Journal of Morphology and Anatomy

Research Article Open Access

Aging Method for the Mandibular Fossa in Juvenile Skeletons

Madden G[1]*, Karsten J[2] and Otieno S[3]

[1]*Department of Anthropology, Grand Valley State University, 223 Lake Michigan Hall, 1 Campus Drive, Allendale, MI, USA*
[2]*Department of Anthropology, Department of Religious Studies and Anthropology, University of Wisconsin-Oshkosh, 800 Algoma Blvd, Oshkosh, WI, USA*
[3]*Department of Statistics, Grand Valley State University, MAK A-1-166, 1 Campus Drive, Allendale, MI, USA*

Abstract

A subadult method of age estimation was tested using measurements of themandibular fossa. Length, width and depth of the mandibular fossa were measured from subadults in the known age-at-death Hamman-ToddCollection (59), the Esqueletos Identificados Museu Anthropologio at Coimbra University (94) and the Museu Bocage Collection, Lisbon (36). The data was used to create multiple regression formulae for age estimation. Tested individually the Hamann-Todd sample was the best predictor of age, explaining about 86.2% of the variability. The three collections when pooled provide a model that explains about 68% of the variability in age. The model was then tested on an archaeological sample of burials housed at the Museum of London (49), predicting age, explains about 81.25% of the variability in age. Further work including individuals of known age at death is necessary to increase the numbers in each age group as some ages had very small samples.

Keywords: Aging; Mandibular fossa; Temporal bone; Juvenile; Skeletal

Introduction

Bioarchaeological and forensic fieldwork often involve the analysis of fragmentary, comingled, and poorly preserved human burials. Estimating demographic information in these situations can be extremely challenging. In these cases more traditional methods of aging juvenile remains include dental development [1], long bone lengths [2,3], and epiphyseal union [2-4]. While dental development, long bone lengths, and epiphyseal union are useful in determining age of subadults, if there are no teeth or complete long bones the methods do not apply and fusion of the epiphyses is only helpful at older subadult ages. Therefore, it is necessary to develop new techniques to determine subadult age-at-death from various skeletal elements as have been carried out for the occipital [5-7] and petrous process of the temporal [8]. Due to the density of the temporal, it is frequently recovered in both archaeological and forensic contexts, including in situations where preservation is poor. However, the temporal has received surprisingly little attention in terms of its value as an indicator of age-at-death. Weaver [9] created an age determination method for infants and children based on the developmental sequence of the tympanic plate of the temporal. Unfortunately, the development of the tympanic plate was shown to only differentiate fetuses from newborns and infants and was not useful in determining the age in older subadults [10]. The goal of this research was to create a new method for estimating age-at-death for subadult skeletal remains using three measurements of the mandibular fossa on the temporal bone.

Materials and Methods

Following repeated observations of isolated temporal bones in the field, the hypothesis was developed that size change to the mandibular fossa occurs over the course of growth and development and may be associated with an increase in age. To test the hypothesis, a series of measurements were collected from the mandibular fossa on a sample of 59 subadults of known age-at-death from the Hamann-Todd (HTC) skeletal collection. The age of individuals in the sample range from neonatal to 18 years, with an average age at death of 10.186 years. Two additional known age at death series were also measured: Esqueletos Identificados (EI) housed at the Museu Anthropologio at Coimbra University (N=94) and the Museu Bocage (MB) collection in Lisbon (N=36). Average age for the EI was 12.55 and the age range 6 to 18 years of age, while average age for the MB was 4.66 and the age range fetal to 14 years of age.

The utility of this model was then independently tested on a blind sample by two trained undergraduate students with limited osteological experience on an archaeological population from the Museum of London's (MoL) Centre for Human Bioarchaeology. This sample was composed of 49 individuals from post-medieval period cemeteries. The MoL sample was comprised of individuals from St. Brides Lower, St. Benet Sherehog, St. Thomas Hospital, Chelsea Old Church, and Broadgate Cemeteries. Individuals from the MoL collection range in age from fetal to 15 years of age, with an average age of 5.78. Age comparison data for the MoL collection are based on dental eruption after Gustafson and Koch [1].

