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Determination of Pelvic Limb Alignment in Small-breed Dogs

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Abstract : The present study determined the normal reference ranges for overall pelvic limb alignment of small-breed dogs. For this purpose, 60 cadaveric canine pelvic limbs from normal small-breed dogs (Maltese, Poodle, Shih Tzu, Yorkshire Terrier). A frontal full-limb radiograph of each pelvic limb was obtained, and mechanical tibiofemoral angle (mTFA), mechanical metatarsotibial angle (mMTTA), mechanical axis-femur angle (MAFA), and mechanical axis-metatarsus angle (MAMTA) were measured from each radiograph, along with mechanical deviation of the stifle (SMAD) and tarsal joints (TMAD). The 95% CI for radiographic values of all pelvic limbs were mTFA, 5.7-7.4; mMTTA, −2.2 - −0.8°; MAFA, 3.5-4.5°; MAMTA, 1.0-2.0; SMAD, 2.1-2.7%; TMAD, 0.5-1.0%. There values varied among the breeds, except for mTFA. The reference ranges can be used for diagnosing pelvic limb deformities in small-breed dogs and for planning corrective osteotomies.

Key words **:** pelvic limb alignment, angular deformity, joint reference angles, corrective osteotomy, small-breed dog.

Introduction

Angular deformities occur in the femur, tibia, and metatarsus of canine pelvic limbs. These bones can be affected alone or in conjunction with adjacent bones. Even a deformity isolated to a single bone can generate a weight-bearing force effect on the entire alignment (4). Developmental angular deformities of a single bone within a pelvic limb of a dog can result in compensatory angulation of the other bones, which can lead to mechanical axis deviation of the pelvic limbs and malorientation of the joints above and below the level of deformity (10). Also, the malposition of the mechanical axis of the quadriceps femoris muscle is a risk factor for patellar luxation, cranial cruciate ligament (CrCL) insufficiency and medial meniscal injury. In humans, the total intrinsic compressive load transmitted across the knee joint on the medial compartment in the normal state is 60-80% (1). However, in a varus knee joint, the medial shift of the mechanical axis leads to greater stress on the medial compartment; stress is increased in the lateral compartment in a valgus knee joint imbalance (13). Abnormal contact stresses and malalignments result in articular degenerative changes and osteoarthritis of the associated joints over time, independent of CrCL insufficiency (14).

To assess lower limb alignment, the tibiofemoral angle (TFA), metatarsotibial angle (MTTA), and mechanical axis deviation (MAD) must be determined. TFA is defined as the angle between the long axes of the tibia and the femur in the frontal plane at the level of the knee and can be determined using the mechanical (mTFA) or anatomical (aTFA) axis. TFA and MAD can reliably be used in human patients to determine the presence of lower limb deformities, predict the progression of knee osteoarthritis, and evaluate postoperative surgical management such as anterior cruciate ligament reconstruction, total knee replacement, or tibial osteotomy (4,6, 15,16). A greater than 3-5° varus or valgus malalignment of mTFA increases contact stresses in the knee joint (7,12). mTFA also influences Q-angle alteration which contributes to CrCL insufficiency and patellar luxation (8). MAD plays an important role in asymmetrical loading around the knee joint (5). In veterinary medicine, mTFA and MAD have not been used clinically, and only two reports address pelvic limb alignment. One study measured normal pelvic limb alignment in large-breed dogs, and the other examined cats (4,11). The methodology and reference ranges for small-breed dogs have not been investigated. Information about overall pelvic limb alignment may be useful in diagnosing, quantifying, and planning surgical correction in small-breed dogs.

The objectives of present study were to report a standardized method for radiographic determination of overall pelvic limb alignment in small-breed dogs, and determine and report reference ranges for pelvic limb alignment in small-breed dogs.

Materials and Methods

Specimen Inclusion Criteria

Small adult canine cadavers were collected after euthanasia for reasons unrelated to this study. Cadavers were similar in size and body weight (~6 kg) and had no apparent orthopedic abnormalities. Cadavers were examined to evaluate extension and flexion movements of the hip, stifle, and tarsal joints by gross and palpable observation of the frontal plane alignment of the entire pelvic region in an extended position.

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The position of the patella and CrCL sufficiency were also evaluated, and cadavers were excluded if any abnormalities were noted. Cadavers were also excluded if open physis, patellar luxation, tibial rotation, or angular deformity was seen on radiographic examination. For each of the 30 dogs (60 pelvic limbs), body weight (kg), sex, and breed were recorded.

