A Method for Assessing Mandible Blunt Impact Biomechanics During Anterior-Posterior Impacts to a Restrained Jaw

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Biomechanical, mandible, Blunt impact, Fracture, Anterior-posterior impacts
A METHOD FOR ASSESSING MANDIBLE BLUNT IMPACT BIOMECHANICS DURING ANTERIOR-POSTERIOR IMPACTS TO A RESTRAINED JAW

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INTRODUCTION

Injury risk functions and biofidelity corridors for the human mandible are critical for the evaluation of maxillofacial protection devices that are under development. Currently the mandible is the only facial bone without any injury criterion for use with the Facial and Ocular Countermeasures Safety (FOCUS) headform. Previous attempts to develop an injury criterion for anterior-posterior (A-P) impacts to the mandible have been unsuccessful due to the mandible opening when impacted [1]. In order to investigate the fracture tolerance of the mandible to A-P impact and determine a mandible injury criterion for the FOCUS headform, a closed jaw boundary condition was needed to mitigate the previous limitation. Additionally, the proposed condition would be representative of a helmeted population (military, athletics, etc.), where movement of the mandible is restricted by headgear.

METHODS

A restraint fixture was designed to prevent the jaw from opening during blunt impacts using a Monorail Drop Tower (MDT). The restraint consisted of an angled ridge aluminum plate (2.5 cm wide, 15.2 cm long) with beveled edges positioned against the body of the mandible. The aluminum plate was connected to a six degree of freedom load cell (Humanetics) and braced against the MDT (Fig. 1). The load cell was used to measure any forces transferred through the mandible into the restraint fixture and allowed for the angle of the aluminum plate to be adjusted. The entire restraint fixture was designed to be adjustable in the vertical and horizontal directions, allowing the aluminum plate to be aligned with the mandible of the specimen.

![Figure 1: (A) Restraint fixture attached to MDT. (B) Experimental test setup with restraint fixture aligned with the mandible.](image)

Two fresh-frozen male cadaveric heads (IBD012, 67 yrs; IBD016, 69 yrs) were used to assess proof of concept in accordance with the Army Policy for Use of Human Cadavers [2]. Each specimen was sectioned between the C2 and C3 vertebrae to keep the foramen magnum from being exposed. Extraneous tissue was removed. The specimen was potted in a polyurethane resin (Golden West Manufacturing) using screws and polymethylmethacrylate. To align the specimen while potting, the Frankfurt plane was identified by the exterior auditory meatus and the infraorbital foramen and oriented vertically, ensuring reproducibility and a natural position of the head. The mandible of each specimen was instrumented at both rami with strain gauges and acoustic emission sensors to assist with fracture detection. The specimen’s jaw was exercised by hand before being closed with a 10 N force using the restraint fixture. Impacts were performed at 5 J increments until
fracture was detected using a guided impactor mass with a circular $6.45 \, \text{cm}^2$ impact area. After each test, the presence of fractures was detected using specimen mounted sensors, x-ray imaging, and palpation. Additionally, 5 J baseline impacts were conducted to aid in fracture detection. The presence of a fracture was verified using a computed tomography (CT) scan and then the dissection of the mandible. During each test, impact velocity was recorded using a velocimeter (GHI Systems). Impact force and acceleration were measured using a load cell (Honeywell, NJ) and accelerometer (Endevco) on the impactor mass. Force transmitted though the specimen to the base of the MDT was measured using a load cell (Humanetics). Data were collected at 1 MHz using a Synergy Data Acquisition System (Hi-Techniques Inc.) and analyzed using MATLAB (MathWorks) scripts. All data were filtered using a 4th order low-pass Butterworth filter with a 500 Hz cutoff frequency. High-speed video was collected for all tests using a MIRO and a Phantom v9 (Vision Research Inc.) camera at 2,000 frames per second.

