KJVR
Korean Journal of Veterinary Research

Original Article

Medical Imaging

pISSN 2466-1384 · eISSN 2466-1392
Korean J Vet Res 2024;64(2):e14
https://doi.org/10.14405/kjvr.20240018

*Corresponding author:
Hee Chun Lee
Institute of Animal Medicine, College of Veterinary Medicine, Gyeongsang National University, 501 Jinju-daero, Jinju 52828, Korea
Tel: +82-55-772-2327
E-mail: lhc@gnu.ac.kr
https://orcid.org/0000-0001-5936-9118

†These authors contributed equally to this work.

Conflict of interest:
The authors declare no conflict of interest.

Received: Apr 12, 2024
Revised: May 9, 2024
Accepted: Jun 10, 2024

Ultrasonographic evaluation of pennation angle in canine tibialis cranialis muscle in South Korea: an observational study

Jaehwan Kim[1,†], Tae Sung Hwang[2,†], Hee Chun Lee[2,*]

[1]Gimhae Veterinary Medical Center, Gimhae 50948, Korea
[2]Institute of Animal Medicine, College of Veterinary Medicine, Gyeongsang National University, Jinju 52828, Korea

Abstract

In human, ultrasonography is used to measure the pennation angle in various muscles to identify muscle functions such as force production, and to study alterations of the pennation angle during muscle contraction, hypertrophy, and atrophy. However, assessments of the pennation angle have not yet been conducted in dogs. This study aims to assess the normal pennation angle of the tibialis cranialis muscle in dogs using ultrasound and to detect changes in this angle in dogs with muscular atrophy. Sixty-eight healthy dogs were examined to establish normal values, while 12 ataxic and 12 lame dogs with suspected hindlimb muscle atrophy were also included. The pennation angle was measured using ultrasound at the midpoint between the proximal end of the tibia and the malleolus, measuring the angle between the muscle bundle and the deep aponeurosis. To confirm the significance between the 5 breeds and to identify a difference between normal and atrophied muscles, statistical analysis was conducted. The study found no significant difference in pennation angle between breeds, with mean values (± standard deviation) of 4.97° (± 1.88) in neutral, 7.25° (± 2.68) in flexion, and 3.31° (± 1.33) in extension positions. Decrease of the pennation angle was identified in muscle atrophy and the flexion position was determined to be the most appropriate for pennation angle measurement of tibialis cranialis muscle. We recommend considering the pennation angle as a valuable indicator of muscle health in dogs, as it demonstrates significant potential for diagnosing and monitoring muscular conditions.

Keywords: pennation angle; muscular atrophy; tibialis cranialis

Introduction

Pennation angle and muscle physiological cross-sectional area are important factors related to muscle force generation [1–3]. The pennation angle originates from the term 'pennate', meaning "shaped like a wing". It is the angle between the muscle fiber and the aponeurosis. In human medicine, the pennation angle has been studied for muscle action such as force generation and for musculoskeletal modeling [2,4]. Several studies have examined the pennation angle of each muscle and alteration of pennation angle in muscle contraction, hypertrophy, and atrophy [5–8].

Ultrasonographic studies provide a better knowledge of the muscular architecture and can be used to explain the biomechanical muscle contraction in human [9–12]. Measurement of the pennation angle using ultrasound allows for the evaluation of the functional state and efficiency of muscles during contraction [10–

12], and can assess the degree of recovery and the effectiveness of the recovery process after muscle damage [13]. This method offers advantages as it is non-invasive, allows for repeated measurements, and can capture and analyze the muscle's state in real-time, enabling the assessment of dynamic muscle movement changes [12]. Additionally, ultrasonographic examinations provide high-resolution images that allow for accurate observation of detailed structural changes in muscles [12]. Ultrasound waves are reflected by the collagen-rich connective tissue between the muscle fibers, enabling visualization of the muscle fiber arrays [14]. Ultrasonographic images of normal muscle appear hypoechoic or anechoic with echogenic striations. The fascia, tendon, and aponeurose appear as hyperechoic lines. The angle between the fascicles and the tendons gives the angle of the muscle fibers to the line of the pennate muscle [15–17].

Muscle atrophy is defined as a decrease in the mass of the muscle [18]. Maintenance of muscle mass depends on intact innervations, proprioceptive activity, mechanical load, the ability to participate in the shortening-stretch cycle, and joint mobility [19]. Muscle atrophy can be induced by the absence of weight bearing activities such as denervation and chronic disuse [20,21].