Radiographic Technique

All radiographs were taken by digital radiographic machine (CM-150, Comed Medical Co., Ltd. Korea). Cadavers were positioned in sternal recumbency on a radiographic table. The cadavers were secured on the table with the pelvic limb secured in full extension of the hip, stifle, and tarsus without application of any force in order to prevent artificial distortion on the radiographic images. True frontal plane positioning of the pelvic limb was determined by positioning the patella over the trochlear groove of the femur, presentation of bisected medial and lateral fabellae by their respective femoral cortices, observation of 50% of the lesser trochanter at the proximal medial femur, and the medial edge of the calcaneus aligning near the distal intermediate ridge of the tibia between the cochlea tail of the tibia.

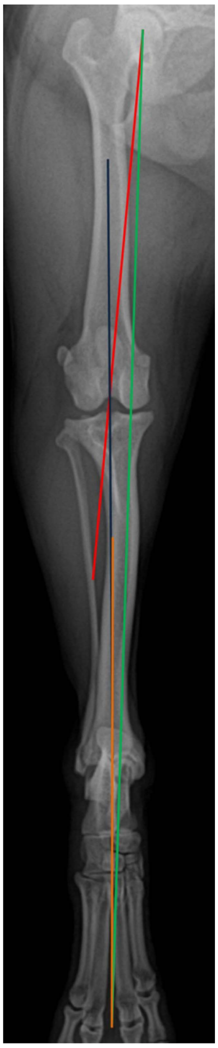

Fig 1. Frontal radiograph of the pelvic limb of a small-breed dog. The mechanical axes of the pelvic limb (green line), femur (red line), tibia (blue line), and metatarsus (yellow line).

Measurement Technique

A digital image measurement program (Infinitt Vet PACS, Infinitt Healthcare Co., Ltd. Korea) was used for all lines, angles, and measurement. The mechanical pelvic limb axis (mPLA) was defined as a straight line from the center of the femoral head to the distal ends of the third and fourth metatarsal bones, called the weight-bearing axis, and the length of the mPLA was measured. The joint center points of stifle and tarsal joints were defined as a point at the most proximal aspect of the top of the intercondylar fossa and a point at the most-distal point of the subchondral bone of the distal intermediate tibial ridge, respectively. The mechanical axis of the femur was defined as a line connecting the center of the femoral head to the joint center point of stifle joint. The mechanical axis of the tibia was defined as a line that passed through the joint center points of stifle and tarsal joints. Finally, the mechanical axis of the metatarsus is a line runs from the joint center point of tarsal joint to the distal ends of the third and fourth metatarsal bones (Fig 1). The mTFA was defined as the angle created between the mechanical axes of the femur and tibia. The mechanical metatarsotibial angle (mMTTA) was defined as the angle created between the mechanical axes of the tibia and metatarsus. The mPLA and the mechanical axis of the femur or metatarsus formed the mechanical axis-femur angle (MAFA) or the mechanical axis-metatarsus angle (MAMTA), respectively (Fig 2). All angles of each pelvic

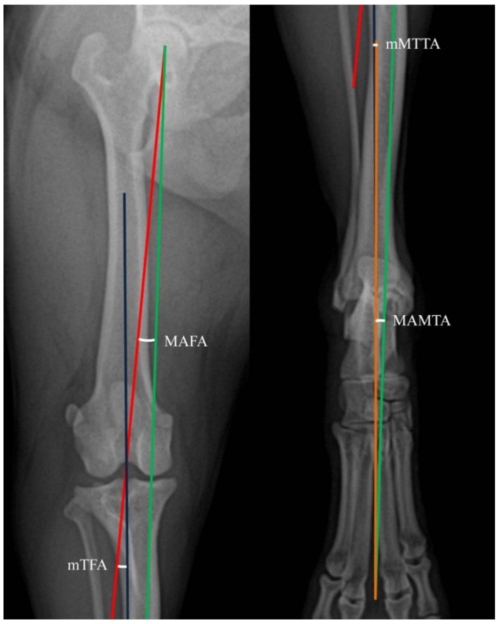

Fig 2. The measurements of angles of pelvic limb alignment in a small-breed dog. The mechanical tibiofemoral angle (mTFA) is measured as the angle between the mechanical axes of the femur (red line) and tibia (blue line). The mechanical metatarsotibial angle (mMTTA) is measured as the angle between the mechanical axes of the metatarsus (yellow line) and tibia (blue line). The mechanical axis-femoral angle (MAFA) is measured as the angle between the mechanical axes of the pelvic limb (green line) and femur (red line). The mechanical axis-metatarsus angle (MAMTA) is measured as the angle between the mechanical axes of the pelvic limb (green line) and metatarsus (yellow line).

