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SHORT REPORT

Age Estimation by Tympanic Bone Development in Foetal and Infant Skeletons

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ABSTRACT This article analyses age-related changes in the development of the temporal bone in a sample of foetal and infant skeletons to contribute to the estimation of age by means of this skeletal element in bioarchaeological and forensic contexts. The sample was selected from a contemporary documented skeletal collection and is constituted by the temporal bones of individuals of both sexes ($n = 37$) with ages from 23 weeks of gestation up to 11 postnatal months. Different states of fusion of the tympanic ring and development of the tympanic plate were scored separately, and intra-observer consistency was evaluated. Both documented chronological age and skeletal estimated age were examined in relation to successive stages of fusion and development in the pre- and postnatal periods. It was found that the state of fusion of the tympanic ring is especially useful in the discrimination of foetal and postnatal individuals, whereas the development of the tympanic plate is helpful in the differentiation of individuals from and below 3 postnatal months. Even though a certain degree of overlap between successive stages was observed, the fusion of the tympanic ring and the development of the tympanic plate constitute good indicators of age in foetal and infant skeletons.

Key words: age estimation; forensic anthropology; bioarchaeology; Lambre Collection; temporal bone development

Introduction

The ossification of the temporal bone is a complex process that involves both the endochondral and intramembranous ossification of different embryonic tissues. By the sixth gestational week, the cartilages that will take part in the formation of the cranial base are already present, as well as the otic, optic and nasal capsules that will include the sense organs (Carlson, 2005).

At birth, many components of the temporal bone approximate their adult form. At that time, the temporal bone is constituted by the middle ear bones; the petromastoid part, which originates in the ossification of the otic capsule; the squamous portion, which is a component of the neurocranium and from which the zygomatic process projects anteriorly; and the tympanic part, represented by an osseous flat ring that is fixed to the squamous and petrous portions and later grows to shape the external auditory meatus (Nemzek *et al.*, 1996; Scheuer & Black, 2000).

The development of the temporal bone, and in particular the tympanic portion, has been used to estimate age. This process starts with the ossification of the tympanic ring, followed with the fusion to the petromastoid portion and continues with bone proliferation up to the constitution of the foramen of Huschke and its closure (Weaver, 1979; Curran & Weaver, 1982; Humphrey & Scheuer, 2006).

When human bones are found, it is necessary to obtain biological information about the skeletal material, and the estimation of age at death is one of the first individual attributes sought (White *et al.*, 2012). Even though some skeletal elements preserve better than others in the soil (Mays, 2010), the petromastoid portion of the temporal bone is one of the better preserved

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elements in foetal and infant skeletons in bioarchaeological and forensic contexts (Weaver, 1979; García-Mancuso, 2008).

The utility of the development of the temporal bone as an indicator to estimate age from the foetal period up to 6 years of age was initiated by Weaver (1979) in his study of the Grasshopper Pueblo skeletal collection. Later, Curran & Weaver (1982) evaluated the former proposal on the documented skeletal collection of the Smithsonian Institution.

The morphological variations of the temporal bone during development have also been studied by Humphrey & Scheuer (2006) in the skeletons of 65 individuals from British collections with documented ages between 15 days and 19 years. Their results indicate that the development of the tympanic bone follows a progression that could be usable in the estimation of age and, even though each one of the stages lasts a long period of time, each stage can be linked to a range of chronological ages.

The present study analyses a sample of temporal bones from a contemporary skeletal collection in order to evaluate the development of the temporal bone as indicator of age. Focusing on the period comprised between foetal life and 11 postnatal months, this study evaluates the fusion of the tympanic ring and the development of the tympanic plate to achieve a better resolution in the estimation of age in the mentioned period.

Materials and methods

The sample selected for this study is constituted by the temporal bones of 37 individuals of both sexes with ages from the foetal period up to 11 month of documented chronological age. The sample belongs to the Prof. Dr. Rómulo Lambre Skeletal Collection, housed in the School of Medical Sciences (Facultad de Ciencias Médicas, FCM) at the National University of La Plata (Universidad Nacional de La Plata, UNLP) (Salceda *et al.*, 2012). The skeletons forming the collection were ceded by the local cemetery to the FCM to be used for research and teaching purposes. Documentary information on sex, age and date and cause of death is associated with the skeletal material in the Lambre Collection, which shows that the majority of the individuals died in the last third of the twentieth century.

