pISSN 1598-298X / eISSN 2384-0749
J Vet Clin 37(4) : 169-174 (2020)
https://doi.org/10.17555/jvc.2020.08.37.4.169

Journal of Veterinary Clinics
www.ksvc.or.kr

Measurement of Thoracic Limb Joint Reference Angles in Purebred Shih-Tzu Dogs by Computed Tomography

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(Received: March 07, 2020 / Accepted: July 01, 2020)

Abstract : The purpose of this study was to establish normal values for the thoracic limb joint reference angles in Shih Tzu dogs and to describe the standardized CT methodology for measuring the joint reference angle of the humerus. Five pairs of thoracic limbs of Shih Tzu dogs were collected for the CT scans in this study. Three blinded observers measured the joint reference angle of the humerus and radius for each dog by using CT scans in the frontal, sagittal, and axial planes. The means (± SDs) for the average of the right and left humeral joint reference angles were as follows: mMPHA, 83.74 ± 3.95°; mLDHA, 85.04 ± 2.57°; mCaPHA, 46.75 ± 2.20°; mCrDHA, 79.47 ± 1.97°; and HTA, 19.16 ± 2.38°. Means (± SD) for the average of right and left of the radial joint reference angles were as follows: aMPRA, 85.04 ± 1.58°; aLDRA, 87.59 ± 1.37°; aCrPRA, 84.60 ± 1.46°; aCdDRA, 84.27 ± 1.79°; and RTA, 20.91 ± 3.00°. The intraclass correlation coefficients (ICCs) of the joint reference angles for the inter- and intraobserver reliability were good to excellent, except those for the mCrHA and HTA were moderate. Our results suggest that the method of measuring joint reference angles of other long bones by using CT can be applied to thoracic limbs and can extract valid values for one specific breed.

***Key words* :** joint reference angle, computed tomographic methodology, intraobserver reliability, shih-tzu dog.

Introduction

Long-bone angular limb deformities (ALDs) are a common orthopedic disease in dogs that can result from various causes, such as trauma, metabolic disturbances, hormonal effects, and genetic factors. Limb malalignment arising from an ALD can cause secondary pain, lameness and osteoarthritis (OA) due to maldistribution of weight bearing on joint cartilage.

The goal of surgical intervention for ALDs is to reorient the affected limbs for prevention of OA progression and improvement in joint function (1,2). The center of rotation of angulation (CORA) methodology has been widely used to measure and assess the magnitude, location and plane of deformities (3,4). With a unilateral ALD, the unaffected contralateral limb can be used for targeted surgical values, but it is difficult to substitute the value of the opposite limb with bilateral ALDs (5,6). Therefore, standard values of the joint reference angle in normal limbs are necessary, and several studies have described radiographic methods for canine humerus (7), radius (1), femur (8) and tibia (5) evaluation. However, previously published values vary widely across breeds and weights, so iatrogenic translation or malalignment may result from corrective osteotomy surgery due to inappropriate reference values for certain breeds (1). In particular, chondrodystrophic dogs have a relatively shorter extremity bone than the length of their axial skeleton, owing to impaired longitudinal bone growth so that they have a higher incidence of multiapical ALDs than nonchondrodystrophic breeds (9-11). However, to the best of our knowledge, only two studies have documented the joint reference angles in chondrodystrophic dogs, which are not even based on specific breeds (6,12).

The present study was based on Shih Tzu dogs, as they are one of the most common chondrodystrophic dog breeds. The purposes of the study were (1) to report normal values of the joint reference angles in the frontal, sagittal, and axial planes for thoracic limbs in a single breed of Shih Tzu dogs and (2) to describe the standardized method for measuring the joint reference angle of the humerus by Computed tomography (CT). Our hypothesis was that CT methods previously reported for the other long bones can be applied to the entire thoracic limb and can extract valid values for the joint reference angles for one specific breed.

