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Musculoskeletal analysis focusing on the gait of small dogs walking on slippery wooden floors*

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Abstract— **The objective of this study is to analyze the load on the musculoskeletal system of the lower limbs of small dogs walking on slippery flooring, focusing on differences in the walking patterns of small dogs. In Japan, small dogs such as Poodles, Corgis and Chihuahuas are often kept indoors on slippery flooring. Based on veterinary experience, these small dogs often suffering from lower limb joint diseases, and it is thought that this is caused by stress on the musculoskeletal system of the lower limbs when walking on slippery floors. Therefore, in this study, we investigated the gait of small dogs walking on slippery floors and estimated which muscles are stressed. Furthermore, we measured the gait of small dogs using motion capture and force plate system, and entered the measurement results into a musculoskeletal simulation model of small dogs that we developed. The simulation results identified that the muscles involved in adjusting balance during walking are heavily stressed in the gait of small dogs walking on slippery floors.**

I. INTRODUCTION

In Japan, many dogs are pet animals, and particularly small dogs such as Poodles, Corgis and Chihuahuas are increasingly being kept indoors in families [1]. Because people in Japan have a culture of taking their shoes off indoors, flat, smooth flooring or tatami mats are widely used as flooring in homes. Especially, wooden floor is popular for indoor dogs because it is easy to clean. However, such as flat, smooth wooden floors are slippery and can be stressful for dogs that have adapted to environments with enough friction, such as soil.

According to the experience of veterinarians, dogs kept indoors with wooden floors are more likely to suffer from lower limb joint diseases such as herniated discs [2]. When lower limb joint diseases become serious, dogs have difficulty walking and their quality of life declines significantly [3]. Furthermore, treatment for lower limb joint disease requires long-term rehabilitation by a physical therapist [4,5], and because dogs have a shorter lifespan than humans, many dogs die before the treatment period is over and end their lives without a complete cure. Therefore, it is important for owners of small dogs to prevent lower limb joint disease.

We have developed a coating material that increases the friction coefficient of slippery wooden floor, based on the assumption that walking on slippery flooring causes stress on the lower limbs of small dogs, which can lead to lower limb joint disease [6]. We have also developed a musculoskeletal simulation model that approximates small dogs in order to identify the stress on the muscles of small dogs walking on flooring that has been made less slippery by the coating material [7-9]. Furthermore, using the musculoskeletal simulation model we developed, we analyzed the lower limb muscle activity of small dogs walking on slippery flooring and flooring coated with the coating material, and found that small dogs use their lower limb muscles differently on slippery flooring and flooring coated with the coating material [10].

However, dogs have different gaits from humans (walk, trot), there are many muscles in the lower limbs to be analyzed, and it is difficult to have the test dogs walk with the same gait every time in measurement experiments. Therefore, although we could vaguely see that the stress on the lower limb muscles calculated using the musculoskeletal simulator differed between walking on a slippery floor and walking on a floor coated with a non-slip material, we did not know what the difference in the way the lower limb muscles were used meant [10]. On the other hand, veterinarians judge how dogs walk based on their gait, walking speed, stride length, and stance and swing phases [11]. Therefore, we believe that qualitative differences in walking motions can be identified by classifying the walking motions of small dogs on slippery and non-slippery floors from these perspectives. Furthermore, if we can see qualitative differences in walking motions, we can limit the types of muscles to be analyzed, enabling quantitative analysis of musculoskeletal simulation data.

Therefore, the objectives of this paper are to qualitatively explain the differences in gait between small dogs walking on slippery and non-slippery floors by classifying them based on veterinary knowledge, and to analyze the functions of the muscles related to this explanation using musculoskeletal simulation in order to quantitatively identify the effects of slippery and non-slippery floors on the musculoskeletal system of small dogs.

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II. MUSCULOSKELETAL MODEL OF A SMALL DOG

It is difficult to measure the amount of muscle activity in small dogs directly with muscle electromyography (EMG) sensors. This is because small dogs are difficult to attach electrodes to due to their small size, and because their body hair makes it difficult to measure surface muscle potential. Therefore, in this paper, we developed a musculoskeletal model of a small dog on a musculoskeletal simulator. We measured the posture of a small dog during walking motion using a motion capture system and measured the kicking force of the lower limbs using a force plate. By inputting the measured posture data and force data into our musculoskeletal dog model, it is possible to estimate the amount of force exerted by each muscle when a dog walks.

