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BASIOCCIPUT AGE AT DEATH ESTIMATION ASSESSMENT IN SUBADULTS FROM PUNTA TEATINOS, CHILE

ABSTRACT: In bioarchaeological and forensic research, the identification and differentiation of foetal, neonatal, infant, and children remains is plagued with difficulties. These difficulties arise from a series of factors including poor preservation, excavation damage or loss, and differential mortuary treatment that leads to the low representation of foetal, neonatal, infant, and children's remains in archaeological sites. Although palaeodemography aspires to accurately reconstruct the age structure of skeletal populations the degree of accuracy of age at death estimation techniques continues to be problematic due to the lack of population-specific standards. To remedy this, we assess the reliability of the basiocciput aging method using a South American sample. Immature individuals (n=12) from the Punta Teatinos archaeological site (Chile) were aged based on dental development (dental age), linear growth of the basiocciput, and the maximum diaphyseal length (MDL) of the femur and humerus. Age at death estimates obtained using the three methods were classified as foetal (<40 foetal weeks), infant (birth–0 year), child I (1–5 years), and child II (6–12 years). Results indicate that the methods are largely concordant (80.0% matches). Basiocciput age at death estimations were supported by dental development estimates in 77.8% of the cases and by long bone age in 90.0% of the comparisons. Partial matches and mismatches between the methods are mostly the result of higher age-estimations rendered by dental development estimates. Statistical comparisons between the methods did not reveal significant differences. Overall, these results show that the basiocciput age at death estimations are generally in agreement with most estimates based on dental development and MDL. The basiocciput method can, therefore, be applied to South American prehistoric populations.

KEY WORDS: Basiocciput method – Age at death estimation – South America

INTRODUCTION

This study assesses the accuracy of the basiocciput method of age at death estimation in a sample of prehistoric South Americans from Punta Teatinos, Chile. We compare the age at death estimates based on the basiocciput method (Fazekas, Kósa 1978, Scheuer, McLaughlin-Black 1994) with those based on dental development (Moorrees *et al.* 1963a, 1963b, Smith 1991, Ubelaker 1999) and maximum diaphyseal length (MDL) of the femur and humerus (Maresh 1970, Scheuer *et al.* 1980). To date, no other study has analyzed the reliability of the basiocciput method in South American samples and so this work addresses the question of whether this method is population-specific and/or if it is accurate across different populations.

In bioarchaeology, the recovery and reliable identification of foetuses, neonates, infants, and children is plagued with difficulties. These complications arise from the differential mortuary treatment that subadults may have received, the excavator's lack of familiarity with subadult

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osteology, and the natural fragility and subsequent poor preservation (due to low mineral content) of immature skeletal remains (Gordon, Buikstra 1981, Guy *et al*. 1997, Scheuer, Black 2000, Walker *et al*. 1988). In spite of these difficulties, distinguishing foetuses, new-borns, infants, and children is of critical importance to archaeological, palaeodemographic, palaeopathological, and palaeogenetic studies (Crist 2005, Halcrow *et al*. 2008, Mays, Eyers 2011, Tocheri *et al*. 2005, Tocheri, Molto 2002).

From an archaeological point of view, the differentiation of pre-natal, peri-natal, and post-natal remains, and their association with, or absence of, specific burial practices informs us about issues of personhood and the social position of the unborn child and his/her mother (Becker 2007, Burnston 1982, Crist 2005, Halcrow *et al*. 2008, Liston, Papadopoulos 2004). However, the low representation of foetal, neonatal, and infant remains in archaeological sites is an all too common fact. Studies of subadult mortality, nonetheless, are vital to palaeodemographic analyses (Lewis, Gowland 2007). Thus, a complete assessment of the impact of behaviour, economics, social structure, and the environment (Frankenberg, Konigsberg 2006, Wood *et al*. 1992) can only be attained by the inclusion of these accurately aged subadults (Lewis, Gowland 2007, Reidpath, Allotey 2003). While other issues in palaeodemography have been addressed with a variety of statistical tools (Hoppa, Vaupel 2002, Konigsberg, Frankenberg 1994, Piontek, Weber 1990), one of the most pervasive and fundamental problems continues to be the degree of accuracy of age at death estimations (Bocquett-Appel, Massett 1982).