As the foetal individuals have no documentary information on chronological age (CA), it was decided to use the skeletal age (SA) to analyse the complete sample ($n = 37$). To evaluate the continuity of development both in the pre- and postnatal periods, it was decided to use weeks as the time unit to analyse age, considering the year as being composed of 52 weeks and assuming that birth occurred in the fortieth week of gestation.

Humerus and femur diaphyseal length were used to estimate SA. A regression curve that summarises the relationship between age and long bone length was calculated from humerus and femur diaphyseal lengths, using the raw data of Fazekas & Kósa (1978) for the foetal period, and the information published by Maresh (1970) from the second month up to the second year of postnatal life. The selection of these references builds on the works of Fazekas & Kósa (1978) and Maresh (1970), which are widely disseminated and are the most frequently used to estimate age and evaluate growth in skeletal elements of ancient populations and forensic cases (Buikstra & Ubelaker, 1994; Scheuer & Black, 2000). By fitting linear, quadratic and exponential curves to the data, it was found that fitting exponential curves gives the highest correlations, showing a higher determination coefficient (R^2) (García-Mancuso, 2013).

Following the method proposed by Humphrey & Scheuer (2006), two different processes involved in the development of the temporal bone were scored separately: the fusion of the tympanic ring to the petrous portion of the temporal bone (FTR) and the development of the tympanic plate (DTP).

The tympanic ring was considered fused or not fused. The ring was considered fused (FTR 1) if there was a continuity of bone connecting the ring and the petrous portion at the posterior side or inferior part of the ring; this continuity may be represented by small bridges between either parts or by a complete fusion in the cited region. The tympanic ring was scored as not fused (FTR 0) even if the tympanic ring was fused to the squamous portion, but a small gap between the petrous portion and the ring can be observed.

The development of the tympanic plate was scored by observing the growth of the internal margins of the tympanic ring and describing them as smooth, irregular or with approaching anterior and posterior tubercles and, if the tympanic ring was not found with the other elements of the skeleton, it was scored as absent (DTP 0). In the first case, the internal margins of the tympanic ring are smooth (DTP 1); in the second, the internal margins of the ring have developed irregularities (DTP 2) and, in the third one, the addition of bone in the internal surface, reducing the internal dimensions of the ring, is evident, whereas the posterior tubercle approaches the anterior tubercle but without forming a continuous bridge (DTP 3).

The skeletal material under study was obtained after exhumation from the local cemetery, and it can be observed that the flat bones of the cranial vault are usually broken due to taphonomic processes, but the petromastoid portion of the temporal bone is one of the better preserved elements in the collection (García-Mancuso, 2008). Even though the squamous portion of the temporal bone is commonly found —especially the highly diagnostic zygomatic process —in this collection it was never found attached to the tympanic ring unless both were fused to the petrous portion. Also, when the tympanic ring was partially fused, the anterior limb of the ring was frequently lost and broken, along with the inferior part of the squamous plate (Figure 1).

The development of the tympanic plate was analysed by direct observation. Taking into account the preservation of the material, the observation focused on the posterior side and the inferior part of the tympanic ring and its associated parts in the petrous portion of the temporal bone. The observation was done preferentially on the left side, but the right side was selected when the left one was lost or damaged.

The assessment of the fusion and development of the tympanic plate was done by the first author (RGM), and to evaluate intra-observer consistency, this assessment was repeated after a two-week interval and the *k* coefficient was calculated. This coefficient constitutes a measure of agreement beyond chance and is an indicator of the degree of agreement between pairs of observations (Gwet, 2010).

To test if the different FTR and DTP show differences in SA ($n = 37$) the Kruskal–Wallis test, a non-parametric analysis of variance, was used. The same test was performed in the subsample of individuals with documented CA ($n = 25$). The SA and CA variables were tested for normality using the Kolmogorov–Smirnov test and show a normal distribution, but Levene's test for equality of variances indicated that variances were significantly different between the groups defined by FTR and DTP.

Figure 1. Temporal bone from the Lambre Collection showing the petrous portion with fused tympanic ring and an absent squamous portion. Scale 1 cm. This figure is available in colour online at wileyonlinelibrary.com/journal/oa

Statistical analyses were performed in SPSS (Version 14.0) using a 0.05 significance level ($p \leq 0.05$). The results are discussed in relation to the constitution of the sample, and the development of the tympanic plate as an indicator of age is examined.