In this paper, we developed a musculoskeletal model for small dogs based on a musculoskeletal model of a large dog (Greyhound [12]) developed for the musculoskeletal simulator OpenSim [13], with reference to the opinions of veterinarians. Fig. 1 shows a whole-body musculoskeletal model of a small dog, and Fig. 2 shows a detailed view of the lower limbs. Based on interviews with veterinarians, this paper analyzed the lower limb muscles (Fig. 2 and Table 1) that are thought to be particularly related to walking motion.

In order to accurately estimate the muscle activity of the test dogs participating in the measurement experiment in the next section, the musculoskeletal model developed was adjusted according to the body parameters (height, length, leg length, weight, etc., Table 3) of the test dogs.

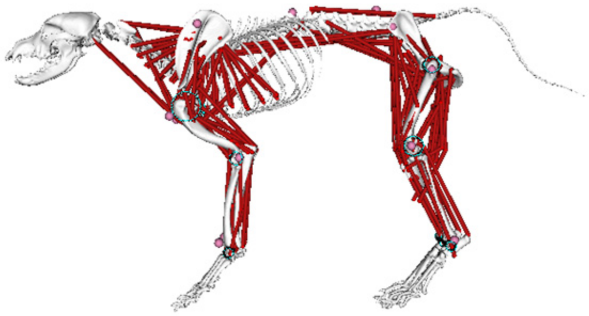
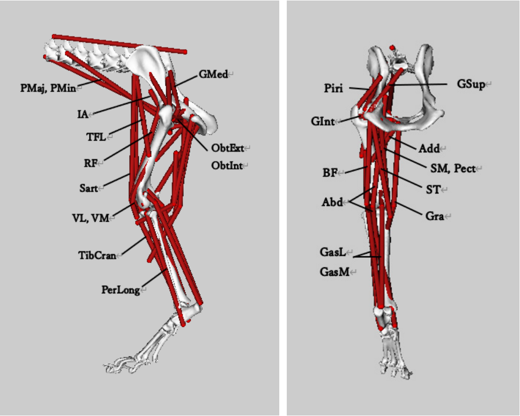


Figure 1. Musculoskeletal model of a small dog (Test dog A).



(a) Front view (b) Side view

Figure 2. Detail of lower limb section of a small dog musculoskeletal model.

III. MEASURING A SMALL DOG'S WALKING MOTION

A. Experimental Setup

Walking experiments were conducted with test dogs to confirm the differences in walking motion when small dogs walk on slippery and non-slippery floors. The test course floor was made of wooden flooring material [14] widely used in Japan for indoor flooring. Furthermore, as shown in Fig. 3, we prepared two types of flooring: wooden flooring with a coating material developed by us to improve the coefficient of friction [6] (non-slip flooring) and uncoated wooden flooring (slippery flooring).

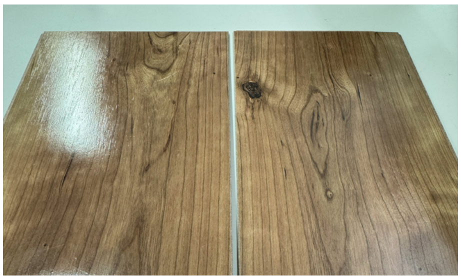
TABLE I. MUSCLES OF A LOWER LIMB DOG MODEL.