Materials and Methods

Study population

CT data of five Shih Tzu dogs that presented to the veterinary medical teaching hospital of Chungnam National University between January 2016 and August 2018 were collected. The inclusion criteria were having a CT scan of appropriate quality to allow reconstruction into the 3D model and with a complete humerus and radius, being skeletally mature, weighing < 5 kg and not having orthopedic diseases including fractures, osteoarthritis or neoplasia. The scan data were considered unacceptable when the thickness or orientation of the scan cut off or flattened the curvature of the humeral head or

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condyle to an extent where accurate measurements could not be made. The breeds, sexes, body weights and ages of the patients were recorded.

Experimental design

The joint reference angle of the humerus and radius for each dog were measured by using CT scans of the frontal, sagittal, and axial planes. The primary investigator (EK) instructed two blinded observers (JM, YE) during the trial of 5 normal limbs to ensure consistent measurement. To assess the interobserver reliability, each set of CT images was reviewed in a single session by three blinded investigators (EK, JM, YE). To determine the intraobserver reliability, the primary investigator repeated the measurements 3 times within a one-week interval.

CT technique

CT scans of the patients were performed under general anesthesia. For this procedure, the dog was administered midazolam (0.2 mg/kg) intravenously for premedication. Anesthesia was induced with propofol (2-6 mg/kg) and maintained via inhalation of isoflurane (2%) with 100% oxygen. The patients were positioned in sternal recumbency with cranial extension of both forelimbs, allowing the carpal, elbow and shoulder joints to lie in their neutral positions. CT scan images were produced by a 16-slice helical CT scanner using a 1 mm slice thickness with 50% overlap (Aquilion, Toshiba, Japan). Multiplanar reconstruction (MPR) was implemented, and each humerus and radius were adjusted in the frontal, sagittal and axial planes based on landmarks.

CT measurements

The frontal, sagittal and axial plane angles of the humerus and radius were assessed for each limb using multiplanar reconstructed CT images by proposing methods previously reported except that for the humeral torsion angle.

Measurements for the humerus

In the frontal plane, the mechanical axis was connected to the center of the oval surrounding the humeral head and the midpoint of the distal joint reference of the humeral condyle as described by Wood *et al.* (Fig 1A) (7). The angle between the mechanical axis and the proximal joint reference line, which was drawn as a line connecting the most prominent point of the greater tubercle to the tangential line for the humeral head, formed the mechanical medial proximal humeral angle (mMPHA). The mechanical lateral distal humeral angle (mLDHA) was defined between the mechanical axis and distal joint reference line on the lateral aspect.

To determine the sagittal humeral mechanical axis, the center of the best-fit oval superimposed on the lateral humeral condyle and humeral head was identified (Fig 1B). The proximal humeral joint reference line was determined to be the line connecting the most caudodistal aspect of the humeral head and cranioproximal eminence of the greater tubercle. The landmarks for the distal humeral joint reference line were the center of the circle of the lateral humeral condyle and most caudal point of the medial humeral epicondyle, as previously reported (7). The angles formed between the mechanical axis and the proximal humeral joint reference line and distal joint reference line were measured as the mechanical cranial proximal humeral angle (mCaPHA) and the mechanical distal humeral angle (mCrPHA), respectively.

In the axial plane, the landmark for the proximal humeral axis (PHA) was identified at the most caudal eminence of the greater tubercle (CdGT) and the tubercle placed at the mid-

