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Comparison of radiographic bone density measurements of the radius in dogs using 6063 and 6351 aluminum scales

Comparação da densiometria óssea radiográfica do rádio de cães com escalímetros de alumínio 6063 e 6351

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Abstract: The measurement of bone mineral densitometry (BMD) is an analytical method used to aid in the identification of bone tissue alterations, such as osteoporosis. Thus, the present study aims to evaluate the correlation index between radiographic bone densitometry using aluminum step wedges 6063 and 6351 ABNT. In this manner, the quantification of bone mineral content in this study was performed with five simple digital radiographs of five dry bones (radii) from healthy adult male and female dogs, along with the aluminum reference scales. These radiographs were digitized and analyzed using ImageJ software version 1.54f, which compares the grayscale shades of the ultra-distal epiphysis of the radius with the pixel intensity of the step wedges, with values expressed in millimeters of aluminum (mmAl). The study demonstrated that as the thickness of the anatomical piece increased, the density and absorption of radiation also increased. A perfect correlation ($r = 0.9999$ with $p < 0.01$) was observed between the values of the two step wedges, making it feasible to use aluminum alloys 6351 and 6063 as densitometric references for the determination of radiographic bone mineral density (rBMD).

Key-words: dogs; bone mineral density; radiology

Resumo: A mensuração da densiometria mineral óssea (DMO) trata-se de um método de análise para auxiliar a identificação de alterações do tecido ósseo, como a osteoporose. Assim, o presente estudo tem como objetivo avaliar o índice de correlação entre a densiometria óssea radiográfica a partir da utilização de escalímetros de alumínio 6063 e 6351 ABNT**.** Dessa forma, a quantificação da matéria mineral óssea neste trabalho foi realizada com cinco radiografias simples digitais de cinco ossos secos (rádios) de cães hígidos, adultos, machos e fêmeas, juntamente com as escalas de referência em alumínio. Estas radiografias foram digitalizadas e analisadas através do programa ImageJ versão 1.54f, no qual compara tonalidades de cinza da epífise ultra distal do rádio com a intensidade de pixel da escala, tendo valores expressos em milímetros de alumínio (mmAl). O estudo demonstrou que à medida que a espessura da peça anatômica aumentava, a densidade e absorção da radiação também aumentavam. Observou-se correlação perfeita ($r = 0,9999$ com $p < 0,01$) entre os valores dos dois escalímetros, o que torna possível a utilização da liga de alumínio 6351 e 6063 como referenciais densitométricos para a determinação da densidade mineral óssea radiográfica (DMOR).

Palavras-chave: cães; densidade mineral óssea; radiologia

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1. Introduction

Veterinarians frequently use radiographic examinations to diagnose various conditions. Radiography is a quick, noninvasive, and cost-effective method for obtaining essential information(1). However, simple radiographs can only detect bone tissue loss when there is more than 30% depletion of bone mineral content. Bone mineral density (BMD), measured by the ratio of bone mass to area, is crucial in evaluating bone mineralization, as bone tissue supports skeletal muscles, protects soft tissues and vital organs, and contains bone marrow(2).

As companion animals have lived longer, there is an increasing need for techniques to detect bone diseases, such as osteoporosis. This condition stems from protein malnutrition and aging, leading to reduced osteoid tissue production and decreased bone mass(3). Quantitative BMD measurement is the most common method for diagnosing osteoporosis, as it identifies bone demineralization(4).

Additional techniques for measuring BDM include ultrasonography(5), quantitative computed tomography (QCT), single (SPA) or dual photon absorptiometry (DPA)(6), and neutron activation analysis (NAA)(7). However, these methods are time-consuming, require the animal to stay still, and cause significant radiation exposure. Therefore, the gold standard for quantitative BMD measurement is dual-energy X-ray absorptiometry (DEXA)(8).

Although BMD measurement is an important diagnostic tool in animals, the high equipment expense limits its routine clinical use(7). Alternatively, analyzing optical density in radiographic images is an accurate, easy-to-perform, and low-cost method(9). Previous studies used radiopaque step wedges made of 6063 aluminum alloy. This study aimed to assess the correlation between radiographic bone density measurements using aluminum radiopaque step wedges classified as 6063 and 6351 by the Brazilian Association of Technical Standards (ABNT).

2. Material and methods

This study was approved by the Committee on Animal Research and Ethics (CARE) at the Federal University of Jataí (UFJ), under protocol no. MB 002/2023. All experimental procedures were conducted according to current ethical standards.