In veterinary medicine, little is known concerning these architectural factors of skeletal muscle. This study was undertaken to measure the normal pennation angle in tibialis cranialis muscles and to confirm proper position for pennation angle measurement by comparison with the pennation angle in atrophied muscle. Muscles can be classified into unipennate, bipennate, and multipennate muscles based on the number of directions in which the fascicles are arranged relative to the tendon. The tibialis cranialis muscle is an unipennate muscle having fascicles angled on one side of the tendon [22]. This muscle was selected because it may be suitable for ultrasound-mediated detection, with no noticeable structural differences of the muscle between selected breeds. We hypothesize that the pennation angle would decrease in dogs with muscluar atrophy.

Materials and Methods

Animal recruitment

This study included dogs with musculoskeletal sonographic evaluation of hindlimbs for diagnostic purposes among clients of the University of Gyeongsang Veterinary Teaching Hospital and Animal Medical Center from April 2015 to September 2022. To be included in this study, patients had to have a body condition score of 4 to 6 on a 9-point scale. Patients with intervertebral disc disease and hormonal diseases were excluded. Dogs were grouped by breed (Maltese, Poodle, and Shih Tzu) and age (mature adult, 2 to 6 years old; senior, 7 to 11 years old; and geriatric, ≥ 12 years old) based on previous study [6].

All procedures were approved (GNU-LA-21) by the Institutional Animal Care and Use Committee of Gyeongsang National University. Three groups were allocated for pennation angle measurement. The normal group comprised clinically healthy dogs that were used to determine the normal pennation angle. Sixty-eight dogs (24 male and 44 female) of 5 breeds were enrolled in this group. Represented breeds were Beagle (n = 32), Maltese (n = 11), Shihtzu (n = 10), Yorkshire Terrier (n = 7) and Pomeranian (n = 8). The ages were 1 to 16 years (5.8 ± 3.4 years old, mean ± standard deviation [SD]). The body weights were 1.8 to 14.6 kg (7.2 ± 3.1 kg, mean ± SD). The second group was the ataxia group. It was comprised of dogs with bilateral hindlimb muscle atrophy caused by neurologic disorders. Twelve dogs were included in this group. The chief complaint of this group was paraparesis or tetraparesis (loss of voluntary movement of hindlimbs). Details of the signalments of the ataxia group are given in Table 1. The third group was the lameness group, which was comprised of dogs with unilateral hindlimb muscle atrophy caused by musculoskeletal abnormalities. The chief complaint of the lameness group was right or left hindlimb lameness, which limited physical function. Twelve dogs in this group had displayed the symptom for at least the prior 2 months.

Positions

For the ultrasonographic examination of the tibialis cranialis muscle, the dogs were positioned dorsal recumbency on the table. Three positions were used for measurement of the pennation angle: neutral, flexion, and extension. The neutral position was the natural posture of the leg, with 100 to 110 rad on the ankle joints. The flexion position involved maximum bending at the ankle joint to facilitate contraction of the tibialis cranialis muscle. The extension position stretched the leg as much as possible to relax the tibialis cranialis muscle. The pennation angle was measured from the left tibialis cranialis muscle in all groups. In addition, the pennation angle of the right tibialis cranialis muscles was measured in the lameness group.

Instrumentation

A real-time B-mode ultrasound apparatus (Xario SSA-660A; Toshiba, Japan) with a 12.0 MHz linear-array probe was used to obtain longitudinal images of the tibialis cranialis muscle. The scanning surface was applied with ultrasound gel or 50% alcohol with the probe placed perpendicular to the skin.