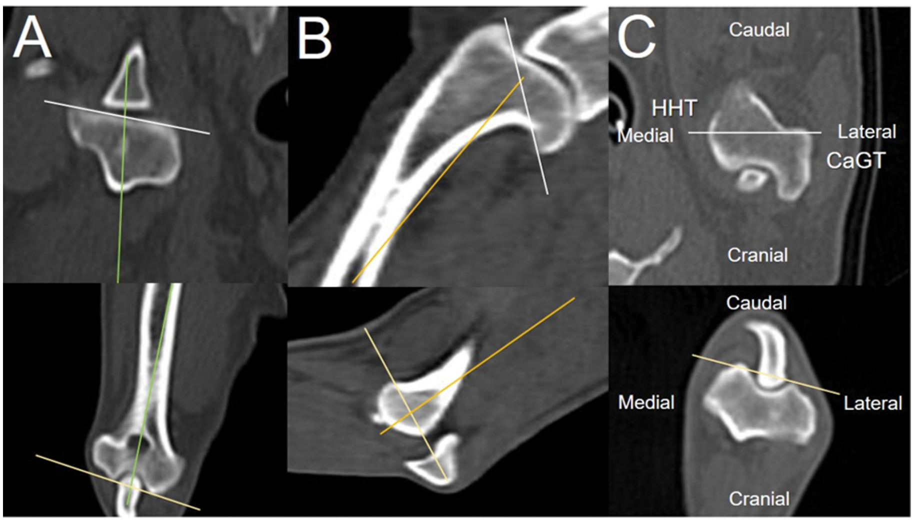

Fig 1. Multiplanar reconstructed CT images of the humerus. The top and bottom images are proximal and distal multiplanar reconstructed CT images, respectively. (A) Frontal plane of the humerus. The green line is the mechanical axis line. The white and yellow lines are the joint reference lines of the shoulder and elbow joints, respectively. (B) Sagittal plane of the humerus. The line connecting the center of the best-fit ovals of the humeral head and lateral condyle represents the mechanical axis (orange line). The white and yellow lines are the joint reference lines of the shoulder and elbow joints, respectively. (C) Axial plane of the humerus. The most caudal eminence of the greater tubercle (CaGT) and tubercle placed at 50% of the caudomedial aspect of the humeral head (HHT) represents the proximal landmark for determining the proximal joint orientation line (pJOL, white line). The most caudal aspect of the medial and lateral humeral trochlear ridge was determined as the landmark for the distal joint orientation line.

dle of the caudomedial line of the humeral head (HHT). The line connecting the most caudal points of both the medial and lateral ridges of the humeral trochlea was described for measuring radial torsion in a previous study and defined as the distal humeral trochlear axis (DHTA) in this study (9). The angle between the DHTA and PHA in the axial plane was measured as the humeral torsion angle (HTA). These landmarks were found at 10 normal humeri in a preliminary study performed by a primary investigator. The positive and negative values indicate external and internal torsion, respectively.

Measurements for the radius

The proximal anatomical axis line of the radius in the frontal plane was defined as connecting the proximal-diaphyseal midpoints at 25% and 50% of the radial length (Fig 2A) at the level of the elbow, and the joint orientation line was drawn either from the most proximolateral aspect to the most proximomedial aspect of the radial head (6). For the carpus, the joint orientation line was drawn along the articular face of the distal radius ignoring the radial styloid process, and the anatomic axis was drawn similar to the proximal axis at midpoints 25% and 50% from the distal side.

In the sagittal plane, the joint orientation line was defined as the line connecting the cranial and caudal aspects of the radial head and the line connecting the cranial and caudal aspects of the distal portion of the radius, as described by Marcellin-Little *et al.* (Fig 2B) (13). The anatomical axis lines were set for 2 separate straight lines for the distal and proximal radii due to natural procurvatum features (6).

The angle of radial torsion was measured in the axial plane by determining 2 lines as described by Kwan *et al.* (9). The tangent line was drawn from the cranial cortex across the fovea at the level of the elbow joint and the joining line to the centers of the medial cortex of the abductor pollicis longus eminence and the line tangent to the cranial eminence of the ulnar notch (9,14).

Statistical analysis

All the statistical analyses of the humeral and radial joint reference angles were performed using SPSS software version 24.0 (IBM SPSS Statistics 24.0, IBM Corp., Chicago, US). Means ± standard deviations (SDs) with 95% confidence intervals (95% CIs) were calculated for each of the joint reference angles (mMPHA, mLDHA, mCaPHA, mCrDHA, and HTA; aMPRA, aLDRA, aCrPRA, aCdDRA and RTA), and unpaired t-tests or Mann-Whitney U tests were used to compare the joint reference angles of the right versus left radii and humeri.

