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Author(s)	Kim, Byung-ju; Yoon, Jang-won; Lee, Hae-beom
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Evaluation of Hindlimb Mechanical Axis by Using Single-Plane Fluoroscopy in Beagle Dogs

Byung-ju Kim ^{†)}, Jang-won Yoon ^{†)} and Hae-beom Lee ^{*})

College of Veterinary Medicine, Chungnam National University, Daejeon 34134, Korea

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Abstract

The mechanical axis has been used as the basis for alignment evaluations in human practice. Many studies have been conducted on the mechanical axis in humans, but there are not many studies that have investigated this in the field of veterinary medicine. The current study compared the values of the mechanical axis of the hindlimb from a stance phase, which is the normal weight-bearing walking posture, to the dorsal recumbent position, without any weight bearing, in beagle dogs. Fluoroscopic images of stifle joints were obtained by using single-plane fluoroscopy during stance phase in 5 healthy beagle dogs. Computed tomography was used to construct a 3D bone model of the hindlimb, and the mechanical axis of the hindlimb was measured after using the shape-matching technique. The mechanical axis of the hindlimb was also measured with X-ray which were taken in the conventional stretched out leg position in dorsal recumbency. The mechanical lateral proximal femoral angle (mLPFA), mechanical lateral distal femoral angle (mLDFA), mechanical medial proximal tibial angle (mMPTA) and mechanical medial distal tibial angle (mMDTA) were measured in both methods. Comparison between the weight bearing stance phase and the non-weight bearing recumbent position, showed significant differences in mLPFA and mLDFA. Differences between the two methods were demonstrated and suggested that measuring the mechanical axis in a natural standing posture of a dog should be considered correct for a more accurate measurement. This data should be utilized as a reference value for surgery of pelvic limb deformity in beagle dogs.

Key Words: beagle dogs, femoral angle, mechanical axis, single-plane fluoroscopy, stance phase

Introduction

Angular limb deformity causes unequal force distribution which results in joint malalignment, osteoarthritis, lameness, and pain^{5,10,21}. Normal limb alignment helps in equal distribution of forces transmitted through the soft-tissue envelope. This equal distribution is crucial in the

proper function of joints³. Recognizing normal limb alignment is important for diagnosis, surgical planning, treatment and prognosis of canine limb deformities^{4,10}.

Limb alignment is evaluated by the mechanical axis and anatomic axis³. The mechanical axis of the pelvic limb is a straight line connecting the center points of the proximal and distal joints^{3,5,7}.

[†]The first two authors contributed equally to this work.

^{*}Corresponding author: Hae Beom Lee, College of Veterinary Medicine, Chungnam National University, 99, Daehak-ro, Yuseong-gu, Daejeon 34134, Korea
Phone: +82-42-821-6757. Fax: +82-42-821-8903. E-mail: seatiger76@cnu.ac.kr
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The pelvic mechanical axis can be subdivided into the femoral mechanical axis and tibial mechanical axis. The femoral mechanical axis is a line connecting the center of the femoral head to the center of the intercondylar notch. The tibial mechanical axis connects the center of the intercondylar notch of the femur to the center of the distal intermediate tibial ridge^{4,12,20}.

The anatomic axis of the pelvic limb is correlated to the intramedullary canals^{3,12,20}. The anatomic axis of the femur is a line created by connecting the proximal and distal intramedullary canals, dividing the femur in half. The anatomic axis of the tibia is created by the same method on the tibial bone^{3,12,20}.

The mechanical axis has advantages over preoperative planning and postoperative evaluation because it can accurately determine the weight-bearing axis of the bone compared to the anatomic axis^{3,9}. Another advantage of the mechanical axis over the anatomical axis is that it is a more accurate value to measure in case of hindlimb deformities because it is always a straight line³. Therefore, during preoperative and postoperative radiologic planning, the mechanical axis has been used as the basis for alignment evaluations in human practice^{2,16,17,19}.

