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Research Article

Lumbosacral Biometrics and its Relevance to Patient-Specific Evaluation of Bone Mechanical Strength in Some Canine Breeds

Nicole Rosenberger, Erica De Capitani, Seamus Hoey, David Kilroy, Arun HS Kumar*

ABSTRACT
Lumbosacral problems are commonly encountered in canine practice. However, breed specific biometric data of the lumbosacral vertebrae are lacking. Such biometric data may be useful to assess the predisposition of an individual animal or breed to lumbosacral defects, or in the events of such defects may help select an optimal surgical correction strategy. This study used digital radiographs and dissections of cadavers to develop the following biometric parameters of lumbar vertebra 7 and the sacrum: Area-Mean Grey Value Ratio (AMR) and Height-Length Ratio (HLR). The AMR and HLR values were compared between the following four canine breed categories i.e., Working Breeds (WB), Large Breeds (LB), Giant Breeds (GB) and Cross Breeds (CB). Additionally, we compared the AMR and HLR values between 10 different dog breeds. We observed significant differences in the AMR and HLR values between the various dog breeds as well as the HLR values within the canine breed categories. We consider that the differences observed in the AMR and HLR values warrant exploring the feasibility of including these biometric measurements into digital imaging systems to enhance understanding of the mechanical features of bone.

Key words: Bone strength, Diagnostic imaging, Canine bone injuries.

INTRODUCTION

The canine vertebral column is normally organised into seven cervical vertebrae, thirteen thoracic vertebrae, seven lumbar vertebrae, fused sacral vertebrae and nine to twenty caudal/coccygeal vertebrae depending on the breed of dog.[1-3] This study examined the lumbar and sacral regions of the vertebral column. The canine lumbar vertebral column is made up of seven separate lumbar vertebrae, each consisting of a uniformly-shaped vertebral body, with long and flattened transverse processes that project cranially and ventrolaterally. The lumbar vertebrae have short spinous processes that project dorsally from the vertebral body. All seven lumbar vertebral bodies articulate using synovial joints at the articular process and by a thick, flexible two-part intervertebral disc, an outer annulus fibrosus (Containing multiple collagen fibres) and inner gelatinous nucleus pulposus that provide both support and shock-absorptive properties to the vertebral column.[1,3,4] The sacrum is formed by the fusion of three sacral vertebral bodies and processes (S1-S3), forming a single bone that aids in the transmission of the propulsive forces from the pelvic limbs to the vertebral column.[5] The sacrum is curved and narrows caudally, giving the pelvic cavity a concaved dorsal surface.[1,3,4] It articulates with the wings of the ilium via the sacroiliac joint. At its apex, the sacrum articulates with the first caudal vertebrae, while articulating with the last lumbar vertebrae (L7) at its base, forming a highly mobile synovial, lumbosacral joint. The mobility of the lumbar spine, coupled with the immobility of the sacrum, forms a transition zone at the joint, making it a possible point of weakness.[6-10] Subsequent stress that is placed on the joint and the lumbosacral intervertebral disc uniquely predisposes animals to degenerative diseases, comparable to those that cause lower back pain in humans.[6,10-14] Several large and giant breeds of dogs are prone to serious conditions affecting the lumbosacral region, with some breeds being more predisposed than others due to a combination of genetic and environmental factors; for example, hip dysplasia affecting German Shepherds, Labrador Retrievers and Golden Retrievers and Lumbosacral Stenosis affecting Boxers. In addition, the mobility of the lumbosacral joint and its function in force transmission makes L7 and the sacrum prone to fracture, frequently because of trauma to the area.[4,6,7,14,15] There have been several studies on the occurrence of transitional vertebrae in dogs and their relationship to sacroiliac morphology,[16-19] but little research on lumbosacral morphology. The aim of the study was, to investigate the canine breed-specific biometrics of lumbosacral anatomy using a radiographic and dissection-based approach.