The sample consisted of five dry radii from adult male and female dogs with no history of metabolic disease or musculoskeletal illness. The bones were provided by the Department of Veterinary Anatomy at UFJ, Jataí, GO, Brazil. Each bone had five craniocaudal digital radiographs taken with two radiopaque step wedges placed close to, but not in contact with, the bones. One step wedge was made of the ABNT 6063 aluminum alloy, composed of 97.90% aluminum, 0.90% magnesium, 0.35% iron, 0.1% copper, 0.60% silicon, and 0.15% other chemical elements, with a density of 2.71 g/cm^3.

The other was made of the ABNT 6351 aluminum alloy, composed of 97.45% aluminum, 0.80% magnesium, 0.50% iron, 0.1% copper, 1.30% silicon, and 0.15% other chemical elements, also with a density of 2.71 g/cm^3. Both radiopaque step wedges measured 12 x 55 mm and had 11 graduations of 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 5.0, 6.0, 7.0, 8.0, and 9.0 mm (Figure 1).

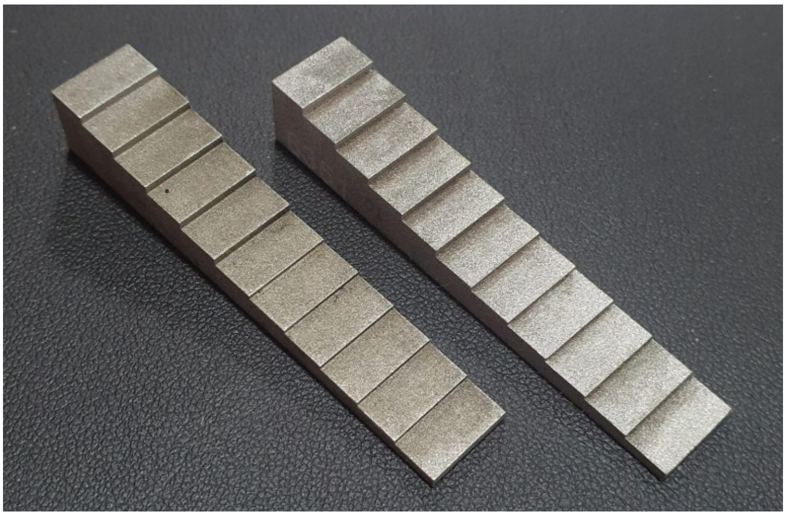

Figure 1. Aluminum step wedges used for the determination of radiographic densitometry of dry bones (radii) obtained from adult male and female dogs, with no history of metabolic disease or musculoskeletal disorders, sourced from the veterinary anatomy department of the Federal University of Jataí – Goiás – Brazil.

The radiographs were acquired using the Diafix X-ray equipment (500 milliampere-seconds (mAs) and 125 kilovolts (kV)) with a Regius Cassette RC-300 and phosphor plate, a Regius Sigma reader, and the ImagePilot software version 1.70 for digitization. The exposure was set at 40 KV, 30 mAs, with a focus-film distance of 95 cm for all tests.

Pixel intensities (PI) of the eleven scale graduations and the ultra-distal regions of each specimen were measured using the the RadiAnt DICOM Viewer software (https://www.radiantviewer.com) and with the histogram tool in the ImageJ software version 1.54f, with 8-bit image processing (256 shades of gray) (Figure 2). Mean PI values were calculated for all regions analyzed.

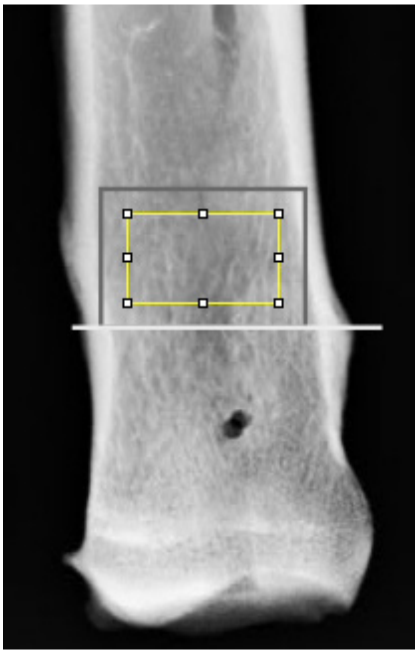

Figure 2. Radiograph of the selected bone region of the ultra-distal epiphysis of a canine radius in craniocaudal projection.

The Pearson's correlation coefficient was used to compare PI values between the 6063 and 6351 step wedges. The results were interpreted as: r = 0, no correlation; 0 < r ≤ 0.2, very poor correlation; 0.2 < r ≤ 0.4, poor correlation; 0.4 < r ≤ 0.6, moderate correlation; 0.6 < r ≤ 0.8, good correlation; 0.8 < r < 1, very good correlation; and r = 1, perfect correlation[11]. Radiographic BMD (rBMD) was determined using quadratic equations. The PIs of the ultra-distal radii were then compared with those of the 6063 and 6351 step wedges and expressed as mmAl6063 and mmAl6351. Results in mmAl 6063 and mmAl6351 were compared between specimen regions using analysis of variance followed by the Tukey test. All statistical analyses, including quadratic equations and correlation coefficients, were implemented using the R software (R Core Team, 2023).

