Assessment of the Integrity of Adult Human Mandibular Angle

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Abstract

The purpose of this study was to analyze the integrity of the adult human mandibular angle. The left hemimandibles of 24 human cadavers were selected and divided into three groups based upon remaining dental status. The height of the left mandibular body was measured. Hemimandibles were mounted in acrylic bone cement at the mandibular condyle. The left mounted hemimandibles were secured into an Instron 5565 mechanical unit and the occlusal plane was sequentially loaded until fracture of the mandibular bone occurred. Minimum, maximum, mean, and standard deviations for compressive force as well as displacement of the occlusal plane were derived and compared for descriptive statistics. The correlations between the gender, mandibular body height, and maximal load were examined. The mean mandibular heights among males and females were 22.44 mm and 17.53 mm, respectively. Results portrayed a significant correlation between gender and mandibular height. The mean maximal loads among males and females were 1,174.17 and 828.14 N, respectively. Results portrayed a statistically significant difference between males and females regarding maximum load as well as the height of the mandible (p = 0.0103 and p = 0.0067, respectively). No statistically significant association between maximum load and dental status (presence/absence of molar teeth) was found (p > 0.05). The maximal load of human mandibular angle was found to be higher than that of the heavily investigated polyurethane synthetic mandible replica. The average height of the mandibular body in males was found to be greater than that of females. Mandibular body height showed a direct correlation to maximal load of the hemimandibular angle. In maxillofacial research, biomechanical evaluations of mandibular angle fractures and plating techniques with human cadaveric bone should be considered alongside or in place of conventional synthetic polyurethane mandibles.

Keywords

► mandible
► fracture
► integrity
► human

Previous reports have elucidated biomechanical variabilities exist between specific regions of the mandible in cadaveric subjects.¹⁻⁵ Such variabilities correlate with regions and subsequent treatments of mandibular fractures. Fractures of the mandibular angle demonstrate the highest rate of complication of all mandibular fractures.⁶ Various

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osteoosynthetic fixation techniques have been reported for mandibular angle fracture stabilization.\textsuperscript{7–12} Similarly, various materials have been used as human bone substitutes in mandibular rigid fixation research.\textsuperscript{13–17} These bone substitutes may behave differently than human cadaveric bone in maxillofacial research. Testing of human mandibular integrity with typical mandibular angle fractures have not been widely reported in the literature. This study serves to provide biomechanical information of the cadaveric human mandibular angle under load.

**Materials and Methods**

Under federal law, research involving deceased persons, generally, is not human subject research and does not require Institutional Review Board review and approval. The authors have read the Helsinki Declaration and have followed the guidelines in this investigation. Twenty-four human cadavers were provided by the University of Alabama at Birmingham School of Medicine’s Anatomical Donor Program. All donors underwent the embalming procedure and protocol at the School of Medicine Anatomy Laboratory. Embalming chemicals including State of Maryland Anatomical Mix, Metaflow, Rectifiant, and Plasdo 25 (The Dodge Company) were used for preparation of formalin-fixed tissues. Only left hemimandibles were utilized in this study. Inclusion criteria were male or female who presented with an intact edentulous, partially edentulous, or dentate mandible. Exclusion criteria of the donors included presence of osteoporosis, metastatic bone cancer, metabolic bone disorders, or mandibular tumors at time of death. All mandibles were inspected for the presence of third molars. Mandibles with fully impacted third molars that only became evident upon fracture of the mandibular angle were excluded from the study. The personal identities of all donors were kept confidential. Ethnicity was not identified in this study. All cadaveric skulls and mandibles were previously hemisected in the midsagittal plane. Mandibles were dissected by skilled oral maxillofacial surgery residents and faculty.

Mandibles were divided in three groups by the remaining dental status. The edentulous mandible group (EM) had no dentition at the first and second molar position. If teeth were present at either the first or second molar region, the mandible was classified as partially edentulous (PE). If teeth were present in both the second and first molar position, the mandible was classified as a dentate mandible (DM). The left mandibular body height was measured from the area of confluence of the alveolar crest and external oblique ridge to the inferior border of the mandibular body (\textit{\textsuperscript{-Fig. 1}}). The height of the left mandibular body was measured twice and averaged.

