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.

Methods (continued)

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

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.

Results

For preliminary results, see Figures 5 & 6 below.

Polynomial Curve-fitting:

Figure 5: Fourth-degree polynomial curve fit 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 the 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 Comu Distance Left and Condyle-Greater Comu 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 the 3D models themselves to provide a detailed picture of mandibular growth.

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