3. Results and discussion

The same radiopaque step wedges (ABNT 6063 and 6351) were used for all the five X-rays. As the height of the graduations increased, the mean shade of gray values also increased (Table 1). These results are consistent with findings from other authors[10].

Table 1. **Results of the average pixel intensity of the steps of the aluminum step wedges 6063 and 6351 ABNT.**

Steps		Average Pixel Intensity	
Sequence	**Height (mm)**	**Aluminum Step Wedge 6063**	**Aluminum Step Wedge 6351**
Step 1	1.5	56.29	51.27
Step 2	2.0	70.26	66.58
Step 3	2.5	89.05	85.42
Step 4	3.0	109.49	106.14
Step 5	3.5	131.00	128.03
Step 6	4.0	150.52	148.48
Step 7	5.0	181.39	182.16
Step 8	6.0	201.97	203.89
Step 9	7.0	216.75	218.91
Step 10	8.0	228.48	230.24
Step 11	9.0	237.94	239.47

The coefficient of variation used for statistical analysis is a recognized method for analyzing the reproducibility of bone measurements[11,12]. This study determined rBMD using a technique based on x-radiation, which produced a two-dimensional image of a three-dimensional structure formed from radiation absorption by the analyzed tissue. Greater specimen density and thickness resulted in greater radiation absorption, meaning that the amount of X-rays received at each pixel of the device sensor formed a gray tone equivalent to the attenuation occurring[13]. In clinical practice, rBMD does not account for the attenuation caused by soft tissues. However, this experiment analyzed dry bones, with no interference from soft tissues.

The optical density analysis of radiographic images using aluminum radiopaque step wedges is less accurate for determining BMD than the gold standard test (DEXA). However, it can serve as a good screening test at a lower cost for the clients[14]. Although most authors hae reported using 6063 aluminum step wedges as the standard for measuring rBMD [7,15,16], the correlation between PIs obtained with ABNT 6063 and 6351 step wedges was perfect (r = 0.9999, p < 0.01) (Figure 4). This indicates that rBMD can be measured with an aluminum alloy other than ABNT 6063, expanding the options for rBMD measurement without compromising accuracy.