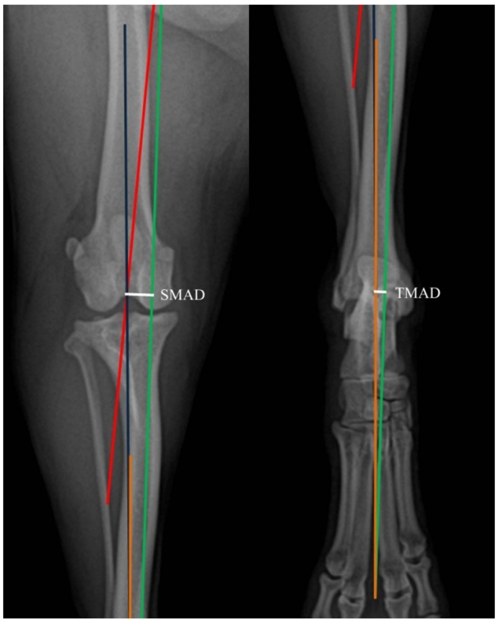

Fig 3. The measurements of SMAD % and TMAD % in a small-breed dog. The stifle mechanical axis deviation (SMAD) is determined as the distance along a perpendicular line from the mechanical axis of the pelvic limb (green line) to the intersection of the mechanical axes of the femur and tibia. The tarsal mechanical axis deviation (TMAD) is determined as the distance along a perpendicular line from the mechanical axis of the pelvic limb (green line) to the intersection of the mechanical axes of the tibia and metatarsus. These values were divided by the length of the mechanical axis of the pelvic limb, then multiplied by 100%. For example, MAD % = (length of deviation / length of mechanical axis of pelvic limb) × 100%.

limb were measured and assigned a positive or negative value. The values of mTFA and mMTTA were assigned a positive or negative value if the distal adjacent bone was varus (medial) or valgus (lateral) to the proximal adjacent bone, respectively. If the mechanical axis of the bone was lateral or medial to the mPLA, the values of the MAFA and MAMTA were assigned a positive or negative value, respectively. The MAD values of the stifle joint (SMAD) and the tarsal joint (TMAD) were measured as a linear distance and expressed as a percentage of the length of the mPLA in order to normalize the data and negate the effect of body size. The distance from the mPLA to the joint center point was measured along a line perpendicular to the mPLA, divided by the length of the mPLA, and multiplied by 100% in order to determine the SMAD or TMAD (Fig 3). The SMAD and TMAD values were assigned a positive or negative value if the joint center point was lateral or medial, respectively, to the mPLA. All values of determined length and the angles of each pelvic limb were measured and recorded.

Statistical Analysis

Data from each variable were combined, and means ± SD and 95% CI were determined. A paired t-test and the Wilcoxon-signed rank test were performed to determine the outcome variables differences between limbs from male and female dogs. An ANOVA was performed, and values of $P < 0.05$ were accepted as significant for determining differences among breeds. All analyses were performed with commercial statistical software (GraphPad Prism v5.0, GraphPad Software Inc., USA).

Table 1. Angles of pelvic limb alignment

	mTFA (°)	mMTTA (°)	MAFA (°)	MAMTA (°)
	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)	Mean ± SD (95% CI)
Overall	6.5 ± 3.2 (5.7-7.4)	−1.5 ± 2.7 (−2.2 - −0.8)	4.0 ± 2.0 (3.5-4.5)	1.5 ± 1.8 (1.0-2.0)
Male	5.9 ± 3.5 (4.6-7.3)	−1.7 ± 3.1 (−2.9 - −0.5)	3.5 ± 2.3 (2.6-4.4)	1.2 ± 2.2 (0.3-2.0)
Female	7.1 ± 2.8 (6.1-8.1)	−1.3 ± 2.3 (−2.1 - −0.5)	4.4 ± 1.7 (3.8-5.0)	1.8 ± 1.5 (1.3-2.4)
Maltese	5.8 ± 3.5 (4.3-7.3)	−0.5 ± 2.5[a] (−1.6-0.6)	3.8 ± 2.3 (2.9-4.8)	2.0 ± 1.8[d] (1.8-2.7)
Poodle	6.3 ± 3.1 (3.7–8.9)	−3.1 ± 1.8 (−4.6 - −1.6)	3.5 ± 1.5 (2.2-4.7)	0.8 ± 1.4 (−0.4-1.9)
Shih Tzu	7.9 ± 3.1 (6.3-9.4)	−0.8 ± 2.2[b] (−1.9-0.3)	5.0 ± 1.9[c] (4.1-6.0)	2.3 ± 1.4[e] (1.6-3.0)
Yorkshire	6.1 ± 1.7 (4.9-7.4)	−3.6 ± 2.7[a,b] (−5.6 - −1.6)	2.9 ± 0.9[c] (2.3-3.6)	−0.3 ± 1.8[d,e] (−1.6-0.9)