Results

The FTR and the DTP were scored for each individual in the sample. Intra-observer agreement tests indicate no significant difference between subsequent observations ($p > .000$). Cohen's kappa reproducibility coefficients for FTR and DTP scores were 0.892 and 0.856, respectively, indicating that the assignment of scores is coherent in successive observations.

In Figures 2 and 3, it can be seen that there is a progression of ages with consecutive stages of fusion and development. The Kruskal–Wallis test showed there is a statistically significant difference in SA ($n = 37$) between the different states of FTR ($df = 1$; $H = 24.533$; $p > .000$), and between scores of DTP ($df = 3$; $H = 23.949$; $p < .000$). The results obtained in the subsample of individuals with documented CA ($n = 25$) also show significant differences in CA for each state of FTR ($df = 1$; $H = 12.469$; $p < .000$), and for the different stages of DTP ($df = 3$; $H = 14.564$; $p = .002$).

Observing SA in relation to FTR scores, it can be seen that there is an overlap between stages 0 and 1; this overlap represents the fusion of the tympanic ring to the petrous portion at around 40 weeks, which is the moment of birth. All the individuals with a FTR score of 0 have skeletal ages below 42 weeks, and all the individuals with a FTR score of 1 have a SA above 36.6 weeks (Table 1).

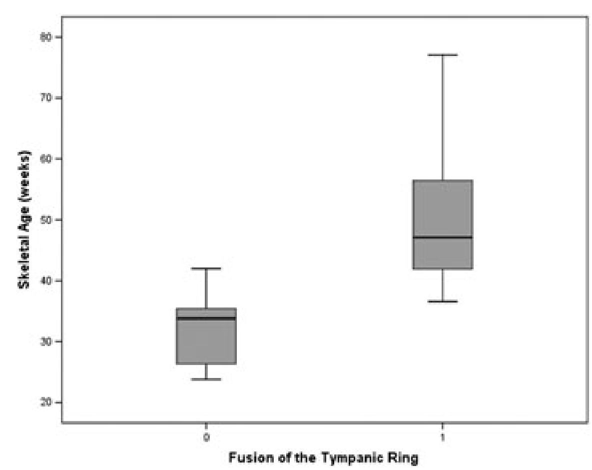

Figure 2. Skeletal ages for each state of fusion of the tympanic ring.

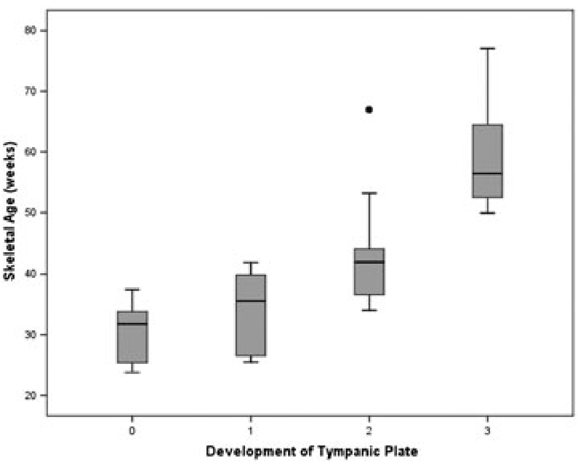

Figure 3. Skeletal ages for each stage of development of the tympanic plate.

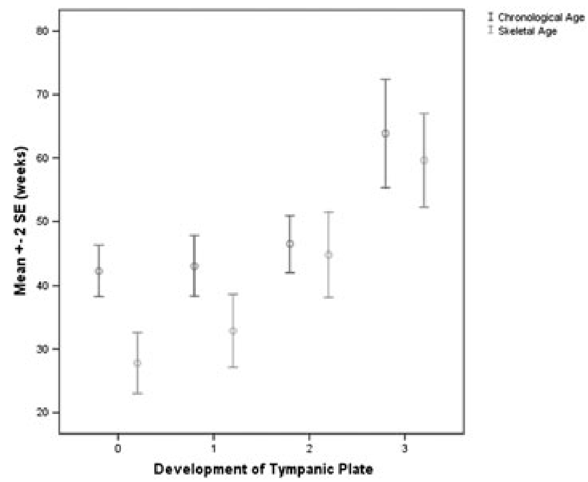

Figure 4. Comparison of mean skeletal age and chronological age for subsequent stages of development of the tympanic plate.