Left hemimandibles were cleaned and mounted in acrylic bone cement in 9.5 \( \times \) 3 \( \times \) 3 cm block molds made of silicone. Acrylic polymerized in a pneumatic curing unit set to 20 psi for 5 minutes. The acrylic cement was placed from sigmoid notch to the angle, encompassing the condyle and posterior border of the ramus (\textit{\textsuperscript{-Fig. 2}}). Upon acrylic polymerization, blocks with mounted hemimandibles were removed from their mold and labeled with the donor number. The bone cement at the condyle region was clamped in a custom-fabricated jig for vertical loads at the left first molar area (\textit{\textsuperscript{-Fig. 3}}). The custom-fabricated jig with a hemisected mandible was fixed and compressive force was applied to the first molar region utilizing an Instron 5565 mechanical testing unit (Instron Corp.). The testing was done in compression mode at a crosshead speed of 1 mm/minute (\textit{\textsuperscript{-Fig. 4}}). A vertical mechanical force with a linear displacement was applied to the left first molar region. Data were acquired and stored through the use of Bluehill 2 software (Instron, Illinois Tool Works Inc.).\textsuperscript{18} The loading was continued at the aforementioned rate until mandibular fracture occurred (\textit{\textsuperscript{-Fig. 5}}). Maximal load is defined as peak force recorded prior to fracture (\textit{\textsuperscript{-Fig. 6}}). The maximal load of mandibular fracture was determined and recorded in newtons. Displacement at maximal load is the amount of vertical displacement present when mandible fracture occurs. Minimum, maximum, mean, and standard deviations were derived and compared for descriptive statistics. The

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image1.png}
\caption{The left hemimandible height was determined from the area of confluence of the alveolar crest and external oblique ridge to the inferior border of the mandibular body.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image2.png}
\caption{Left hemimandible mounted in an acrylic bone cement block. This was carried from the condylar head to the posterior mandibular ramus.}
\end{figure}
correlation between the gender, mandibular body height, and maximal load were examined.

Sample characteristics and biomechanical measurements of mandible fracture were summarized using descriptive statistics (mean and standard deviation for continuous variables; frequency and percentage for categorical variables). The differences in gender, mandible height, displacement and force between dental status were assessed using two-sample t-tests and Chi-squared (or Fisher’s exact) tests as appropriate. The mandible height and force were compared between gender and dental status using the two-sample t-tests. A p-value < 0.05 was considered statistically significant in two-tailed statistical tests. All analyses were conducted using SAS 9.4 (SAS Institute).

Results

Cadaveric donors ranged from 54 to 95 years old at the time of death (Table 1). The mean age was 79.5 years old. Fifteen donors were female and nine were male. The range and mean of mandibular body height of the left hemisected mandibles were 12 to 31 mm and 19.38 mm, respectively. There was a significant correlation between gender and mandibular height.

The range of maximal load in the male specimens was 891.82 to 1,783.57 N. The range of maximal load in the female specimens was 579.46 to 1,396.39 N. The mean of maximal load in male and female were 1,174.17 and 828.14 N, respectively. The range of mandibular height in males was 16 to 31 mm. The range of mandibular height in females was 12 to 25 mm. The means of mandibular heights in males and females were 22.44 and 17.53 mm, respectively.

There was a statistically significant difference between males and females in the maximum load as well as the heights of the mandibles (p = 0.0103 and p = 0.0067, respectively). There was no significant correlation of maximum load and dental status (presence/absence of molar teeth; p > 0.05).

Discussion

Results of our study indicated the range of maximal loads of human mandibular angle including both male and female subjects to be 579.46 to 1,783.57 N. The average strain was
4.98 mm (standard deviation 1.39 mm). The means of maximal load in males and females were 1,174.17 and 828.14 N, respectively. The maximal load of human mandibular angle was higher than the polyurethane synthetic mandible replica. Literature reported polyurethane synthetic mandible replicas (Synbone) failed between 350 and 675 N.\[^{10,15}\]

Several former studies used this polyurethane synthetic mandible replica for analysis of mandibular fractures and subsequent fixation techniques.\[^{7-17}\] With large different peak load values from the human cadaveric model, the outcomes of biomechanical reaction with fixation might be different from one of the human mandible. In human subjects, the maximum force produced by the masticatory muscles at the first molar locus has been reported to be

![Fig. 6](image)