Abbreviation	Muscular Name	The way muscles work
GMed	Gluteus medius	Extension and abduction of the hip joint. Internal rotation of the hind limb.
GInt	Gluteus profundus	
GSup	Gluteus superficialis	External rotation of the hip joint. Abduction of the limb.
ObtExt	Obturator externus	External rotation of the hind limb.
ObtInt	Obturator internus	Abduction of the hindlimb at the hip joint.
Add	Adductoren	Hind limb adduction.
Abd	Abductor cruris	Hind limb abduction.
Pect	Pectineus	Hind limb adduction.
Piri	Piriformis	External rotation of the hip joint.
Sart	Sartorius	Flexion of the hip joint. Flexion of the knee joint .
VL	Vastus lateralis	Extension of the knee joint.
VM	Vastus medialis	
RF	Rectus femoris	Extension of the knee joint. Flexion of the hip joint.
TFL	Tensor fascia lata	Tension of the lateral thigh fascia. Extension of the knee joint. Flexion of the hip joint.
IA	Iliacus	Hip flexion, external rotation.
QF	Quadratus femoris	Extension of the hip joint. External rotation of the hind limb.
Gra	Gracilis	Hind limb adduction, knee joint flexion. Extension of hip and tarsal joints.
ST	Semitendinosus	Extension of the hip joint, flexion of the knee joint and extension of the tarsal joint.
SM	Semimembranosus	Extension of the hip joint . Flexion and extension of the knee joint.
BF	Biceps femoris	Extension of the hip, knee and tarsal joints. Flexion of the knee joint.
GasL	Gastrocnemius lateralis	Extension of the tarsal joints. Flexion of the knee joint.
GasM	Gastrocnemius medialis	
TibCran	Tibialis cranialis	Flexion of the tarsometatarsal joint. External rotation of the foot. (turning the foot plantar surface inwards)
PerLong	Peroneus longus	Flexion of the tarsal joint. Internal rotation of the foot. (turning the foot plantar surface outwards).

The C.S.R.D value has been proposed in previous studies as an indicator of the slip resistance of flooring required for the daily life of small dogs [15]. According to previous studies, a C.S.R.D value of 0.497 allows small dogs to walk normally with a probability of 99%, while a value of 0.218 allows them to walk normally with a probability of 50%. In this study, we measured the friction coefficient between a foam rubber sheet approximating the softness of paw pads and two types of flooring based on the C.S.R.D value measurement method. The measurement results are shown in Table 2. These results suggest that small dogs have difficulty walking on slippery floors, but can walk normally on non-slippery floors.

The test course as Fig. 3(a) is 3[m] long and 0.9[m] wide, and the test dogs walk along it as directed by the veterinarian. There are two types of flooring for the test course: non-slip and slippery. Both types are identical in size and appearance so that the test dogs are not able to distinguish between them. The posture of the test dogs when walking was recorded using a three-dimensional motion capture device. Motion capture markers were attached to the test dogs over clothing that fit their body types, as shown in Fig. 3(b), to prevent the markers from shifting due to their fur. A force plate for dogs was installed in the center of the test course to measure the force exerted by the lower limbs of the test dogs when walking.

In this study, measurement experiments on the test dogs were executed under the supervision of veterinarians. In addition, the measurement experiments were conducted in full compliance with the animal ethics rules of the Kyoto AR Animal Advanced Medical Center.

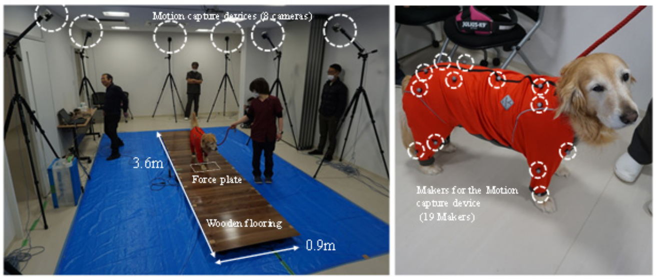


(a) With coating material (b) Without coating material

Figure 3. Wooden flooring used in the experiment.

TABLE II. THE FRICTION COEFFICIENTS OF FLOORING MATERIALS

	With coating material	**Without coating material**
coefficient of static friction	0.506	0.295



(a) Experimental environment (b) Markers attached to the dog

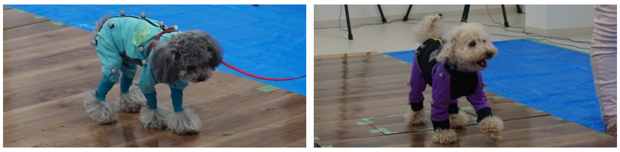
Figure 4. Experimental Setup.

B. Test dogs

The dogs that participated in this study are shown in Table 3 and Fig. 2. The test dogs were kept indoors on a daily basis.

