European Journal of Orthopaedic Surgery & Traumatology (2019) 29:389–396
https://doi.org/10.1007/s00590-018-2311-y

ORIGINAL ARTICLE • UPPER LIMB - ANATOMY

# Study of human radius construction systematics: evaluation by DXA in dry bone

Soledad Aguado-Henche[1] · Pascual Morante-Martínez[1] · Soledad Cristóbal-Aguado[2] · Celia Clemente de Arriba[1]

Received: 14 June 2018 / Accepted: 10 September 2018 / Published online: 15 September 2018


## Abstract
This study has been undertaken in order to describe the bone mass distribution of the dry human radius via dual x-ray absorptiometry (DXA) with a Norland XR-800 densitometer machine. A sample of 39 dry radius bones was used. Two projections were made: antero-posterior and lateral, and five regions of interest were selected. The bone densities and the bone mineral contents of the various regions of the radius in the two projections were compared using Student's *t* tests for paired samples, with statistically significant differences being found in all of the values, except in the proximal extremity (P Ext). The area of greatest bone mineral content (BMC) was the medial diaphysis (M Diaph), followed by the distal extremity (D Ext), with the lowest value being found in the proximal extremity (P Ext). As for bone mineral density (BMD), a great symmetry is observed if we take the mean point of the longitudinal axis as a reference, with it being distributed from highest to lowest from the central part to the extremities. A correlation study of the BMD and BMC values between the segments themselves and with the total, in both positions, provides us with a high correlation ($p \leq 0.01$), with the highest correlation value being found for the proximal diaphysis (P Diaph) region, indicating the heterogeneous nature of the distribution of the radius bone mass. Bone densitometry via DXA is useful in order to establish an overview of the structural construction of the human radius.

**Keywords** Dual x-ray absorptiometry · Human radius · Dry bone · Bone mineral density · Bone mineral content · Densitometry

## Introduction

Modern bone mass measurement instruments, such as the DXA (dual x-ray absorptiometry) and pQCT (peripheral quantitative computed tomography), allow us to quantify mineral bone density so as to diagnose different illnesses affecting the skeleton and to follow their evolution and the results of distinct treatment applications [1, 2].

For some time now, well-known osteology masters, such as Wolf, have told us that bones subject to different loads modify their architecture and the quality and quantity of their tissue [3]. The different forces exercised in an appropriate manner over the bone stimulate its formation and remodeling, but those that are excessive and continuous may act negatively, producing atrophy.

Bone density initially adapts to the external loads during the growth phases, while the trabecular architecture adapts later, during development [4]. It is well known that the osteogenic effect of a force is produced over the site of its application, in both young and mature bones [5], and is directly proportional to its quantity [6].

Studies have been conducted on the mechanical loads supported by the forearm, taking into account sporting activity (such as tennis, squash) in which the demand of forces supported by the bone (due to said activity) has a direct effect on its formation, remodeling and design and, therefore, on its final structure and morphology [7–9].

Some studies relate the cortical and trabecular areas in terms of the percentage found in the different zones of the radius [10], while others describe "partial" values of bone mass in the form of BMD (bone mineral density) and BMC (bone mineral content) [9, 11–13], but only for values of the

✉ Soledad Aguado-Henche
soledad.aguado@uah.es

1 Teaching Unit of Human Anatomy and Embryology, Department of Surgery, Medical and Social Sciences, Faculty of Medicine and Health Sciences, University of Alcalá, Ctra. Madrid-Barcelona - Km 33600, 28805 Alcalá de Henares, Madrid, Spain

2 National Health System, "La Paz" University Hospital, Madrid, Spain

isolated portions and without relating or correlating them between one another, or with the totality of the bone. Furthermore, these studies were conducted on the forearms of living individuals.

The purpose of this study is to establish the systematics of construction of the human radius, through the use of dry and mature radius bones, without taking into account any specific demands or extraordinary forces. Furthermore, given the assessment technique used (DXA), we make no distinction between cortical and trabecular bones, nor do we differentiate between the endo-cortical or periosteum areas, but rather, we assess both BMD and BMC collectively, to verify that bone tissue distribution is not homogeneous and that this distribution corresponds to the bone's trabecular architecture.

## Material and method

A random sample of 39 dry human radius bones, 20 right and 19 left, from the skeletal collection of the Department of Surgery, Anatomy Social Medical Sciences of the University of Alcalá (Alcalá de Henares, Madrid—Spain), was studied.

The bones came from unidentified (with regards to gender and age) adults. The analyzed samples were normal in terms of morphology and constitution (shape, size, weight), excluding any bones having signs of deterioration caused by deficiencies in preservation, prior pathologies or any other cause that may alter a proper analysis and thereby undermine the results.

