Case Report

Assessment of hind limb muscle activity after stair-climbing in a dog using ^{18}F-FDG PET/CT: A case report

Heesoo Ahn[1†] Seungho Lee[1†] Yoocheol Shin[1†] Byoungho An[1]
Dongwook Kim[1] Byeong-Teck Kang[1] Gonhyung Kim[1*]

Abstract

Accurate assessment of functional muscle activation is important for planning rehabilitation exercises in canine patients. Conventional methods, such as electromyography and gait analysis, have limitations in evaluating deep muscles and providing a comprehensive assessment of muscle activity. This case study used ^{18}F-fluorodeoxyglucose (FDG) positron emission tomography/computed tomography (PET/CT) to assess hind limb muscle activity in a dog after stair-climbing exercise. A 4-year-old castrated male Beagle underwent 1 h of stair-climbing exercise followed by FDG PET/CT scanning. Increased FDG uptake was observed in multiple hind limb muscles, particularly the gluteus medius and quadratus femoris muscles. The quadratus femoris, a deep muscle that is difficult to assess using conventional methods, showed prominent FDG uptake among the hind limb muscles evaluated. Differences in FDG uptake were also observed between the semitendinosus and semimembranosus muscles despite their similar functions. Relatively lower uptake was noted in the psoas major and psoas minor muscles involved in hip flexion. These findings suggest that FDG PET/CT may be useful for evaluating exercise-related muscle activity, including activity in deep muscles, in dogs.

Keywords: dog, FDG PET/CT, muscle activation, rehabilitation, stair-climbing

[1]*Veterinary Teaching Hospital, College of Veterinary Medicine, Chungbuk National University, Cheongju 28644, Republic of Korea*

†These authors contributed equally to the work.

***Correspondence:** *ghkim@cbu.ac.kr* (G. Kim)
Received June 4, 2026
Accepted September 21, 2026
https://doi.org/10.56808/2985-1130.4085

Introduction

Understanding muscle activation patterns is important for designing effective rehabilitation strategies in canine patients, as coordinated muscle activity contributes to joint stability and normal movement (Cholewicki and McGill, 1996). Canine rehabilitation is commonly indicated for orthopedic conditions such as fractures and joint or tendon disorders, as well as for recovery following orthopedic surgery (Davidson *et al.*, 2005; Baltzer, 2020). These conditions frequently result in muscle weakness and altered neuromuscular control, compromising joint stability and functional performance (Berté *et al.*, 2012; Millis and Ciuperca, 2015). Stair-climbing is a functional exercise commonly used to strengthen the quadriceps and gluteal muscles more effectively than walking or trotting. Unlike level walking, stair-climbing requires elevation of the body against gravity, shifting the center of mass and increasing loading on the hip and stifle joints, thereby placing greater demands on the quadriceps and gluteal muscle groups (Andriacchi *et al.*, 1980; Protopapadaki *et al.*, 2007; Durant *et al.*, 2011; Millis and Levine, 2013). Several methods have been used to evaluate hind limb muscle activity during rehabilitation, including kinematic analysis, instrumented muscle strength testing, and electromyography (EMG) (Holler *et al.*, 2010; McLean *et al.*, 2019; Zink and Van Dyke, 2025). While kinematic analysis and muscle strength testing provide valuable information on functional performance during rehabilitation, they do not directly assess the activation of individual muscles. Although EMG can assess muscle activation patterns, it is limited by its inability to comprehensively evaluate deep muscles and by the restricted number of muscles that can be assessed simultaneously (Besomi *et al.*, 2019). Consequently, comprehensive assessment of coordinated muscle activation across multiple superficial and deep muscles remains challenging. ^{18}F-fluorodeoxyglucose (FDG) positron emission tomography/computed tomography (PET/CT) enables simultaneous evaluation of metabolic activity across multiple muscle groups throughout the body. Despite requiring specialized equipment, radiation exposure, and sedation or general anesthesia in veterinary patients, this technique offers a unique whole-body evaluation of exercise-induced muscle activation that cannot readily be achieved using conventional methods. Because FDG uptake reflects muscle glucose metabolism during the tracer uptake period, the timing of exercise, tracer administration, and image acquisition is an important methodological consideration when interpreting exercise-induced muscle activity. In human medicine, FDG PET/CT has been used to evaluate muscle activation following exercise and to provide insight into whole-body metabolic responses (Tashiro *et al.*, 1999; Bojsen-Møller *et al.*, 2010; Shiozawa *et al.*, 2018). However, its application in veterinary medicine remains limited. To our knowledge, no previous studies have evaluated canine muscle activation patterns after functional exercise using FDG PET/CT. Therefore, this case study aimed to assess hind limb muscle activity in a dog following stair-climbing exercise using FDG PET/CT and to explore its potential application in canine rehabilitation.