TABLE III. BODY PARAMETERS OF TEST DOGS

Subject		**A**	**B**	**C**	**D**
Name		TOTO	QOO	MARU	KUERU
Type		Poodle	Poodle	Poodle	German Shepherd
Sex		M	M	M	M
Age		10	9	2	1
Weight [kg]		3.0	3.0	5.0	38.2
Length [m]	***Body length***	0.26	0.23	0.31	0.60
	Body height	0.28	0.30	0.29	0.63
	Femur	0.10	0.13	0.10	0.25
	Tibia	0.08	0.11	0.09	0.20
	Hock	0.07	0.07	0.08	0.12
	Metatarsus	0.06	0.07	0.07	0.09
Living Environment		Wooden Flooring		Linoleum	Artificial turf



(a) Subject A (b) Subject B

(c) Subject C (d) Subject D

Figure 5. Test dogs.

C. Evaluation Index for Experiment Results

We conducted interviews to find out what indicators veterinarians use to determine whether a dog's gait is normal. As a result, we decided to classify dogs' gaits in this study using the following indicators that veterinarians focus on.

- Walking speed, stride length and kicking force
- Balance between stance phase and swing phase
- Walking Gait (walking or trotting? Are there phases where the gait is disordered?)

In this paper, as shown in Fig. 6, the period from the moment the lower limb of a dog touches the ground to the moment it leaves the ground is defined as the stance phase, and the period from the moment it leaves the ground to the moment it next touches the ground is defined as the swing phase [16].

Figure 6. Stance phase and swing phase [16].

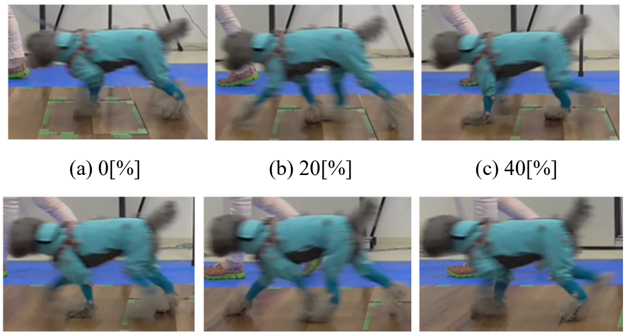
D. Experimental Results

In this measurement experiment, all test dogs walked on two types of flooring courses about 10 times. Fig. 7 shows an example of test dog A walking on the test course with non-slip flooring. Furthermore, Fig. 8 shows walking speed, Fig. 9 shows stride length, Fig. 10 shows lower limb kick-off force, and Fig. 11 shows stance phase length.

Figs. 10(a), (b) and (c) show that test dogs A to C, which are small dogs, exerted greater kicking force with their lower limbs on slippery flooring than on non-slippery flooring. On the other hand, as shown in Fig. 10(d), test dog D, which is a large dog, showed no change in the kicking force of its lower limbs depending on the friction coefficient of the flooring. It is thought that small dogs increased the positive pressure at the point of contact with the ground on slippery flooring, thereby increasing the friction force that pushed their bodies forward in the direction of travel. On the other hand, large dogs are heavy, so they can generate enough friction even on slippery flooring, and therefore there was no difference in the kicking force of their lower limbs.

Test dog A increased its walking speed on slippery flooring (Fig. 8(a)), but its stride length decreased (Fig. 9(a)). Furthermore, the variation in the length of the stance phase decreased (Fig. 11(a)). From these results, test dog A is presumed to have moved quickly while taking small steps on slippery flooring, i.e., walking cautiously.

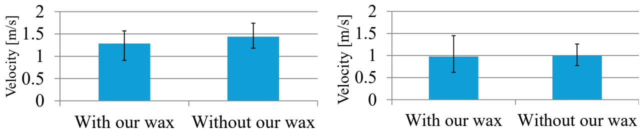
Test dogs B and C showed no difference in walking speed on slippery and non-slippery flooring (Figs. 8(b) and (c)). On the other hand, their stride length increased on slippery flooring (Figs. 9(b) and (c)), and the variation in stance phase length decreased (Figs. 11(b) and (c)). From this, the test dogs B and C walked with same strides length on slippery flooring. In other words, similar to test dog A, these dogs are presumed to have walked cautiously on slippery flooring.