https://doi.org/10.14405/kjvr.20240018

Table 1. Signalments of patients in ataxia and lameness groups

Group	Breeds	Sex	Age	Body weight (kg)	Chief complain	Duration
Ataxia	Maltese	Male	6 y	4.2	Paraparesis	2 mo
	Maltese	Female	4 y	6.8	Paraparesis	2 mo
	Maltese	Female	4 y	5	Paraparesis	2 mo
	Maltese	Male	4 y	2.7	Tetraparesis	2 mo
	Pomeranian	Female	1 y	3.3	Paraparesis	4 mo
	Pomeranian	Female	7 mo	5.7	Paraparesis	4 mo
	Shih Tzu	Female	2 y	5.7	Paraparesis	2 mo
	Shih Tzu	Female	7 y	6.8	Paraparesis	2 mo
	Pekinese	Male	3 y	5.5	Tetraparesis	3 mo
	Pekinese	Male	6 y	6	Paraparesis	2 mo
	Yorkshire Terrier	Female	4 y	3.2	Paraparesis	2 mo
	Mixed	Male	3 y	6.2	Paraparesis	5 mo
Lameness	Maltese	Female	1 y	1.2	Right hindlimb lameness	4 mo
	Maltese	Male	4 y	5.4	Left hindlimb lameness	2 mo
	Maltese	Female	4 y	3.3	Left hindlimb lameness	2 mo
	Maltese	Male	4 y	4.6	Right hindlimb lameness	2 mo
	Maltese	Male	6 y	4.6	Left hindlimb lameness	2 mo
	Maltese	Male	3 y	5.2	Right hindlimb lameness	2 mo
	Shih Tzu	Male	7 y	5.4	Right hindlimb lameness	2 mo
	Shih Tzu	Male	3 y	5.2	Left hindlimb lameness	2 mo
	Yorkshire Terrier	Female	4 y	4.1	Left hindlimb lameness	1 y
	Yorkshire Terrier	Male	4 y	3.8	Left hindlimb lameness	2 mo
	Poodle	Male	4 y	5.9	Right hindlimb lameness	3 mo
	Sapsal	Female	2 y	12	Left hindlimb lameness	3 mo

Measurement of pennation angle

All pennation angle measurements were made at the central region, half-way between the proximal end of the tibia and the malleoli. The probe was positioned in the mid-sagittal axis of the tibialis cranialis muscle centered and the pennation angle measurement was taken at the level of the tibia and long digital extensor muscle confirmed by ultrasonography. The ultrasonographic image consisted of the superficial hypoechoic muscle with hyperechoic striations and the deep tibial surface with acoustic shadowing. The angle between the fascicles and deep aponeurosis represented the pennation angle of the tibialis cranialis muscle. The value of the angle was measured automatically in the ultrasound device by pointing to the fascicle and the aponeurosis (Fig. 1).

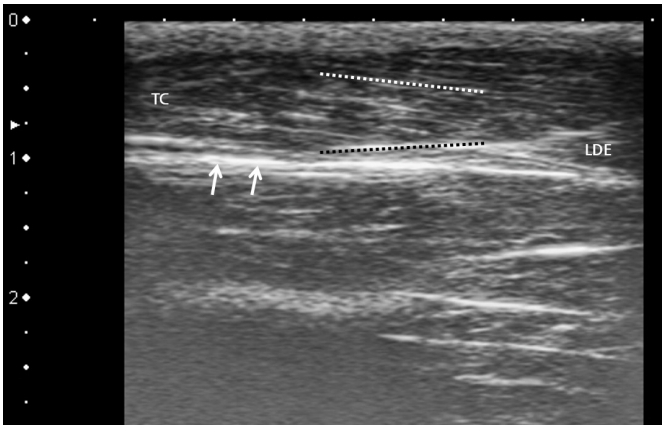

Fig. 1. Pennation angle measurement of tibialis cranialis muscle (TC). Measurement was taken at the middle of the muscle. To scan exactly the same region each time, the tibia surface (white arrows) and long digital extensor muscle (LDE) were used as markers. The angle between the fascicles (white dotted line) and deep aponeurosis (black dotted line) was measured.

Statistical analysis

Three models of statistical comparison were utilized: (1) comparing the normal pennation angle between 5 breeds, (2) comparing the normal pennation angle with that of atrophied muscle, and (3) comparing the pennation angle between limbs with suspected muscle atrophy and their contralateral limbs. Statistical analyses were conducted using SPSS ver. 12.0 (SPSS Inc., USA), with one-way ANOVA and multiple comparison Scheffe test for the first 2 comparisons, and paired t-test for the last comparison. The significance level was set at $p < 0.05$ for all analyses.

Results

Normal pennation angle

No significant differences of the pennation angle were found among the breeds in each posture (Fig. 2). However, there was a significant difference of the pennation angle with posture; generally, the angle was increased in the flexion position and decreased in the extension position (Fig. 3). The mean values (± SD) of the pennation angle in the 68 clinically healthy dogs were 4.97° (± 1.88) in the neutral position, 7.25° (± 2.68) in the flexion position, and 3.31° (± 1.33) in the extension position.

Comparison between normal and atrophied muscle

The pennation angle of the normal group was significantly different from the ataxia and lameness groups in all positions (Fig. 4), especially in the flexion position where there was a notable difference compared to the other positions ($p < 0.005$). The p-value of the neutral and extension positions was < 0.05. The pennation angles of the ataxia and lameness groups did not display a significant difference in all positions. The mean pennation angles (± SD) for the dogs with ataxia were 3.39° (± 2.43) in the neutral position, 4.23° (± 2.86) in the flexion position, and 2.00° (± 1.08) in the extension position. For the dogs with lameness, the mean pennation angles were 3.31° (± 2.21) in the neutral position, 3.08° (± 2.69) in the flexion position, and 1.46° (± 1.39) in the extension position.