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MATERIALS AND METHODS

In this retrospective study, radiographic images from 109 dogs obtained from the University College Dublin (UCD) Veterinary Hospital were examined. 10 breeds were selected from two of the main body size classes, i.e., for the large breeds (25-50kg), the Boxer, Labrador Retriever, Golden Retriever and German Shepard were chosen; for the giant breeds (> 50kg), the Rottweiler, Bernese Mountain Dog, Newfoundland and Saint Bernard were selected. As athletic/working breeds rarely succumb to lumbosacral conditions despite their level of activity, we also analysed data from two medium sized breeds (The Greyhound and Collie). Four Greyhound cadavers were dissected and lumbosacral parameters were measured. The tenth breed category consisted of cross breed dogs that were a combination of any of the previous nine breed categories. The Height-Length Ratio (HLR) and Area-Mean Ratio (AMR) of both the L7 vertebral body and Sacrum (S1-S3) was measured and analysed. The study was reviewed and approved by UCD-Animal Research Ethics Committee (Approval number: AREC-E-19-05-Kilroy).

Right Lateral (RL) and Ventro Dorsal (VD) radiographic views of the pelvic region were reviewed, measured and analysed from 109 suitable patients across 10 different breeds. The number of dogs per breed included in this study is shown in Table 1. DICOM images were downloaded and viewed using HOROS (DICOM Medical Image Viewer) software. Images in JPEG Format were saved after adjusting the resolution of each digital image to 72 Pixels/Inch (72 DPI). Using the NIH ImageJ Software, the images were analysed for L7 vertebral body and sacrum height on the RL view (Figure 1) and for L7 vertebral body and sacrum length on the VD view (Figure 2). Straight line and freehand selection tools were used for the measurements. The presence or absence of transitional vertebrae was also recorded. Although the dogs in this study varied in age, breed and sex, differences within the breeds were normalised using the ratio-metric approach during the data analysis. All results were recorded on a Microsoft Excel sheet and analysed for L7 vertebral body and sacrum Height-Length Ratio (HLR) and L7 vertebral body and sacrum Area-Mean Ratio (AMR). The height to length ratio signifies the available surface area on the bone for a unit length, i.e., the smaller the ratio, the higher will be the rectangularity of the bone. The area to mean grey value ratio signifies the relative density of the bone, i.e., the lower the ratio, the higher the bone density. The data from different dog breeds or breed categories (i.e, Working Breeds (WB), Large Breeds (LB), Giant Breeds (GB) and Cross Breeds (CB)) were statistically analysed using One-way ANOVA in Graph Pad PRISM software Version 5.

RESULTS

We first analysed the Area-Mean Ratio (AMR) and Height-Length Ratio (HLR) of L7 and the sacrum for each of the breed categories (Figure 3). The AMR of L7 and the sacrum and the HLR of the sacrum were similar among all the four categories of dog breeds (Figure 3 A, C and D). However, the HLR of L7 was significantly ($p<0.05$) higher in giant breeds compared to working or large breeds (Figure 3 B). We subsequently compared the data between different dog breeds (Figure 4). The AMR of the sacrum was similar among all the dog breeds evaluated in this study (Figure 4 C). In contrast, the AMR of L7 was significantly ($p<0.05$, 0.001) higher in the Greyhound compared to all the other breeds (Figure 4 A). The AMR of L7 was lowest in the Boxer (Figure 4 A). The HLR of L7 and the sacrum was significantly different among the dog breeds (Figure 4 B and D). It was observed that the Boxer and the Greyhound had the highest HLR of L7 and the sacrum respectively (Figure 4 B and D), while the Rottweiler and the Saint Bernard had the lowest HLR of L7 and the sacrum respectively. In addition to the inter-breed differences we also observed considerable intra-breed variations (Figure 5).

Table 1: Number of Dogs Per Breed Included in this Study Cohort.