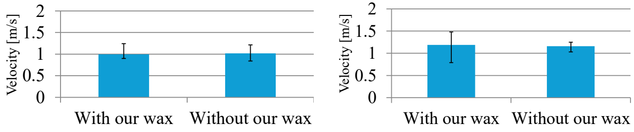
(a) 0[%] (b) 20[%] (c) 40[%]

(d) 60[%] (e) 80[%] (f) 100[%]

Figure 7. Test dog A walking on a non-slip floor.

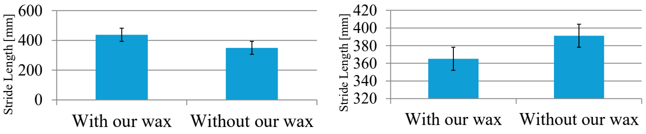


(a) Subject A (b) Subject B

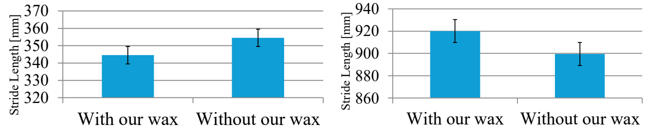


(c) Subject C (d) Subject D

Figure 8. Walking speed.

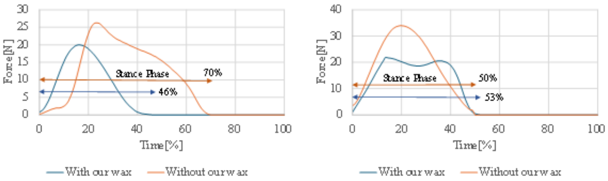


(a) Subject A (b) Subject B

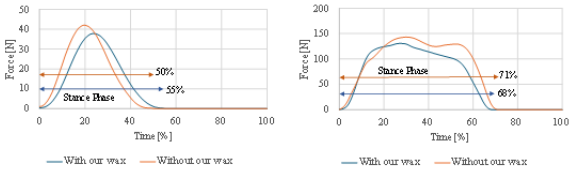


(c) Subject C (d) Subject D

Figure 9. Stride length.

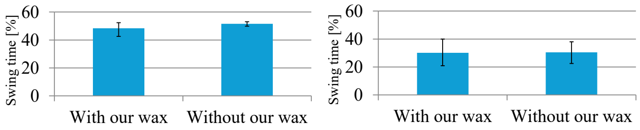


(a) Subject A (b) Subject B

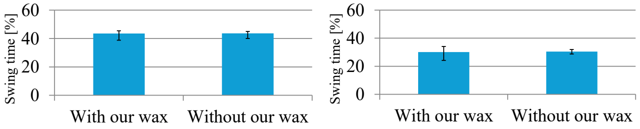


(c) Subject C (d) Subject D

Figure 10. Kicking force when a dog walks at maximum speed.



(a) Subject A (b) Subject B



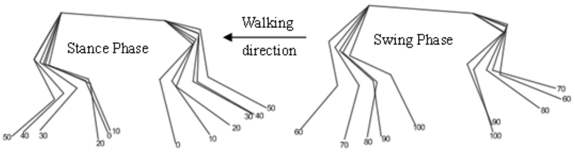
(c) Subject C (d) Subject D

Figure 11. Stance length.

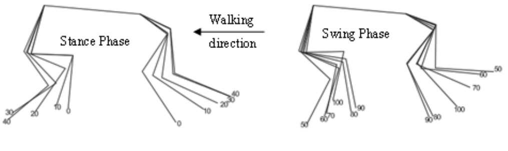
Test dog D showed less variation in walking speed and stance phase length on slippery flooring (Fig. 8(d) and Fig. 11(d)). From this, like test dogs A, B and C, test dog D is thought to have walked cautiously on slippery flooring.

E. Walking gait

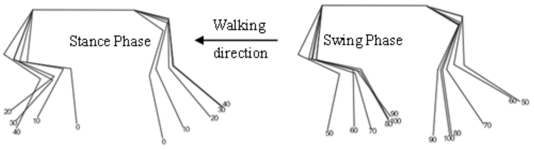
The previous section showed that the test dogs walked cautiously on slippery floors. This suggests that dogs tend to lose their posture on slippery floors. Therefore, Fig. 12 shows the changes in the walking posture of the test dogs when walking at the fastest speed, which is considered to be the most likely to cause loss of posture.