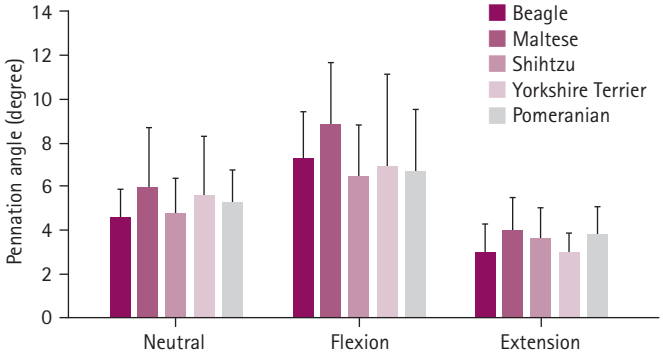

Fig. 2. Comparison of the normal pennation angle between the 5 breeds. No significant differences were evident in the neutral, flexion, and extension positions.

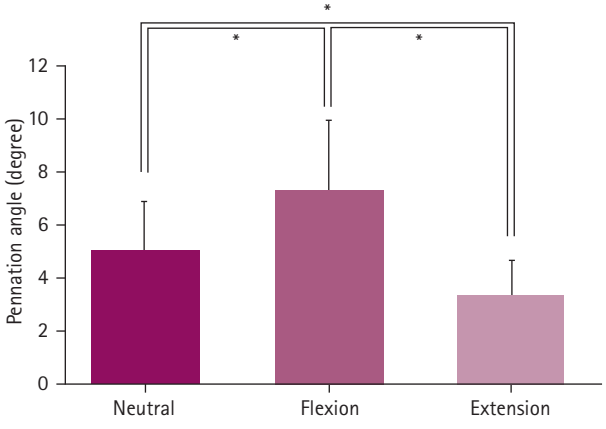

Fig. 3. Means of the normal pennation angle in 68 clinically healthy dogs. The mean of the normal pennation angle was 4.97° (± 1.88) in the neutral position, 7.25° (± 2.68) in the flexion position, and 3.31° (± 1.33) in the extension position. Pennation angles changed significantly in each of the neutral, flexion, and extension positions (*$p < 0.05$).

Comparison between muscular atrophied legs and contralateral legs in lamed dogs

Significant differences were shown in the neutral position and flexion position between muscular atrophied legs and contralateral legs (clinically normal) in the lameness group ($p < 0.05$). But, there was no significant difference in the extension position (Fig. 5). The mean pennation angles for the dogs with muscle atrophy were 3.08° (± 1.94) in the neutral position, 3.61° (± 2.33) in the flexion position, and 1.46° (± 1.40) in the extension position.

Discussion

In human medicine, muscle atrophy can be measured functionally or structurally. Structural measurement of muscle atrophy involves the measurement of the circumference of a limb by

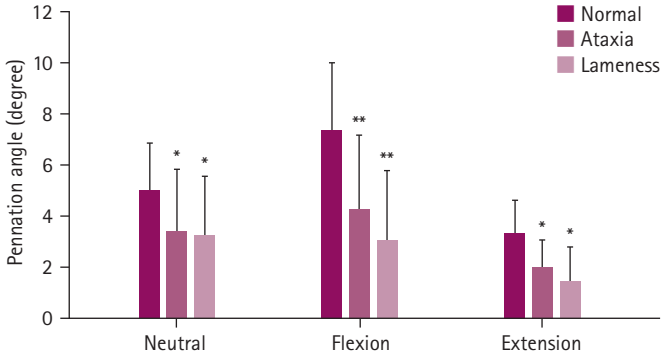

Fig. 4. Comparison of the pennation angle between the normal, ataxia, and lameness groups. The pennation angle of the normal group was significantly different from the ataxia group and lameness group. The flexion position produced a greater significant difference than the neutral and extension positions between normal and muscle atrophy. The ataxia and lameness groups had no significant differences in any position. Differences statistically significant compared to the normal dogs ($p < 0.05$, **$p < 0.005$).