Three measurements were taken on the mandibular fossa of the left and right temporal bone. All measurements were taken to the nearest hundredth of a millimeter (Mitutoyo digital calipers, 965 Corporate Boulevard Aurora, Illinois 60502). The first measurement taken was the depth of the mandibular fossa, which is taken by resting the distal end of the calipers on the articular eminence and sliding the depth probe out until it touches the dome of the glenoid fossa. The second measurement taken was the length of the mandibular fossa, which is defined as the distance between the medial margin of the post-glenoid process and the medial margin of the anterior eminence, where the articular meets the non-articular surface (Figure 1). The final measurement collected was the width of the mandibular fossa, which is defined as the distance from the medial point (projection) of the petrotympanic fissure to the medial border of the glenoid fossa (Figure 1). To assess the value of these mandibular fossa measurements as predictors of age, analysis of

***Corresponding author:** Madden G, Department of Anthropology, Grand Valley State University, 223 Lake Michigan Hall, 1 Campus Drive, Allendale, MI 49401, USA, Tel: 616-331-2721; E-mail: maddeng@gvsu.edu

Received April 30, 2018; **Accepted** September 18, 2018; **Published** September 25, 2018

Citation: Madden G, Karsten J, Otieno S (2018) Aging Method for the Mandibular Fossa in Juvenile Skeletons. J Morphol Anat 2: 116.

Figure 1: Measurements of the Mandibular Fossa. The left side shows measurement of the width, in the center depth, and on the right length.

variance regression analyses were performed (ANOVA). Regression formulae were created to access the usefulness of the measurements in age assessment. Backward elimination was then carried out to find the measurements that were most predictive of age (Table 1).

Finding a difference in the length and width of the right versus the left side was not unexpected when Cohlmia et al.'s [11] findings are considered, that the mean size of the mandibular fossa joint space is consistently smaller on the left side. Therefore side specific equations were developed. Intra-observer error was calculated for GDM on 20 individuals from the HTC, measured two weeks apart. ICC3(1) was performed using SPSS version 24. Inter-observer error was also calculated based on two undergraduate student's measurements taken at the MoL. Both students were anthropology minors, neither having completed an osteology course, but being trained prior to research on the measurement methods described here. Once again, ICC3(1) was computed using SPSS version 24.

Results

For intra-observer error single measures, length had the lowest ICC estimates between the right and left sides ranging from 0.803 to 0.823, respectively (Table 2). The highest ICC estimates were found for width of the right 0.961 and left 0.934 sides. Inter-observer error single measures displayed the lowest ICC estimates for Chelsea Old Church between the left length and width ranging from 0.666-0.688 (Table 3). The highest interobserver ICC estimates for single measures was found for St. Thomas Hospital was left length and width, both at 1. If all six measurements are known, variability in age can be approximated by an R-square of 0.862, when only the HTC sample is used (Table 4). For the right side only, predicted variability for age presented an R-square of 0.857 with all three measurements and 0.851 when using width and length. For the left side all three measurements predicted variability of age at an R-square of 0.835 with all three measurements at 0.832 when using width and length.

When applied to the mandibular fossa of the MB sample only, if all six measurements are present, variability in age can be explained based on an R-square of 0.757 (Table 4). For the right side if all three measurements are present variability in age can be estimated based on an R-square of 0.681 and 0.68 when using width and depth. On the left side for all three measurements in MB the R-square for predicted variability for age accuracy was 0.703 and 0.693 when using width and depth. If the three measurements are known for the left and right sides together, age predicted variability for the EI sample has an R-square of only 0.373 (Table 4). When only the right three measurements were present there was an R-square for predicated age variability of 0.356 and 0.355 when using width and depth. For the left side, using all three measurements the model produced an R-square for predicted age variability of 0.826 and 0.821 when using width and length.