**Fig. 6** Maximal load is defined as peak force recorded prior to fracture.

**Table 1** Left hemisected mandibles were tested on an Instron 5565 mechanical testing unit

<table>
<thead>
<tr>
<th>Donor number</th>
<th>Age (y)</th>
<th>Gender</th>
<th>Dental status</th>
<th>Mandible body height (mm)</th>
<th>Peak load (N)</th>
<th>Mandible displacement at peak load (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>89</td>
<td>F</td>
<td>0</td>
<td>25</td>
<td>959.2</td>
<td>4.9</td>
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<tr>
<td>2</td>
<td>80</td>
<td>F</td>
<td>0</td>
<td>12</td>
<td>738.0</td>
<td>3.8</td>
</tr>
<tr>
<td>3</td>
<td>64</td>
<td>F</td>
<td>2</td>
<td>16</td>
<td>680.1</td>
<td>5.3</td>
</tr>
<tr>
<td>4</td>
<td>54</td>
<td>F</td>
<td>0</td>
<td>18</td>
<td>1,396.4</td>
<td>6.5</td>
</tr>
<tr>
<td>5</td>
<td>84</td>
<td>F</td>
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<td>18</td>
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<td>3.5</td>
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<tr>
<td>6</td>
<td>92</td>
<td>F</td>
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<td>16</td>
<td>7,19.5</td>
<td>5.7</td>
</tr>
<tr>
<td>7</td>
<td>80</td>
<td>F</td>
<td>2</td>
<td>18</td>
<td>5,79.5</td>
<td>2.9</td>
</tr>
<tr>
<td>8</td>
<td>67</td>
<td>F</td>
<td>0</td>
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<tr>
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<tr>
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<td>95</td>
<td>F</td>
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<td>M</td>
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<tr>
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<td>M</td>
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<td>25</td>
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</tr>
<tr>
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<td>M</td>
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<td>1, 2</td>
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<td>891.8</td>
<td>4.6</td>
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<tr>
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<td>M</td>
<td>1</td>
<td>26</td>
<td>1,247.5</td>
<td>6.2</td>
</tr>
</tbody>
</table>

Note: Dental Status: 0 = edentulous; 1 = 1st mandibular molar present; and 2 = 2nd mandibular molar present.
between 600 to 700 N. The polyurethane synthetic mandible replica may not accurately represent the biomechanics of the mandibular integrity. A finite element (FE) is one of several attempts to simulate human biomechanics. A computational meshed FE model must be scanned and replicated from a human mandible. The meshed model will be needed to testify several data from strain distributions and restraint conditions of a human mandible.

The height of the mandibular body in males was found to be greater than that in females. As such, the higher maximum load found in males may be partially explained by this anatomical difference. In general, males tend to have stronger and taller mandibles than females. The incidence of fractures of the mandibular angle may not be different in dentate versus edentulous mandibles.

Limitations of this study include limited age range of donors, potential differences in biomechanical properties of formalin-fixed mandibles compared with in vivo subjects, and analysis of hemimandibles instead of intact mandible. Our study received a lot of support from the University Cadaver Laboratory. Unfortunately, all cadaveric craniums and mandibles had to be hemisected for anatomy classes. Ideally, whole nonhemisected mandibles should be utilized in similar studies. Due to extensive cross-linking of proteins, embalmed tissues are more rigid than normal tissues. As such, the embalming process may have incurred some effects on the subsequent mechanical/biomechanical testing. Though the embalmed human mandibular model does not represent the real condition of human biomechanics, we believe it is a close feasible model with which future studies may utilize. To determine precise biomechanical differences between cadaveric and synthetic mandibles, the methodology of a future study will be designed such that all factors are similar in study set up with the only variable being that of a human cadaveric mandible versus synthetic mandible. A detailed comparison between human cadaveric and synthetic mandibles was not the purpose of this preliminary study. With this report, our goal is to provide preliminary descriptive data on the use of human cadaveric mandibles as a fracture model. This initial data will prompt other research teams (including our own) to define the extent of variation between these two model systems and hopefully design the ideal study model.

Biomechanical studies focusing upon evaluation of mandibular angle fractures may consider using human cadaveric bone in maxillofacial research. Though, bone substitute materials may mitigate the economical, ethical, and health-associated considerations associated with use of cadaveric tissues and synthetic human bone substitutes may not accurately represent the mechanical behavior of the human mandible.

Conflicts of Interest
None declared.

Acknowledgments
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