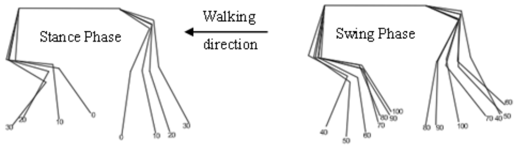
(a) Test dog A on non-slippery flooring (Trot gait).



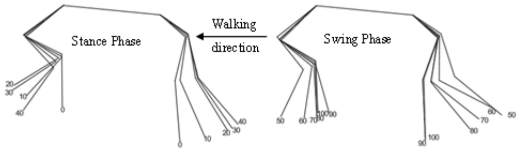
(b) Test dog A on slippery flooring (Trot gait).



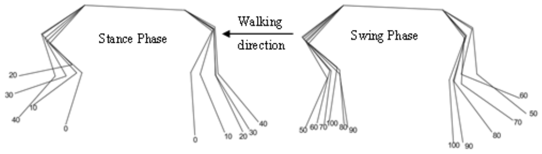
(c) Test dog B on non-slippery flooring (Trot gait).



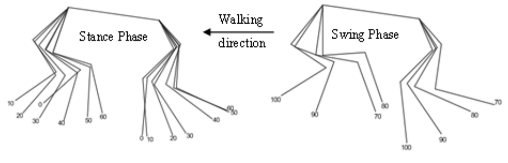
(d) Test dog B on slippery flooring (Trot gait).



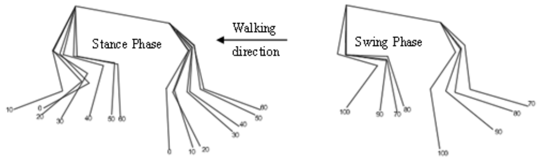
(e) Test dog C on non-slippery flooring (Trot gait).



(f) Test dog C on slippery flooring (Trot gait).



(g) Test dog D on non-slippery flooring (Walk gait).



(h) Test dog D on slippery flooring (Walk gait).

Figure 12. Stick pictures which show walking motion of test dogs. Divided into the stance phase and swing phase of the hind legs. The numbers on the front and hind legs indicate the degree of progress of one step (0-100%).

Comparing Figs. 12(a) and (b), test dog A kicked its hind legs less during the hind leg stance phase (0–50%) on slippery flooring than on non-slippery flooring. This indicates that test dog A was unable to perform the kicking motion necessary to obtain forward traction for walking on slippery flooring. Furthermore, on slippery flooring, the front legs make small adjustments to their position during the hind leg swing phase (50-100%, with the front legs standing at this time), and the hind legs also make small, discontinuous movements to adjust their ground contact position during the transition from the hind leg swing phase to the hind leg swing phase (100-0%). It is suggested that these movements are performed by the dogs to avoid slipping.

From Figs. 12(c) and (d), test dog B shows a smaller kick with its hind legs during the hind leg stance phase (0-50%) on slippery flooring. During the same period, the movement of the front legs, which are in the swing phase, becomes larger in order to maintain body balance. Figs. 12(e) and (f) show that test dog C's hind leg kick during the hind leg stance phase (0-50%) did not differ significantly between the slippery and non-slippery flooring. However, as in test dog B, the movement of the front legs, which were in the swing phase, increased during the same period to maintain body balance.

As seen in Figs. 12(g) and (h), there was no significant difference in the gait of test dog D between slippery flooring and non-slippery flooring. Test dog D was a large dog and the test course was narrow, so test dog D walked the test course using a walk gait. Because the walk gait is slower than the trot gait, it is thought that test dog D was able to walk without any problems even on slippery flooring.

IV. MUSCULOSKELETAL ANALYSIS

Through walking measurement experiments and classification of walking motions from a veterinary perspective, we believe that the following two problems occur when small dogs walk on slippery flooring.

