The Risk of Injury of the Metacarpophalangeal and Interphalangeal Joints of the Hand

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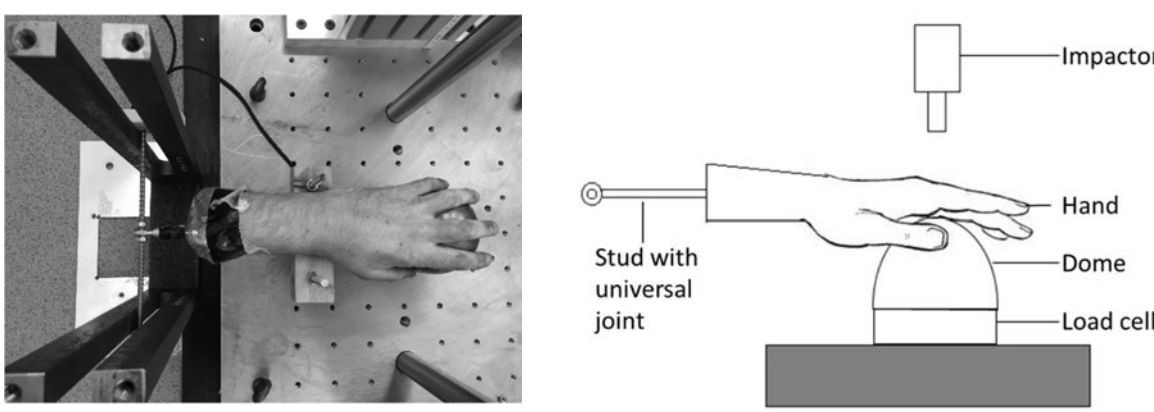
I. INTRODUCTION

Due to the effect of hand trauma on the ability to perform even the simplest of activities, injuries to the hand can have a dramatic effect on function in daily life and at the workplace. In World War II, 15% of troop evacuations to the United States were as a result of hand trauma [1]. In a recent study of traumatic hand injury in a British Military Hospital in Iraq [2] it was found that hand injuries were common and formed a large proportion of the workload seen at the military field hospital on operations. The mean period of restricted duties on discharge due to hand injury was 8 days and 38 patients (8% of all hand injuries) were aero-medically evacuated as a result of hand trauma. Hand injuries lead to a significant reduction in capacity of a unit and long term functional degradation to the injured individual.

Current standards for hand protection (for example BS EN 13594:2015) are not based on injury curves from cadaveric experiments, as is the case for other body parts, such as the head or the lower extremities. Specifically, the metacarpophalangeal (MCP) and interphalangeal (PIP) joints of the hand are particularly disabling and, therefore, the aim of this study was to evaluate the probability of fracture of the PIP and MCP joints of the human hand.

II. METHODS

Impact testing was conducted on the MCP and PIP joints of 22 fresh-frozen cadaveric hands with a mean age of 56 years (range 41–73 years) that were stored at -20°C. Prior to testing, the hands underwent Computed Tomography (CT) scanning (Siemens Somatom Definition AS 64, Erlangen, Germany) in order to exclude any pre-existing orthopaedic pathology. The specimens were taken out to thaw overnight prior to testing. Each joint was rested on the polished steel surface of a hemispherical dome, 100 mm in diameter (standard BS EN 1621-1:2012), which was mounted on a 6-axis load cell. Each hand was intact approximately up to half of the forearm's length. A stud was secured tightly into the intramedullary canal of the radius and screwed into a universal joint at other end. The universal joint was connected to a horizontal rod that could rest at a height of choice on a permanent fixture. Essentially, this meant that the hand would rest on the dome at one end and the simulated elbow at the other whilst allowing physiological motion at every joint (Figure 1). The drop striker had a mass of 2.5 kg (BS EN 13594:2015) with a flat face, 25 mm in diameter. Load and speed-at-impact data were recorded at 25 kHz using a National Instruments PXIe data acquisition system.



(a) (b)

Fig. 1. Experimental set-up at the drop tower. (a) Photograph from the top. (b) Schematic of the set up from the side.