Case Description

A 4-year-old castrated male Beagle dog weighing 11.5 kg presented for orthopedic evaluation. The dog showed no clinical signs of lameness, and physical examination revealed no significant abnormalities. Vital signs were within normal ranges, and the dog was considered clinically healthy based on physical, laboratory, and imaging assessments. Informed consent was obtained prior to anesthesia and imaging procedures. Prior to FDG PET/CT scanning, the dog performed stair-climbing exercise for 1 h on a standard indoor staircase ascending to the fourth floor. After each ascent, the dog returned by elevator to avoid additional muscle activity associated with descent. The stair-climbing exercise was repeated 2–3 times per set, with approximately 5 min of rest between sets to prevent excessive fatigue. The dog was guided using a harness during the stair-climbing exercise. A whole-body FDG PET/CT scan was performed using a PET/CT system (Discovery STE 72, GE Healthcare, USA). Immediately after completion of the stair-climbing exercise, FDG was administered intravenously at a dose of 5.46 MBq/kg as a slow bolus, followed by flushing with 0.9% NaCl. After a 1-hour uptake period under resting conditions, anesthesia was induced with intravenous alfaxalone (3 mg/kg; Alfaxan, Jurox Pty Ltd., Australia) and maintained with isoflurane (Terrell, Piramal Critical Care Inc., USA). Anesthesia was induced only after completion of the FDG uptake period to minimize its potential influence on FDG distribution and muscle metabolism. A whole-body helical CT scan was performed, followed by PET image acquisition. PET images were analyzed using OsiriX MD v10.0 (Pixmeo, Bernex, Switzerland). Regions of interest were manually drawn for 19 muscles across four anatomical regions (trunk, pelvis, thigh, and calf). For each muscle, the standardized uptake value (SUV) was calculated, and the maximum standardized uptake value (SUVmax) was recorded. SUV was calculated as the tissue concentration of FDG (MBq/mL) divided by the injected dose (MBq), normalized to body weight (g). Reference data were obtained from a clinically healthy 3-year-old intact male Beagle dog (10.4 kg) that had previously undergone FDG PET/CT under similar experimental conditions (Institutional Animal Care and Use Committee approval no. CBNUA-1413-20-01). To minimize physiological FDG uptake unrelated to exercise, body movement and stress were minimized by maintaining the dog in a quiet and low-light environment prior to imaging. Except for the omission of stair-climbing exercise, all other conditions, including fasting, anesthesia protocol, FDG dose and imaging procedure, were consistent with those used in the exercised dog. Three-dimensional PET maximum intensity projection images provided an overview of FDG distribution prior to detailed evaluation (Fig. 1). In the control dog, FDG uptake in skeletal muscle was relatively low, whereas higher uptake was observed in

