Quantification of mandibular growth through three-dimensional modeling of CT scans

Waisman Center

Vocal Tract Development Lab

http://www.waisman.wisc.edu/vocal/

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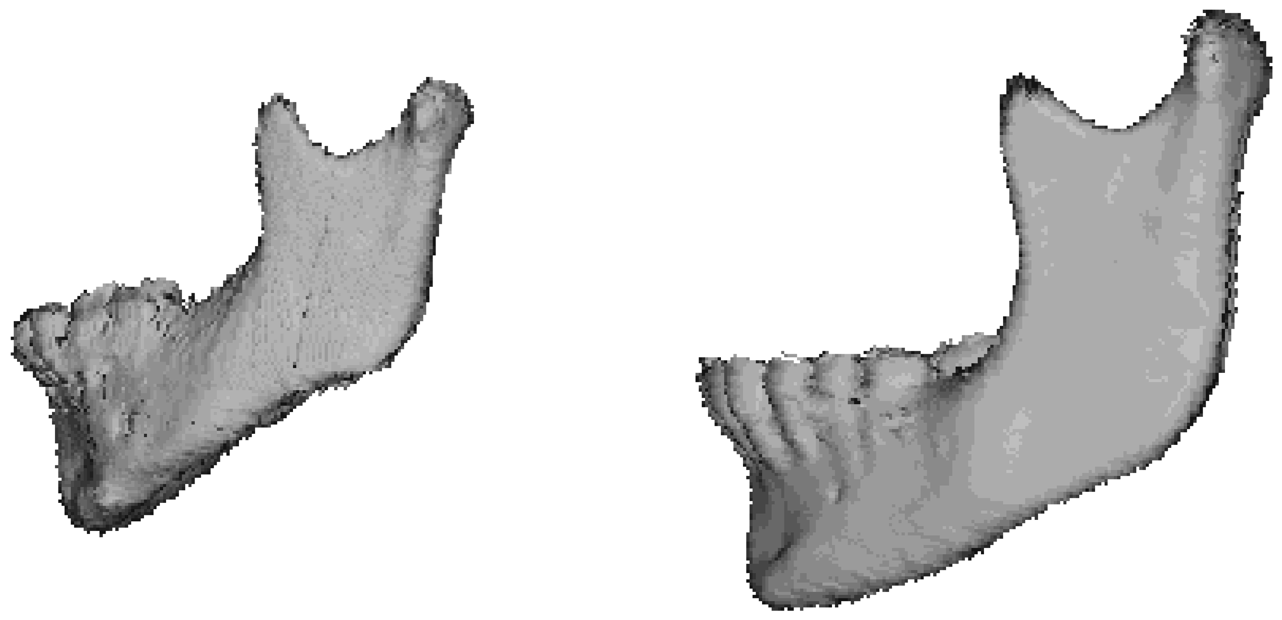
MathBio 4: Scale

Introduction

Background:

Retrospective medical imaging studies are an invaluable resource in characterizing the growth trends of anatomic structures. However, accurate assessment of developmental trends of these structures can present problems, including:

- The need for an abundance of data spanning the developmental age range.
- A lack of consistent scanning parameters.
- Difficulties in characterizing complex, nonlinear growth.



3 year old mandible *16 year old mandible*

Figure 1: *Structural changes of the mandible during the developmental period.*

Purpose:

The purpose of this study is to describe our efforts towards accurately quantifying the growth of the mandible throughout the developmental period by:

- Employing a large number of imaging studies selected from a previously established retrospective imaging database. This database consists of over 1000 head and neck imaging studies representative of the entire life span (birth to old age).
- Applying a three-dimensional (3D) volume rendering approach to quantify mandibular shape and dimensions, including the placement of landmarks on key anatomical locations.
  - The use of landmarks enables linear and angular measurements to be made in any orientation.
- Utilizing complex statistical analysis techniques to quantify growth, including:
  - Fitting data (i.e., distance and/or angle between specific landmarks) with a polynomial growth model as a first approach to quantifying the nonlinear growth of the mandible.
  - Employing diffeomorphic deformable surface modeling to determine the local areas on the 3D models where the most rapid growth is taking place over time.

This is the first study, to our knowledge, utilizing 3D rendering techniques to quantitatively analyze and model the long-term growth of the mandible.