Age at death estimation of immature individuals is often problematic due to the lack of population-specific standards (Halcrow *et al*. 2007, Lampl, Johnston 1996). Foetal, neonatal, infant, and children's remains are commonly aged using dental development as well as long bone length. Deciduous teeth mineralization begins prenatally (12th–16th week), with partial completion of the crowns reached by the time of birth, and root development commonly completed by the age of three years (Smith 1991). Calcification of the permanent teeth, on the other hand, is mostly a postnatal process that extends for 8–12 years (Smith 1991). Teeth emergence (timing at which the gingiva is pierced by the tooth) and eruption (process by which a tooth moves from the depths of the alveolar bone to the occlusal level), unlike mineralization, can be affected by malnutrition, which is why dental development is regarded as the most reliable age marker for subadults (Danforth *et al*. 2009, Hoppa 1992, Smith 1991). However, age at death estimations based on tooth calcification in foetal and neonatal remains are notoriously difficult given that the buds are small, easily damaged, and commonly lost (Clement, Kósa 1992, Danforth *et al*. 2009, Lewis, Gowland 2007, Tocheri *et al*. 2005).

The second most commonly used age marker is diaphyseal bone length (Lewis, Gowland 2007). *In utero*, long bone growth is normally protected from a variety of external factors and can be used to accurately determine age at death (Clement, Kósa 1992, Fazekas, Kósa 1978, Mahon *et al.* 2010). In contrast, long bone length age at death estimations, even in young infants, are considered unreliable given population variability and the effects of age structure mimicry in regression equations (Hoppa 1992, Mays, Eyers 2011, Tocheri *et al*. 2005).

Age at death estimations of foetal, neonatal, and infant remains, based on the basiocciput method are relatively rare in bioarchaeological studies (Redfield 1970, Tocheri, Molto 2002, Tocheri *et al.* 2005). This rarity is somewhat surprising given that the basiocciput is easy to identify and it shows sequential changes in size and shape that can be used to determine age at death. Moreover, the basiocciput is relatively resistant to destructive taphonomic processes and thus it is among the most frequently recovered skeletal segments of immature individuals (Clement, Kósa 1992, Fazekas, Kósa 1978, Redfield 1970, Zuckerman 1955).

The base of the skull (basicranium), of which the basiocciput is an important component, is the most complex structure of the skeleton. Its main function is to protect and support the brain and to provide a platform for facial growth (Gruber, Brockmeyer 2003, Nie 2005, Ranly 2000). The basicranium is an ancient and highly conservative structure through which many vital nerves, arteries, and veins pass. Thus, extensive deformations of the region are indeed incompatible with life (Bastir *et al.* 2006, Laitman 1985, Nie 2005). In fact, the basicranium is normally unaffected by the stresses of birth and is unmodified by conditions such as scaphocephaly (early fusion of the cranial sutures), hydrocephaly, or anencephaly (Gruber, Brockmeyer 2003, Redfield 1970).

The pars basilaris or basioccciput, a single bone located at the center of the base of the skull, anterior to the foramen magnum, arises from two ossification centers during the first trimester (Gruber, Brockmeyer 2003, Mann *et al.* 2000, Ricciarelli 1995). The basal plate, which forms the basioccipital cartilage, becomes visible by the end of the 8th week of foetal development (Gruber, Brockmeyer 2003). Mineralization of the region commences between the 10th and 14th weeks of foetal life. While the posterior portion fuses to the lateral part during early childhood II (age 7 years), the anterior portion does not fuse to the base of the sphenoid until adulthood (Nie 2005, Ranly 2000, Redfield 1970, Ricciarelli 1995).