A Norland XR-800 densitometer with "Illuminatus 4.3.0" application and analysis software was used for all studies with an investigation mode.

Each scan session was preceded by a calibration routine using a standard calibration block supplied by the manufacturer. All radius bones used in the study came from cemetery ossuaries. They were donated voluntarily by the authorities to the Alcalá Medical School.

This technique has a high degree of accuracy and precision, approaching 1%. Scanning speed was 60 mms, with and interlineal space of 1 mm and point resolution of 1 mm horizontal × 1 mm vertical. The defined exploration was completed as outlined, in an average time of 10–12 min. Scan acquisition and scan analyses were performed by one investigator.

The bone was placed well-centered on the examining board. It was important to verify stability so that its position did not vary during the study. Cotton gauze may be useful for optimal stabilization. The bones were exposed directly, without water or other materials that may resemble soft tissue.

Dry radius calculations were performed for the following magnitudes:

- BMD: bone mineral density, in g/cm$^2$.
- BMC: bone mineral content, in grams. BMC is defined as the mass of mineral per unit bone length. Bone mineral content is obviously a size-dependent parameter (Schoenau, 2004).
- Area: measured area, in square centimeters (cm$^2$).
- Length: total length of the bone, in centimeters (cm).
- Width: total width of the bone, in centimeters (cm).

For the densitometric analysis of the human radius structure, two projections were performed:

- *Postero-anterior* position (PA): the longitudinal axis that passes by the "Margo posterior-Tuberculum dorsale" is perpendicular to the axis of the examining board.
- *Latero-medial* position (LM): the axis that passes by the "Margo interosseous-Incisura ulnaris" is perpendicular to the axis of the examining board.

To begin the scan, the starting point was situated 0.5 cm directly above the proximal extremity. A baseline point was marked below the distal extremity. A third point (goal line) was marked at 1 cm from the more lateral part of the bone.

For the purpose of this study, the complete bones were scanned in the two previously mentioned projections (Fig. 1). Once scanned and for their subsequent analysis, it was subdivided into five regions of equal length. Specific equipment system software divides the total bone length

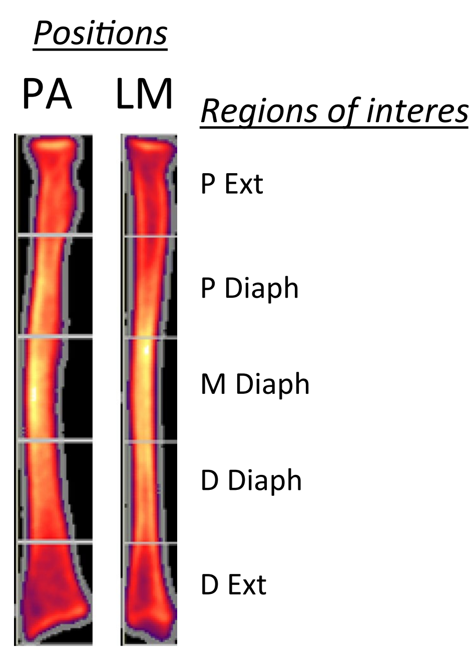


**Fig. 1** Densitometric image of the radius, scan positions and region of interest for DXA measurement of BMD and BMC. P Ext (proximal extremity); P Diaph (proximal diaphysis); M Diaph (medial diaphysis); D Diaph (distal diaphysis); D Ext (distal extremity)

**Table 1** Descriptive statistics of BMD and BMC for the total radius and for regions in both positions

| | BMD | | BMC | |
|---|---|---|---|---|
| | PA | LM | PA | LM |
| | Media ± SD | Media ± SD | Media ± SD | Media ± SD |
| Total | 0.5631 ± 0.113 | 0.6357 ± 0.128 | 22.873 ± 6.125 | 22.184 ± 5.982 |
| P Ext | 0.5218 ± 0.113 | 0.5210 ± 0.115 | 4.074 ± 1.200 | 4.049 ± 1.199 |
| P Diaph | 0.6197 ± 0.127 | 0.6729 ± 0.139 | 4.608 ± 1.238 | 4.505 ± 1.224 |
| M Diaph | 0.6678 ± 0.130 | 0.7668 ± 0.144 | 4.943 ± 1.243 | 4.831 ± 1.244 |
| D Diaph | 0.5827 ± 0.119 | 0.6835 ± 0.139 | 4.583 ± 1.218 | 4.349 ± 1.161 |
| D Ext | 0.4665 ± 0.104 | 0.5765 ± 0.130 | 4.802 ± 1.388 | 4.588 ± 1.342 |