The three populations were then pooled. If all 6 measurements were available, an R-square of 0.678 explains the variability in age for the pooled sample (Table 4). For all three measurements on the right side only, R-square for age predicted variability was 0.66. For the left side only, age predicted variability presented an R-square of 0.446 with all three measurements, and 0.446 when using depth and length. Right width and left width together, display an R-square of

Age	EI[1] (n=94)	HTC[2] (n=59)	MB[3] (n=36)	MoL[4] (n=50)
	Percent	Percent	Percent	Percent
Under 1	0	8.5	16.7	14
1	0	10.2	27.8	0
2	0	0	8.3	0
3	0	3.4	2.8	36
4	0	5.1	5.6	0
5	0	3.4	5.6	0
6	1.1	5.1	2.8	0
7	4.3	0	2.8	0
8	7.4	6.8	0	8
9	2.1	0	2.8	18
10	3.2	6.8	8.3	0
11	5.3	3.4	8.3	0
12	7.4	5.1	2.8	0
13	6.4	1.7	0	0
14	5.3	3.4	5.6	0
15	14.9	3.4	0	24
16	9.6	6.8	0	0
17	13.8	6.8	0	0

[1]Esqueletos Identificades Lisbon; [2]Hamann-Todd Collection Cleveland; [3]Museum Bocage Coimbra; [4]Museum of London, London.

Table 1: Percentage of Individuals by Age in Each Sample Collection. (Pooled HTC, MB and EI represent 189 individuals).

Measure	ICC Estimate	ICC 95% Confidence Interval	
		Lower End	Upper End
Width –LT	0.934	0.819	0.975
Width –RT	0.961	0.764	0.988
Depth-LT	0.869	0.702	0.945
Depth-RT	0.861	0.685	0.942
Length-LT	0.823	0.611	0.925
Length-RT	0.803	0.569	0.917

Table 2: Intra-Observer Error for Width, Depth, Length, and Sides Based on Measurements Taken by the First Author on the Hamman-Todd Collection (n=20). (Based on absolute agreement of measures).

Citation: Madden G, Karsten J, Otieno S (2018) Aging Method for the Mandibular Fossa in Juvenile Skeletons. J Morphol Anat 2: 116.

Cemetery	SBL[1]				SBS[2]			STH[3]			COC[4]			BG[5]	
ICC 95% Confidence	ICC	Lower	Upper	ICC	Lower	Upper	ICC	Lower	Upper	ICC	Lower	Upper	ICC	Lower	Upper
Measure															
Interval	**Estimate Bound**		**Bound**	**Estimate**	**Bound**	**Bound**	**Estimate Bound**		**Lower**	**Estimate Bound**		**Lower**	**Estimate Bound**		**Bound**
Width-LT	0.928	0.85	0.967	0.992	0.976	0.998	1	1	1	0.67	0.11	0.905	0.993	0.97	0.998
Width-RT	0.923	0.84	0.965	0.986	0.958	0.996	1	0.98	0.999	0.98	0.92	0.995	0.992	0.97	0.998
Depth-LT	0.953	0.9	0.979	0.985	0.955	0.995	0.99	0.96	0.999	0.79	0.36	0.944	0.958	0.86	0.989
Depth-RT	0.966	0.93	0.985	0.971	0.913	0.991	0.97	0.87	0.994	0.83	0.45	0.954	0.913	0.71	0.976
Length-LT	0.913	0.86	0.96	0.971	0.992	0.999	1	1	1	0.68	0.14	0.91	0.999	1	1
Length-RT	0.908	0.81	0.958	0.994	0.981	0.998	1	1	1	0.99	0.96	0.979	0.999	1	1

[1]St. Brides Lower; [2]St. Benet Sherehog; [3]St. Thomas Hospital; [4]Chelsea Old Church; [5]Broadgate

Table 3: Inter-Observer Error for Width, Depth, Length, and Sides for 2 Undergraduate Students, based on 5 Cemeteries at MoL. (ICC 95% Confidence Interval based on a consistency definition).