Growth of the skull's base involves dramatic changes in size and shape that are directly related to the growth of the brain (Bastir *et al.* 2006, Nie 2005, Ranly 2000). Thus, it is not surprising that the basiocciput grows and achieves its adult size and shape at a predictable ontogenic age (Bastir *et al.* 2006). As a consequence, subadults younger than 7 years of age normally present a basiocciput that is unfused and easily measured. However, the accuracy of the age at death estimations based on measurements of this element has not been tested across populations. This study will therefore contribute new knowledge about the efficacy of this method in an alternative population.

MATERIALS AND METHODS

Sample

Twelve young subadult individuals from Punta Teatinos, a Late Archaic site located in the coast of the semi-arid region of central Chile (4905±100 BP, 4560±95 BP, 4000±90 BP), were included in this study. In this region of central Chile, the Late Archaic period is characterized by heightened economic diversification, variable stone tool types, and an increased emphasis on vegetable resources in comparison to earlier periods (Niemeyer 1989, Quevedo 1998). Punta Teatinos (*Figure 1*), composed mostly of a large shell midden (15,000 m^2), is one of the largest sites identified for this period (Llagostera 1989, Niemeyer 1989).

Archaeological analyses of Punta Teatinos showed that the site was occupied by a foraging and fishing population that effectively supplemented inland resources with the abundant local seafood (Llagostera 1989, Niemeyer 1989). Excavations of the southeast portion of the site revealed a large cemetery composed of 211 skeletons, of which 83 (39.3%) were deemed immature (Quevedo 1998, Schiappacasse, Niemeyer 1965–1966). Adult and immature bodies were deposited in lateral flexed and hyperflexed positions surrounded by rocks and occasionally covered with mortars (Quevedo 1998). The gentle deposition of the bodies, their placement on sandy soil, the relatively low humidity, as well as the carefully conducted excavations, resulted in the recovery of well-preserved adult and subadult skeletons. Among subadults, the presence of complete teeth, long bones, and unfused basioccipital bones provides us with an opportunity to conduct a detailed comparison of age at death estimation methods.

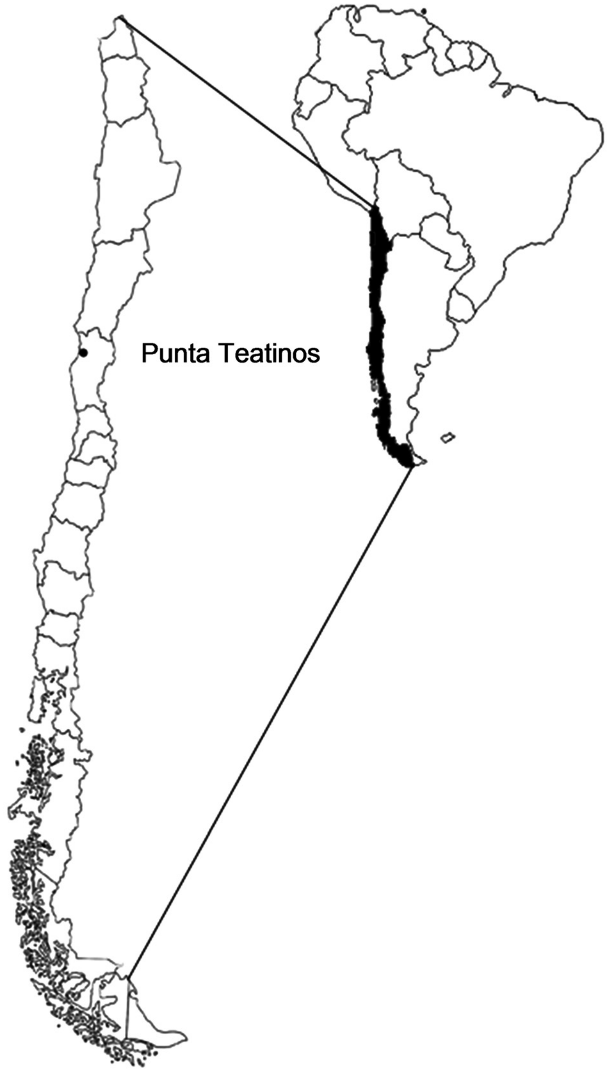

FIGURE 1. Location of the archaeological site Punta Teatinos.