*BMD* bone mineral density, *BMC* bone mineral content, *PA* postero-anterior position, *LM* latero-medial position, *SD* standard deviation, *P Ext* proximal extremity, *P Diaph* proximal diaphysis, *M Diaph* middle diaphysis, *D Diaph* distal diaphysis, *D Ext* distal extremity

into the indicated number of regions. The total region corresponded to the overall area of the bone's length and height. The regions of interest were:

- P Ext (proximal extremity).
- P Diaph (proximal diaphysis).
- M Diaph (medial diaphysis).
- D Diaph (distal diaphysis).
- D Ext (distal extremity).
- Total: The total regions correspond to the area of the full length and height of the bone.

All statistical calculations were performed using "Statgraphics Plus" (Version 5.1) and "SPSS" (Statistical Package for Social Sciences) (Version 15.0). The means and standard deviations (SD) were calculated for bone mineral density (BMD) and bone mineral content (BMC). The bone densities and the bone contents of the various regions of the radius in the two projections were compared using the Student's *t* tests for paired samples.

Using Pearson's correlation analysis, the relationships have been studied, in terms of bone mass and bone density, between the different parts of the bone, and the relationship of each predetermined region with the totality of the bone, seeking potential differences and correlations between the same. Finally, regression lines have been found along with prediction equations for the total BMD and total BMC.

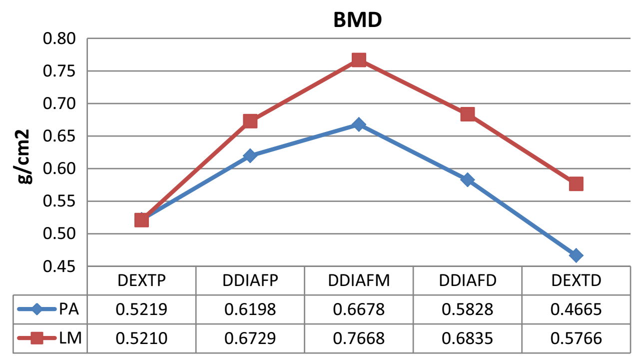


**Fig. 2** BMD values by regions in both positions

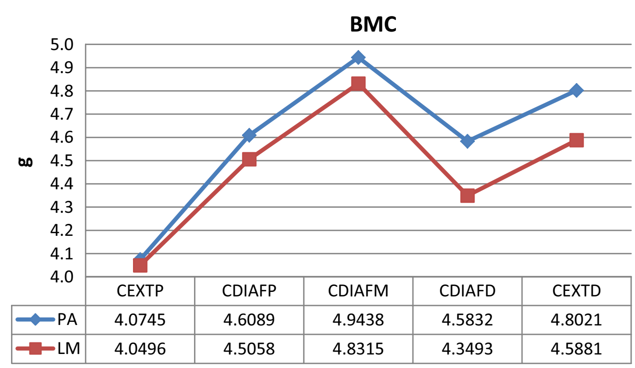


**Fig. 3** BMC values by regions in both positions

## Results

The values obtained for BMD and BMC are observed in Table 1.

When using the middle point of the radius diaphysis as the reference (in terms of its longitudinal axis), BMD decreases from greater to smaller, from the central part of the bone, toward the extremities (Fig. 2). The highest values of BMC are also found in the middle region of the diaphysis (Fig. 3).

When using the Student's "T" for independent samples to compare BMD and BMC of the different segments and of the total radius between left and right radius bones, we did not encounter any statistically significant differences.

Upon comparing the mean values of the bones in the antero-posterior and lateral positions (of each segment and of the total) using the Student's *T* test for paired samples,