The evaluation of the intra- and interobserver reliability of the CT measurement method for the humeral and radial joint reference angles was performed with intraclass correlation coefficients (ICCs) and 95% CIs. The interpretation of the ICC was made according to the criteria of Portney and Watkins: poor reliability is indicated by values less than 0.5, moderate reliability is indicated by values between 0.5 and 0.75, good reliability is indicated by values between 0.75 and 0.9, and excellent reliability is indicated by values greater than 0.9 (15). The ICCs with 95% CIs were evaluated based on a single-measurement, absolute-agreement, 2-way mixed-effects model for the intraobserver reliability and a single-rating, absolute-agreement, two-way random effects for the interobserver reliability (16). The statistical significance was set at a p-value < .05.

Results

Five Shih Tzu dogs (2 intact males, 1 castrated male, and 2 spayed females) were included; the mean (± SD) body weight

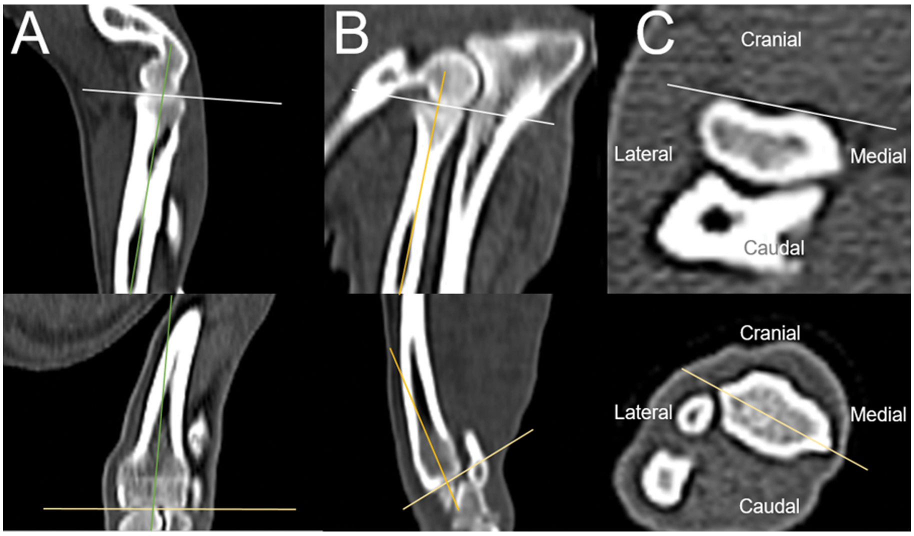

Fig 2. Multiplanar reconstructed CT images of the radius. The top and bottom images are proximal and distal multiplanar reconstructed CT images, respectively. (A) Frontal plane of the radius. The anatomical axis of the radius is drawn in green. The joint orientation line was drawn from the lateral to the medial aspect of the radial head and distal portion of the radius. (B) Sagittal plane of the radius. The anatomical axis of the radius is drawn in orange. The articular tangential line of the radial head is the white line, and the yellow line is for the distal part. (C) Axial plane of the radius. The angle of radial torsion was measured between 2 lines: the line tangent to the cranial cortex across the fovea and the joining line tangent to the medial cortex of the abductor pollicis longus eminence and the cranial eminence of the ulnar notch.

Table 1. Summary of measurements of humeral joint reference angles in normal Shih-Tzu dogs

Limb	Frontal plane				Sagittal plane		Axial plane			
	mMPHA (°)		mLDHA (°)		mCaPHA (°)		mCrDHA (°)		HTA (°)	
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI
Right	83.09 ± 4.70	80.49-85.70	84.21 ± 2.28	82.95-85.47	46.65 ± 2.54	45.25-48.06	80.21 ± 1.91	79.15-81.27	19.45 ± 2.64	17.99-20.92
Left	84.39 ± 3.06	82.70-86.09	85.86 ± 2.66	84.39-87.33	46.85 ± 1.89	45.80-47.89	78.72 ± 1.78	77.74-79.70	18.87 ± 2.14	17.69-20.06
Overall	83.74 ± 3.95	82.27-85.22	85.04 ± 2.57	84.08-86.00	46.75 ± 2.20	45.93-47.57	79.47 ± 1.97	78.73-80.20	19.16 ± 2.38	18.27-20.05

