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Are we using the appropriate reference samples to develop juvenile age estimation methods based on bone size? An exploration of growth differences between average children and those who become victims of homicide

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ABSTRACT

The population on which forensic juvenile skeletal age estimation methods are applied has not been critically considered. Previous research suggests that child victims of homicide tend to be from socioeconomically disadvantaged contexts, and that these contexts impair linear growth. This study investigates whether juvenile skeletal remains examined by forensic anthropologists are short for age compared to their normal healthy peers. Cadaver lengths were obtained from records of autopsies of 1256 individuals, aged birth to eighteen years at death, conducted between 2000 and 2015 in Australia, New Zealand, and the U.S. Growth status of the forensic population, represented by homicide victims, and general population, represented by accident victims, were compared using height for age Z-scores and independent sample t-tests. Cadaver lengths of the accident victims were compared to growth references using one sample t-tests to evaluate whether accident victims reflect the general population. Homicide victims are shorter for age than accident victims in samples from the U.S., but not in Australia and New Zealand. Accident victims are more representative of the general population in Australia and New Zealand. Different results in Australia and New Zealand as opposed to the U.S. may be linked to socioeconomic inequality. These results suggest that physical anthropologists should critically select reference samples when devising forensic juvenile skeletal age estimation methods. Children examined in forensic investigations may be short for age, and thus methods developed on normal healthy children may yield inaccurate results. A healthy reference population may not necessarily constitute an appropriate growth comparison for the forensic anthropology population.

1. Introduction

In order to perform well, an age estimation method must employ a reference sample which accurately represents its target individual(s). This idea has received much attention in the paleodemographic literature with respect to adult age estimation [1–4], but has remained less explored by forensic anthropologists. Dirkmaat et al. [5] recognize the need to work with "modern" samples that are representative of the subset of the population actually studied by forensic anthropologists in their day-to-day work, i.e. the forensic sample. Recently however, Komar and Grivas [6] have shown that the forensic sample is not representative of the living population from which it is drawn, and acknowledged the implications that this has for the accuracy of age estimates in adults. The forensic and general populations are not necessarily congruent, and yet forensic methods are often developed using non-forensic data sources. These are not necessarily unsuitable to address forensic questions [7], but their reference samples should be appropriate for use in a forensic target population.

The appropriate reference sample for developing juvenile age estimation methods intended for use in a forensic setting is particularly problematic. Juvenile forensic age estimation methods are often adapted from studies of living children, which are designed to be representative of "normal" children in the population being sampled. By using these methods, forensic anthropologists are using healthy children to estimate age in the population they confront. This means that the two groups are assumed to have similar growth or developmental statuses. This assumption is likely to be flawed. Several indirect sources of

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evidence, outlined in the following paragraphs, strongly suggest that children whose deaths undergo medicolegal investigation are not representative of the overall population of children.

The very few published case studies of forensic anthropological analysis of juvenile remains suggests that these are largely homicide cases often associated with situations of abuse and/or neglect [8–13]. While the juvenile forensic anthropology population is poorly understood, juvenile homicide victims are a frequently studied population. Gaining an understanding of this group may provide insight into the potential composition of the forensic anthropology sample. In high-income nations, rates of violence against children and child mortality are consistently inversely correlated with socioeconomic status [14–19]. Child homicide victims come primarily from socially marginalized or economically disadvantaged contexts [20–28]. Since the juvenile forensic anthropology population is a probable subset of the homicide population, it is likely to be drawn from disadvantaged, low socioeconomic status, and urban backgrounds.

Even in wealthy countries, children from lower socioeconomic status backgrounds are in poorer health than their better-off peers. Disadvantaged, low socioeconomic status children are subject to more adverse growth environments, because socioeconomic status is linked to a series of factors that affect growth including: sufficient and adequate nutrition, exposure to disease, access to medical care, housing quality, exposure to neglect and abuse situations, chronic psychosocial stress, and overall poverty [29–36]. Consequently, low socioeconomic status children show compromised or retarded physical growth, often expressed in terms of stunting and wasting [37–46]. If the forensic population includes a disproportionate number of children that are of low socioeconomic status, then it will also include a disproportionate number of children who show various degrees of stunting and wasting.