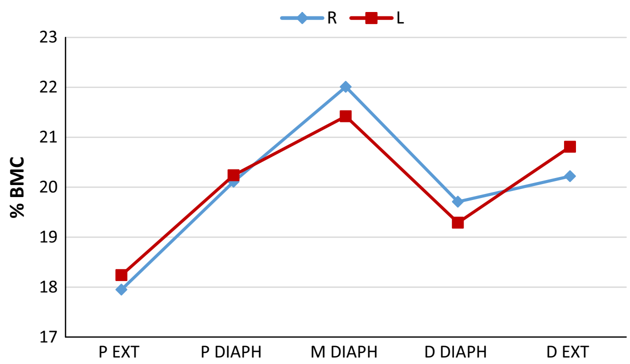


**Fig. 4** Distribution of the % of BMC of left and right radius in LM position. R: right radius. L: left radius

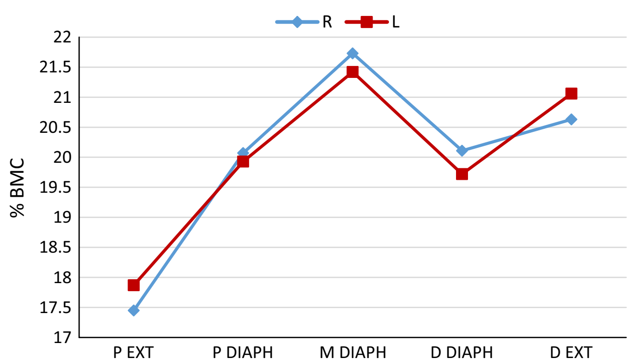


**Fig. 5** Distribution of the % of BMC of left and right radius in PA position. R: right radius. L: left radius

for BMC and BMD, we find statistically significant differences in all of the values except in the proximal extremity (P Ext). The mean values were greater for BMD in the latero-medial position and for BMC in the postero-anterior position (Figs. 1, 2).

In the analysis of the distribution of BMC across the bone and taking into account the regions that we have differentiated, we calculated the percentage of BMC that is represented by each region with regards to the total radius and in the two scan positions (Figs. 4, 5).

The region having the greatest % BMC is the M Diaph, followed by the D Ext. They are followed by the P Diaph and D Diaph regions, of similar content, and finally, we observe that the radius region with the lowest % BMC is the P Ext.

A study of correlations of the BMD and BMC values was conducted, for each of the segments and with the total, in both positions, finding a high correlation between them (Table 2), with the greatest correlation value being found for the P Diaph region.

Figure 6 shows the regression lines with variance bands at 95%, and the prediction equations for total BMC and total BMD based on the values of the segment of the proximal diaphysis (P Diaph) in both positions.

## Discussion

Today, DXA continues to be considered the top means of diagnosing osteoporosis [14] and although it cannot reveal the micro-architecture of the bone as is the case with the "high-resolution Peripheral Quantitative Computed Tomography" HR-pQCT [15, 16] or "high-resolution Magnetic Resonance" (hrMR) and other more current methods [17], it eliminates important factors positioned against imaging studies for the radius in living individuals, such as the interposition of soft tissues and others that are caused by the RNM and microTC devices. These devices require the application of algorithms for the processing of the images so as to correct for the variation of the results that they offer, given that they depend directly on the quality of the images obtained [18].

Despite the recent appearance of these new techniques for the assessment of the bone strength and quality [19], densitometry continues to be the technique of choice given its lower cost and increased ease of application in clinical practices. The other techniques only provide additional information [20]. Currently, there is very limited research on the study of bone micro-architecture in the dry radius [21], and very few studies of this type have used the DXA, and those that we have found have considered the ulna [22] and other long bones such as the femur, the tibia and the humerus, [23] or short bones such as the calcaneus [24]. Specifically, and in our case, this is the first study to examine the complete dry radius via densitometry, given that some studies of this type have limited their work to the study of the distal extremity of the bone [21].

Studies have been conducted on variations of BMD and BMC of human forearms [7, 8, 25–27], the relations, in terms of width and volume, of the different parts of the forearm bones [7–9, 11, 28–30] and the variation of these parameters in their areas of cortical, trabecular or mixed predominance [31]. Other research has compared the values of dominant forearm bones with non-dominant values for a specific sporting activity and in distinct populations such as in girls [12, 28] or prepubescent boys [4]. With pQCT, some have found that physical exercise produces a geometric adaptation of the bone, as well as an improvement in BMD [31].

We compared our results with those obtained in another parallel study conducted on the ulna [32]. In this forearm bone, the greatest BMD was found in the region that is the most proximal to the diaphysis and the greatest BMC was found in the proximal end. In the case of the radius, the maximum BMD and maximum BMC were found in the middle part of its diaphysis (M Diaph). This is the part of the radius receiving the most mechanical requests, where muscular insertions are the widest, since the mass