the brain, myocardium, and abdominal organs. In the exercised dog, FDG uptake in abdominal organs was reduced, while myocardial activity increased, and marked uptake was observed in the hind limbs (Fig. 2). SUVmax values of hind limb muscles were generally higher in the exercised dog than in the control dog. The SUVmax values for each muscle are summarized in Table 1. In the control dog, SUVmax values were low across all muscles (range, 0.46–0.99). Following stair-climbing, marked increases in FDG uptake were observed, with mean SUVmax values reaching 8.06 in the gluteus medius and 8.01 in the quadratus femoris. Among the evaluated muscles, the gluteus medius showed the highest SUVmax, followed by the quadratus femoris. Increased FDG uptake was also observed in the biceps femoris, adductor, quadriceps femoris, and semimembranosus muscles, whereas relatively lower uptake was noted in the psoas major and minor. Differences in FDG uptake were observed between muscles with similar functions. In particular, the semimembranosus showed higher uptake than the semitendinosus.

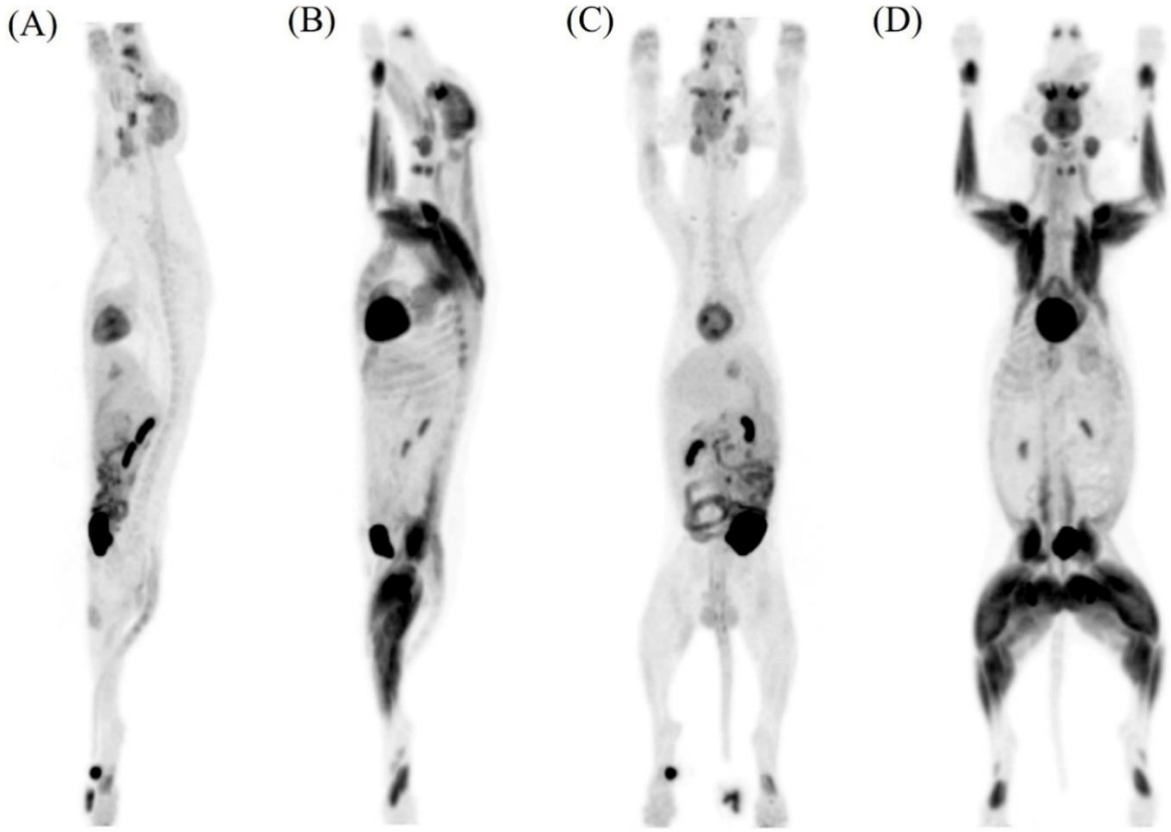

Figure 1 Maximum intensity projection (MIP) images of the whole body. The same upper threshold for the standardized uptake value was applied to the grayscale intensity of the positron emission tomography images. Sagittal MIP views are shown for the control dog (A) and the exercised dog (B), whereas dorsal MIP views are shown for the control dog (C) and the exercised dog (D).