Population	Equation	SE	R-square
HTC, all measures	Age=20.68+0.187 (LMFW)+0.999 (RMFW)+-0.240 (RMFD)+0.353 (LMFD)+0.223 (RMFL)+0.379 (LMFL)	2.28	0.862
HTC, all right measures	Age=-20.28754+1.26699 (RMFW)+0.04221 (RMFD)+0.49886 (RMFL)	2.14	0.85
HTC, RMFW and RMFL	Age=-20.45331+1.28964 (RMFW)+0.50055 (RMFL)	1.94	0.85
HTC, all left measures	Age=-20.31204+1.00928 (LMFW)+0.25791 (LMFD)+0.72931 (LMFL)	2.32	0.835
HTC, LMFW and LMFL	Age=-21.55473+1.13144 (LMFW)+0.77699 (LMFL)	2.05	0.831
MB, all measures	Age=-21.184+0.666 (LMFW)+0.477 (RMFW)+-0.989 (RMFD)+0.567 (LMFD)+-0.153 (RMFL)+0.226 (LMFL)	3.7	0.757
MB, all right measures	Age=-15.76378+0.86877 (RMFW)+1.69671 (RMFD)+-0.04746 (RMFL)	3.52	0.681
MB, RMFW and RMFD	Age=-16.47081+0.86624 (RMFW)+1.67852 (RMFD)	2.63	0.68
MB, all left measures	Age=-20.26006+1.20114 (LMFW)+1.04350 (LMFD)+0.19084	3.29	0.07
MB, LMFW and LMFD	Age=-18.05280+1.25767 (LMFW)+1.08799 (LMFD)	2.89	0.693
EI, all measures	Age=-8.089+0.0006 (LMFW)+0.824 (RMFW)+-0.557 (RMFD)+0.056 (LMFD)+0.114 (RMFL)+-0.049 (LMFL)	0.37	0.377
EI, all right measures	Age=-7.30180+0.82964 (RMFW)+0.57327 (RMFD)+0.04482	3.56	0.356
EI, RMFW and RMFD	Age=-6.56707+0.83465 (RMFW)+0.56967 (RMFD)	2.8	0.356
EI, all left measures	Age=7.28939+0.00042280 (LMFW)+0.47231 (LMFD)+0.13549 (LMFL)	2.89	0.082
EI, LMFD and LMFL	Age=7.27993+0.47417 (LMFD)+0.13593 (LMFL)	2.88	0.082
Collections Pooled, all measures	Age=-15.5+0.0005(LMFW)+0.846(RMFW)+0.579 (RMFD)+0.353 (LMFD)+0.138 (RMFL)+0.163 (LMFL)	1.67	0.678
Collections Pooled, all right measures	Age=-14.95720+0.88271 (RMFW)+0.95872 (RMFD)+0.20994 (RMFL)	1.66	0.66
Collections Pooled, all left measures	Age=-2.94190+0.00053001 (LMFW)+1.20427 (LMFD)+0.32832 (LMFL)	1.43	0.446
Collections Pooled, RMFW and LMFW	Age=-9.50017+1.22767 (RMFW)+0.00211 (LMFW)	1.64	0.452
Collections Pooled, RMFD and LMFD	Age=-2.49023+1.18616 (RMFD)+0.62201 (LMFD)	0.94	0.543
Collections Pooled, RMFL and LMFL	Age=-0.13488+0.14881 (RMFL)+0.60401 (LMFL)	1.75	0.208
Collections Pooled, RMFW	Age=-9.44802+1.22781 (RMFW)	1.63	0.45
Collections Pooled, LMFL	Age=0.32152+0.72510 (LMFL)	1.66	0.206

Table 4: Age Estimation Equations Using Width, Depth, Length and Side, Standard Error, and R-Square Values by Individual Sample and Pooled (SAS 9.4). (Backwards stepwise elimination was carried out to arrive at the best variables to predict age; providing equations with the fewest measurements possible to arrive at predicted age by variable and sample.)