Many studies have been conducted on the mechanical axis in humans, but not much has been investigated in the field of veterinary medicine. When measuring the mechanical axis in human medicine, it is performed in a standing posture that is weight-bearing^{19,21}. Because measuring the mechanical axis in weight bearing conditions in dogs is difficult due to their quadrupedal nature and requiring high levels of cooperation from the dogs, their mechanical axis values are measured in dorsal recumbency, without any weight bearing, while the legs are extended.

It is doubtful whether this is an accurate way of obtaining the mechanical axis value since this posture is not a weight-bearing posture in dogs. In human research, the experimental results show that the weight-bearing state is different

from the non-weight bearing state and weight bearing radiography is the gold standard method for measuring limb alignment^{9,15,21}. Therefore, a more accurate value of the mechanical axis would be obtained at a stance phase during normal gait, since this is the normal weight bearing posture.

The main objective of this study was to calculate and compare the values of the mechanical axis of the pelvic limb from a stance phase, which is the normal weight-bearing posture of a dog, to that of the conventionally used stretched out leg position in dorsal recumbency. One of the main reasons for studying the pelvic limb alignment is the high percentage of orthopedic diseases such as cranial cruciate ligament rupture and medial patella luxation.

We hypothesized that there is a difference between the conventional measurement method and the mechanical axis value at the stance phase, which is the normal weight-bearing posture of a dog.

Materials and Methods

Animals: This study was approved by Chungnam National University Animal Care and Use Committee (No. CNU-00838). 5 beagle dogs between the ages of 4 and 6 years (mean age of 4.6 years) were used for this study. All dogs weighed between 9.2 to 11.2 kg (mean body weight of 10.1 kg) and body condition scores (BCS) ranged from 4 to 5 out of 9 (mean BCS of 4.6). No dogs had abnormal results on orthopedic examinations and radiographic examinations at the initiation of the study.

Computed tomography: All dogs were fasted 8 hours prior to CT scans. The pelvic limbs of all 5 beagle dogs positioned in the ventral recumbency were scanned with a 32-detector row Computed Tomography (CT) scanner (AlexionTM, Toshiba, Japan). Acquired CT images were used to construct 3-dimensional bone models of the femur, patella, and tibia. The same CT images

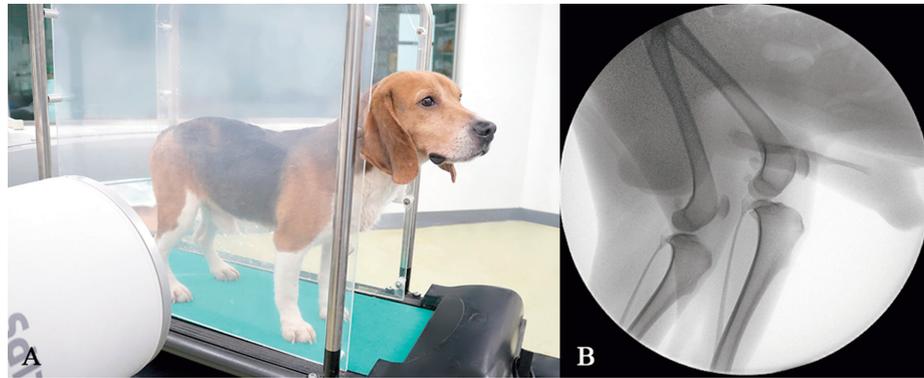


Fig. 1. Preparing a beagle dog for a fluoroscopic scan (A), Obtained mediolateral view fluoroscopic image (B).

were also used to prove the results of orthopedic examinations and no opposing data were found. Anesthesia was performed with intravenous administration of alfaxalone (Alfaxan[®] inj., Jurox Pharm. Co. Ltd., Australia) 2 mg/kg and 1.0–2.0% isoflurane (Ifran[®], Hana Phar. Co. Ltd., Korea) inhalation narcotic. The CT scan was set at 120 kV, 150 mA, 512×512 image matrix, 0.547×0.547 pixel spacing and 1 mm slice thickness.

