Journal of Equine Veterinary Science 33 (2013) 1131–1135

Contents lists available at SciVerse ScienceDirect

Journal of Equine Veterinary Science

journal homepage: www.j-evs.com

Original Research

Radiographic Calibration for Analysis of Bone Mineral Density of the Equine Third Metacarpal Bone

Amber J. Bowen MS [a,*], Mathew A. Burd MS, DVM [a], John J. Craig PhD [b], Monique Craig [b]

[a] Department of Animal Science, California Polytechnic State University, San Luis Obispo, CA
[b] EponaTech Inc., Creston, CA

ARTICLE INFO

Article history:
Received 25 January 2013
Received in revised form
16 April 2013
Accepted 24 April 2013
Available online 22 June 2013

Keywords:
Radiographic absorptiometry
Digital
Bone mineral
Density

ABSTRACT

Digital radiography represents the primary diagnostic tool the veterinarian uses to diagnose skeletal injuries in the horse. Advances in digital radiography have provided the veterinarian with opportunities to make simple radiographic assessments from calibrated digital radiographs such as dimensional analyses; however, more complex variables such as radiographic opacity have yet to be standardized. Therefore, we investigated the quantification of bone mineral density (BMD) via computed radiographic absorptiometry at various radiographic exposure intensities (kV), times (sec), and milliamps (mA) in the third metacarpal in the horse. By developing a brightness/darkness index (BDI), the grayscale of radiographs, calibrated with an aluminum (Al) marker of various known thicknesses and uniform densities, can be compared to the average BMD of a region of interest at various radiographic exposures. Al BDI was a significant predictor of bone BDI ($r^2 = 0.960$, $P < .001$) and BMD ($r^2 = 0.971$, $P < .001$). This method of calibration can be used for quantitative noninvasive bone mineral analysis and allows direct comparison of radiographs taken under different exposure settings.

1. Introduction

Dual energy x-ray absorptiometry (DEXA) is the most precise, accurate, and widely accepted method of measuring bone mineral density (BMD) for assessment of skeletal integrity and fracture risk in humans [1]. In horses, DEXA analyses show BMD, measured in g/cm^2, to be a valid predictor of bone strength [2], exercise-induced bone remodeling in young horses [3-5], and risk for fracture development [6-8]. Unfortunately, the generalized use of DEXA has limited use for equine practitioners as it is expensive, time consuming, and not portable. Radiography and particularly digital and computed radiography represent the primary diagnostic tools the veterinarian uses to diagnose skeletal injuries in the horse. Radiographic absorptiometry and computed digital absorptiometry (CDA) using a single-energy X-ray system has been shown to accurately assess BMD in humans [9,10] and horses [11]. Inclusion of aluminum (Al) markers of various known thicknesses and uniform densities, the grayscale of a region of interest (ROI), termed the brightness/darkness index (BDI), may be calibrated from image to image. The BDI of bone measured from a radiographic ROI can then be related to average BMD, dependent on thickness. However, opacity determined from radiographs taken with different radiographic techniques cannot be directly compared. Calibration of radiographic opacity with various radiographic exposure intensities (kV), times (sec), and milliamps (mA) would allow for quantification of BMD, assuming that the area measured includes minimal soft tissue and has consistent thickness and attenuation properties.

Digital radiography has the advantage of being portable, relatively inexpensive, and practical in a field setting. By using CDA techniques, digital radiography may be used to

* Corresponding author at: Amber J. Bowen, MS, University of California, Davis, School of Veterinary Medicine, Davis, CA 95616.
E-mail address: ajbowen@ucdavis.edu (A.J. Bowen).

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http://dx.doi.org/10.1016/j.jevs.2013.04.016

determine BMD. Therefore, our objective was to develop a method to calibrate radiographic images such that BMD determined from radiographs taken with different techniques could be accurately compared. By calibrating the BDI of digital radiographs, we formed a standardized relationship allowing comparison of computer-determined BDI values with physical properties of BMD regardless of radiographic settings of exposure intensity (kV) and time (sec). This would allow us to account for changes in the opacity of radiographs due to changes in exposure, affording standardization of any radiograph. By including an Al wedge of known density and thickness (g/cm^2) in the radiograph, BMD can be determined from BDI by creating a standard curve. Next, BMD can be correlated with BDI by creating a bone step-wedge of known density and thickness. We believe that calibration of digital radiographs to determine BMD from an Al wedge standard will provide a tool for quantification of BMD from common digital radiographs, regardless of radiographic technique.

