The Predictive Utility of Temporal Bone Anatomy in Anticipating Morphology of the Ossicular Chain

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Abstract

With our team's previous development of a custom middle ear prosthesis, a prosthesis can be sized to the middle ear anatomy of a patient for ossiculoplasty. Proper sizing of our device requires knowledge of a patient's ossicular morphology. Although clinical CT imaging resolution has advanced, the resolution is not sufficient for the precise measurement of the ossicular chain. We believe there may be anatomical correlations between temporal bone anatomy and the geometric morphology of the ossicular chain which would provide further insight for accurate preoperative prosthesis sizing. The literature was reviewed to define major landmarks identifiable on CT imaging. These landmarks were then and limited to those whose position may be identified with limited variability between users. 5 cadaveric temporal bones were isolated, and both clinical high-resolution spiral CT and micro-CT scans were taken. Measurements were made between all landmarks using the spiral CT, leading to over 155 total measurements per bone. These measurements were then compared to the ossicular chain anatomy of each temporal bone as measured by micro-CT. Statistical analysis was then performed to observe any correlation between these measurements. This study has provided preliminary evidence of the predictive quality of temporal bone anatomy in reference to ossicular chain anatomy.

Introduction

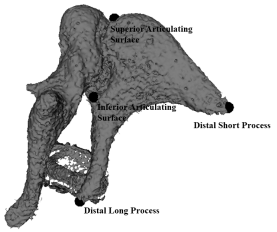
Ossiculoplasty is a technically demanding procedure involving the repair of a disrupted ossicular chain. In cases with damage isolated at the incus and a preserved stapes superstructure, a partial ossicular reconstruction prosthesis (PORP) is commonly utilized for repair[1]. Prosthesis sizing dependent on the judgement of the surgical team at the time of the procedure. Improper determination of PORP length can lead to poor surgical outcomes[2,3].

Our team has developed a novel incus prosthesis which recreates the normal anatomy of ossicular chain with hopes of reproducing sound conduction better than conventional prostheses. We would like to assess if the morphology of the incus correlates with temporal bone anatomy as measured on HRCT, providing an opportunity to predict the ossicle's anatomy through indirect measurements.

Methods and Materials

- 5 left cadaveric temporal bones were isolated and scanned with microCT and HRCT
  - MicroCT at 25 micron resolution and HRCT at 670 micron
- 3D reconstruction of the ossicular chain created from microCT scans. Anatomical measurements were taken from these reconstructions (**Figure 1**)
- HRCT scans were used to mark 18 critical landmarks and take 2 measurements from each bone **(Table 1).** The distance between each landmark was calculated, providing 155 total measurements.
- The linear correlation between each landmark measurement and each morphological length of the incus was calculated. Coefficient of determination (R2) was determined for each value.
- R2 were analyzed to find most correlated measurements and compare landmark measurements correlating to multiple incus morphology.

Figure 1: Incus Morphology Measurements. 6 measurements were taken from 3D renders from CT imaging of the cadaveric temporal bones. Articulating surface height is measured from the superior articulating surface to the inferior articulating surface. Short process length is from the superior articulating surface to the distal short process. Long process length is from the superior articulating surface to the distal long process. Functional length is from the inferior articulating surface to the distal long process. Angle of the long process is then calculated between the functional length and long process length. Lenticular process length is the longitudinal length of the lenticular process and is not pictured.



	Landmark or Measurement		
1	Malleus head	11	Common crus
2	Incus body	12	Scutum
3	Short process	13	Tensor tympani
4	Incudostapedial junction	14	Pyramidal eminence
5	Oval window	15	Apex of cochlea
6	Anterior genu	16	Base of cochlea
7	Vestibular aqueduct	17	Lateral semicircular canal
8	Promontory	18	Posterior semicircular canal
9	Round window	19	Cochlea Base 1
10	Posterior canaliculus	20	Cochlea Base 2

Table 1: Landmark and Measurements Captured from Temporal Bone. 18 discrete and readily identifiable landmarks located in each temporal bone. In addition to these 18 landmarks, two measurements of the base of the cochlea were found, one from the round window to the opposing end of the cochlea base and the other length perpendicular to the prior measurement.