Breed (Abbreviation)	Number of patients
Greyhound (Gho)	8
Collie (Col)	20
Boxer (Box)	5
Retriever (Labrador/Golden) (Ret)	15
German Shepherd (GSh)	12
Rottweiler (Rot)	22
Bernese Mountain Dog (Ber)	10
Newfoundland (New)	6
Saint Bernard (Sai)	4
Cross-breeds (Cro)	7

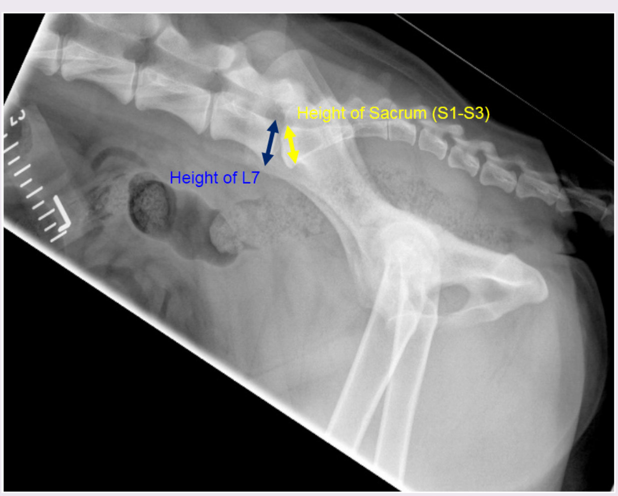

Figure 1: Right Lateral View of Canine Pelvis.

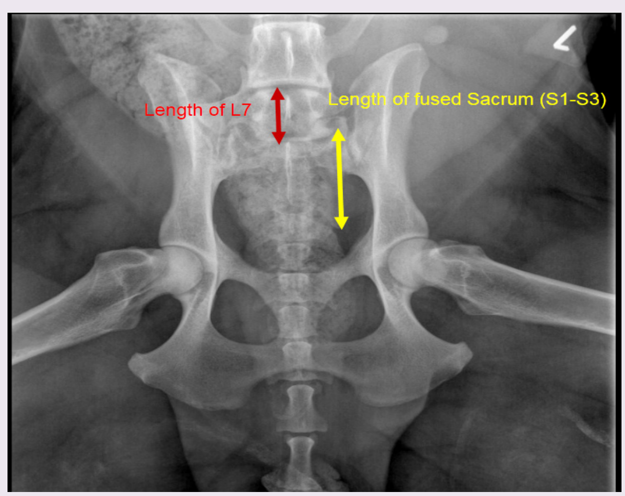

Figure 2: Ventrodorsal View of Canine Pelvis.