Methods

The sagittal length basilaris, maximum width basilaris, and maximum length basilaris of all basiocciputs were measured with a digital spreading calliper calibrated to the nearest 1/10th mm. None of the measured basiocciputs had fused to the lateral element. The age at death of each individual was estimated by comparing the measurements and relative dimensions with those published by Fazekas and Kósa (1978; *Figure 2*), and Scheuer and McLaughlin-Black (1994).

The developmental maturity of each available tooth or tooth bud, in both hemimandible and hemimaxilla, was assessed macroscopically and/or radiographically. Each tooth was individually assigned a dental stage, and an age at death was then assigned by comparing the results with the guidelines published by Moorrees *et al.* (1963a, 1963b), Smith (1991), and Ubelaker (1999).

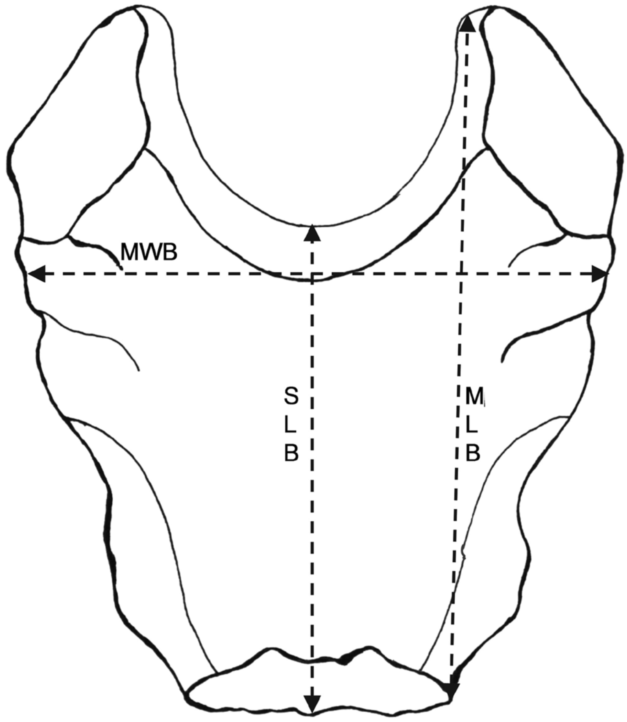

FIGURE 2. Illustration showing the maximum width basilaris (MWB), sagittal length basilaris (SLB) and maximum length basilaris (MLB) measured in the basiocciput.