Results

The R^2 between incus morphology and temporal bone measurements was found, and for this study we limited our search to those greater than or equal to 0.90. These values can be found in **Table 2**. Articular surface height provided 12 R^2 values greater than 0.80, 7 of which were greater 0.90. Short process length provided 17 R^2 values greater than 0.80, 6 of which were greater than 0.90. Long process length provided 30 R^2 values greater than 0.80, 9 of which were greater than 0.90. Lenticular process length provided 6 R^2 values greater than 0.80, 3 of which were greater than 0.90. Functional length provided 20 R^2 values greater than 0.80, 4 of which were greater than 0.90. Long process angle provided 20 R^2 values greater than 0.80, 5 of which were greater than 0.90.

Of the 34 R^2 greater than 0.90, 6 measurements were highly correlated to more than one anatomical length of the incus (**Table 3**). The remaining 149 measurements taken from temporal bones did not correlate with multiple aspects of the incus. 5 out of these 6 measurements were highly correlated to two measurements of the incus. The measurement from the common crus to the posterior semicircular canal was highly correlated with three incus measurements.

From	To	R^2
Articulating Surface Height		
1 Malleus head	Incudostapedial junction	0.966
2 Round window	Common crus	0.941
3 Common crus	Lateral semicircular canal	0.928
4 Common crus	Base of cochlea	0.923
5 Common crus	Posterior semicircular canal	0.920
6 Oval window	Common crus	0.918
7 Vestibular aqueduct	Posterior canaliculus	0.903
Short Process Length		
1 Short process	Tensor tympani	0.956
2 Round window	Common crus	0.940
3 Anterior genu	Base of cochlea	0.926
4 Incudostapedial junction	Vestibular aqueduct	0.924
5 Oval window	Common crus	0.907
6 Posterior canaliculus	Common crus	0.903
Functional Length of the Long Process		
1 Common crus	Posterior semicircular canal	0.957
2 Malleus Head	Incudostapedial junction	0.954
3 Common crus	Lateral semicircular canal	0.930
4 Vestibular aqueduct	Posterior canaliculus	0.923

From	To	R^2
Long Process Length		
1 Vestibular aqueduct	Common crus	0.975
2 Promontory	Posterior semicircular canal	0.953
3 Promontory	Common crus	0.946
4 Common crus	Apex of cochlea	0.946
5 Scutum	Pyramidal eminence	0.938
6 Incudostapedial junction	Lateral semicircular canal	0.917
7 Common crus	Posterior semicircular canal	0.906
8 Promontory	Posterior canaliculus	0.906
9 Posterior canaliculus	Posterior semicircular canal	0.902
Lenticular Process Length		
1 Incudostapedial junction	Posterior canaliculus	0.992
2 Tensor tympani	Apex of cochlea	0.970
3 Round window	Apex of cochlea	0.922
Long Process Angle		
1 Common crus	Scutum	0.957
2 Incudostapedial junction	Common crus	0.931
3 Incus body	Tensor tympani	0.918
4 Short process	Promontory	0.914
5 Posterior canaliculus	Pyramidal eminence	0.913

Table 2: Linear Regression Comparing the 6 Measurements taken from the Incus on MicroCT to Temporal Bone Measurements. A linear regression was performed comparing the measurements found between major landmarks in the temporal bone and incus morphology. Only measurements with a coefficient of determination (R^2) greater than 0.90 are included in this table. The first two columns reflect which two landmarks a measurement is being taken from.

	From	To	Articular Surface Height	Short Process Length	Long Process Length	Lenticular Process Length	Functional Length	Long Process Angle
1	Round window	Common crus	X	X				
2	Oval window	Common crus	X	X				
3	Common crus	Posterior semicircular canal	X		X		X	
4	Malleus head	Incudostapedial junction	X				X	
5	Common crus	Lateral semicircular canal	X				X	
6	Vestibular aqueduct	Posterior canaliculus	X				X	

Table 3: Comparison of Measurements Correlating with Multiple Incus Measurements. Multiple measurements found between landmarks of the temporal bone had a coefficient of determination (R^2) greater than 0.9 in a linear correlation with incus measurements. Those which had a R^2 greater than 0.9 for multiple incus measurements are listed below. The first two columns list the landmarks which measurements were taken between. An X demonstrates which incus measurement the landmark measurement had an R^2 greater than 0.9.

Conclusions

Our team has developed a custom middle ear prosthesis requiring preoperative knowledge of incus morphology for proper implementation. Indirect measurement of the incus through use of landmarks in the temporal bone may provide an alternative solution to measuring incus morphology; however, more date is needed to clarify this possibility.

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