In relation to the DTP, it can be seen that there is a progression of SA with consecutive stages (Figure 3) but showing remarkable overlaps. All the cases in which the tympanic ring is not present (DTP 0) represent individuals in the foetal period, and nearly the same applies to the individuals whose tympanic ring has smooth internal walls (DTP 1). Those individuals whose tympanic ring started to develop irregularities (DTP 2) have a SA over 34 weeks, and up to 6 months after birth (66 weeks). However, the development of the tubercles (DTP 3) and the reduction of the space in the internal margins of the tympanic plate clearly indicate that the individual is over 2 months of postnatal life (>49.9 weeks).

Documentary information on chronological age is particularly suitable to evaluate development in the postnatal period because death records at the cemetery archive only report age for individuals born alive (Figure 4). A DTP of 2 represents individuals with a CA between 0 and 5 postnatal months and a DTP of 3 represents individuals aged between 3 and 11 postnatal months with a mean near 5.5 months (63.9 weeks).

Table 1. Skeletal ages (weeks) for each state of fusion of the tympanic ring

		Skeletal age (weeks)		
		Mean	Minimum	Maximum
Fusion of the tympanic ring (FTR)	0	32.2	23.8	42.0
	1	50.6	36.6	77.0
Development of the tympanic plate (DTP)	0	30.4	23.8	37.5
	1	34.0	25.5	41.9
	2	42.8	34.0	67.0
	3	59.6	49.9	77.0

Discussion

In this study, the observation of the fusion of the tympanic ring focuses on the posterior side and the inferior part of the tympanic ring and its associated parts in the petrous portion of the temporal bone. This specific observation focus did not allow the detection of the initial fusion of the tympanic ring to the squamous portion but, considering that this part of the bone is usually deteriorated due to taphonomic processes, it should not be informative in forensic or archaeological contexts either.

In the present study, it was observed that all the individuals with a tympanic ring not fused to the petrous portion of the temporal bone (FTR 0) have skeletal ages up to 42 weeks, and those with a fused ring (FTR 1) have skeletal ages from 36.6 onwards. In spite of the overlap, and considering that at 40 weeks a foetus is regarded as full term, it could be said that the fusion of the tympanic ring to the petrous portion divided the sample into foetal and postnatal specimens and that this result shows that the fusion of the tympanic ring is a good indicator that the foetus reached full term.

This result is in accordance with the observations made on the Forensic Foetal Osteology Collection at the Smithsonian Institution by Curran & Weaver (1982), who observed a nonfused tympanic ring in foetal skeletons. They also observed that the ring can be scored as fused from the fifth month in the foetal period; however, this information must be taken with caution, because there could be discrepancies between the documented chronological age and the age estimated by biological indicators (Huxley, 2005).

The stages of development of the tympanic plate are also informative of age, and are especially revealing in the postnatal period. It was observed that when the internal margins of the tympanic ring are smooth (DTP 1) the SA corresponds to the foetal or early postnatal period. The tympanic rings which had developed irregularities to the interior (DTP 2) represent individuals with skeletal ages from the foetal period up to 6 months (34–67 weeks). Finally, when the addition of bone in the internal surface reduces the dimensions of the ring and the posterior and anterior tubercles are evident (DTP 3), the SA averages 4.5 postnatal months with a minimum of 2.3 months (49.9–77 weeks).

As CA has an inferior limit in week 40 (birth), because death records at the cemetery archive only report CA for individuals born alive (independently from gestational age, which is not stated), documented CA is especially useful to analyse DTP 2 and 3 when skeletal development is in accordance with documentary information.

The age range of CA for DTP 2 and 3 is coincidental with Stages B and C by Humphrey & Scheuer (2006), as they include individuals in the age range of birth to 18 months. However, our results show that those individuals with DTP 3 have a SA of over 2.3 months of postnatal life (>49.9 weeks) and a CA of over 3 postnatal months, showing that the development of the temporal bone could be useful in the interpretation of infant mortality in skeletal collections.

Conclusion

It is evident that the temporal bone undergoes a succession of developmental modifications that could be distinguished and associated with age. Even though a certain degree of overlap between successive stages was observed, the fusion of the tympanic ring and the development of the tympanic plate constitute good indicators of age in foetal and infant skeletons. The fusion of the tympanic ring is especially useful in the discrimination of foetal and postnatal individuals, whereas the development of the tympanic plate differentiates individuals from and below 3 postnatal months.

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