Construction of 3D bone model: 3D bone models of femur, patella, and tibia were constructed with the use of a software program (Mimics, Materialise, Belgium).

Acquiring Fluoroscopic images: Continuous mediolateral view fluoroscopic images of the stifle joint were taken during walking with five full gait cycles on the treadmill (Carrydori, CDATA, Korea) with a diagnostic X-ray image acquisition system (BV Pulsera, Philips, Netherlands) at 53 kVp and 3.86 mAs with a pulse rate of 30 frames/s and pulse width of 11.1 ms (Fig. 1). Of the five gait cycles captured for the walk, the one stance phase that subjectively was finest and center-positioned in the field of view, was chosen for analysis. Fluoroscopic images of the mediolateral view of the stifle joints were obtained at stance phase while walking on a treadmill.

3D to 2D image matching: Based on the CT images,

the corrected images and 3D bone models were transferred to an open source shape-matching software program (JointTrack, University of Florida: <http://sourceforge.net/projects/jointtrack/>). 3D bone models were superimposed on 2D fluoroscopic images with the use of an automatic optimizing function in the software program and by manually altering the position and orientation of the 3D bone models on display¹¹⁾ (Fig. 2).

Radiography: All dogs were placed under anesthesia for an accurate view and positioned in the dorsal recumbency on a radiographic table. The dogs were secured on the table with the pelvic limb secured in full extension of the hip, stifle, and tarsus. X-ray was taken in the conventional stretched out leg position with the entire pelvic limb. The craniocaudal radiographs showed that positioning the patella was in the center of the distal femur, the medial and lateral fabellae were bisected by their respective femoral cortices, and the medial edge of the calcaneus aligning close to the distal intermediate ridge of the tibia between the cochlea of the tibia^{4,5)}. The exposure condition was 64 kVp and 6.3 mAs.

Measurement of mechanical axis: The mechanical lateral proximal femoral angle (mLPFA) is an angle formed between the mechanical axis and the reference line of the proximal femoral joint. The mechanical lateral distal femoral angle (mLDFA) is an angle formed between the

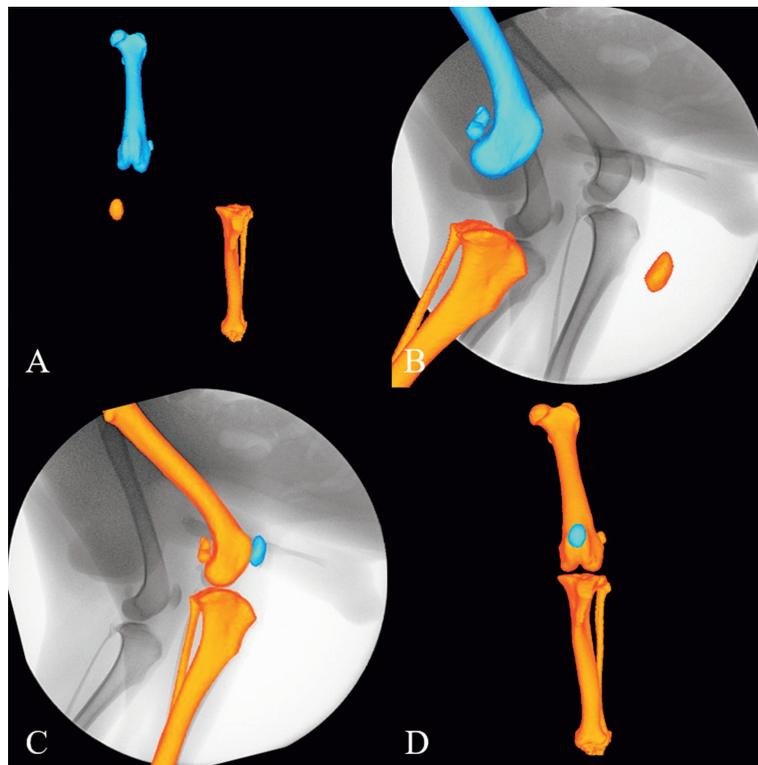


Fig. 2. Shape-matched fluoroscopic images. 3D bone models were transferred to the shape-matching software program (A). Superimposing 3D bone model on 2D fluoroscopic image by manually altering the position (B, C). After the shape-matching is completed, the true frontal plane of the 3D bone model is visible (D).