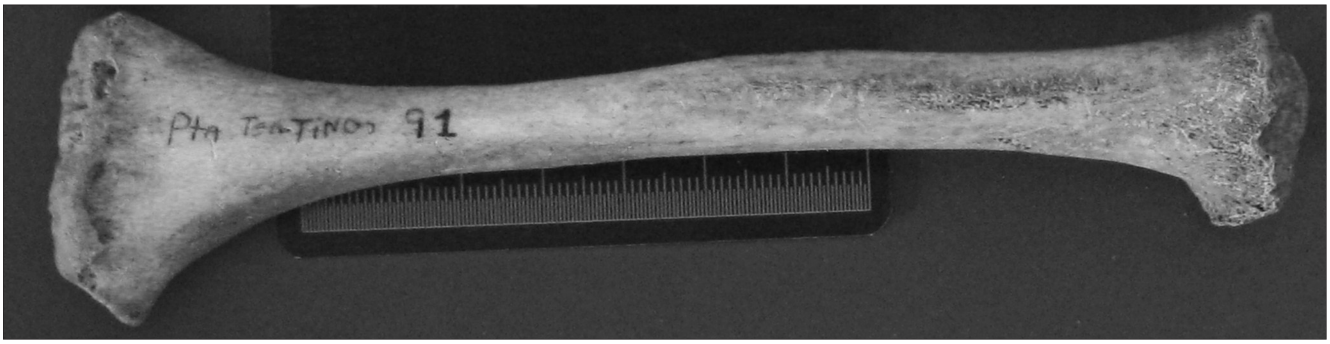

FIGURE 3. Example of a humerus used to estimate age at death based on maximum diaphyseal length (MDL).

The maximum diaphyseal length (MDL) of the left femora and humerus were measured with a mini-osteometric board, to the closest 1/10th mm (*Figure 3*). When the left femur or humerus was absent or non-measurable, the right one was measured. Age at death estimations were conducted by comparing the measurements obtained with those published by Fazekas and Kósa (1978) and Maresh (1970). Additional age at death estimates were obtained by plugging the measurements into linear and non-linear regression equations (Institute Child Health males and females data combined; Scheuer *et al.* 1980). Mean age estimates were then calculated to provide an overall age at death assessment for each individual, based on maximum diaphyseal length (MDL).

Age estimates based on each method were classified as foetal (<40 foetal weeks), infant (birth–0 years, where 0 means <1 year of age), child I (1–5 years), and child II (6–12 years; Bogin 1999). These age categories are biologically meaningful, as they correspond to life history stages (Roksandic, Armstrong 2011). Age at death estimates obtained based on dental mineralization, maximum diaphyseal length, and the basiocciput measurements were then compared. The methods were deemed a match when the results classified the individual in the same age-category (as described above). When the upper or lower limits of the estimated ages overlapped the comparison was classified as a partial match. Cases in which no overlap was observed and in which the age categories did not match were considered a mismatch. The percentage for matches, partial matches, and mismatches are presented. The results obtained with the methods were compared with Fisher's test due to the small sample size. Calculations of Fisher's test were carried on the software R 2.15.0 (R Development Core Team, 2005).

TABLE 1. Osteometric data for the basiocciput, humerus, and femur from foetal and immature remains from Punta Teatinos.

	Basiocciput			**Long Bones**	
Burial #	**MWB**	**SLB**	**MLB**	**Humerus MDL**	**Femur MDL**
PT 163	13.1	12.5	14.9	57.8	n.a.
PT 31	13.8	12.8	14.8	60.1	64.8*
PT 130	14.9	13.4	15.6	62.4	72.4
PT 68	17.6	14.7	16.6	75.8	89.7*
PT 93	18.2	13.8	18.3	78.6	95.6*
PT 53	17.9	15.3	19.0	83.6	104.1
PT 103	19.7	16.9	20.6	84.5	104.0
PT 64	19.5	14.4	19.5	85.6	107.3
PT 88	15.0	15.0	19.5	n.a.	109.1
PT 89	21.7	15.0	21.8	99.4*	122.1
PT 6	28.2	20.1	26.3	157.0	220.0
PT 125	28.9	19.9	27.7	183.5	260.5

* Indicates the right osteological element was measured.
n.a. Indicates missing data due to absence of the element or lack of measurable bone.
MWB, maximum width basilaris; SLB, sagittal length basilaris; MLB, maximum length basilaris.
MDL, maximum diaphyseal length.

TABLE 2. Mineralization stages of the deciduous dentition among subadults from Punta Teatinos.