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Each joint was tested at target energy levels of either 5 J (1.98 m/s), 14 J (3.13 m/s), or 20 J (4.08 m/s). All hands were CT scanned post impact. Joints for which no injury was detected at the CT scans post-testing at the 5 J energy level, were tested again at a higher energy level.

For each joint a survival analysis was conducted using a Weibull distribution for the recorded axial force. The Weibull regression model is $P(x) = 1 - e^{-(x/\lambda)^{\kappa}}$, where P is the probability of injury, x is the predictor variable, and λ and κ are the scale and shape parameters, respectively.

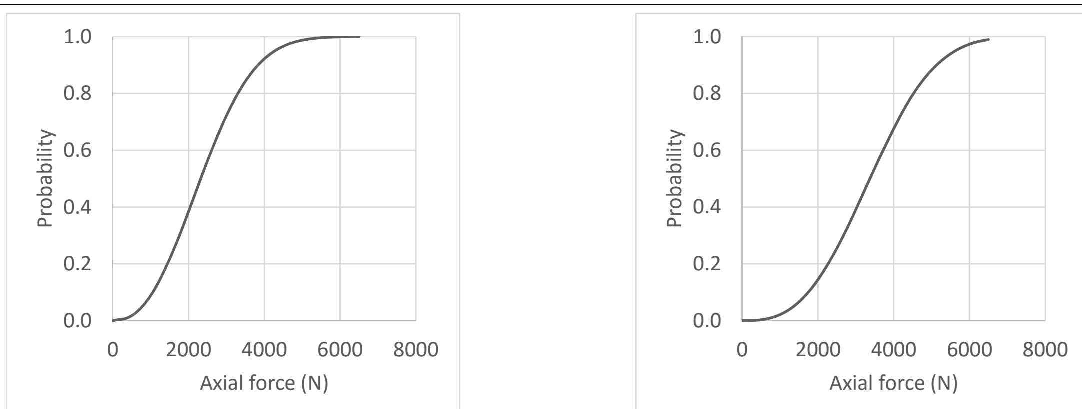
To derive the survivability curves, data were split into left and right censored. Left censored data included samples that sustained either a simple shaft fracture, a comminuted shaft fracture, or an intra-articular fracture. Right censored data included samples that sustained no injury or a chip of the bone (including sesamoid bones).

III. INITIAL FINDINGS

The constants of the Weibull regression model and the axial force at 50% injury risk for each of the MCP and PIP joints are shown in Table 1. The Weibull constants for the MCPs were similar and so were the constants for PIPs 2-4; an aggregate injury risk curve for each one of those groups of joints is plotted in Figure 2.

TABLE I
CONSTANTS OF THE WEIBULL REGRESSION AND AXIAL FORCE AT 50% INJURY RISK FOR EACH JOINT

	MCP joints					PIP joints			
	1	2	3	4	5	2	3	4	5
Axial force (kN) at 50% injury risk	2.55	2.23	2.57	2.32	2.03	3.49	3.46	3.14	2.54
Shape, κ	3.17	2.24	2.39	2.07	1.89	2.75	2.59	2.75	4.12
Scale, λ (N)	2861	2621	3000	2773	2462	3990	3983	3590	2779



(a) (b)

Fig. 2. Injury risk curves for (a) the MCP joints, (b) the PIP joints, excluding PIP 5. The Weibull shape and scale constants are 2.67 and 2740, and 2.86 and 3835 for (a) and (b), respectively.

IV. DISCUSSION

This is the first study to have investigated the injury tolerance of the MCP and PIP joints under impact loading at different energy levels. Axial force was considered as the best predictor of injury. The joints were tested whilst the hand was passive; the injury risk of a functional hand where the finger flexors are taut, thus simulating an 'active', grasp posture should be considered in the future. The injury survivability curves proposed here may be used for designing targeted protective solutions such as gloves.

V. REFERENCES

[1] Burkhalter WE, J Hand Surg Am, 1983
[2] Anakwe RE, Standley DM, J Hand Surg Br, 2006.