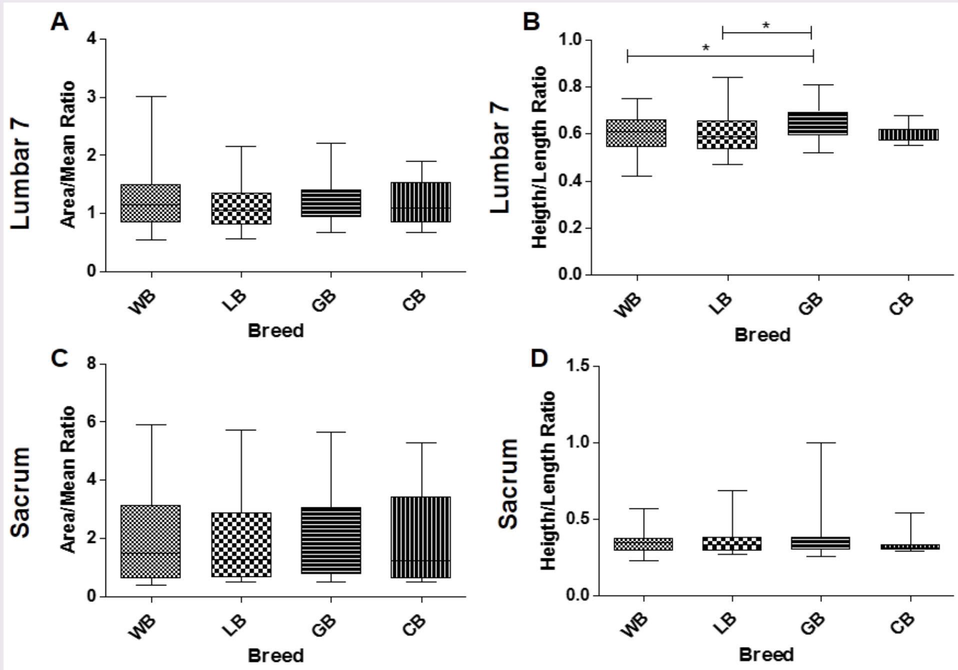

Figure 3: Area-Mean Grey Value Ratio (AMR) and Height-Length Ratio (HLR) of Lumbar 7 and Sacrum based on categories of canine breeds i.e., Working Breeds (WB), Large Breeds (LB), Giant Breeds (GB) and cross breeds (CB). *$p < 0.05$.

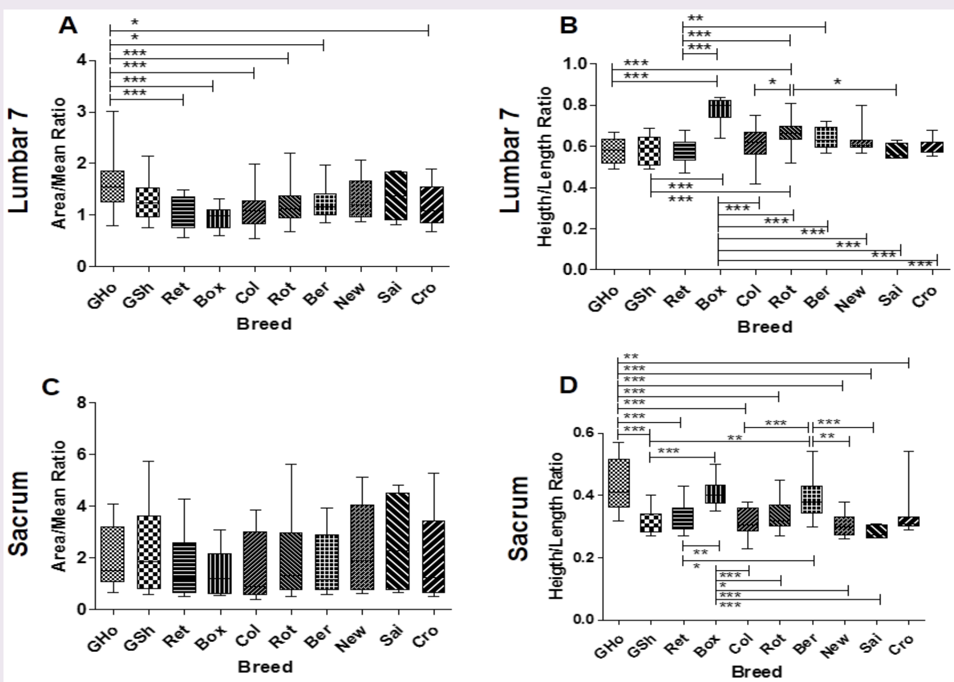

Figure 4: Area-Mean Grey Value Ratio (AMR) and Height-Length Ratio (HLR) of Lumbar 7 and Sacrum in various dog breeds. Greyhound (Gho), Collie (Col), Boxer (Box), Retriever (Labrador/Golden) (Ret), German Shepherd (GSh), Rottweiler (Rot), Bernese Mountain Dog (Ber), Newfoundland (New), Saint Bernard (Sai) and Cross-breeds (Cro). Data is presented as Mean ± SD of *n*=4-22. * $p<0.05$, **$p<0.01$, ***$p<0.001$.