	Superior dentition					Inferior dentition				
Burial #	**m2**	**m1**	**C**	**I2**	**I1**	**m2**	**m1**	**C**	**I2**	**I1**
PT 163										
PT 31						CR1/2	CR1/2			
PT 130			CR1/2	CR3/4	CR3/4					
PT 68	CR3/4	CRc	CRc		R1/4					
PT 93	CR3/4	CRc	CR3/4	Ri	Ri					R1/4
PT 53						CR3/4	CRc	CRc		
PT 103	CR3/4	Ri	CRc	R1/4	R1/4	CR3/4	CRc	R1/2		
PT 64						CR3/4				
PT 88	CR3/4	Ri	CRc	R1/4	R1/4	CR1/2	CR3/4	CRc	R1/4	R1/2
PT 89	Ri	R1/4	R1/2	R1/2	R1/2	Ri	R1/4			R3/4
PT 6										
PT 125						Ac	Ac			

Note: The highest developmental stage is presented in this table, for those cases in which the antimeres differed.

CR1/4, crown one-quarter; CR1/2, crown one-half; CR3/4, crown three-quarters, CRc, crown complete; Ri, root initiated; R1/4, root one-quarter; R1/2, root one-half; R3/4, root three-quarters.

TABLE 3. Comparison of basiocciput, dental formation, and maximum diaphyseal length aging methods.

	Basiocciput		Dental age		Max. diaphyseal length		Agreement (match) between methods		
Burial #	**Range**	**Category**	**Range**	**Category**	**Range**	**Category**	**BO/Dental**	**BO/MDL**	**Dental/MDL**
PT 163	30–40 Fwk	Foetal			33–38 Fwk	Foetal	n.a.	Yes	n.a.
PT 31	30–40 Fwk	Foetal	0–6 m	Infant	34–39 Fwk	Foetal	No	Yes	No
PT 130	30 Fwk–3 m	Foetal/Infant	0–9 m	Infant	35–40 Fwk	Foetal	Partial	Partial	No
PT 68	40 Fwk–5 m	Infant	0–9 m	Infant	1.5–3 m	Infant	Yes	Yes	Yes
PT 93	>40 Fwk–11 m	Infant	0–9 m	Infant	1.5–3 m	Infant	Yes	Yes	Yes
PT 53	2 wk–8 m	Infant	0–6 m	Infant	3–6 m	Infant	Yes	Yes	Yes
PT 103	5–21 m	Infant	0–9 m	Infant	3–6 m	Infant	Yes	Yes	Yes
PT 64	5–14 m	Infant	0–6 m	Infant	3–6 m	Infant	Yes	Yes	Yes
PT 88	5–14 m	Infant	0–12 m	Infant	3–6 m	Infant	Yes	Yes	Yes
PT 89	8–20 m	Infant	0–12 m	Infant	6–12 m	Infant	Yes	Yes	Yes
PT 6			4–6 y	Child I	3.5–4.0 y	Child I	n.a.	n.a.	Yes
PT 125			6–8 y	Child II	5–6 y	Child I	n.a.	n.a.	No

BO, Basiocciput; MDL, Maximum diaphyseal length.

Fwk, fetal week; m, month; y, year.

n.a. Indicates missing data due to absence of the element or lack of measurable bone.

RESULTS

Table 1 lists the three measurements collected for the basiocciput, as well as those obtained for the maximum diaphyseal length of the femur and humerus of each individual. *Table 2* summarizes the results obtained for dental mineralization of the deciduous dentition only, although permanent teeth were also considered in the final age at death estimation. For those cases where the development of the antimeres differed, the stage of the more developed tooth is presented.

