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Implementation of Synthetic Human Hands for the Evaluation of Impact Load Protection of Metacarpal Gloves

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Abstract: This research focuses on measuring the performance of metacarpal gloves commonly used in different industrial sectors in Spain. The protection levels are evaluated via controlled impact tests on synthetic hand models manufactured from a combination of medical-grade ballistic gel and a 3D-printed bone structure previously calibrated to closely reproduce the behavior of an actual hand. Two configurations are assessed: unprotected hands and hands with metacarpal gloves. Results indicate that current commercially available metacarpal gloves offer varying degrees of protection against impact loads depending on the impact's position and the metacarpal glove's design. Results also show that quantifying the degrees of performance under impact loads allows better identification and selection of the metacarpal gloves that are more suitable for the workers' different activities.

Keywords: Impact protection, Metacarpal gloves, Hand

1. Introduction

The percentage of occupational accidents in the upper extremities and hands is one of the highest compared to other areas of the human body. In many production sectors, manual tasks with high-risk factors can produce hand injuries with varying severity. These injuries often result in functional limitations or long-lasting disabilities and have significant financial implications (Trybus et al. 2006; Pollard et al. 2014; Alessa et al. 2020; Heberger et al. 2022). In order to reduce the likelihood of severe damage to the hands, workers are required to use industrial gloves or metacarpal gloves. These gloves are sturdy, comprised of multiple layers of cut and puncture-resistant fabrics, as well as reinforcements typically designed to protect the dorsal region of the hand, mainly the metacarpal zone and phalanxes, against impacts. Understanding the impact protection offered by various metacarpal gloves will allow users to identify the most suitable protection for the task under consideration. Experimental studies with cadaveric hands have been completed to measure the forces resulting from low-velocity impacts on different regions of the hand (Schuurman & Kauer, 2002; Carpanen et al., 2019; Sosa & Alessa, 2021). Few studies have analyzed the resistance levels of industrial metacarpal gloves against impacts, such as Loshek (2015) and Sosa and Alessa (2021). Understanding the protection offered by various metacarpal gloves will allow employers to provide the most suitable protection for the task under consideration.

2. Materials and Methods

Surrogated hands were manufactured from a combination of medical-grade ballistic gel for soft tissue and 3D-printed bone structure. The gel selected is an oil-based, medical-grade, 100% synthetic, and clear gel produced by Humimic Medical (Greenville, SC, USA) (Humimic, 2021), commonly used for making tissue mockups typically used in medical training. The bone structure was first digitally constructed from 3D scans of human hand bones. A nylon-type material (PA6 Nylstrong; Smartfil, Spain) was used to manufacture the bone structure. This nylon material has a density of 1.52 g/cm^3 and a bending strength of 120 MPa. The selected hand shape was nearly flat, open, and relaxed posture, reproducing the same position as the cadaveric hand specimens used in previous studies (Loshek, 2015; Sosa & Alessa, 2021).

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Low-velocity (1.5 to 1.6 m/s) impact tests were performed using an instrumented drop-weight tower (Instron, CEAST Fractovis 6785). The impactor had a hexagonal cross-sectional shape with an outer diameter of 32 mm and a total mass of 5 kg. Impact tests were conducted in two configurations: First, impacts on an unprotected hand, and then impacts on protected hands. The protection was provided by metacarpal gloves commercially available in Spain. Specimens were placed in a nearly flat position. They were subjected to 15 impacts on the PIP (proximal interphalangeal) joints, the MCP (metacarpophalangeal) joints, and at the center of the diaphyseal region of the metacarpal bones MET (metacarpals). The peak reaction force (PRF) was measured for each impact. A total of 32 impacts were performed, 17 tests on unprotected hands and 15 on protected hands.

3. Results and Preliminary Conclusions

The primary objective of this study was to implement surrogate hand models that accurately replicated the biomechanical characteristics of the human hand. These surrogate hands were meticulously constructed using 3D printing technology for the bone structure and employing medical-grade synthetic gel to cast the surrounding soft tissues. The authors characterized the gel material in a previous study, and the mechanical properties are reported in Sosa & Moure (2022). To validate the accuracy of the manufactured surrogate hand specimens, the experimental data obtained from cadaveric hand specimens and similar surrogate models reported by Sosa and Alessa (2021) and Alessa and Sosa (2022) were utilized as a benchmark for comparison. The results of impacts on unprotected hands obtained in this research are similar in magnitude to the values reported in those studies.

The secondary objective of this research was to evaluate the impact resistance of different metacarpal gloves using the calibrated surrogate hands. The assessment involved measuring the changes in PRF values and determining the percentages of injurious impacts by comparing data obtained from surrogate hands with and without protection. Test results indicate that the magnitude of the impact forces changes as the design of the protections included in the glove design changes. Results obtained in the present study demonstrated that metacarpal gloves can effectively mitigate a portion of the impact energy. Still, the level of mitigation depends on the impact position and thickness of the protection. Test results also indicate a notable decrease in the average PRF values for each assessed glove compared to the unprotected barehand condition.

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