No significant differences in any joint orientation angles between sides (right vs. left) were detected.
mLDHA, mechanical lateral distal humeral angle; mMPHA, mechanical medial proximal humeral angle; mCaPHA, mechanical caudal proximal humeral angle; mCrDHA mechanical cranial distal humeral angle; HTA, humeral torsional angle.

Table 2. Summary of measurements of radial joint reference angles in normal Shih-Tzu dogs

Limb	Frontal plane				Sagittal plane		Axial plane			
	aMPRA (°)		aLDRA (°)		aCrPRA (°)		aCdDRA (°)		RTA (°)	
	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI	Mean ± SD	95% CI
Right	84.93 ± 1.73	83.97-85.88	87.22 ± 1.20	86.56-87.88	85.23 ± 1.54	84.38-86.08	84.47 ± 1.12	83.85-85.10	20.35 ± 3.61	18.35-22.36
Left	85.15 ± 1.47	84.34-85.97	87.96 ± 1.48	87.14-88.78	83.96 ± 1.09	83.36-84.56	84.07 ± 2.29	82.80-85.34	21.46 ± 2.23	20.23-22.69
Overall	85.04 ± 1.58	84.45-85.63	87.59 ± 1.37	87.08-88.10	84.60 ± 1.46	84.05-85.14	84.27 ± 1.79	83.60-84.94	20.91 ± 3.00	19.79-22.03

No significant differences in any joint orientation angles between sides (right vs. left) were detected.
aMPRA, anatomical lateral distal radial angle; aLDRA, anatomical lateral distal radial angle; aCrPRA, anatomical cranial proximal radial angle; aCdDRA anatomical caudal distal radial angle; RTA, radial torsional angle.

Table 3. Intraclass correlation (95% CI) for measurement of humeral joint reference angles in normal Shih-Tzu dogs

	N	Interobserver[a]	Intraobserver[b]
mMPHA	10	0.94 (0.83, 0.99)	0.99 (0.97, 1)
mLDHA	10	0.92 (0.53, 0.94)	0.97 (0.91, 0.99)
mCaPHA	10	0.85 (0.57, 0.96)	0.97 (0.92, 0.99)
mCrDHA	10	0.73 (0.21, 0.93)	0.98 (0.93, 0.99)
HTA	10	0.75 (0.27, 0.93)	0.98 (9.93, 0.99)

[a]Measured by 3 observers.
[b]Measured by 1 observer repeated assessment three times with at least one week intervals.
Value of the intraclass correlation was interpreted as follows: 0-0.5 = poor; 0.5-0.75 = moderate; 0.75-0.9 = good; and > 0.9 = excellent (15).

Table 4. Intraclass correlation (95% CI) for measurement of radial joint reference angles in normal Shih-Tzu dogs

	N	Interobserver[a]	Intraobserver[b]
aMPRA	10	0.92 (0.76, 0.98)	0.95 (0.86, 0.99)
aLDRA	10	0.83 (0.52, 0.96)	0.82 (0.47, 0.95)
aCrPRA	10	0.91 (0.72, 0.98)	0.89 (0.67, 0.97)
aCdDRA	10	0.87 (0.63, 0.97)	0.95 (0.86, 0.99)
RTA	10	0.94 (0.83, 0.98)	0.98 (0.94, 1.00)

[a]Measured by 3 observers.
[b]Measured by 1 observer repeated assessment three times with at least one week intervals.
Value of the intraclass correlation was interpreted as follows: 0-0.5 = poor; 0.5-0.75 = moderate; 0.75-0.9 = good; and > 0.9 = excellent (15).

was 4.48 ± 0.55 kg, and the mean (± SD) age was 10.80 ± 5.22 years. There was no significant difference among all the humeral joint reference angles between the right and left humerus. The means ± SDs with 95% CIs of the mLDHA, mMPHA, mCaPHA, mCrDHA and HTA measured from CT scans are shown in Table 1, and those of the aLDRA, aMPRA, aCrPRA, aCdDRA and RTA measured from CT scans are shown in Table 2.