Table 3 presents all age at death estimates obtained for each of the individuals analyzed. The comparisons show that the age at death estimates based on the basiocciput, dental development, and maximal diaphyseal length matched in 80.0% (24/29) of the cases. A Fisher's test comparison confirmed that no significant difference was observed between the methods (P=0.34). A partial match was observed in 6.7% (2/30) of the comparisons, whereas mismatches accounted for 13.3% (4/30) of all the comparisons. Age at death estimates based on the basiocciput were supported by those based on dental development in 77.8% (7/9) of the cases, and no significant difference between the methods was identified (P=0.33). Partial matches and mismatches between basiocciput and dental development age at death estimates were observed in

3.5% (1/9) of the cases respectively. Similarly, comparisons between the basiocciput and MDL methods showed 90.0% (9/10) of matches and 10.0% (1/10) of partial matches. No mismatches were found between the basiocciput and long bone methods, and no significant differences between the two methods were identified (*P*=0.66). Dental and MDL methods also showed a higher percentage of matches (72.7%; 8/11), than partial matches (0.0%; 0/11) or mismatches (27.3%; 3/11). As in the previous comparisons no significant difference between the dental and the MDL methods were identified (*P*=0.33).

When all comparisons are considered, five out of the six partial matches and mismatches (83.3%) arose from older age-estimations obtained using the dental age at death methods. Furthermore, most of these mismatches and partial matches correspond to cases in which the basiocciput and long-bone method indicated that the individual was a foetus, whereas the dental age at death predicted the individual to be an infant. The other mismatch corresponds to the individual PT125 who was aged as a Child II by the dental method but as a Child I by the long-bone method.

DISCUSSION

The results indicate that the basiocciput method is in agreement with most of the estimates obtained with the more traditionally used dental development and maximum diaphyseal length (MDL) methods. These findings show that the application of the basiocciput method is a reliable way to distinguish between foetal and infant remains in the South American archaeological record. The phylogenetic stability of the basilar portion of the skull (Bastir *et al.* 2006, Laitman 1985, Nie 2005), as well as the intrauterine protection of brain growth, even under conditions of deprivation (Cameron, Demerath 2002, Ellison 2005), likely accounts for the reliability of the basiocciput method.

The high percentage of matches between the basiocciput method and the MDL (90%) confirms that *in utero* longitudinal bone growth is a robust process (Clement, Kósa 1992, Fazekas, Kósa 1978, Mahon *et al.* 2010). Thus, the use of the MDL method also seems to be reliable for age at death estimation of foetal and infant remains in South American prehistoric populations.

Although most of the dental development/basiocciput and dental development/MDL comparisons match, the majority of the mismatches and partial matches arise from higher age at death estimations based on the dental development method. Overall, the dental method did not identify foetal remains in this sample and, in fact, results in older age at death estimates for these individuals. Although an earlier study did not identify this issue, that analysis was conducted in a prehistoric Egyptian group and differed from the present one in that it combined dental and long bone age at death estimates in the comparisons (Tocheri, Molto 2002). A study in modern South East Asian populations has shown that dental age at death estimations lead to over-estimations (Halcrow *et al.* 2007). Although Liversidge (2003) has shown that variation in tooth mineralization is greatest in later stages, the results obtained in this study suggest that more extensive comparative studies are needed in order to determine the degree and pattern, if any, of inter-population variability in dental mineralization.

Although we only have one individual whose age at death was close to childhood II, the discrepancy between the age at death estimation based on the MDL and dental development methods may be the result of this individual's (PT125) exposure to conditions that hindered his/her longitudinal bone growth. Differences in this individual's age at death estimations are in agreement with what is known about the robustness and sensitivity of dental development and linear growth respectively. In fact, discrepancies at the transition between childhood I and II may result from an adaptive response to environmental or nutritional conditions (Hochberg 2009). However, it would be important to explore whether or not there is a systematic difference between these two methods in this and other South American prehistoric and/or Native South American groups.

CONCLUSION

In conclusion, the basiocciput method is a reliable alternative (or addition) to more well-established age at death estimation methods for use on South American prehistoric populations. Unlike the dental method applied in this study, the basiocciput allows for the accurate identification of foetal remains. Moreover, the older age at death estimates rendered by the dental development methods in foetuses signals that more extensive comparative studies are needed in order to determine whether or not Native South American populations' dental development deviates from the standards commonly used in bioarchaeology and forensic anthropology.

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