Photodensitometry: a useful method for studying bone mineral density in the skeletal remains of children

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Bull Int Assoc Paleodont. 2014;8(1):187-194.

Abstract

Bone mineral density studies are frequently undertaken in both human bioarchaeology and zooarchaeology in order to investigate taphonomic processes, health and disease in past populations. In this short study, seventy-two non-adult skeletons from the assemblages of Edix Hill, Cambridge, UK (n=15) and St Oswald's Priory, Gloucester, UK (n=57) were studied to develop a method of measurement using photodensitometry and to determine the density of the femur and radius and assess which bone portions (i.e proximal, mid-shaft, distal) had the highest density values, which may influence the overall preservation of the skeletal remains and or elements belonging to children. Overall, in this study using this method there appeared to be a continual increase and decrease in bone density at the three areas (proximal, mid-shaft, and distal) of both the femur and radius during early and mid childhood. It would also appear that the density at the mid-shaft of the long bones varies immensely, thus perhaps suggesting that a low bone density reading does not have a profound effect on the survival of this portion of bone.

Keywords: Radius; Femur**;** Cortical Bone Thickness; X-Rays; Medieval England

Introduction

The study of bone mineral density (BMD) is frequently undertaken in bioarchaeology as bone density is a mediating factor in taphonomic studies (1, 2) of both human (3,4) and animal remains (5-12). It has long been recognised that certain parts of a skeleton preserve better than others, whether that skeleton be human or non-human, this is especially true of non-human bone where many studies have confirmed the relationship between taphonomy and bone density (5-12). The relative survival of certain bone elements and even certain parts of a given element preserve better than other parts of the same element, this is due to the differences in bone density. Bone density of specific portions of long bones was studied on the Crow Creek skeletal assemblages, where Willey and colleagues (4) found that the radius, ulna, tibia and femur were among the bone portions with the highest density. A study on human skeletal elements from Tierra del Fuego in Argentina, Suby and colleagues (1) found that the shafts of the long bones had the highest densities using dual-energy x-ray absorptiometry (DEXA) and quantitative computed tomography (QCT). More recently, Kendell and Wiley included the skeletal data of non-adults to investigate the relationship between BMD and element representation. It was noted that for both adults and non-adults the greatest element representation observed was the proximal femur, distal femur and proximal tibia (13).

In order to assess BMD in children, several techniques have been employed in archaeology: such as dual-energy absorptionmetry (DEXA), computed tomography (QCT), quantitative ultrasound (QUS) and radiography (14). Several clinical studies have used dual-energy x-ray absorptionmetry (DEXA) to measure normal values of BMD and BMC in children of different ages (15-18). These techniques can be used to some extent in comparing archaeological samples. Other researchers have used digital photodensitometry to measure bone density in animals (19) and child remains (20). In addition, energy dispersive low angle x-ray scattering techniques have been employed to measure BMD in archaeological bone (21). Porosimetry techniques may also be used to measure the total volume and shape of pore spaces within the bone, as bone density is the macroscopic expression of porosity (22). When considering techniques, it must be remembered that any non-invasive density determination technique that is applied to archaeological bone, whether adult or non-adult, which does not examine the mineral make-up of the sample analysed may produce errors. Bones which appear to be well preserved on the outside may have undergone considerable change internally and microscopically (21, 23).

The purpose of this short study is twofold; firstly, to outline the method used in the examination of bone density in the femur and radius of non-adult skeletons from England and secondly, to determine which bones and/or bone portions had the highest density values, which may influence the overall preservation of the skeletal remains of children.