For the humerus, the ICC values of both the inter- and intraobserver reliability for measurements in the frontal plane (mLDHA and mMPHA) were excellent (Table 3). The interobserver reliability for measurements in the sagittal plane (mCaPHA and mCrDHA) was moderate to good and the intraobserver reliability for these angles were excellent. The ICC value of the axial plane measurement (HTA) was good for the interobserver reliability and excellent for the intraobserver reliability.

The ICC values for the inter- and intraobserver reliability of the radius were excellent for the aMPRA in the frontal plane and the RTA in the axial plane (Table 4). The inter- and intraobserver reliability of aLDRA in the frontal plane was good and excellent, respectively. In the sagittal plane of the radius, the interobserver reliability for the aCrPRA and the intraobserver reliability for the aCdDRA were excellent, and the intraobserver reliability for the aCrPRA and the interobserver reliability for the aCdDRA were good.

Discussion

The current study focused on establishing the reference joint angle value of the thoracic limb in the Shih Tzu dog breed by assessing CT images. The reference values of the radial joint angles were obtained by methods used by other authors (9,14,16), and the measurement method of the humeral joint angle using CT was developed based on previous radiographic methodology (7). It was demonstrated that the computed tomographic evaluation of joint reference angles for both the radius and humerus was a repeatable and reliable method for determining standardized values. These results allowed us to confirm our hypothesis that previous methods for measuring other long bones are applicable to thoracic limbs, and it possible to establish valid values in one specific breed.

Several studies have measured the joint reference angle of the radius by setting the landmark for the joint reference line as a physeal scar on CT images, which can be difficult to distinguish in older animals (6,14). Therefore, we cited the alternative technique that draws a more certain and discernible carpal joint orientation line for the radial distal portion, ignoring the styloid process, becoming the landmark that was found in all 5 dogs (9,16). The radial torsion angle (RTA) in the transverse plane was estimated using methods previously described by Meola *et al.* (14). Although it was difficult to directly compare the results in the current study and previously published studies because heterogeneous breeds with a wide variety of body weights and radiographic methodologies were included previously, it is almost consistent with the aMPRA and aLDRA (1,17). For sagittal plane measurements, the value of the aCrPRA ($84.60 \pm 1.46^{\circ}$), showed a significant difference compared to that of previous studies (92°), and the aCdDRA obtained in this study ($84.27 \pm 1.79^{\circ}$) was approximately 3° greater than that from a previous study (81°), which was assessed in a non-Labrador Retriever group (17). Two studies were published on the RTA with mean values of 4.88° and $3.6 \pm 6.4^{\circ}$; however, our mean RTA was $20.91 \pm 3.00^{\circ}$, which was the greatest difference from previous results and might be considered a characteristic limited to a single breed (6,14). Earlier studies did not classify specific species, and the averages across several breeds with various thoracic limb bone shapes are inevitably different from those of the chondrodystrophic group. Our findings demonstrated that the Shih Tzu breed has external torsion greater than that of other nonchondrodystrophic breeds. There was no significant difference between the left and right sides.