RESULTS AND DISCUSSION

A total of sixteen impacts were conducted on the two specimens. The tested impact energies ranged from 4.6 J to 22.4 J. Test velocities ranged from 1.7 m/s to 3.4 m/s. Fracture was observed in the strain data collected (Figure 2) during testing. Post-test CT imaging and dissection confirmed the presence of fractures in both specimens. Specimen IBD012 had a subcondylar non-displaced transverse linear fracture on the left side of the mandible. Specimen IBD016 had a commuted transverse linear fracture of the right mandible condyle. Fracture patterns were consistent with those reported in the literature [2]. Measured impact peak force (Table 1) for both fracture cases compared well with fractures produced during previous work examining A-P mandible impacts [3] and mandible impacts directed through the temporomandibular joint [4].

![Figure 2: Impact force and strain recorded for specimen IBD016.](image)

CONCLUSIONS

A method has been developed that is able to reliably allow for the creation of mandible fractures during A-P impacts. Future investigation of mandible impact biomechanics will focus on evaluation of mandible fracture tolerance and the development of an injury criterion for the FOCUS headform.

REFERENCES


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Table 1: Fracture impact test conditions

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Specimen</th>
<th>Impactor Mass (kg)</th>
<th>Energy (J)</th>
<th>Velocity (m/s)</th>
<th>Peak Force (N)</th>
<th>Loading Rate* (kN/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDT000010</td>
<td>IBD012</td>
<td>3.7 kg</td>
<td>22.0</td>
<td>3.5</td>
<td>3059.4</td>
<td>1261.1</td>
</tr>
<tr>
<td>MDT000150</td>
<td>IBD016</td>
<td>3.2 kg</td>
<td>22.4</td>
<td>3.5</td>
<td>3217.0</td>
<td>1267.3</td>
</tr>
</tbody>
</table>

* Calculated from slope between 20% peak force and 80% of peak force
Background

- Injury risk functions for the human mandible are critical for the evaluation of maxillofacial protection devices.
- The mandible is the only facial bone without any injury criterion and associated injury assessment criterion for mechanical surrogates, like the Facial and Ocular CountermeasUre for Safety (FOCUS) headform.
- Previous efforts have been unsuccessful due to the mandible opening when impacted in the anterior-posterior (A-P) direction [1].
- We hypothesize a closed jaw boundary condition is needed, and more relevant, for the development of an injury criterion for the mandible.

Methods

Custom Restraint Fixture (Figure 1A):
- Angled, ridge aluminum plate (15.2 x 2.5 cm) with beveled edges connected to a 6-DOF load cell.
- Adjustable in the vertical (X) and horizontal (Z) directions as well as angularly allowing the aluminum plate to be aligned with the mandible of the specimen.

Test Setup:
- Guided impactor (6.45 cm² circular impact area) instrumented with 1-DOF load cell and accelerometer.
- Reaction forces measured with 6-DOF load cell.
- Data sampled at 1 MHz and filtered using a 4th order Butterworth filter with 500 Hz cutoff in MATLAB.
- Two high speed video cameras (2,000 FPS) recorded specimen response.

Test Series:
- A walk up study (5 J increments) with repeated baseline impacts (5 J) after each progressively higher impact was conducted.
- Test series was halted when fracture was detected.

Results

- Sixteen impacts were conducted on two specimens (Figure 2, Table 1, Table 2).
  - Velocity: 1.7 m/s - 3.4 m/s; Energy: 4.6 J - 22.4 J
  - Fractures confirmed via CT scan and dissection (Figure 3 and Figure 4).

Discussion

- Fracture patterns consistent with those reported by Craig et al. (2008).
- Peak impactor force in fracture cases were lower than fracture-producing forces in previous work examining A-P mandible impacts [3] and mandible impacts directed through the temporomandibular joint [4].
- A method has been developed to allow for the creation of mandible fractures during A-P impacts.
- Future investigation will include measurement of mandible displacement for assessment of biofidelity.
- Additional testing is needed for the development of an injury assessment criterion for the FOCUS headform.

References


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