Methods

Patient Selection:

- 77 CT scans (41 Male, 36 Female) ranging in age from 1 to 19 years.
  - 60 of the 77 scans were longitudinal data, representing 16 different patients over the course of the developmental age range.

Volume Rendering and Landmark Placement:

- DICOM (Digital Imaging and Communications in Medicine) files were loaded into the biomedical image visualization and analysis software Analyze 10.0® (AnalyzeDirect®; Overland Park, KS).
- Once loaded, scans were segmented based on Hounsfield Units (HU), which are representative of tissue density, to create a 3D model of the mandible.
  - Based on the findings of Kuszyk et al. (1996), a range of 150-3071 HU was used for segmentation.
- Next, a series of 24 landmarks were placed on the mandible models using a predefined set of anatomic points. All three anatomical planes (axial, coronal, and sagittal) were used to ensure accurate landmark placement:

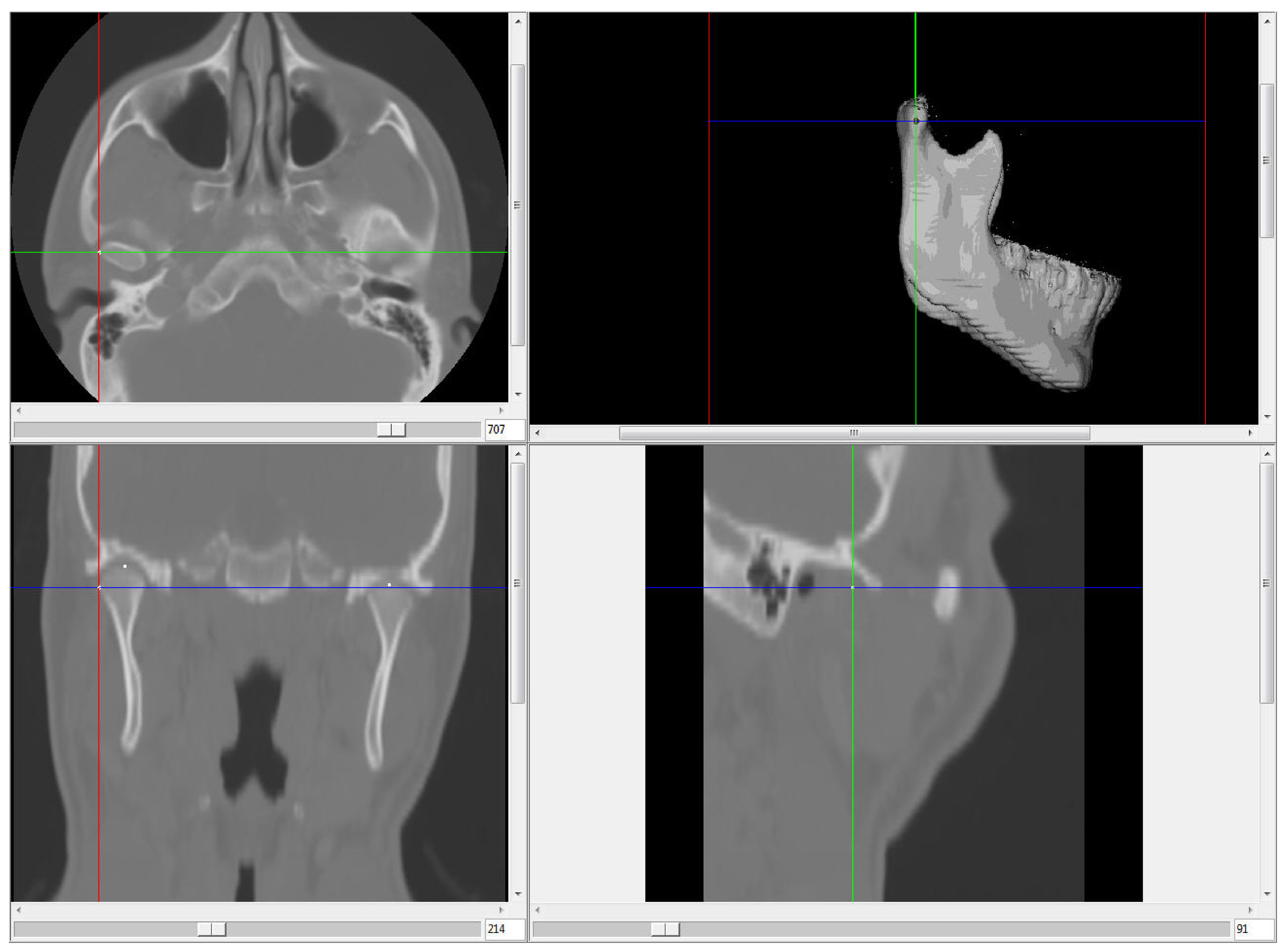


Figure 2: *Placement of mandibular landmark (**Condyle Lateral Right**) on 3D model.*

