tie so the proximal end of the femur was 9 inches from the gauge side (i.e. inside) of the track (Figure 2). Each pot was fastened to the wooden blocks via hinges to allow the specimen to swing away from the locomotive after bone fracture occurred. Each bone was run over by the leading wheel of a locomotive (GE B-B-100/100-2GE733) traveling approximately 5 mph. The orientation of the legs was precisely controlled. Testing included two orientations (supine/prone) and two locomotive directions (medial/lateral). Fracture patterns were recorded and analyzed following each test.

Figure 1: Illustration of test setup

RESULTS

All 12 specimens fractured as a result of contact from the railroad wheel. The fracture of all 12 specimens was located on the gauge side the rail as a result of contact from the flange on the railroad wheel (Figure 2). None of the specimens were crushed. The most common fracture pattern was a butterfly wedge (n=6) (Figure 3). Interestingly, the other cases (comminuted; n=3, oblique; n=2, transverse; n=1) produced similar "Y" shaped crack propagation patterns, but the wedge fracture was incomplete (Figure 3). The fracture pattern was dependent on the orientation of the femur and direction of locomotive movement. Specifically, the "Y" shaped fracture pattern opened up towards the flange in all 12 specimens (Figure 3).

Figure 2: Illustration of a typical railroad wheel and rail

DISCUSSION

The results of the current study support the hypothesis that human bones contacted by moving railroad equipment develop a distinct fracture pattern that is dependent on the direction and impact location of the wheel on the limb/bone. Additionally, results demonstrated that the fracture patterns were all indicative of bending failure.

The results presented here are similar to previous experimental studies involving bending of human cadaveric long bones, which also generated similar patterns of fracture, including the typical butterfly, oblique and transverse fractures [4]. During bending, the fracture initiates on the tensile side and propagates to the neutral axis before bifurcating on the compression side to form the characteristic "Y" shape [5]. In the current study, the flange contacted the bone and attempted to push the bone out of the way resulting in 3 point bending.

This study shared the limitations inherent in utilizing composite bones. However, the use of cadaveric specimens was not possible given the nature and location of testing. Regardless, the 4th generation composite femur bones have been validated for use as a surrogate to healthy human bones for biomechanical testing [6]. The flexural rigidity has been shown to be less than 8% of the biological range of healthy adult bones and the failure modes closely match published findings of human bones [6]. It is also noteworthy that intra-specimen variations are under 10%, which permit greater experimental control, greater repeatability, and more meaningful comparisons between different scenarios.

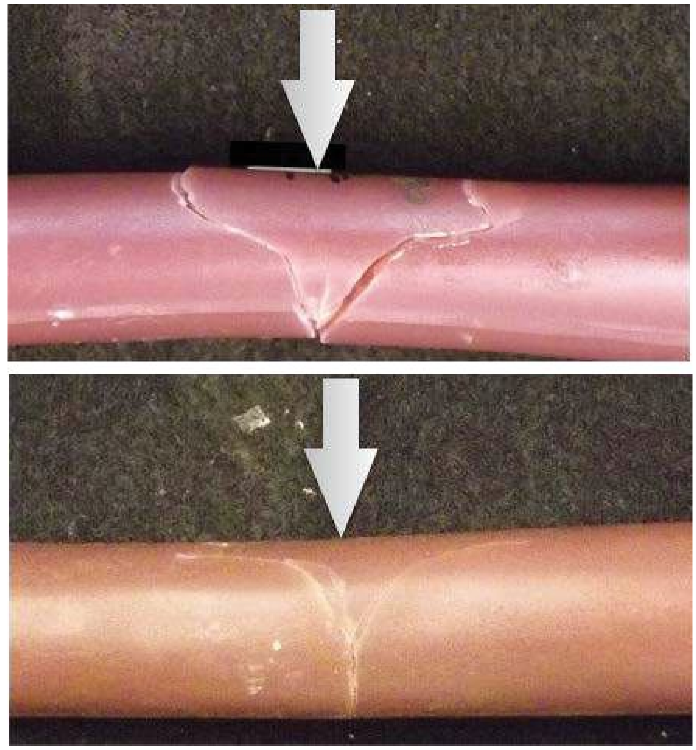

Figure 3: Illustration of the typical fracture patterns observed. Top: Butterfly wedge pattern; Bottom: Oblique / incomplete wedge pattern. Arrow indicates direction of impact

This study contradicts the conventional wisdom in forensic biomechanics that bones are crushed when run over by rail equipment. These results indicate that a bending fracture mechanism occurs. Therefore, it may be possible to determine the orientation of a body that was stuck and run over by moving railroad equipment. This is an important finding that will assist investigators when analyzing the circumstances surrounding a trespasser or railroad worker that sustained a traumatic amputation as a result of being run over by moving rail equipment.

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Matthew Goodman from the Henry Ford DT&M Roundhouse for serving as our railroad engineer and allowing access to the facility and equipment.

REFERENCES

[1] Safetydata.fra.dot.gov
[2] Shapiro, M., et al., *Am J Emerg Med*, 12(1):92-3, 1994
[3] Thompson, G., et al., *J Ped Orth*, 3:443-8, 1983
[4] Porta, D., *Forensic Science and Medicine*, 279-310, 2005
[5] Sharir, A., et al., *Vet J*, 177:8-17, 2008
[6] Gardner, M. et la., *Ann Biomed Eng*, 38(3):613-20, 2010