The data are reported as the mean ± SD and lower and upper 95% CIs of the angles of pelvic limb alignment.
mTFA, mechanical tibiofemoral angle; mMTTA, mechanical metatarsotibial angle; MAFA, mechanical axis-femoral angle; MAMTA, mechanical axismetatarsal angle.
Means with the same alphabet in a column are different from each other by Tukey's test at 5% significance.

Results

Sixty pelvic limbs from 30 adult small-breed dogs were analyzed. The mean weight of the cadavers was 2.90 ± 1.21 kg (mean ± SD, range 1.32-5.89 kg), and no limbs were excluded because of weight (> 6 kg). The number of male stifles was 28 and that of female stifles was 32. The breeds of the specimens were Maltese (n = 24), Shih Tzu (n = 18), Poodle (n = 10), and Yorkshire Terrier (n = 8).

Angles of Pelvic Limb Alignment: mTFA, mMTTA, MAFA, and MAMTA

The angles of pelvic limb alignment in small-breed dogs obtained from the radiographs were normalized and are reported in Table 1. The mean mTFA of all dogs was 6.5 ± 3.2°. No significant differences were found between male and female dogs or among the four breeds. The mean mMTTA of all dogs was −1.5 ± 2.7°. Between male and female dogs, no significant difference was found. In comparison among the four breeds, Maltese and Shih Tzu had significantly larger values than Yorkshire Terriers ($P < 0.05$). No other significant differences were found. The mean MAFA of all dogs was 4.0 ± 2.0°. Between male and female dogs, no significant difference was found. In comparison among the four breeds, Shih Tzu had a significantly larger value than Yorkshire Ter-

Table 2. Deviation from the mechanical axis of the pelvic limb

	SMAD (%)	TMAD (%)
	Mean ± SD (95% CI)	Mean ± SD (95% CI)
Overall	2.4 ± 1.2 (2.1-2.7)	0.7 ± 0.9 (0.5-1.0)
Male	2.1 ± 1.3 (1.6-2.6)	0.6 ± 1.0 (0.2-1.0)
Female	2.6 ± 1.1 (2.2-3.0)	0.9 ± 0.7 (0.6-1.1)
Maltese	2.2 ± 1.3 (1.7-2.8)	0.9 ± 0.8[b] (0.6-1.3)
Poodle	2.2 ± 1.0 (1.3-3.0)	0.3 ± 0.6 (−0.1-0.8)
Shih Tzu	3.0 ± 1.1[a] (2.4-3.5)	1.2 ± 0.6[c] (0.8-1.5)
Yorkshire	1.8 ± 0.6[a] (1.4-2.2)	−0.2 ± 0.8[b,c] (−0.8-0.4)

The data are reported as the mean ± SD and lower and upper 95% CIs of the mechanical deviation of the stifle and tarsal joints.
SMAD, stifle mechanical axis deviation; TMAD, tarsal mechanical axis deviation.
Means with the same alphabet in a column are different from each other by Tukey's test at 5% significance.

riers ($P < 0.05$). No, other significant differences were found. The mean MAMTA of all dogs was 1.5 ± 1.8°. Between male and female dogs, no significant difference was found. In comparison among the four breeds, Maltese and Shih Tzu had significantly larger values than Yorkshire Terriers ($P < 0.05$). No other significant differences were found.

Deviation from the Mechanical Axis of the Pelvic Limb: SMAD and TMAD

Table 2 summarizes data for the deviation from the mechanical axis of the pelvic limb. The mean SMAD of all dogs was 2.4 ± 1.2%. Between male and female dogs, no significant difference was found. In comparison among the four breeds, Shih Tzu had a significantly larger value than Yorkshire Terriers ($P < 0.05$). No other significant differences were found. The mean TMAD of all dogs was 0.7 ± 0.9%. Between male and female dogs, no significant difference was found. In comparison among the four breeds, Maltese and Shih Tzu had a significantly larger values than Yorkshire Terriers ($P < 0.05$). No other significant differences were found.

Discussion

The present study provide reference ranges and correlations for the angular relationships between the axes of the pelvic limbs, and the MAD from both the stifle and tarsal joint in a population of Maltese, Poodle, Shih Tzu, and Yorkshire Terriers.