**Table 2** Pearson's correlations for BMD by segments in PA position and LM position; Pearson's correlations for BMC by segments in PA position and LM position

| | Total | P Ext | P Diaph | M Diaph | D Diaph | D Ext |
|---|---|---|---|---|---|---|
| BMD/PA | | | | | | |
| Total | 1 | .949(**) | .981(**) | .970(**) | .964(**) | .966(**) |
| P Ext | .949(**) | 1 | .964(**) | .868(**) | .873(**) | .913(**) |
| P Diaph | .981(**) | .964(**) | 1 | .939(**) | .929(**) | .922(**) |
| M Diaph | .970(**) | .868(**) | .939(**) | 1 | .969(**) | .908(**) |
| D Diaph | .964(**) | .873(**) | .929(**) | .969(**) | 1 | .911(**) |
| D Ext | .966(**) | .913(**) | .922(**) | .908(**) | .911(**) | 1 |
| BMD/LM | | | | | | |
| Total | 1 | .958(**) | .984(**) | .970(**) | .979(**) | .963(**) |
| P Ext | .958(**) | 1 | .940(**) | .886(**) | .896(**) | .939(**) |
| P Diaph | .984(**) | .940(**) | 1 | .957(**) | .955(**) | .930(**) |
| M Diaph | .970(**) | .886(**) | .957(**) | 1 | .977(**) | .887(**) |
| D Diaph | .979(**) | .896(**) | .955(**) | .977(**) | 1 | .920(**) |
| D Ext | .963(**) | .939(**) | .930(**) | .887(**) | .920(**) | 1 |
| BMC/PA | | | | | | |
| Total | 1 | .955(**) | .984(**) | .970(**) | .983(**) | .967(**) |
| P Ext | .955(**) | 1 | .932(**) | .881(**) | .898(**) | .927(**) |
| P Diaph | .984(**) | .932(**) | 1 | .973(**) | .969(**) | .924(**) |
| M Diaph | .970(**) | .881(**) | .973(**) | 1 | .981(**) | .898(**) |
| D Diaph | .983(**) | .898(**) | .969(**) | .981(**) | 1 | .939(**) |
| D Ext | .967(**) | .927(**) | .924(**) | .898(**) | .939(**) | 1 |
| BMC/LM | | | | | | |
| Total | 1 | .960(**) | .982(**) | .967(**) | .981(**) | .967(**) |
| P Ext | .960(**) | 1 | .937(**) | .875(**) | .896(**) | .943(**) |
| P Diaph | .982(**) | .937(**) | 1 | .966(**) | .966(**) | .917(**) |
| M Diaph | .967(**) | .875(**) | .966(**) | 1 | .985(**) | .890(**) |
| D Diaph | .981(**) | .896(**) | .966(**) | .985(**) | 1 | .928(**) |
| D Ext | .967(**) | .943(**) | .917(**) | .890(**) | .928(**) | 1 |

**The correlation is significant at 0.01 (bilateral)

of the cortical bone is proportional to the value of the tensions that it supports. In the middle part of the diaphysis, the *flexor digitorum superficialis*, *supinator*, *pronator teres*, and main thumb muscles (*flexor pollicis longus*, *abductor pollicis longus* and *extensor pollicis brevis*) are inserted. This musculature conditions the main function of the thumb and, therefore, is very important for hand pressure. This same circumstance occurred in the densitometry study of the calcaneus bone by Fernández-Camacho et al., where the greatest value of BMD was found in the middle region of the bone. This is in line with the functional importance of the regions corresponding to the thalamus with respect to load support.

Cortical thickness and external diameters are the bone dimensions serving as the main determinants of bone strength [33]. The highest % BMC found in the M Diaph followed by the D Ext may be justified by the bone's anatomy: The long narrow medullary cavity is enclosed in a strong wall of compact tissue which is thickest along the interosseous border and thinnest at the extremities. Its lower end is large, since it forms the main part of the wrist joint [34]. On the other hand, the highest values of % BMC in M Diaph and in both projections appear in the right radius bones, suggesting a clear right laterality in the handling of the upper limbs.

In the results obtained from studies carried out with DXA in children and young adults who play tennis in France, the distal region of the radius has the lowest BMD and progressively increases until the middle region of the diaphysis, as occurred in our study, despite the fact that we examined dry bone, and it is similar in the dominant and non-dominant arm [11].

As for the parameters measured for BMD and BMC in the different regions and taking into account the two scanning incidences, we observe that in the LM position, the BMD values are significantly higher than in the PA position and the BMC values in the PA position are significantly greater than in the LM position, except in the "P Ext" region (proximal extremity) where in both incidences the mean values of BMD and BMC do not have significant differences. The "cylindrical" morphology of the proximal extremity of the radius results in