https://doi.org/10.14405/kjvr.20240018

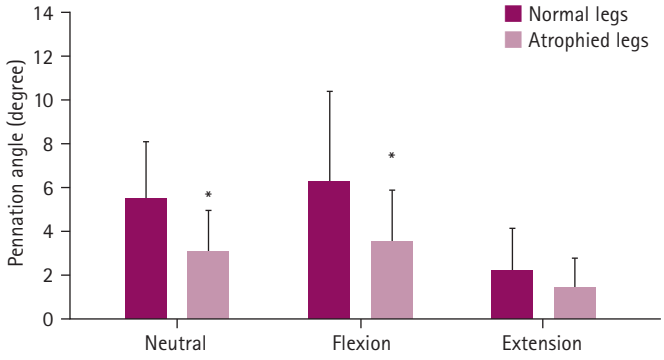

Fig. 5. Comparison of the pennation angle between the normal legs (contralateral legs) and muscular atrophied legs in the lameness group. Significant differences between the legs were apparent in the neutral and flexion positions. The extension position displayed no significant difference. *Differences statistically significant compared to the normal legs ($p < 0.05$).

sonography determination of muscle mass and microscopy-mediated evaluation of muscle fiber diameter [19]. In the veterinary clinic, however, there are no formal methods for measurement of muscle atrophy. Typically, muscle atrophy can be diagnosed compared with the other leg in the same dog using physical examination or radiography. But, these methods are limited in their capacity to diagnose muscle atrophy when muscle atrophy of both legs or muscle hypertrophy of the other leg has occurred. This study also used ultrasonography to measure the pennation angle, with the goal of observing the biomechanical structure in living tissue and to derive accurate data for skeletal muscle. In a previous human report, muscle atrophy decreased the pennation angle [7]. The same results were obtained in this study. In this study, comparison between the normal, ataxia, and lameness groups revealed a notable difference between the pennation angle in normal and atrophied muscle in the flexion position compared to the other positions. The results show that the flexion position is better to detect the change of pennation angle and the flexion position is proper to measure the pennation angle of tibialis cranialis muscle. Additionally, there was no significant difference between the pennation angle of the ataxia group and lameness group. It may indicate that the causes of muscle atrophy (denervation or disuse) may not affect the pennation angle.

In this study, the normal pennation angle of the tibialis cranialis muscle displayed no significant differences between the 5 breeds (Beagle, Maltese, Shihtzu, Yorkshire Terrier, and Pomeranian). While limited to only 5 breeds, these results revealed a similar pennation angle of the tibialis cranialis muscle in the different breeds. This study also revealed that the pennation angle changes according to the state of the muscle, being increased during contraction and decreased during muscle relaxation. These results similar to previous studies in human medicine [5,6,14].

For the more accurate comparison between the pennation angle of normal and atrophied muscle, statistical comparison between the normal leg and muscle atrophy leg in individual dogs should be conducted, rather than comparison between groups. According to this statistical comparison, the neutral and flexion positions can enable detection of the change in the pennation angle, but the extension position cannot distinguish the pennation angle of normal and atrophied legs. This result is considered to be due to the reduction of normal pennation angle values, so extension position is not appropriate for pennation angle measurement of tibialis cranialis muscle.

Pennation angle measurements using ultrasonography have some limitation related to the precise derivation of the angle. One of them is hard to know the exact location of the muscle when the scan is being taken. Although the transducer is placed in the same location in the middle of the tibia, it is hard to scan the same muscle region in all dogs unless there is a distinguishing mark on the leg. To minimize this problem, in this study, pennation angle measurements were conducted when long digital extensor muscle was identified caudally on the ultrasound screen at the level of the tibia surface. Another limitation is the change of the muscle shape according to transducer pressure and posture. It is important to maintain the muscle shape because the pennation angle can be affected by the form of the muscle. Proper probe pressure (soft contact) and correct posture are required for accurate measurement of pennation angle.

In conclusion, there was no significant difference in normal pennation angle of tibialis cranialis muscle between the 5 breeds of dogs. The pennation angle is reduced in atrophied muscle and that the flexion position is the most appropriate for pennation angle measurement of the tibialis cranialis muscle. This suggests that the pennation angle could serve as a valuable indicator of muscle health in dogs.

ORCID

Jaehwan Kim, https://orcid.org/0000-0001-9037-3406
Tae Sung Hwang, https://orcid.org/0000-0001-6730-6061
Hee Chun Lee, https://orcid.org/0000-0001-5936-9118

Author's Contributions

Conceptualization: all authors; Data curation: all authors; Investigation: Kim J, Hwang TS; Methodology: Kim J, Hwang TS;

Project administration: Hwang TS, Lee HC; Supervision: Lee HC; Validation: Lee HC; Writing–original draft: Kim J, Lee HC; Writing–review & editing: Hwang TS, Lee HC.

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https://doi.org/10.14405/kjvr.20240018