mechanical axis and the orientation line of the distal femoral joint. To establish the mechanical medial proximal tibial angle (mMPTA) and mechanical medial distal tibial angle (mMDTA), angles created between the mechanical axis and the joint orientation lines were measured on proximomedial and distomedial aspects, respectively. These 4 angle values were measured and compared between superimposed 2D fluoroscopic images and conventional X-ray scans (Fig. 3). These 4 angle values were evaluated 3 times by a first observer and independently evaluated by three observers.

Statistical analysis: All statistical analyses were executed with the use of a statistical software program (IBM SPSS Statistics 24.0, IBM Corp, US). The data are expressed as mean \pm SD and 95% confidence intervals (CI) of the means within the population were determined. Data were compared using a Mann-Whitney U-test

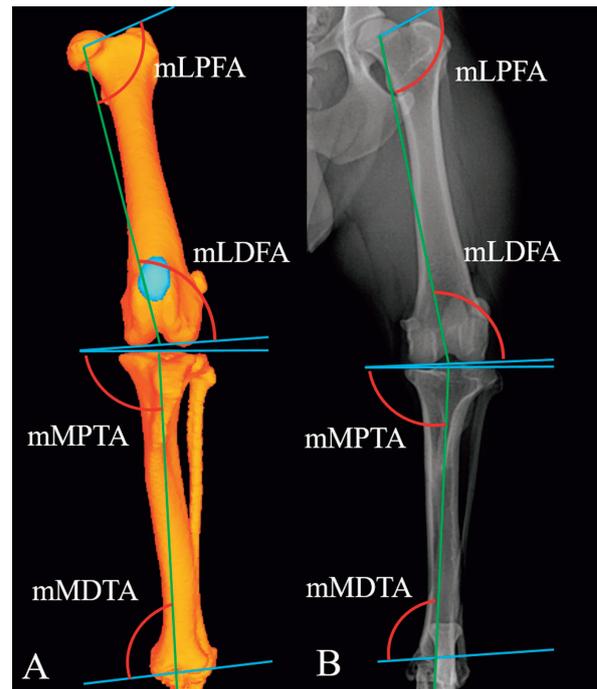


Fig. 3. Measurement of mechanical axis at stance phase (A), Measurement of mechanical axis on conventionally used stretched out leg position (B).

(mechanical joint angles) as appropriately based on data normality. Values of $P < 0.05$ were considered significant. Intra- and inter-observer agreement was assessed to secure objectivity using the intraclass correlation coefficient (ICC) of 95% confident intervals (CIs). The interpretation of ICC was performed according to the criteria of Portney and Watkins, which is poor when lower than 0.5, moderate between 0.5 and 0.75, good between 0.75 and 0.9, and excellent when higher than 0.9.

Results

Epidemiologic Data

10 pelvic limbs were evaluated from 5 beagle dogs: 8 limbs from males and 2 limbs from females. The mean \pm SD weight of dogs was 10.1 ± 0.7 kg. Body condition scores varied within the range of 4 to 5 out of 9 (Mean \pm SD, 4.6 ± 0.5).

Mechanical joint angles in conventional radiography

All mechanical joint angles were measured in frontal radiographs. The mean values (\pm SD) of mLPFA, mL DFA, mMPTA and mMDTA were $105.0^\circ \pm 1.7^\circ$, $99.1^\circ \pm 0.9^\circ$, $93.4^\circ \pm 0.8^\circ$ and $96.1^\circ \pm 0.6^\circ$, respectively.

Mechanical joint angles in standing Leg Position

All mechanical joint angles were measured in frontal view 3D bone models. The mean values (\pm SD) of mLPFA, mL DFA, mMPTA and mMDTA were $93.7^\circ \pm 3.5^\circ$, $103.8^\circ \pm 2.2^\circ$, $92.5^\circ \pm 1.0^\circ$ and $95.9^\circ \pm 1.3^\circ$, respectively.