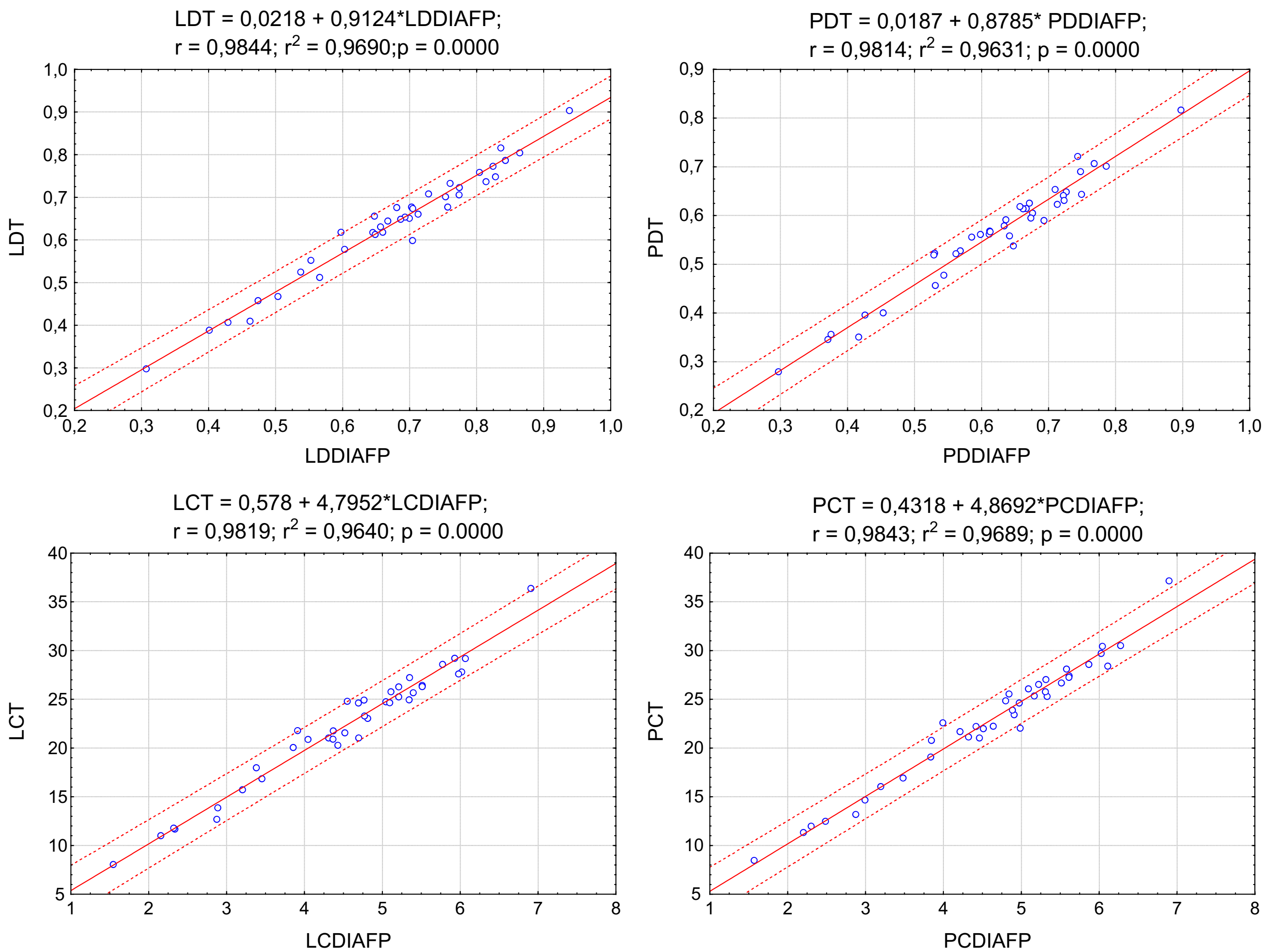


**Fig. 6** Correlation of the P Diaph region, regression line with variance bands at 95%

both incidents having values that are constant or at least that have no significant differences between them. These findings are consistent with the gross anatomy.

The distal fractures of the radius represent one-sixth of all fractures that are treated by traumatology departments. Taking only the forearm into account, 74.5% of these are fractures of the distal metaphysis and/or epiphyses in Spain [35]. Schalamon et al. [36] found that distal fractures of the radius are most common in young Austrians, coinciding with the lower values of BMD with respect to the rest of the bone and as revealed in this study.

The main limitation of our study is that it is based on a random sampling of "dry radius bones" without knowing "a priori" their origin with regards to gender, age, physical activity of donor, etc.

## Conclusion

DXA is capable of explaining the heterogeneous nature of the construction of the human radius bone and, therefore, its construction systematics.

Moreover, these data not only reveal morphological aspects, but also provide information on biomechanical properties. These can be derived from cortical bone thickness or density of cancellous bone by finite element analysis. Such biomechanical data, together with morphometric parameters, can significantly contribute to the development of new prosthesis and implants, which account for both morphological diversity and biomechanical aspects.