2. Materials and Methods

Radiographs of a single third metacarpal equine cadaver bone and Al wedge taken at various exposures were used to determine the relationship between BDI and radiographic exposure for both bone and Al. Each radiograph contained an Auto-Scaler,[1] an Al wedge and cadaver bone. The Al wedge was simply machined from type 6061 Al and was 20.36 cm in length and 0.2-31.8 mm in thickness, with a constant density of 2.70 g/cm^3. The Auto-Scaler contained metal markers that standardized the dimensions of the radiographic image when imported into the software program Metron-DVM.[1] All radiographs were taken with a portable X-ray system[2] and X-ray sensor.[3] All radiographs were taken at 15 mA, the only setting available for this system. The cadaver bone was positioned perpendicular to the ground in the center of the line of exposure with the Al wedge and Auto-Scaler positioned on either side. The bone and X-ray system was placed to produce a standard dorsal palmar radiograph. The focal distance was 26 cm, with the plane of interest containing the cadaver bone, Al wedge, and Auto-Scaler positioned against the face of the sensor. Radiographs were taken at all available combinations of preset exposure intensities ranging from 55-80 kV in 5-kV intervals and exposure times from 0.02-0.14 seconds every 0.02 second.

The BDI of the Al wedge and cadaver bone was measured on each radiographic image (Fig. 1). To determine BDI, a unitless value was assigned to each 16-bit pixel on a grayscale from 0-65,500, with zero being completely black and 65,500 being completely white. A predetermined ROI on either bone or Al was generated by forming a rectangle using Metron-DVM software.[1] BDI was determined by averaging the grayscale value of each pixel in the ROI. In determining BDI, we did not include background pixels. BDI of the Al wedge was measured by creating a rectangle

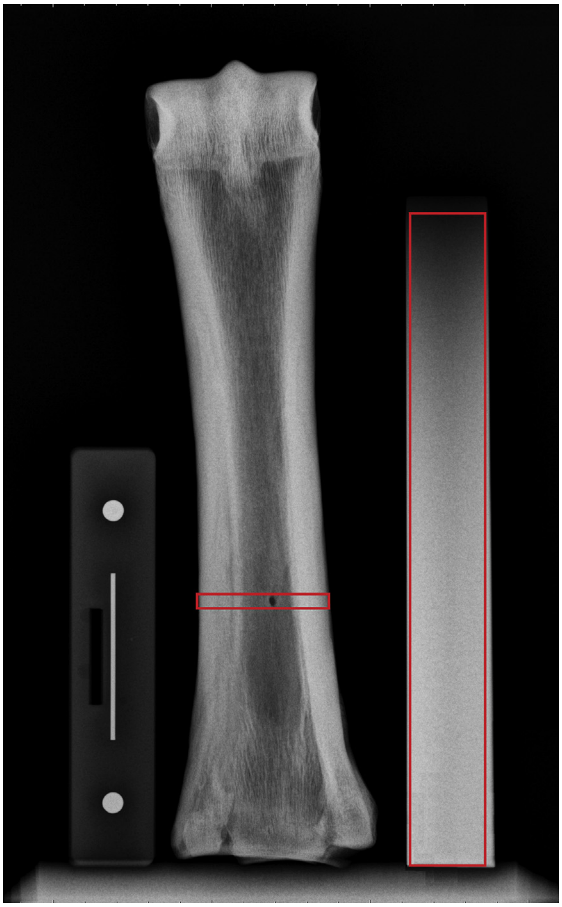

Fig. 1. Dorsal palmar radiograph of third metacarpal cadaver bone with Auto-Scaler (left) and Al wedge (right), taken at 60 kV, 0.08 seconds, and 15 mA. ROIs (red) were selected for measuring bone BDI at the nutrient foramen and Al BDI from an Al wedge.

encompassing the entire wedge. BDI of the cadaver bone was characterized by an ROI with the width larger than the cross-sectional width of the bone perpendicular to the sagittal plane and the height equal to the diameter of the nutrient foramen. To ensure change in BDI was due solely to effects of radiographic exposure, the same ROI was used in each radiographic image. BDI of the Al wedge was compared to BDI of the cadaver bone in the same radiographic image at various X-ray intensities and exposure times to ensure the relationship between BDI and radiographic exposure was similar for both materials.

BMD was correlated with BDI by measuring BDI from a radiograph of cortical bone of known density and thickness, determined as g/cm^2. A bone step-wedge of known BMD was made from cortical bone obtained from a equine cadaver third metacarpal bone in the mid-diaphysis region. The cortical bone was cut into slices using a diamond blade tile saw. The average dimension of each slice was 15.28 $\pm$ 3.3 mm square and 4.23 $\pm$ 1.0 mm thick. A bone step-wedge was created by stacking each bone slice face-to-face in increasing thickness from one slice to 6 slices thick, consecutively, from step 1-10. The thickness, weight, and volume corresponding to each bone slice was determined

[1] EponaTech Inc., Creston, CA.
[2] MinXray HF80, Northbrook, IL.
[3] Thales FS23, Vetel Diagnostics, San Luis Obispo, CA.