0.452 of variability in age, right width alone explains about 0.45 of the variability in age. On the other hand, right depth and left depth show an R-square of 0.544 of the variability in age. Right length and left length together demonstrate an R-square of 0.208 of the variability in age, with left length alone exhibiting and R-square of 0.206. Application of the age estimation equation to the left and right mandibular fossa of archaeological specimens from the MoL sample resulted in no correct age assignment for the one individual in the infant category, 7/7 (100%) correct age assignment for the 1-5 age group, 5/13 (38.46%) for the 6-11 age group, and 7/11 (63.63%) for the 12-17 age group (Table 5).

Discussion and Conclusion

The undergraduate students had a broader range of accuracy in their measurements than the first author, but higher overall accuracy across MOL cemeteries (Tables 2 and 3). Results for interobserver error of measurements ranged between .107 and 1. For both intra- and interobserver error values of .9 or higher are considered excellent, while outcomes over 5 are considered moderate agreement [12]. Measurements by the undergraduate students on COC have the lowest ICC estimates, it is surmised this was due to data entry error. Except

Observed Age	Predicted Age					
Frequency						
Col Pct	Missing	Infant	1-5	6-11	12-17	Total
Missing	0	0	0	1	0	1
	0	0	0	7.69	0	
1-5	29	0	7	6	1	43
	50.88	0	100	46.15	9.09	
6-11	17	1	0	5	3	26
	29.82	100	0	38.46	27.27	
12-17	11	0	0	1	7	19
	19.3	0	0	7.69	63.64	
Total	57	1	7	13	11	89

Table 5: Comparing Number of MOL Individuals by Observed Age Correctly Estimated Using HTC Equations (Observed age was estimated by MOL staff after Gustafson and Koch [1]; predicted ages show the results of using the equations created by this research shown in Table 4).

for the low COC values interobserver error was excellent to the high end of moderate. Width displayed the highest ICC estimates between 0.934-0.961 for the first author, followed by ICC estimates for depth and length with values at the higher end of moderate agreement (Table 2). Based on this data it is suggested that the measurements are easy to learn, as undertaken by the 2 undergraduate students with minimal osteological knowledge, viewed together 25 of 30 ICC estimates for the measurements scored over 0.9. Two of the six measurements taken by the first author predicted an ICC estimate over .9 with the remaining 4 measurements over .8 suggesting good to excellent precision. Overall, the right side appears to have slightly better accuracy than the left based on the age prediction equations R-square (Table 4), possibly due to the smaller size of the left fossa as suggested by Cohlmia et al. [11]. The HTC had the highest R-square of 0.862, followed by MB with 0.757, pooled at 0.678, and the EI at 0.377 when all measurements were included. Bivariate correlations were undertaken to observe if the structure of the HTC, MB, and EI collections affected the outcomes. It was found that there was no significant difference regarding the models ability to predict age based on the age structure of the three collections. All three collections are considered to be made up of individuals of low socio-economic standing, it may be possible that the lower the socio-economic status, the greater the impairment in the "normal" process of growth and development. Historic records from the regions making up the collections may possibly offer information to substantiate such a claim.

Standard error had a relatively high top value for estimating age in children ranging from 0.37 for EI to 3.7 for MB when using all measurements. For the HTC the standard error ranges from 1.94 to 2.32 offering a maximum potential age range of 4.64 years. While this is not ideal for aging children like observation of the dentition, a 4 year range may be acceptable if dentition was not present for aging. The current research shows HTC offers the best case scenario in terms of a higher R-square and lower standard error in explaining the relationship between growth and size of the mandibular fossa. MoL is an archaeological sample and thus age at death has been estimated using standard methods in osteology, when possible multiple methods were combined to establish age. In a number of cases individuals predicted age fell just 1 year above or below the age assigned through standard methods. Overall the ability to predict age for MoL was 59.37, however the 100% prediction rate in the 1-5 category shows promise (Table 5).