It is also likely that a large proportion of the low socioeconomic status children comprising the forensic population have a history of abuse and neglect [20–22,25,27]. There is now ample evidence showing that victims of abuse and neglect are particularly susceptible to significant growth deficits. Foster children who have a history of neglect and abuse show a very high prevalence of stunting, wasting, and a myriad of health problems [47–49]. More importantly, a series of studies document severe stunting and wasting in child victims of abuse and neglect [29,50–55], particularly in fatal neglect cases [56–67]. Growth deficits in abused children seem to have the greatest impact on the growth of the leg [68], which echoes studies involving stunted children growing in other adverse conditions [69–74].

Considering the evidence reviewed above leads us to conclude that if the group of children whose deaths are under medicolegal investigation (the forensic sample) includes a disproportionate number of low socioeconomic status, abused, and/or neglected children, then it will also include a disproportionate number of children who are stunted and wasted. The forensic population will therefore differ in growth status from the average population of children it is derived from. This discrepancy directly impacts juvenile age estimation because physical anthropologists assess growth and development (skeletal or dental age) in order to estimate chronological age. Using a method developed on a healthy population to estimate age in this growth-compromised forensic sample may result in consistent underestimation of age, and consequently, to potential problems or delays in the identification of juvenile remains.

Although juvenile age estimation based on dental mineralization are considered more accurate and less affected by external factors, such as socioeconomic status [75–77], situations do arise where the dentition is not available for study and in these cases, long bone length is the preferred method of age estimation. Existing juvenile age estimation methods based on bone size are currently recognized as inadequate for forensic use because they are based on known-age skeletal collections [78–82], or longitudinal growth studies of living children born up to the mid-20th century [83–88]. These recent but non-modern samples are deemed inadequate for modern forensic application because of the well-documented secular increase in childhood stature over the last century [89]. We suggest that a larger problem which must be addressed by new forensic age estimation methods is that the forensic sample may not present the same growth patterns as their contemporary healthy peers, as indicated by the literature reviewed above.

The nature of the target population, i.e. the forensic population, has not been taken into consideration when devising methods for forensic use. Some studies assert the forensic relevance of their historical reference samples, but ignore important secular effects in the target population [79–81]. Other studies have drawn on medicolegal samples, but either supplemented them with clinical material [90], or asserted that these are not ideal for forensic use [91]. Others yet specifically exclude abuse and neglect victims from their clinical samples [92], eliminating that segment of the population which is of the most interest to the forensic anthropologist. Consistently, researchers have failed to consider the target population when designing sampling strategies, thus potentially selecting inappropriate or biased reference samples.

Historical known-age skeletal collections and older longitudinal studies are not necessarily irrelevant for developing forensic age estimation methods, and modern samples of living children are not necessarily ideal for the same purpose. Pfau and Sciulli [91] used a medicolegal sample of juvenile homicide and accident victims deceased in 1990 and 1991 to document bone length for age. When interpolating lengths from their plots, their sample falls between the 5th and 95th percentiles given by Maresh [85]. Although there is some deviation between the samples after age six (Fig. 1), their data is a good match for Maresh's much older data. This consistency suggests that older longitudinal growth data may still be relevant for age estimation in forensic contexts.

In this study, we investigate whether there is a noticeable or significant difference in growth status between the forensic and the average juvenile populations. We address the question of whether a sample of children drawn from the general population is an appropriate reference sample to develop age estimation methods based on bone size meant to be applied to children in a forensic setting. Using cadaver lengths collected from coronial institutions in Australia, New Zealand, and the United States, we compare height for age between homicide victims, taken to represent the forensic population, and accident victims, taken to represent the normal population. Although height is not a direct source of information about long bone length, the very high correlation between the two dimensions means that observed differences in height for age are likely to reflect similar differences in long bone length for age.

2. Materials and methods

Data for this study were drawn from autopsy records of children aged birth to 18 years at death, obtained from coronial bodies in Australia, New Zealand, and the United States. The Australian sample included data from the following states: the Northern Territory, the Australian Capital Territory, Victoria, Tasmania, Queensland, and New South Wales. The New Zealand sample is national. The United States is represented by three locations: the state of New Mexico, New York City, and Cuyahoga County in Ohio. Cases where significant decomposition, chronic disease impacting growth, or thermal damage to the cadaver were noted in the