Stance phase versus Conventional radiography

Comparison between the mechanical joint angle values obtained from 3D bone models at stance phase and the values acquired from conventional radiographs, showed significant differences in mLPFA ($P < 0.001$) and mL DFA ($P < 0.001$). However, no significant differences were found in the values of mMPTA ($P = 0.088$) and mMDTA ($P = 0.568$; Table 1). The ICC

values of both stance phase and conventional radiographic posture for intra- and inter-observer reliability were good to excellent (Table 2).

Left Versus Right

There were no significant differences between the angle values of the right and left pelvic limbs in cases of both stance phase and conventional radiographic posture ($P > 0.05$).

Discussion

The present study evaluated and compared the values of the mechanical axis obtained at stance phase, which is the normal weight bearing walking posture, to that of the conventionally stretched out leg position in a dog. Comparison of the mechanical joint angles in 3D bone models and radiography of pelvic limbs showed significant differences in mLPFA ($P < 0.001$) and mL DFA ($P < 0.001$) but did not exhibit significant differences in mMPTA ($P = 0.088$) and mMDTA ($P = 0.568$).

The mechanical axis value is used for pre-surgical planning and postoperative evaluation in procedures, such as total knee replacement and others involving bone deformity. In human research, the mechanical axis is an important value for evaluating post-surgical complications, such as aseptic loosening^{2,3,14,18,19}. Therefore, obtaining an accurate value of the mechanical axis is critical.

To obtain an accurate value, the mechanical axis was measured using the fluoroscopic technique in the weight-bearing stance position with bent pelvic limbs. There were significant differences in the femoral angle values when compared with the values obtained from the conventional, non-weight bearing dorsal recumbency position.

A study conducted by Goodrich ZJ *et al* compared 12 forelimb alignment values by taking frontal radiographs of healthy dogs in standing positions and in recumbent postures. Significant

Table 1. Mechanical joint angles at stance phase and conventional radiography of pelvic limbs. $P < 0.05$ indicates a significant difference between groups

	mLPFA°	mLDFA°	mMPTA°	mMDTA°
	Mean \pm SD (95% CI)	Mean \pm SD (95% CI)	Mean \pm SD (95% CI)	Mean \pm SD (95% CI)
Conventional radiography	105.0 \pm 1.7 (104.0–106.1)	99.1 \pm 0.9 (98.5–99.6)	93.4 \pm 0.8 (92.9–93.8)	96.1 \pm 0.6 (95.7–96.4)
Stance phase	93.7 \pm 3.5 (91.5–95.9)	103.8 \pm 2.2 (102.4–105.1)	92.5 \pm 1.0 (91.9–93.2)	95.9 \pm 1.3 (95.0–96.7)
<i>p</i> -value	< 0.001	< 0.001	0.088	0.568

SD: standard deviation; CI: confidence interval.

The data are reported as the mean \pm SD and lower and upper 95% CIs for mechanical joint angles.

Table 2. Intra- and inter-observer reliability static of stance phase and conventional radiography of pelvic limbs

	mLPFA°	mLDFA°	mMPTA°	mMDTA°
	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)	ICC (95% CI)
Intra-observer Reliability of Conventional Radiography	0.908 (0.730–0.975)	0.899 (0.704–0.973)	0.890 (0.678–0.970)	0.897 (0.699–0.972)
Intra-observer Reliability of Stance Phase	0.969 (0.910–0.992)	0.936 (0.812–0.983)	0.904 (0.719–0.974)	0.894 (0.689–0.971)
Inter-observer Reliability of Conventional Radiography	0.891 (0.679–0.970)	0.903 (0.716–0.974)	0.872 (0.626–0.966)	0.902 (0.714–0.974)
Inter-observer Reliability of Stance Phase	0.958 (0.876–0.989)	0.933 (0.804–0.982)	0.897 (0.698–0.972)	0.899 (0.705–0.973)

ICC: intraclass correlation coefficient; CI: confidence interval.

differences were found in the limb alignment values between a weight-bearing standing position and a non-weight-bearing recumbent position⁶. Human research also indicates that non-weight-bearing radiographs can produce a different mechanical axis compared to the loaded limb and stresses the importance of implementing surgical planning on weight-bearing radiographs⁹.