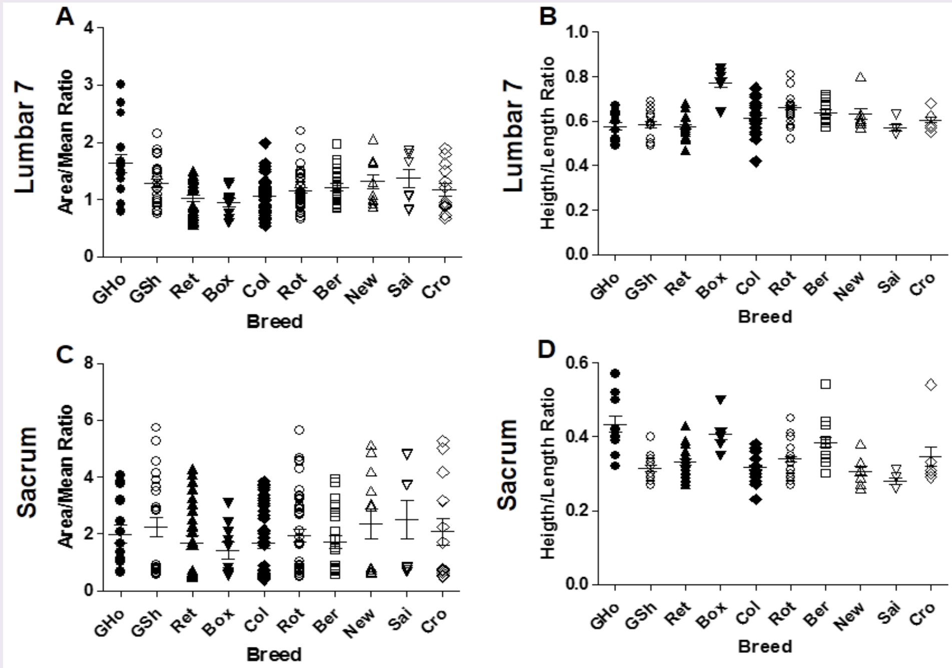

Figure 5: Area-Mean Grey Value Ratio (AMR) and Height-Length Ratio (HLR) of Lumbar 7 and Sacrum in various dog breeds. Greyhound (Gho), Collie (Col), Boxer (Box), Retriever (Labrador/Golden) (Ret), German Shepherd (GSh), Rottweiler (Rot), Bernese Mountain Dog (Ber), Newfoundland (New), Saint Bernard (Sai) and Cross-breeds (Cro). Individual data points are presented to show intra breed variations. *n*=4-22.

DISCUSSION

Although bone is a multicellular unit, its primary function is to offer mechanical load-bearing and provide anchorage to skeletal muscles.[3,6-8,13,17] It is imperative that bone is dynamically subjected to stress and strain mechanics.[9,10] Thus, each bone has an innate strain threshold, which when compromised will lead to fracture/s and bone deformity. Knowledge of the bone stress threshold is vital in preventing and treating bone defects. For instance, an objective measure of bone-stress-threshold can help predict animals which are prone to skeletal injuries and may also help the surgeons select the right surgical materials to provide optimal mechanical support in correcting bone defects.[4,20-22] In this study we evaluated two such objective measures of bone-stress-threshold i.e., AMR and HLR values. By normalising the bone density to its area, the AMR provides a measure of bone density that is independent of the age, sex or breed of the animal. Likewise, the HLR indicates the available surface area on the bone for a unit length and offers a vital index to assess the stress and strain mechanics. AMR and HLR together can be used to objectively measure the bone-stress-threshold of any bone.[9,10]