Methods (continued)

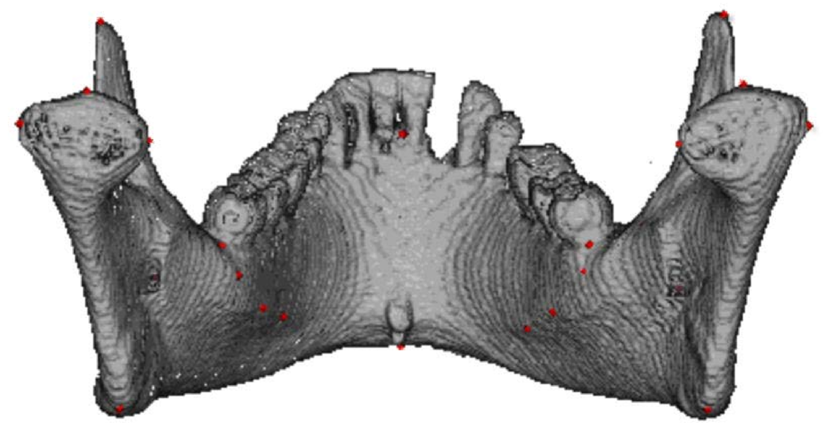


Figure 3: *Posterior view of a completed mandible model. Anatomic landmarks shown in red.*

Landmark-based measurements:

- Locations of landmarks in a 3D Cartesian coordinate system were obtained (x,y,z).
- Coordinates of landmarks were entered into a Microsoft Excel® spreadsheet containing formulas, allowing for the automatic calculation of 12 previously established linear and angular measurements.

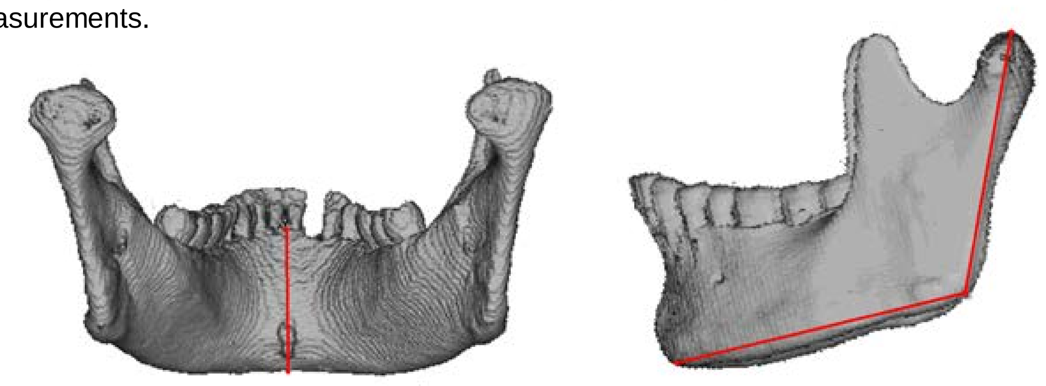


Figure 4: *Examples of linear and angular measurements obtained from landmarks.*
*Left: **Mental Depth**; Right: **Gonion Angle Left.***

Statistical Analyses:

Polynomial Curve Fitting (Figure 5):

- Landmark-based linear and angular measurements were fitted with a fourth-degree polynomial curve in an attempt to characterize mandibular development.
  - In order to allow for comparisons in the timing and rate of growth across gender, data from males and females was analyzed separately.