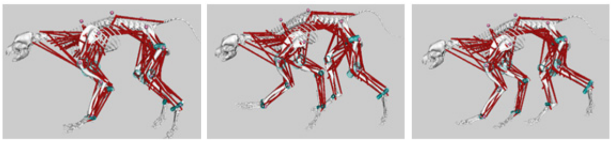
- They cannot kick their supporting legs backward with enough force.
- They perform discontinuous, small movements with their free legs to maintain their balance.

In order to confirm the stress on the muscles caused by these movements, this paper analyzed muscle performance, focusing on the muscle groups that extend the knee joint to kick backward and the muscle groups that adjust posture.

In this paper, posture data (measured using motion capture) and lower limb kick-off force (measured using a force plate) of test dogs A, B, C walking on a test course were input into a musculoskeletal model applying the physical parameters of each dog, and simulations were performed. As an example, the simulation results of test dog A walking as shown in Fig. 7 are shown in Fig. 13. Musculoskeletal simulation was not performed on test dog D because he was able to walk normally even on slippery flooring.

Fig. 14 shows the amount of muscle activity that stabilizes the posture, particularly from the hip joint to the knee joint. Test dogs A, B, and C all showed increased muscle activity on the slippery floor. According to previous studies, dogs kept indoors are reported to be more prone to ACL (anterior cruciate ligament) injuries [17], and the ACL also acts to stabilize the posture of dogs when walking. Therefore, dogs walking on slippery floors may cause ACL injuries by overusing these muscles.

Fig. 15 shows the amount of muscle exertion required to extend the knee joint and kick the hind legs backward. It can be seen that the amount of muscle exertion was greater for test dogs A, B, and C on non-slip flooring. On the other hand, the amount of muscle exertion was smaller on slippery flooring. This indicates that the test dogs were able to kick backward with sufficient force on non-slip flooring.



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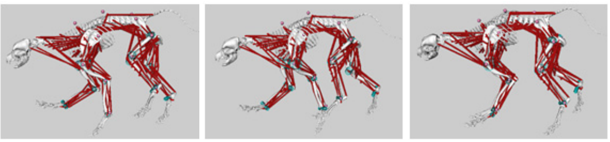
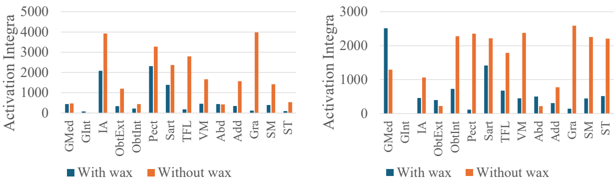
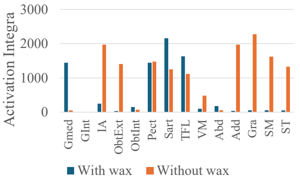


(d) 60[%] (e) 80[%] (f) 100[%]

Figure 13. Musculoskeletal simulation of test dog A walking on a non-slip floor.

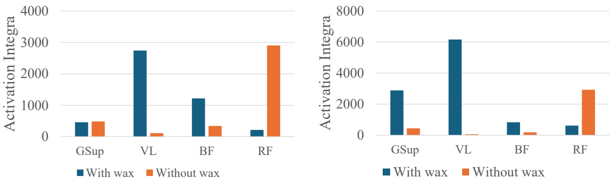


(a) Subject A (b) Subject B

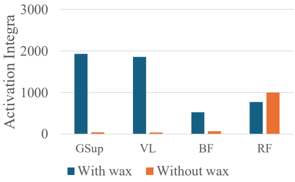


(c) Subject C

Figure 14. Muscle used for posture adjustment (integral value for one step)



(a) Subject A (b) Subject B



(c) Subject C

Figure 15. Muscle used for knee extension (integral value for one step)

V. CONCLUSION

The objective of this paper was to identify the stress on the musculoskeletal system of the lower limbs of small dogs walking on slippery flooring. We interviewed veterinarians and classified the walking motions of small dogs on slippery and non-slippery flooring based on their viewpoint. The results suggested that small dogs walk carefully while maintaining their balance when walking on slippery flooring. On the other hand, on non-slippery flooring, they kick off with sufficient force during the support leg phase. Analysis using a musculoskeletal simulator showed that on slippery flooring, small dogs overuse the muscles that act to stabilize their posture, while on non-slippery flooring, they effectively kick the ground by flexing and extending their knees.