Measuring the mechanical axis with the standing radiographic technique, involves high levels of cooperation from dogs and requires special equipment⁵. These complications lead to routinely measuring the mechanical axis in a non-weight-bearing position.

Despite the high cost and the requirement of CT and fluoroscopic images to perform the single-plane fluoroscopy technique, the mechanical axis could be accurately measured by matching the 3D bone model to the perspective image of the

standing position in this study.

Single-plane fluoroscopy is a method of evaluating two-dimensional images; it is performed with a fluoroscopic device, and CT-based three-dimensionally reconstructed bone images are matched with two-dimensional fluoroscopic images. Single-plane fluoroscopy does not require any anesthetic procedure or special patient postures. Furthermore, it can be performed while the patient is moving because fluoroscopy can provide dynamic two-dimensional images. Thus, single-plane fluoroscopy has been regarded as a valuable research tool for the study of kinematic gait or joints in human medicine.

The advantages of measuring the hind limb mechanical axis via single-plane fluoroscopy are that it can be measured more easily and quickly than with conventional radiography, and it can be measured while the patient is moving. In

addition, the measured error has been reported to be less than 0.5 mm, and the accuracy is high¹³). However, disadvantages are that a single CT and fluoroscopy can be costly to measure the hind limb mechanical axis. However, in clinics, surgery for bone deformity in the pelvic limb or total knee replacement (TKR) has been conducted based on the mean value of the hind limb axis measured in normal patients. Therefore, the mean value of the hind limb mechanical axis of the species, using single plane fluoroscopy, should be established for clinical applications in the future.

This single-plane fluoroscopy is reported to have valid, noninvasive and accurate results^{1,8}). Although bi-plane fluoroscopy has better accuracy than single-plane fluoroscopy, it has limitations in both cost and space for establishing an experimental system. Single-plane fluoroscopy is a highly efficient method because of its relatively low radiation dose in comparison with bi-plane fluoroscopy¹³).

In the clinic, a surgical plan is being established to treat a pelvic bone deformity or for TKR based on the reference values of the hind limb mechanical axis measured by conventional radiography.

Using the conventional mechanical axis values in surgical procedures, such as total knee replacement and others involving bone deformities, may be problematic. The mechanical values obtained in this study will produce much more accurate results. Therefore, these values are also applicable for dogs when performing bone cutting procedures, such as TKR and corrective osteotomy of pelvic limb deformity. Measurements of mechanical axis values at stance phase from different breeds of dogs with no abnormalities, were obtained with the use of the fluoroscopic technique and CT and can be utilized as reference values in the future.

We proposed that the hind limb mechanical axis obtained in this study should be used as a reference in a beagle dog when correcting a bone deformity or performing a TKR. However, more

clinical studies are needed to evaluate whether the surgical outcome will be better when the surgery is performed based on the reference values of the hind limb mechanical axis is measured by single-plane fluoroscopy *versus* conventional radiography.

The reliability of both stance phase and conventional radiographic posture in present study was good to excellent in intra-observer, good to excellent in inter-observer. According to our results, both measurement methods showed good to excellent reliability in measuring mechanical axis.

One of the limitations of this study was the small patient population used for evaluation. In addition, the mechanical axis values measured above have not yet been applied to surgery, and thus significant differences in post-surgical outcomes have not yet been proven. The application of these measurements in surgery and analysis of post-surgical outcomes are needed for further research.

The values of the femoral angles in the mechanical axis differ between the stance phase and the conventional position where the limbs are stretched out. Since the mechanical axis is the weight-bearing axis, it should be considered correct to measure the mechanical axis in dogs in their standing position as it is done in humans.

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