Materials and Methods

Site information

A total of seventy-two child skeletons were studied from two archaeological sites, namely; Edix Hill in Cambridgeshire, UK and St Oswald's Priory in Gloucester, UK. Edix Hill (also known as Kdricks Hill and Edics Hill Hole) is situated on the western edge of Barrington parish and close to the Village of Orwell 15km north of Great Chesterford. These parishes lay 12km south-west of Cambridge, within the Cam Valley, which is part of the south Cambridgeshire district and situated between East Anglia and the Midlands. The Edix Hill cemetery was first documented in 1860 following the discovery of a sword burial in 1840, and other bones in subsequent years, culminating in skeletons and artefacts being recovered in 1860. In the following years, numerous graves were excavated. Much activity at Edix Hill had been reported during the 19th century, and in 1987 and 1988 finds were reported to the County Archaeology office. These finds demonstrate the exact location of the cemetery had been found again. Further excavations were carried out over three summers of 1989-1991 (24). The total number of individuals recovered was 148, forty-six (31%) of which were non-adults, fifteen (32%) skeletons were suitable for study here.

The site of St Oswald's Priory lies in the fertile valley of the River Severn and to the east is the scarp slope of the Cotswold Hills. The site of St Oswald's has been used as a burial ground since the Roman period. Both churches appeared to be dedicated to St Peter in the late Anglo-Saxon period, whereas in the pre-Conquest period they were known as the Old Minster and the New Minster, respectively. This later became known as the abbey church of St Peter and the later Priory church of St Oswald's (25). A total of 487 skeletons were recovered. One hundred and twenty eight (26%) of which were non-adults. Fifty-six (34%) skeletons were suitable for this present study.

Age-at-death

In the present study age-at-death was determined using the standards developed by Moorrees and colleagues (26-27) for the development and resorption of the deciduous dentition, and the development of the permanent teeth. In cases where no teeth were present, the long bone lengths (28) and skeletal development and maturation (29) were employed. The foetal remains were aged using long bone lengths (30) and the occipital bone where the length and width of the pars basilaris was calculated for age estimation (31). Individuals were estimated to be over 17 years if the root of the third molar was complete (27).

Method

Photodensitometry is based on the radiodensity of the human bone through the examination of a radiograph (x-ray) of each bone. Radiodense material appears in a radiograph as a comparatively light grey image. Radiolucent material appears as a darker grey image. The radiodensity of a bone can be described as being the product of a combination of its size and density. An increase in the density of bone will produce a light image. This method requires you to quantify how light or dark images are and each bone to be measured and accounted for, so that differences in the grey level of the radiographic images can be attributed to variation in bone density (19).

Firstly, bone thickness was calculated by taking three measurements at the proximal, mid-shaft and distal parts of both the femur and radius of each skeleton using digital calipers which were then averaged. This was considered to be a more cost and time effective way of calculating bone thickness, rather than repeated radiographs. For each bone that was measured, one radiograph was taken. This image was also used for the radiodensity measurement. The density measurement was then divided by the bone thickness measurement of each of the scan site locations, in order to calculate a more accurate bone density value. The scan sites of each bone were marked by attaching a small piece of lead before radiography was applied. This enables the scan sites to be standardized and also allowed the radiodensity and bone thickness to be measured at the same position each time.

Any bones with signs of disease, trauma or soil infiltration were excluded which limited the numbers of bones available for study. All radiographs were taken using the Hewlett Packard faxitron machine using AGFA structure D4 FW industrial x-ray film. The remains were exposed at 55kv for the smaller bones and 70kv for the larger bones. Exposure time was 55 seconds for all bones. All bones were exposed alongside an eleven step aluminium wedge (Figure 1). The radiographs were developed in deep trays under red safe light at 20°. Each radiograph was developed for three minutes, whilst developing, the films were agitated throughout. Developing was stopped by immersing film in stop solution and then they were placed in fixing solution for three to four minutes. Finally each film was washed for ten minutes before drying. The developed radiographs were then photographed on a light box and digital images were then saved (32). Then bone density of each bone was then calculated using image J software. Each pixel of the greyscale images was assigned a value of between 0 and 255 which relate to the greyscale of that particular pixel, (i.e 0 is white and 255 is black). The greyscale of any part of a radiograph relates to its radiodensity, for example a low (light) greyscale indicates a high radiodensity, whereas, a high (dark) greyscale indicates a low radiodensity (19). Therefore, the software allowed the calculation of the average radiodensity of each radiograph. Each image (radiograph) was standardised by measuring the greyscales of each step of the step wedge. This produced 11 measurements for each image, each of which could be assigned a known density (thickness of aluminium). Each measurement was taken by highlighting an area in at the proximal, mid-shaft and distal areas of each bone, using the selection tool and selecting ‘measure’ from the ‘analysis’ menu. The values returned were the average pixels of that particular scan site.