The current research builds on the work of Weaver [9] and Curran and Weaver [10] by testing a new method for age estimation of the temporal bone of subadults. The results of the present study suggest that size of the mandibular fossa of the temporal does not have a strong correlation with age across populations. However, the ability of the model to accurately predict age with an R-square of 0.862 for the HTC individuals demonstrates the potential utility of the method in both forensic and bioarchaeological applications. In fact accuracy for HTC meets recommendations for application in forensic contexts [13,14]. Aging methods used for adults such as suture closure, morphological change to the pubic symphysis, rib ends, and auricular surface have age ranges that are much wider, up to 40 years [15,16], essentially allowing the individual age estimate to be "adult." These adult aging methods continue to be employed when dealing with archaeological and forensic methods, either with other methods or alone depending on the state of the remains being observed. Currently, the metric mandibular fossa method for aging could be used in conjunction with other aging methods to increase overall accuracy. Further research is required to use only the metric method for the mandibular fossa to estimate age. The number of individuals in age categories where few individuals were represented needs to be increased by observation of additional collections along with a better understanding of the regional historic socio-economic status of the collections.

References

1. Gustafson G, Koch G (1974) Age Estimation Up to 16 Years of Age Based on Dental Development. Odontological Review 25: 297-306.
2. Bass, W (2005) Human Osteology: A laboratory and field manual. (Special Publication No. 2 of the Missouri Archaeological Soc). 5th ed. Missouri Archaeological Society.
3. Ubelaker DH (1989) The Estimation of Age at Death from Immature Human Bone. In: Iscan MY, editor. Age Markers in the Human Skeleton. Springfield, IL: Charles C. Thomas, 55-70.
4. Buikstra JE, Ubelaker DH (1994) Standards for Data Collection from Human Skeletal Remains: Proceedings of a Seminar at the Field Museum of Natural History. Fayetteville, AR: Arkansas Archaeological Survey.
5. Irurita Olivares J, Alemán Aguilera I (2017) Proposal of New Regression Formulae for the Estimation of Age in Infant Skeletal Remains from the Metric Study of the Pars Basilaris. Int J Legal Med 131:781-788.
6. Scheuer L, MacLaughlin-Black S (1994) Age Estimation from the Pars Basilaris of the Fetal and Juvenile Occipital Bone. Int J Osteoarchaeol 4:377-380.
7. Cardoso HFV (2013) Age Estimation of Immature Human Skeletal Remains Using the Post-Natal Development of the Occipital Bone. Int J Legal Med 127: 997-1004
8. Nagaoka T, Kawakubo Y (2015) Using the petrous part of the temporal bone to estimate fetal age at death. Forensic Science International 248:188.e1–188.e7.
9. Weaver, DS (1979) Application of the likelihood ratio test to age estimation using the infant and child temporal bone. Am J Phys Anthropol 50(2): 263-269.
10. Curran BK, Weaver DS (1982) The Use of the Coefficient of Agreement and Likelihood Ratio Test to Examine the Development of the Tympanic Plate Using a Known-Age Sample of Fetal and Infant Skeletons. Am J Phys Anthropol 58: 343-346.

11. Cohlmia JT, Ghosh J, Sinha PK, Nanda RS, Currier GF (1996) Tomographic Assessment of Temporomandibular Joints in Patients with Malocclusion. Angle Orthod 66: 27-35.

12. Koo TK, Li MY (2016) A Guideline of Selecting and Reporting Intraclass Correlation Coefficients for Reliability Research. J Chiropr Med 15: 155-163.

13. Rösing FW, Kvaal SI (1998) Dental Age in Adults-A Review of Estimation Methods. Dental Anthropology Fundamentals, Limits, and Prospects. Vienna Springer: 443-468.

14. Ritz-Timme S, Cattaneo C, Collins MJ, Waite ER, Schutz HW, et al. (2000) Age Estimation: The State of the Art in Relation to the Specific Demands of Forensic Practice. Int J Legal Med 113: 29-136.

15. Brooks S, Suchey J (1990) Skeletal Age Determination Based on the Os Pubis: A comparison of the Acsádi-Nemeskéri and Suchey-Brooks methods. Human Evolution 5: 227-238.

16. Lovejoy CO, Meindl RS, Pryzbeck TR, Mensforth RP (1985) Chronological Metamorphosis of the Auricular Surface of the Ilium. A New Method for the Determination of Age at Death Am J Phys Anthropol 68: 15-28.