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*LETTER TO THE EDITOR*

# A matter of judgement: a response to Carneiro, Cunha and Curate (2017)

Laure Spake[a], Julia Meyers[a], Hugo F. V. Cardoso[a]

[a]Department of Archaeology and Centre for Forensic Research, Simon Fraser University, Burnaby, BC, Canada

*Corresponding author: hcardoso@sfu.ca

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Carneiro *et al.* (2017) provide a critical assessment of Nava *et al.*'s (2017) choice of methods for age estimation of an upper Paleolithic fetal skeleton from Italy. In this response, we would like to caution against hasted and poorly grounded criticism, which can add very little value to discussions about appropriateness of methods and can even inadvertently promote poor practices in the choice of age estimation methods, particularly in juveniles, as is illustrated here.

After comparing long bone age estimates with virtual histological age estimates, Nava *et al.* (2017) conclude that modern reference standards are misleading or inadequate for estimating age of death in pre-industrial fetal remains. Carneiro *et al.* (2017) challenge this statement by applying a skeletal age estimation method developed by the same authors in an earlier paper (Carneiro *et al.*, 2016), which they argue yields an age estimate consistent with the Nava *et al.* (2017) dental age estimate. There are several problems with their analytical approach and discussion of results.

The authors (Carneiro *et al.*, 2017) use their previously published method to estimate the age of the upper Paleolithic fetal remains.

While long bone lengths for the humerus, radius, ulna, femur and tibia are given by Nava and colleagues (2017, supplementary material), Carneiro *et al.* (2017) choose to omit the ulna when calculating their age estimates. The authors do not give a reason for doing this, although age estimation methods were available from the ulna (Carneiro *et al.,* 2016) and would have provided the oldest age estimate compared to other long bones (33.96 weeks, 95% CI: 29.5-38.42, using the inverse calibration method. See Table 1).

**Table 1. Bone lengths (from Nava *et al.* 2017) and estimated ages (in weeks) as according to Carneiro *et al.* (2016).**

| Bone | Length (cm) | Inverse calibration (Carneiro *et al.* 2016) | Classical calibration (Carneiro *et al.* 2016) |
|---|---|---|---|
| Left humerus | 58.5 | 33.3 (28.8-37.8) | 34.1 (30.4-37.8) |
| Left radius | 49.0 | 33.6 (28.7-38.5) | 34.6 (30.6-38.6) |
| Left ulna | 56.3* | 34.0 (29.6-38.4) | 34.9 (30.9-38.9) |
| Left femur | 61.0 | 31.2 (27.3-35.1) | 31.6 (28.6-34.7) |
| Right tibia | 57.2 | 32.9 (28.7-37.1) | 33.6 (30.2-37.0) |
| Mean | | 33.0 | 33.8 |

* Not originally used by Carneiro *et al.* (2017).

In discussing the accuracy and bias of their age estimation method, Carneiro *et al.* (2016) acknowledge that inverse calibration of age estimation methods has the potential to provide biased age estimates (see also Aykroyd *et al.,* 1997). The authors note that the inverse models do not yield a significant improvement in accuracy over the classical calibration models, although they provide methods based on both models (Carneiro *et al.,* 2016). Yet, in their analysis of the fetal remains, the authors choose to use only the inverse calibration models. Classical calibration made available in their paper (Carneiro *et al.,* 2016) provide older age estimates (Table 1). Why not report these, especially considering the discrepancies between the two approaches? Carneiro *et al.* (2017) also highlight the similarity between their age estimates and the dental histological age provided by Nava *et al.* (2017). One wonders if inverse calibration was chosen because it provides estimates closer to the dental histological age reported by Nava and colleagues (31-33 weeks). One also wonders if this is the same reason behind the exclusion of the ulna.