Results and discussion

Firstly, the bone mineral density (grams per cm²) was measured at the proximal, mid-shaft and distal portions of the femur and radius for both St Oswald’s Priory and Edix Hill (Table 1). There appears to be an increase in bone density in those aged less than one year at the proximal, mid-shaft and distal portions of each of the long bones. At St Oswald’s Priory there was a drop in bone density at the proximal portion of each of the bones at one year of age, but an increase in the density of the mid-shaft and distal potions. This may be due to the amount of trabecular bone at the proximal portion compared to the mid-shaft and distal portions. At St Oswald’s Priory, those aged at less than one year of age did appear to show an increase in BMD in the femur and radius. Also there was a decrease in density at one year of age and then a subsequent drop at around 2 years of age, thus following that reported by Guy et al. (33). However, in this study using this method there appeared to be a continual increase and decrease in bone density at the three areas during early and mid childhood. It would also appear that the density at the mid-shaft of the long bones varies immensely, thus perhaps suggesting that a low bone density reading does not have a profound effect on the survival of this portion of bone.

The mean bone density was calculated for the proximal femur and radius and divided into the three age categories, as both the femur and the radius are frequently reported in the literature has having increased density and therefore, more frequently observed in skeletal assemblages. At both sites there is a large decease in bone density in both the femur and radius from infancy to mid-childhood (Tables 2 and 3), with an increase in later childhood (9-15 years).

The BMD of non-adult skeletal remains has rarely been studied with taphonomic purposes (1); this may be due to the difficulty in use of and reliability of methods. The bone mineral density of a child’s skeleton tends to be regarded as less dense than those of adults with the bones of children having a high organic and low mineral content which may make them more susceptible to decay (34). Also the study of bone density in ancient remains can offer insights into the health and wellbeing of past populations. Human bone is subjected to many processes after death which may affect overall bone preservation. This short study demonstrates the use of photodensitonmetry as a quick and easy method to estimate bone density in the bones of children, which appears to show that the density of both the femur and radius increases with age which is comparable with other studies.

Acknowledgements

I thank Sarah Poppy for access to the Edix Hill skeletal collection and David Rice for access to the St Oswald's Priory Collection. I also thank Erika Mueller for her help with developing the x-rays.

References

1. Suby JA, Guichón RA, Cointry G, Ferretti JL. Volumetric BMD values of archaeological human bone remains with pQCT and DEXA. Journal of Taphonomy 2009; 7 (1): 29- 45.

2. Lyman RL. Bone density and bone attrition. In: Pokins J, Symes SA, Roper C. Editors. Manual of Forensic Taphonomy. CRC Press, Boca Raton; 2013. p. 51-72.

3. Galloway A, Willey P, Snyder L. Human bone mineral densities and survival of bone elements: a contemporary sample. In: Haglund WD, Sorg MH. Editors. Forensic Taphonomy: The Post Mortem Fate of Human Remains, CRC Press: Florida; 1997. p. 295-317

4. Wiley P, Galloway A, Snyder L. Bone mineral density and survival of elements and element portions in the bones of the crow creek massacre victims. Am J Phys Anthrop 1997; 104:513-528.

5. Butler VL, Chatters JC. The role of bone density in structuring prehistoric salmon bone assemblages. J Archaeol Sci 1994; 21: 413-424.

6. Carlson KJ, Pickering TR. Intrinsic qualities of primate bones as predictors of skeletal element representation in modern and fossil carnivore feeding assemblages. J Hum Evol 2003; 44:431-450.