Diffeomorphic Deformable Surface Modeling (Figure 6):

- First, an affine registration of all surfaces was performed and a template created by averaging the 77 mandible models.
- Using the template, a vector field representing the displacement from each individual model to the template is created.
- Finally, mean group differences of models with respect to the template are derived, enabling comparisons to be made between males and females, as well as various age groups.
- The application of this technique allow for the determination of local areas on the models where the most rapid growth is taking place over time, as well as the quantification of this growth.

Results

For preliminary results, see Figures 5 & 6 below.

Polynomial Curve-fitting:

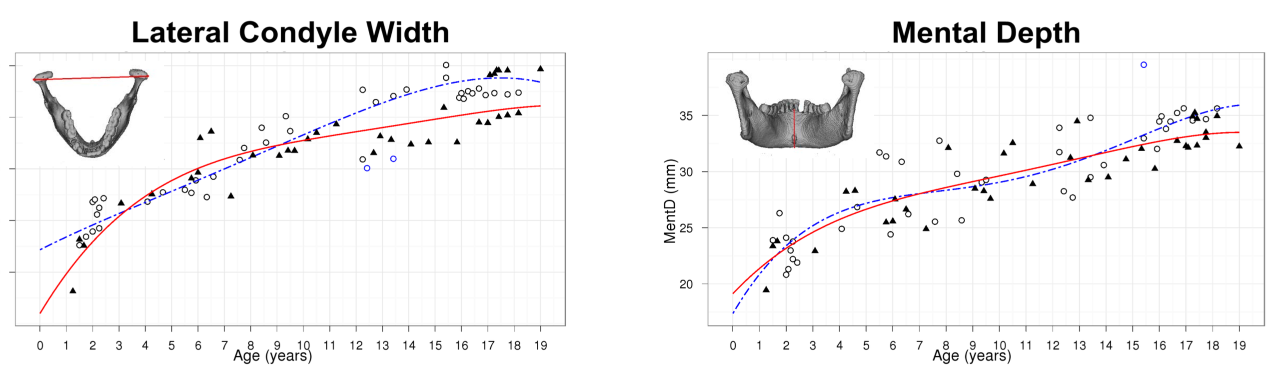


Figure 5: *Fourth-degree polynomial curve fits applied to two mandibular measurements. Male growth curves are displayed in blue, Female growth curves are shown in red.*

Diffeomorphic Deformable Surface Modeling:

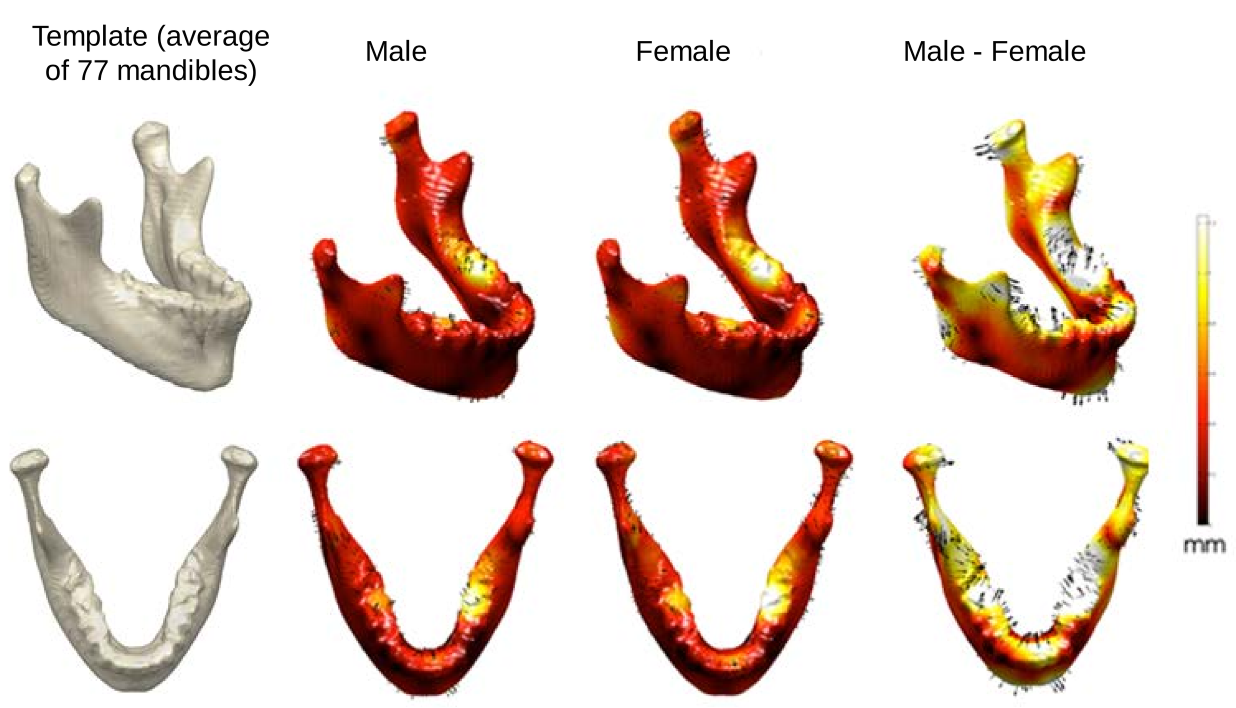


Figure 6: *Shown are the deformable surface models. At the far left, the **Template**, an average of the 77 models is displayed. This template is used as a reference to compare against individual models and average group models. Vectors on the **Male** and **Female** models represent displacement from male and female group models to the template, respectively. Vectors on **Male – Female** model represent displacement from male group model to female group model.*

Discussion

Clinical Implications/Applications:

- As shown, 3D modeling and landmarking methods reveal a detailed and accurate picture of mandibular growth.
  - Such information on the 3D structural changes of the mandible over the course of development can prove valuable to a number of disciplines concerned with craniofacial anomalies, particularly those concerned with the various functions the mandible supports such as food ingestion, speech production, and respiration.

Future Directions:

- Applying this methodology to other structures involved in speech production, such as the vocal tract, hyoid bone, and cervical spine, among others.
- Assessing the relational growth of structures relative to one another (i.e. changes in location and dimensions of the hyoid bone relative to the mandible).
- Characterizing the individual and coordinated growth of the structures involved in speech production in order to develop normative growth trends against which atypical growth can be compared. Ultimately, we hope such knowledge will provide information resulting in improved diagnosis and treatment of speech pathologies among atypically developing populations (i.e., Down Syndrome, Cerebral Palsy, etc.).