The bone structure of the radius may also be studied in living individuals, a possible extension of this study which would serve to compare these results with those obtained in forearm densitometry studies (bone with soft tissues).

## Compliance with ethical standards

**Conflict of interest** Aguado-Henche S, Morante MArtínez P, Clemente de Arriba C and Cristóbal-Aguado S declare that they have no conflict of interest.

## References


1. Aguado-Henche S, Rodríguez Torres R, Clemente de Arriba C, Gómez Pellico L (2008) Total and regional bone mineral content in healthy Spanish subjects by dual-energy X-ray absorptiometry. Skelet Radiol 37(11):1025–1032. https://doi.org/10.1007/s00256-008-0519-3
2. Bossío N, Capiglioni R (2015) Densitometría Mineral Ósea por Tomografía Computada. RAAO LIV(2):19–22
3. Wolff J (1892) The law of bone remodelling (Das Gesetz der transformationder knochen, Kirchwald). Springer, Berlin
4. Tanck E, Homminga J, Van Lente GH, Huiskes R (2001) Increase in bone volume fraction precedes architectural adaptation in growing bone. Bone 28:650–654
5. Heinonen A, Mckay HA, Whitall KP, Forster BB, Khan KM (2001) Muscle cross-sectional area is associated with specific site of bone in prepubertal girls: a quantitative magnetic resonance imaging study. Bone 29:388–392
6. Hsieh YF, Turner CHY (2001) Effects of loading frequency on mechanically induced bone formation. J Bone Miner Res 16:918–924
7. Ducher G, Jaffre C, Arlettaz A, Benhamou CL, Courteix D (2005) Effects of long-term tennis playing on the muscle-bone relationship in the dominant and nondominant forearms. Can J Appl Physiol 30:3–17
8. Ducher G, Courteix D, Meme S, Magni C, Viala JF, Benhamou CL (2005) Bone geometry in response to long-term tennis playing and its relationship with muscle volume: a quantitative magnetic resonance imaging study in tennis players. Bone 37:457–466
9. Ducher G, Prouteau S, Courteix D, Benhamou CL (2004) Cortical and trabecular bone at the forearm show different adaptation patterns in response to tennis playing. J Clin Densitom 7:399–405
10. Schlenker RA, Von Seggen WW (1976) The distribution of cortical and trabecular bone mass along the lengths of the radius and ulna and the implications for in vivo bone mass measurements. Calcif Tissue Int 20:41–52
11. Ducher G, Tournaire N, Meddahi-Pelle A, Benhamou CL, Courteix D (2006) Short-term and long-term site-specific effects of tennis playing on trabecular and cortical bone at the distal radius. J Bone Miner Metab 24:484–490
12. Dowthwaite JN, Flowers PP, Spadaro JA, Scerpella TA (2006) Bone geometry, density, and strength indices of the distal radius reflect loading via childhood gymnastic activity. J Clin Densitom 10(1):65–67. https://doi.org/10.1016/j.jocd.2006.10.003
13. Faulkner KG, McClung MR, Schmeer MS, Roberts LA, Gaither KW (1994) Densitometry of the radius using single and dual energy absorptiometry. Calcif Tissue Int 54(3):208–211. https://doi.org/10.1007/BF00301680
14. Who scientific group on the assessment of osteoporosis at primary health care level. Summary Meeting Report. Brussels, Belgium, 5–7 May 2004. http://www.who.int/chp/topics/Osteoporosis.pdf
15. Evans AL, Paggiosi MA, Eastell R, Walsh JS (2015) Bone density, microstructure and strength in obese and normal weight men and women in younger and older adulthood. J Bone Miner Res 30(5):920–928. https://doi.org/10.1002/jbmr.2407
16. Arruda M, Coelho MC, Moraes AB, de Paula Paranhos-Neto F, Madeira M, Farias ML, Vieira Neto L (2016) Bone mineral density and microarchitecture in patients with autosomal dominant osteopetrosis: a report of two cases. J Bone Min Res 31(3):657–662. https://doi.org/10.1002/jbmr.2715
17. Genant HK, Yebin Jiang J (2006) Imaging assessment of bone quality in osteoporosis. Clin Rev Bone Miner Metab 4(3):213–224
18. Nieto L, Moratal D, Martí-Bonmatí L, Alberich Á, Galant J (2008) Caracterización morfológica de la estructura trabecular ósea mediante resonancia magnética de alta resolución. Radiología 50:401–408
19. Licata AA (2015) Challenges of estimating fracture risk with DXA: changing concepts about bone strength and bone density. Aerosp Med Hum Perform 86(7):628–632. https://doi.org/10.3357/AMHP.4208.2015
20. Eckstein F, Kuhn V, Lochmüller EM (2004) Strength prediction of the distal radius by bone densitometry-evaluation using biomechanical tests. Ann Biomed Eng 32(3):487–503
21. Rausch S, Klos K, Gras F, Skulev HK, Popp A, Hofmann GO, Mückley T (2013) Utility of the cortical thickness of the distal radius as a predictor of distal-radius bone density. Arch Trauma Res 2(1):11–15. https://doi.org/10.5812/atr.10687
22. Aguado-Henche S, Bosch-Martín A, Spottorno-Rubio P, Rodríguez-Torres R (2012) Internal design of the dry human Ulna by DXA. Dual Energy X-Ray Absorptiometry. Published by InTech-Open Access Publisher, ISBN: 978-953-307-877-9, January 2012, pp 97–103
23. Gomez Pellico L, Morante Martínez P, Dankloff Mora C (1993) Definición densitométrica de la morfología estructural de huesos del esqueleto humano. Form Méd Contin XLV(1050):637
24. Fernández Camacho FJ, Morante Martínez P, Rodríguez Torres R, Cortés García A, Gómez Pellico L (1996) Densitometric analysis of the human calcaneus. J Anat 189:205–209
25. Sanchis Moysi J, Dorado C, Vicente-Rodriguez G, Milutinovic L, Garces GL, Calbet JA (2004) Inter-arm asymmetry in bone mineral content and bone area in postmenopausal recreational tennis players. Maturitas 48(3):289–298. https://doi.org/10.1016/j.maturitas.2004.03.008
26. Sanchis Moysi J, Vicente-Rodriguez G, Serrano JA, Calbet JAL, Dorado C (2003) The effect of tennis participation on bone mass is better retained in male than female master tennis players. In: Kahn J-F, Lees A, Maynard I (eds) Science and racket sports III. Routledge, London
27. Haapasalo H, Kontulainen S, Sievanen H, Kannus P, Järvinen M, Vuori I (2000) Exercise-induced bone gain is due to enlargement in bone size without a change in volumetric bone density: a peripheral quantitative computed tomography study of the upper arms of male tennis players. Bone 27(3):351–357
28. Bass SL, Saxon L, Daly RM, Turner CH, Robling AG, Seeman E, Stuckey S (2002) The effect of mechanical loading on the size and shape of bone in pre-, peri-, and postpubertal girls: a study in tennis players. J Bone Miner Res 17:2274–2280
29. Kontulainen S, Sievänen H, Kannus P, Pasanen M, Vuori I (2002) Effect of long-term impact-loading on mass, size, and estimated strength of humerus and radius of female racquet-sports players: a peripheral quantitative computed tomography study between young and old starters and controls. J Bone Miner Res 17:2281–2289
30. Nara-Ashizawa N, Liu LJ, Higuchi T, Tokuyama K, Hayashi K, Shirasaki Y, Amagai H, Saitoh S (2002) Paradoxical adaptation of mature radius to unilateral use in tennis playing. Bone 30(4):619–623