7. Carlson KJ, Pickering TR. Shape-adjusted bone mineral density measurements in baboons: other factors explain primate skeletal element representation at Swartkrans. J Archaeol Sci 2004; 31:577-583.

8. Elkin D. Structural density of South American camelid skeletal parts. Int J Osteoarchaeol 1995; 5: 29-37

9. Lam YM, Pearson OM. Bone density studies and the interpretation of the faunal record. Evol Anthro 2005; 14: 99-108

10. Lam YM, Chen X, Marean CW, Frey CJ. Bone density and long bone representation in archaeological faunas: comparison results from CT and photon densitometry. J Archaeol Sci 1998; 25:559-570.

11. Lam YM, Chen X, Pearson OM. Intertaxonomic variability in patterns of bone density and the differential representation of bovid, cervid and equid elements in the archaeological record. Am Antiq 1999; 64 (2): 343-362.

12. Lam YM, Pearson OM, Marean CW, Chen X. Bone density studies in Zooarchaeology. J Archaeol Sci 2003; 30; 1701-1708.

13. Kendell A, Willey P. Crow Creek bone bed commingling: relationship between bone mineral density and minimum number of individuals and its effect on paleodemographic analyses. In: Osterholtz AJ, Baustian KM, Martin DL. Editors. Commingled and Disarticulated Human Remains: Working Towards Improved Theory, Methods and Data. Springer: New York, 2013. p. 85-104

14. Manifold BM. Bone mineral density in children from anthropological and clinical sciences. (under review).

15. Maynard LM, Guo SS, Chumlea WC, Roche AF, Wisemandle WA, Zeller CM et al. Total body and regional bone mineral content and areal bone mineral density in children aged 8-18y: fels longitudinal study. Am J Clin Nutr 1998; 68:1111-1117.

16. Zanchetta JR, Plotkin H, Alvarez Filgueira ML. Bone mass in children: normative values for the 2-20 year old population. Bone 1995; 16(4): 393S-399S.

17. Mølgaard C, Thomsen BL, Prentice A, Cole TJ, Fleischer Michaelsen K. Whole body bone mineral content in healthy children and adolescent. Arch Dis Child 1997; 79: 9-15.

18. Southard RN, Morris JD, Mahan JD, Hayes JR, Torch MA, Sommer A et al. Bone mass in healthy children: measurements with quantitative DXA. Radiology 1991; 179:735-738.

19. Symmons R. Digital photodensitometry: a reliable and accessible method for measuring bone density. J Archaeol Sci 2004; 31:711-719.

20. Manifold BM. Estimating bone mineral density in non-adult skeletal remains using photodensitonmetry. (Forthcoming).

21. Farquharson M, Speller R, Brickley M. Measuring bone density in archaeological bone using energy dispersive low-angle X-ray scattering techniques. J Archaeol Sci 1997; 24: 765-772.

22. Robinson S, Nicholson RA, Pollard AM, O'Connor TP. An evaluation of nitrogen porosimetry as a technique for predicting taphonomic durability in animal bone. J Archaeol Sci 2003; 30:391-403.

23. Bell L, Skinner M, and Jones S. The speed of postmortem change to the human skeleton and its taphonomic significances. For Sci Int 1996; 82:129-140.

24. Malim T, Hines J. The Anglo-Saxon Cemetery at Edix Hill (Barrington A), Cambridgeshire. Council for British Archaeology Report 112; Council for British Archaeology, York, 1998.

25. Hare M. The documentary evidence for the history of St Oswald's, Gloucester to 1086 AD. In: Heighway C, Bryant. Editors. The Golden Minster: The Anglo-Saxon Minster and Later medieval Priory of St Oswald at Gloucester. Council for British Archaeology Research Report 117: Council for British Archaeology: York, 1999. p. 33-46.

26. Moorrees CFA, Fanning EA, Hunt EE. Formation and resorption of three deciduous teeth in children. Am J Phys Anthropol 1963a; 21:205-213.