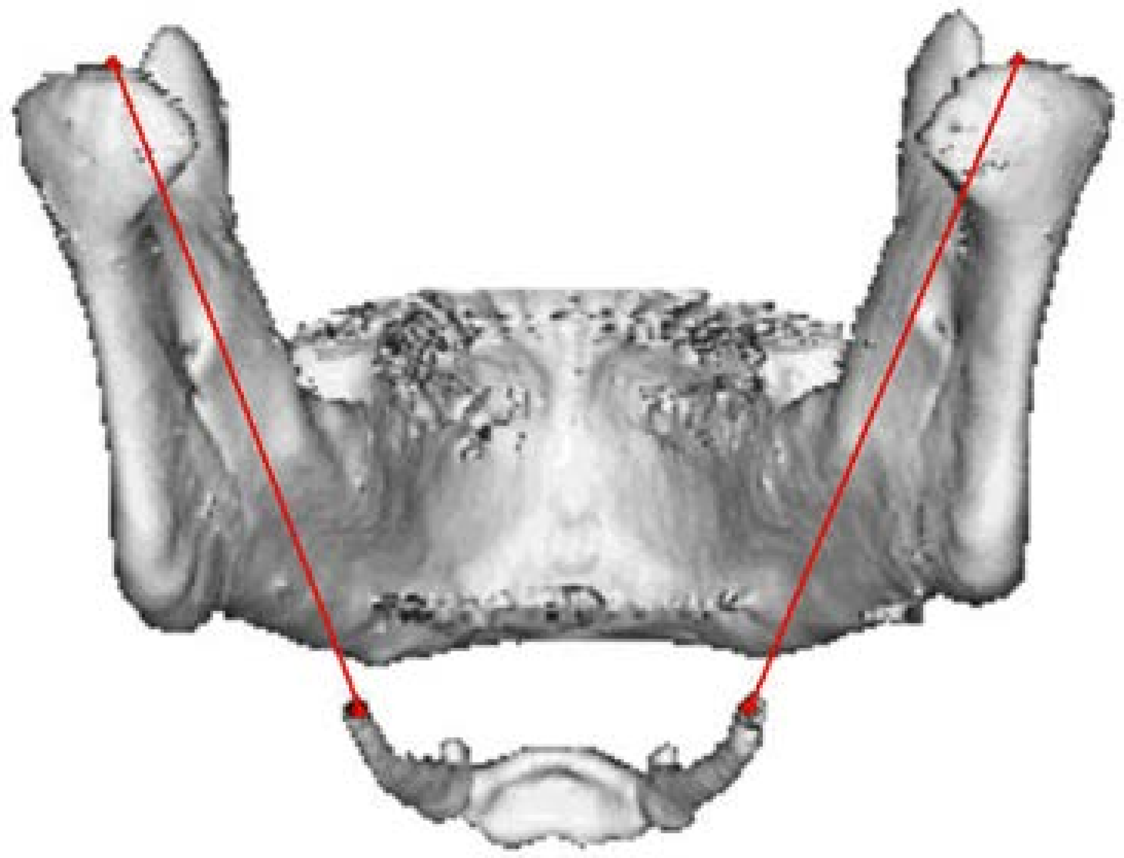


Figure 7: *An example of a relational measurement using the mandible and hyoid. Depicted are **Condyle-Greater Cornu Distance Left** and **Condyle-Greater Cornu Distance Right.***

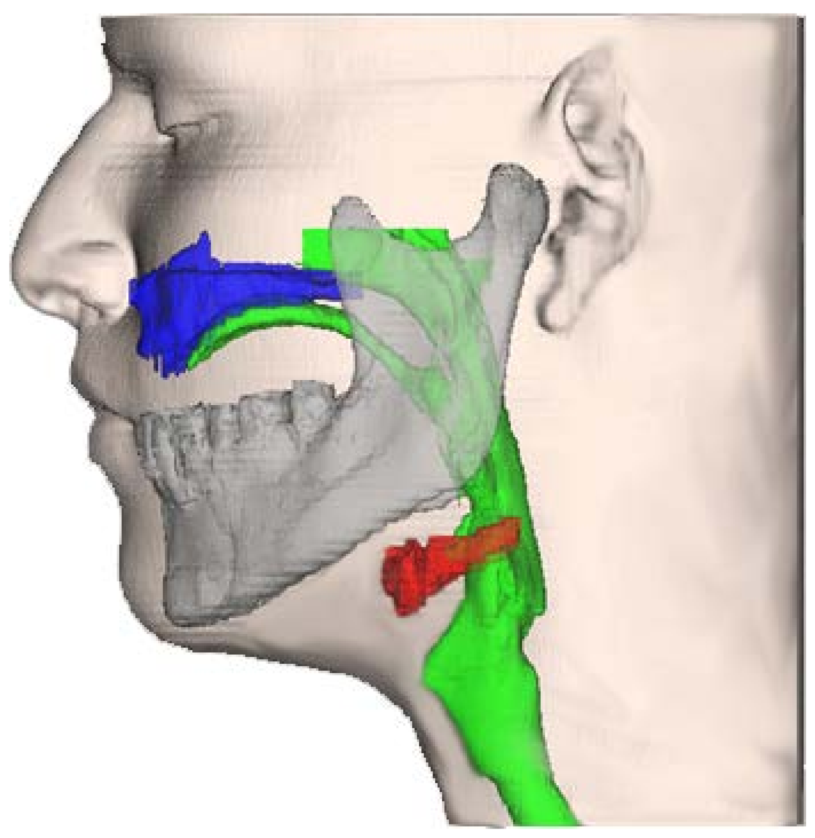


Figure 8: *A composite model displaying a number of structures involved in speech production. Shown are the **mandible** (gray), the **hyoid bone** (red), the **hard palate** (blue), and the **vocal tract** (green).*

Conclusion

Retrospective imaging databases contain a wealth of information on the growth and development of a variety of structures, however, these databases are not without their inherent problems. Through the creation of landmarked 3D mandible models, the proposed methodology represents one way of overcoming these difficulties, allowing for accurate linear and angular measurements to be made in any orientation. Additionally, complex statistical analyses can be applied to both measurement data and to the 3D models themselves to provide a detailed picture of mandibular growth.

Acknowledgements

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