31. Ashizawa N, Nonaka K, Michikami S, Mizuki T, Amagai H, Tokuyama K, Suzuki M (1999) Tomographical description of tennis-loaded radius: reciprocal relation between bone size and volumetric BMD. J Appl Physiol 86(4):1347–1351. https://doi.org/10.1152/jappl.1999.86.4.1347
32. Aguado-Henche S, Clemente de Arriba C, Carrascosa-Sánchez J (2015) Densitometric analysis of the human ulna. Int J Morphol 33(3):902–907
33. Ammann P, Rizzoli R (2003) Bone strength and its determinants. Osteoporos Int 14(Suppl 3):S13–S18. https://doi.org/10.1007/s00198-002-1345-4
34. Anatomia G (1992) Williams & Warwick. Tomo 1. Churchill Livingstone, Edinburgh
35. Serrano de la Cruz Fernández MJ (2008) Fracturas distales de radio. Clasificación. Tratamiento conservador. Rev Esp Cir Osteoartic 46(236):141–154
36. Schalamon J, Dampf S, Singer G, Ainoedhofer H, Petnehazy T, Hoellwarth M, Saxena AK (2011) Evaluation of fractures in children and adolescents in a level I Trauma Center in Austria. J Trauma 71(2):E19–E25. https://doi.org/10.1097/TA.0b013e3181f8a903