REFERENCES

[1] H. Sugita, "The dog ownership rate and the demographic background of dog owners from 2001 to 2006: from keeping dogs outside to inside," *The review of the Osaka Univ. of Commerce*, No.5, Vol.5, p.71-86, 2010.

[2] I. Kathmann, *et al.*, "Daily controlled physiotherapy increases survival time in dogs with suspected degenerative myelopathy," *J. of Veterinary Internal Medicine*, Vol.20, No.4, pp.927-932, 2006.

[3] H. Kamishina, "Degenerative Myelopathy," *Japanese J. of Veterinary Anesthesia & Surgery*, Vol.41, No.3&4, pp.63-69, 2011.

[4] N. Nobuoka, "Current State and Future Directions of Physical Therapy for Animals," *Physical Therapy Japan*, Vol.45, No.4, p.281, 2018.

[5] S. Manabe, *et al.*, "Modeling of lower leg rehabilitation methods for small dogs and development of its teaching system," *19th Japanese Conf. of the Systems Integration Division, the Society of Instrument and Control Engineers*, pp.2631-2633, 2018.

[6] Anti-slip floor coatings for indoor dogs, Rinrei Co., Ltd., https://www.rinrei.co.jp/home_care/pet/01/coating.html

[7] D. Maruyama, *et al.*, "Analysis of Rehabilitation Methods Based on the Lower Limb Musculoskeletal Model of Small Dogs," *21st Japanese Conf. of the Systems Integration Division, the Society of Instrument and Control Engineers*, pp.137-138, 2020.

[8] D. Chugo, *et al.*, "Analysis of Rehabilitation Methods for Small Dogs Based on the Muscular Activity, " in *Proc. of the 32nd Int. Symp. on Industrial Electronics*, 2023, doi: 10.1109/ISIE51358.2023.10228073.

[9] D. Chugo *et al.*, "Analysis of the musculoskeletal effects of lower limb slippage when indoor dogs walk on the wooden floor," in *Proc. of IEEE 33rd Int. Symp. on Industrial Electronics*, 2024.

[10] S. Li *et al.*, "Analysis of the Musculoskeletal Load Generated when a Small Dog Walks on a Slippery Floor*," *in proc of 2025 IEEE/SICE Int. Symp. on System Integration (SII)*, pp. 515-520, 2025.

[11] G. Catavitello *et al.*, "Planar Covariation of Hindlimb and Forelimb Elevation Angles during Terrestrial and Aquatic Locomotion of Dogs," PLoS ONE 10(7): e0133936. doi:10.1371/journal.pone.0133936, 2015.

[12] R. G. Ellis, *et al.*, "Limb Kinematics, Kinetics and Muscle Dynamics During the Sit-to-Stand Transition in Greyhounds," *Frontiers in Bioengineering and Biotechnology*, Vol.6, Article 162, 2018.

[13] S. L. Delp *et al.*, "OpenSim: Open-Source Software to Create and Analyze Dynamic Simulations of Movement," in *IEEE Trans. on Biomedical Engineering*, vol. 54, no. 11, pp. 1940-1950, 2007.

[14] USUI-TA, Panasonic Corp. https://sumai.panasonic.jp/interior/floor/lineup/flooring.php?name=usui-ta

[15] Y. Yokoyama *et. al.*, "A proposal of optimal slip resistance allowing for uninhibited movement of small-breed dogs," in *J. Struct. Constr. Eng., AIJ*, Vol.78, No.690, 1359-1365, 2013.

[16] K. Yoshikawa *et al.*, "Functional assessment of the gluteus medius, cranial part of the biceps femoris, and vastus lateralis in Beagle dogs based on a novel gait phase classification," in *J. Vet. Med. Sci.*, Vol.83, No.1, pp.116-124, 2021.

[17] Binversie EE, *et al.*, "Canine ACL rupture: a spontaneous large animal model of human ACL rupture," in *BMC Musculoskelet Disord*, Vol.23, No.1, pp.116, 2022. doi: 10.1186/s12891-021-04986-z.