27. Moorrees CFA, Fanning EA, Hunt EE. Age variation of formation stages for ten permanent teeth. J Dent Res 1963b; 42:1490-1502.

28. Ubelaker D. Human Skeletal Remains: Excavation, Analysis, Interpretation. Taraxacum, Washington DC. 1989.

29. Buikstra JE, Ubelaker D. Standards for Data Collection from Human Skeletal Remains. Arkansas Archaeological Survey, Fayetteville, 1994.

30. Scheuer L, Musgrave JH, Evans SP. The estimation of late fetal and perinatal age from limb length by linear and longarithmic regression. Ann Hum Biol 1980; 7: 257-265.

31. Scheuer L, MacLaughlin-Black S. Age estimation from the pars basilars of the fetal and juvenile occipital bone. Int J Osteoarchaeol 1994; 4:377-380.

32. Yoder DT. The use of 'soft' X-ray radiography in determining hidden construction characteristics in fiber scandals. J Archaeol Sci 2008; 35: 316-321.

33. Guy H, Masset C, Baud CA. Infant Taphonomy. Int J Osteoarchaeol 1997; 7:221-229.

34. Currey J, Butler G. The mechanical properties of bone tissue in children. J Bone Joint Surg 1975; 57-A; 810-814.

Age	St Oswald's Priory Femur			St Oswald's Priory Radius			Edix Hill Femur			Edix Hill Radius		
	Proximal	**Mid-shaft**	**Distal**	**Proximal**	**Mid-shaft**	**Distal**	**Proximal**	**Mid-shaft**	**Distal**	**Proximal**	**Mid-shaft**	**Distal**
< 1	0.493	0.672	0.698	1.009	0.993	0.925	-	-	-	0.794	0.725	0.984
1	0.437	0.430	0.636	0.793	0.867	0.679	0.383	0.402	0.462	0.614	0.618	0.725
2	0.496	0.544	0.596	-	-	-	0.501	0.467	0.496	0.919	0.804	0.702
3	0.364	0.374	0.606	0.707	0.575	0.685	0.438	0.449	0.462	0.781	0.922	0.588
4	0.406	0.677	0.407	0.834	1.027	0.93	0.274	0.241	0.374	0.614	0.575	0.487
5	0.414	0.461	0.490	0.749	0.777	0.649	0.301	0.324	0.458	0.6	0.399	0.622
6	0.348	0.318	0.387	0.52	0.491	0.543	0.384	0.325	0.506	0.78	0.606	0.586
7	0.5	0.552	0.710	0.708	0.698	0.719	-	-	-	-		
8	0.334	0.261	0.329	0.627	0.62	0.752	0.277	0.342	0.408	0.672	0.566	0.568
9	0.233	0.191	0.245	-	-	-						
10	-	-	-	-	-	-						
11	0.645	1.044	-	1.271	0.983	0.864						
12	0.579	0.391	0.593	0.883	0.719	0.917						

Table 1 Mean BMD (g/cm²) and age at the proximal, mid-shaft and distal portion of the femur and radius at St Oswald's Priory and Edix Hill

	Infancy (0-1 year)	Early Childhood (2-8 years)	Late Childhood (9-15 years)
Proximal femur			
Number	17	18	4
Mean	0.480	0.398	0.509
Standard deviation	0.144	0.092	0.190
Radius			
Number	15	12	3
Mean	0.959	0.701	0.807
Standard deviation	0.115	0.179	0.179

Table 2 Mean BMD (g/cm²) at the proximal femur and radius in the St Oswald's Priory non-adults by age group

	Infancy (0-1 year)	Early Childhood (2-8 years)	Late Childhood (9-15 years)
Proximal femur			
Number	2	8	-
Mean	0.383	0.341	-
Standard deviation	0.137	0.089	-
Radius			
Number	3	7	-
Mean	0.654	0.634	-
Standard deviation	0.061	1.73	-

Table 3 Mean BMD (g/cm²) at the proximal femur and radius in the Edix Hill non-adults by age group

Figure 1 Aluminum Step-wedge