The mTFA has been used in humans to assess lower limb alignment, to predict the progression of the osteoarthritis, and to evaluate postoperative outcomes of corrective osteotomy and total knee arthroplasty. The mean mTFA in humans was 0-2.2° (3,9), and an mTFA of 3° greatly alters the distribution of pressure and load between the medial and lateral tibial plateaus (15). Therefore the surgical goal in total knee arthroplasty or corrective osteotomy is to obtain a value of mTFA less than 3° (12). The mean normal mTFA of small-breed dogs in present study was larger than that of humans, but it was smaller than that reported for large-breed dogs (9.1°) (4). The results here indicate that the stifle joint of small-breed dogs is less varus than that of large-breed dogs. In this study, Shih Tzu had a higher mTFA than other breeds, but no significant differences were found.

In humans, the lower limb axis is determined from the femoral head to the ankle. However, the pelvic limb axis of dogs ends distally at the center point between the distal aspects of the third and fourth metatarsal bones (4). This difference in methodology is based on the primary weight-bearing pattern. Thus, the mMTTA consists of the mechanical axes of the metatarsal bones and the tibia, and the TMAD % is measured at the tarsus joint.

Many significant differences were found among the four breeds. In particular, Yorkshire Terriers had various morphological differences from other small-breed dogs (except mTFA), although the origin of the difference is uncertain. These results suggest the variations in pelvic limb alignment among dog sizes and breeds, which supports the need to determine reference ranges for small breeds. This investigation was performed with only four small-breeds; the variation among dog sizes and breeds casts doubt on the applicability of these reference ranges to the assessment of other breeds. No significant differences were found between male and female dogs, which is consistent with findings for large-breed dogs (4). However, in humans and cats, males have a clear trend for greater distal femoral varus than females (2,11). In the present study, the values were measured from radiographs. Accurate diagnosis of using radiography is technically challenging because of difficulties encountered in patient positioning, and it is frequently time consuming. Additionally, in this study the cadavers with limbs in full extension were affected by the muscle tone and the load of weight. Therefore, with live animal, general anesthesia might be required for precise patient positioning. Because this is the first report of overall pelvic limb alignment in small-breed dogs, the true clinical relevance remains unknown. However, future studies evaluating the incidence and prevalence of stifle and tarsal pathology in relation to pelvic limb deformities are suggested.

Conclusion

Deformity in even a single bone can generate an entire weight-bearing force effect on overall alignment. Developmental angular deformities of a single bone within the pelvic limbs of dogs can result in compensatory angulations of the other bones, leading to articular degenerative changes and osteoarthritis of the associated joints over time, independent of CrCL insufficiency.

The present study provides information on overall frontal plane alignment of normal pelvic limbs in small-breed dogs. The reference ranges can be used for diagnosing pelvic limb deformities in small-breed dogs and for planning corrective osteotomies.

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소형견종의 후지정렬 측정

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요 약 : 후지 전체의 정렬 평가에 필요한 정렬각도의 정상치를 측정하기 위하여, 정형외과적 질환이 없고 육안 또는 방사선 검사에서 각기형이 없는 것으로 판단되는 소형견 사체(말티즈, 푸들, 시추, 요크셔테리어) 의 후지 60개를 사용하였다. 각각의 후지를 완전히 신장시켜 전면 방사선 사진을 촬영하였으며, 이를 통해 기계적경골대퇴골각도(mechanical tibiofemoral angle, mTFA), 기계적중족경골각도 (mechanical metatarsotibial angle (mMTTA) 기계축-대퇴각도(mechanical axis-femur angle (MAFA), 기계축-중족각도(mechanical axis-metatarsus angle (MAMTA)을 측정하였으며, 무릎관절과 뒷발목관절의 기계축변위(mechanical axis deviation, SMAD or TMAD)의 평균값과 95% 신뢰구간 값을 전체 그리고 품종별로 측정하였다. 소형견 전체의 mTFA, MTTA, MAFA, MAMTA의 95% 신뢰구간 값은 각각 5.7-7.4°, –2.2 - –0.8°, 3.5-4.5°, 1.0-2.0°였으며, SMAD와 TMAD는 2.1-2.7%, 0.5-1.0%로 측정되었다. 본 연구에서 제시한 소형견의 후지정렬 측정법과 정상치는 소형견종의 후지 각기형의 진단 및 평가, 수술 계획에 있어 유용하게 사용될 수 있을 것이라 사료된다.

주요어 : 후지정렬, 각기형, 관절방향각, 절골술, 소형견종