Trauma to the hindlimbs commonly occurs in dogs, with a typical sequel being fracture and/or luxation of the lumbosacral region.[23] While a large range of bone displacements can occur, a cranio-ventrally displaced sacral segment, along with an oblique caudo-ventral wedge fracture of the L7 vertebral body is most frequently observed.[24] Conservative management is often used successfully, with analgesia and strict rest being included in the regimen.[25] Surgical management is also an option, for example trans-ilial-pinning. Other techniques have also been described; in one study, attempts to stabilise an L7 fracture was done by placing two String-of-Pearls (SOP) locking plates in combination with bicortical screws to anchor the L6 vertebral body and the sacroiliac joint and ilial wing. Two screws per plate were placed in the vertebra cranial to the fracture site (i.e. In the vertebral body of L6) and two screws in the sacroiliac region, such that a total of eight cortices would be engaged during the stabilisation.[24] However the currently used treatment options are not selected based on objective parameters, hence we believe the AMR and HLR have the potential to be one such objective measure in making optimal treatment decisions.

When we analysed the data based on the breed categories, we observed a statistical difference only in the HLR of L7. The higher HLR among the giant breed of dogs may be indicative of higher risks of L7 deformities (Compression of spinal cord or nerve roots) in these breeds. The lack of statistical differences in the other parameters studied may not be entirely biological. It is likely that the sample size in our study was not sufficiently large to detect the potential biological differences between the various categories of dog breeds. Hence futures studies should look at AMR and HLR values in a larger sample size and by potentially employing artificial intelligence-based measurements in digital images.

We observed a considerable inter-breed variation in the HLR values of L7 and the sacrum and AMR values of L7. The lack of the breed differences in the AMR of the sacrum may be due to its fused nature,[4,14] which may lead to negligible differences in the density of this bone.[7,8] The AMR of L7 was highest in the Greyhound, suggesting that these breeds have the lowest L7 bone density, hence increasing their risk of developing lumbar problems.[6,7,16] As the bone density is low in this breed, wiring rather than plates/screws can be a better approach for surgical corrections of lumbar fractures.[11] A lower HLR of L7 in Greyhounds, suggesting that the available surface area for a given height of the bone is large in this species, further supports a lower mechanical ability of L7 in Greyhounds to hold plates/screws. In contrast to Greyhounds, the Boxer had the least AMR and the highest HLR of L7, indicating a higher bone density and a stronger mechanical support offered by L7 in Boxers to hold plates/screws.

Hence fracture of L7 in the Boxer can be preferentially corrected using plates/screws rather than wiring.[11]

We also observed that the pattern of HLR between L7 and the sacrum of various breeds was different. For instance, the Saint Bernard and Newfoundland had the lowest HLR of the sacrum, but not L7. This observation suggests that some breeds have a mismatch in the mechanical properties of L7 and the sacrum and it remains to be seen if such a mismatch may be responsible for the higher incidence of lumbosacral defects.[1,6,9,11-13,16,19] In addition to inter-breed differences, we also observed significant intra-breed variations in the AMR and HLR of L7 and the sacrum. Although this study wasn't adequately powered to assess the intra-breed variations, it is nevertheless interesting to evaluate if AMR and HLR of L7 and the sacrum would prove to be valuable in assessing bone mechanical properties of an individual patient. The benefits of objectively assessing bone mechanical properties of an individual patient are many, including 1) Prognostic evaluation of the patient prone to musculoskeletal defects 2) Selection of optimal surgical tools or strategies for correcting fractures and 3) Prediction of the success of orthopaedic procedures. With the advancement in artificial intelligence tools,[1,4,20,22] the measurement of AMR and HLR may be built into digital imaging systems to enhance understanding of the mechanical features of bone and to help in making point-of-care decisions in orthopaedic procedures.

CONFLICT OF INTEREST

The authors declear no conflict of interest.

ABBREVIATIONS

AMR: Area-Mean Grey Value Ratio; **HLR:** Height-Length Ratio; **WB:** Working Breeds; **LB:** Large Breeds; **GB:** Giant Breeds; **CB:** Cross Breeds; **L7:** lumbar vertebra 7; **RL:** Right Lateral; **VD:** Ventro Dorsal.

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