Carneiro *et al.* (2017) also choose to ignore 95% confidence intervals, both as provided by their methods but also that of the dental age estimates for the Paleolithic fetus (30.7-34.3 weeks) (Nava *et al.*, 2017). The authors provide a range of point age estimates based on long bone lengths as their final age estimate (31.2-33.6 weeks), most of which fall towards the older end of the dental histological age range. The only exception to this is the femur, which yields point estimates of 31.2 and 31.6 weeks for the inverse and classical methods respectively. Comparing a range of point estimates to a 95% confidence interval misrepresents the level of confidence provided by the skeletal age estimate. The 95% confidence intervals provide estimates ranging from as young as 28.6 to as old as 38.9 weeks (Table 1), which is a considerably larger interval than the one provided by the dental estimates. This alone would render the skeletal age estimates less reliable than the dental age estimates.

Carneiro *et al.* (2017) conclude that the similarity between their age estimate and the dental age estimate provided by Nava *et al.* (2017) justifies the use of their method in historic and prehistoric fetuses. Carneiro *et al.* (2016)'s reference sample is comprised of spontaneous and therapeutic abortions. Although the authors do note that cases involving external limb malformation and pathological alterations which could compromise normal skeletal growth were excluded, the cause of death of those fetuses included in the sample is not known and may include a variety of pathological changes that rendered the fetuses unviable. These fetuses could be a better age estimation reference for cases of natural abortions in history or prehistory, as it is unknown how these would compare to otherwise normal fetuses who died not because of intrinsic reasons related to the pregnancy, but to extrinsic reasons related to the mother (*e.g.* accidental or acute deaths).

There are other problems with Carneiro *et al.* (2016)'s data source. First, it is not clear how closely the x-ray measurements reflect the actual length of long bones. The authors report the presence of a scale in the radiographs. It is not indicated whether that scale was at the same plane as the bones being measured (especially important in lateral x-rays when one side of the body is substantially raised above the x-ray sensor), and whether the position of some long bones in the fully articulated body may not be in the same position if they were removed and dry. For example, in an anterior-posterior radiograph, the knees can be found in a slightly raised position, thus creating an angle on the femur and tibia and distorting their lengths. Additionally, nothing is said about the resolution of the x-rays, which is important as the screen caliper used measures the image pixels. The lower the resolution of the image, the less accurate the measurements.

Carneiro *et al.*'s (2017) analyses of this prehistoric case suggest that one should endeavor to obtain the same age estimate from both dental and skeletal indicators, while in reality important information can be gleaned by comparing, in this case, the more accurate age estimate based on the endogenous record of tooth development (Antoine *et al.*, 2009), with the less accurate age estimate based on the linear growth of a modern reference sample. Ignoring the discrepancy between dental and skeletal age overlooks the fact that the dentition and the skeleton have different embryonic origins and can be used together to inform researchers about the somatic pattern of growth of juvenile fossil specimens to help better understand the evolution of human life history. For example, it could have been interesting to assess dental maturation (independently of dental histological age) in this individual and compare it with skeletal maturation to gain insight into pre-modern growth patterns (*e.g.* Rosas *et al.,* 2017). Additionally, because the dentition and the skeleton have been shown to differ in their sensitivity to environmental insults (Lewis and Garn, 1960; Garn *et al.,* 1965; Demirjian *et al.,* 1985; Cardoso, 2007; Conceição and Cardoso, 2011), comparing dental and skeletal age estimates can provide important clues about whether the child has experienced periods of growth disruption. This is particularly important in this case given the fact that microscopic stress lines were identified in the fetus' teeth. Finally, any potential concerns about the lack of congruence between the dental and skeletal age estimates described by Nava *et al.* (2017) should be discussed in light of crown initiation times being estimated from the literature and not reconstructed by identifying the neonatal line.

Carneiro *et al.* (2017) suggest that all available methods must be considered when estimating age, and that care should be taken to consider advantages and drawbacks of each method. Contrary to their recommendations however, Carneiro *et al.* (2017) opted to estimate the age of the fetus using the calibration method that yielded an age estimate closest to the dental histological age and excluding the bone that was least consistent with it. Their comparison of dental and skeletal growth is also misleading and fails to recognize them as complimentary, not equivalent, estimators of age. We caution against the unproblematized application of age estimation methods to archaeological human remains and ignoring how plasticity in growth and development can impact age estimations based on different tissues.

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