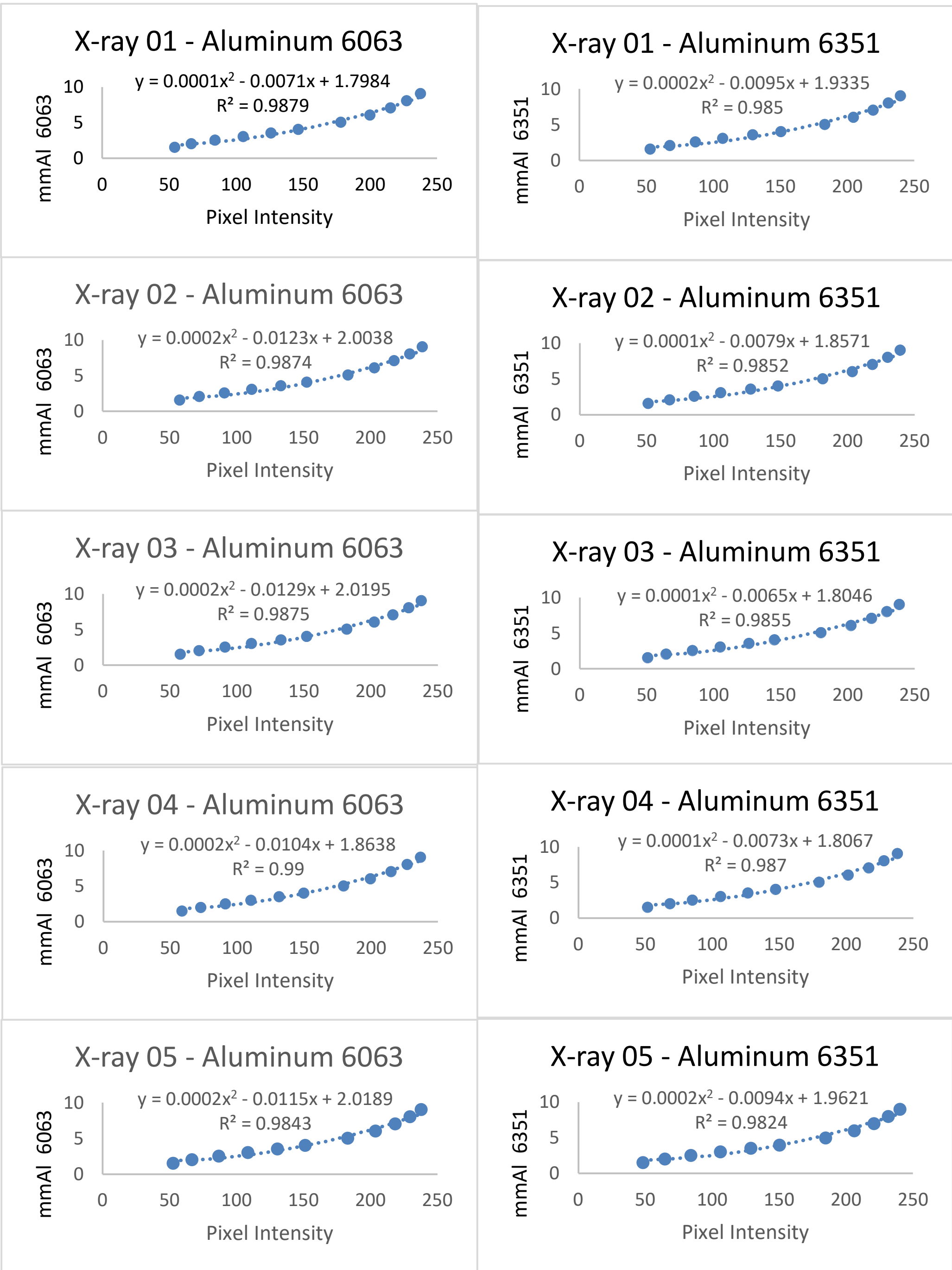

Figure 4. Results of the pixel intensity of the steps of aluminum scales 6063 ABNT and 6351 ABNT, measured in five simple digital radiographs.

Radiographic BMD results for the ultra-distal regions of the radii (Tables 2 and 3) were obtained with quadratic equations[17], allowing us to compare the PIs of each region in mmAl6063 and mmAl6351. Analysis of variance followed by Tukey's test showed no statistical difference between results from different bones across the five radiographs. This finding is confirmed by other studies[18,19,20,21], demonstrating that the rBMD technique has adequate sensitivity and accuracy for measuring BMD.

Table 2. Pixel density values from digital radiographic examinations of the ultra-distal extremities of canine radii, expressed in millimeters of aluminum 6063 (mmAl) based on the application of quadratic linear regression.

	Aluminum Step Wedge 6063				
	X-ray 1	**X-ray 2**	**X-ray 3**	**X-ray 4**	**X-ray 5**
Bone A	5.070 mmAl	5.026 mmAl	2.694 mmAl	5.190 mmAl	5.107 mmAl
Bone B	4.593 mmAl	3.748 mmAl	3.807 mmAl	3.980 mmAl	3.896 mmAl
Bone C	4.226 mmAl	4.008 mmAl	4.046 mmAl	4.204 mmAl	4.161 mmAl
Bone D	3.966 mmAl	3.755 mmAl	3.697 mmAl	3.867 mmAl	3.807 mmAl
Bone E	3.025 mmAl	2.698 mmAl	2.661 mmAl	2.692 mmAl	2.628 mmAl

Table 3. Pixel density values from digital radiographic examinations of the ultra-distal extremities of canine radii, expressed in millimeters of aluminum 6351 (mmAl) based on the application of quadratic linear regression.

	Aluminum Step Wedge 6351				
	X-ray 1	**X-ray 2**	**X-ray 3**	**X-ray 4**	**X-ray 5**
Bone A	4.902 mmAl	5.110 mmAl	2.875 mmAl	5.215 mmAl	5.073 mmAl
Bone B	4.438 mmAl	3.871 mmAl	3.983 mmAl	4.054 mmAl	3.907 mmAl
Bone C	4.082 mmAl	4.125 mmAl	4.215 mmAl	4.270 mmAl	4.163 mmAl
Bone D	3.830 mmAl	3.878 mmAl	3.876 mmAl	3.944 mmAl	3.821 mmAl
Bone E	2.929 mmAl	2.825 mmAl	2.841 mmAl	2.795 mmAl	2.670 mmAl

4. Conclusion

Our experimental results demonstrated that aluminum alloy 6351 is a viable alternative for determining BMD and can effectively replace aluminum alloy 6063 as a densitometric reference. In the future, further clinical studies to confirm the practical applicability of the 6351 aluminum alloy are warranted.

Conflict of Interest Statement

The authors declare no conflicts of interest.

Author contribution

Conceptualization: T. A. C. Costa; Project administration: T. A. C. Costa; Validation: E. Arnhold and V. A. S. Vulcani; Methodology: C. A. P. Fontana; Writing (original draft): I. G. Nogueira; Writing (review & editing): T. A. C. Costa

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