Measuring the angle of the humeral joint is different than for the radial joint because of the complex structure of the shoulder joint, which is a ball-and-socket joint, making it difficult to determine the true center of the joint surface in either plane. The current study applied the earlier technique of drawing a suitable oval encompassing the entire articular surface of the humeral head and condyle to identify the center of a reproducible reference point for the humerus in both the frontal and sagittal planes. The mLDHA, mCaPHA and mCrDHA in the frontal and sagittal planes were measured with the method described by Wood *et al.* using the angle formed by the intersection of the humeral reference line and mechanical axis drawn between the center of the ovals in the humeral head and lateral condyle or midpoint of the distal humeral reference line (7). The method for measuring the mMPHA in the frontal plane was previously unreported, and we defined the proximal humeral reference line as a tangential line of the humeral head across the most proximal prominent aspect of the greater tubercle. The humeral torsional angle (HTA) obtained in the axial plane was measured using the distal and proximal humeral axes. To draw the reference line of the proximal humeral joint, the caudal eminence of the greater tubercle and tubercle placed at the middle of the caudomedial aspect of the humeral head were determined to be landmarks, and these points were identified for all the humeri (10/10) in the current study. The landmarks of the distal humerus were the most caudal aspect of the medial and lateral trochlear ridge.

The mean mLDHA value, $85 \pm 2.6^{\circ}$, of our Shih Tzu group was slightly lower than that measured by Wood *et al.* ($86.92 \pm 1.24^{\circ}$) (7). These results are consistent with a previous study that found a nonperpendicular relationship between the elbow joint reference line and the humeral mechanical axis in the frontal plane, suggesting a normal deviation of the mechanical axis of the humerus in Shih Tzu dogs. Excessive changes in the mLDHA with subsequent mechanical axis shifts could result in nonuniform joint loading. Further research is needed to suggest his relationship clinically because of the much smaller weights of Shih Tzu dogs than those of previously studied breeds. We defined the humeral joint reference angles of the mCaPHA and mCrDHA in the sagittal plane as $46.8 \pm 2.2^{\circ}$ and $79.5 \pm 2^{\circ}$, respectively. These angles are slightly different from those from published data and are considered different between nonchondrodystrophic and chondrodystrophic breeds (7). The mean measurement of the humeral torsion angle in the axial plane was $19.2 \pm 2.4^{\circ}$, which indicated that normal Shih Tzu dogs had a positive value of external torsion. Contrary to other long bones, there was no significant difference in the measured joint reference angles of the humerus between the right and left limbs of individual normal Shih Tzu dogs in all 3 planes (6).

The CT measurement techniques used in this study demonstrated good to excellent reliability for the radius and moderate to excellent reliability for the humerus in normal Shih Tzu dogs. Surface landmarks for the thoracic limbs were easy to identify in all 3 planes, and all the investigators were able to attain consistent results for the measurements with three times of training. Additionally, the intraobserver reliability for the humerus was excellent for all the angles, and the interobserver reliability for the humerus was excellent in the frontal plane and moderate to good in the sagittal and axial planes. All the investigators completed training, and several refinements were required, even for experienced surgeons or surgical residents, to reach consistent results.

Several limitations exist in this study. First, the study had a small sample size; we only had a total of 10 thoracic limbs, which might generate type II errors. Second, only physical examinations, radiographs and computed tomography scans suggested that the humeri and radii were free from orthopedic diseases that could affect the mechanical axis and determine the joint orientation line. No additional diagnostic modalities, such as arthroscopy or magnetic resonance imaging, were included to confirm the true health of the elbow and shoulder joints. Finally, it may be challenging to identify specific clinical landmarks at joint structures for measuring joint reference lines or mechanical axes in dogs with ALDs because we established all the landmarks in normal Shih Tzu dogs without clinical signs regarding orthopedic disease or osteoarthritis. Despite these limitations, the methodology we report for measuring joint reference angles of thoracic limbs in Shih Tzu dogs was similar to the techniques used for the evaluation of the pelvic limb and therefore may serve as a basis for diagnosis and correction of forelimb angular deformities in Shih Tzu dogs.

Conclusion

In conclusion, this report described the humeral and radial reference angle values for Shih Tzu dogs measured by reliable and repeatable CT methodology. Further studies with larger populations and clinical cases of thoracic limbs are needed to establish breed-specific joint reference angles and clinical offsets.

Acknowledgements

This research was supported by Kyungpook National University Research Fund, 2017.

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