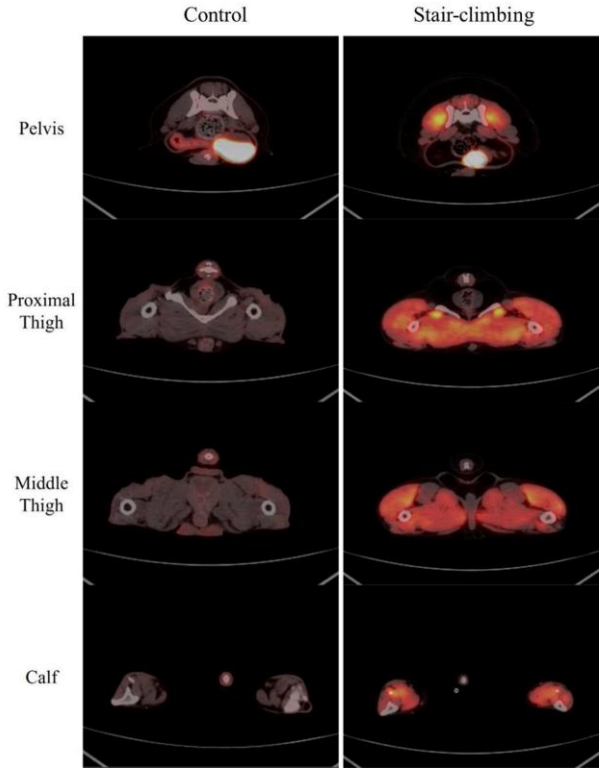

Figure 2 Fused positron emission tomography/computed tomography images using ^{18}F-fluorodeoxyglucose (FDG). The images demonstrate FDG uptake in the pelvis, proximal thigh, mid-thigh, and calf regions. The images on the left represent the control dog, whereas those on the right show the FDG uptake pattern after 1 h of stair-climbing exercise.

Table 1 The maximum standardized uptake value (SUVmax) of selected muscles.

Region (muscle)	Control		Stair-climbing	
	Left	Right	Left	Right
Trunk				
Psoas major	0.78	0.73	1.47	1.91
Psoas minor	0.99	0.90	1.12	1.61
Pelvis				
Gluteus superficialis	0.60	0.61	1.51	1.21
Gluteus medius	0.77	0.90	8.99	7.13
Gluteus profundus	0.65	0.88	3.31	3.57
Quadratus femoris	0.76	0.83	7.99	8.02
Thigh				
Biceps femoris	0.80	0.85	6.00	6.15
Semimembranosus	0.65	0.69	4.24	3.77
Semitendinosus	0.71	0.84	2.35	2.86
Adductor	0.53	0.55	5.25	4.21
Sartorius	0.52	0.60	2.26	1.72
Gracilis	0.61	0.60	1.80	2.20
Vastus medialis	0.46	0.60	4.72	3.96
Vastus lateralis	0.50	0.67	4.03	4.02
Rectus femoris	0.70	0.71	3.88	4.42
Calf				
Tibialis cranialis	0.81	0.67	2.88	2.88
Gastrocnemius	0.62	0.64	5.30	5.54
Fibularis longus	0.87	0.76	3.18	3.41
Extensor digitorum longus	0.92	0.81	4.24	4.66

Discussion

In this case, FDG PET/CT enabled visualization of muscle-specific metabolic activity in the hind limbs following stair-climbing. Increased FDG uptake was observed in multiple hind limb muscles, particularly the gluteus medius and quadratus femoris, as well as the biceps femoris, adductor, quadriceps femoris, and semimembranosus. These muscles are involved in hip extension, flexion, and adduction, suggesting coordinated activation of multiple muscle groups during stair-climbing. These findings are consistent with previous reports describing stair-climbing as a high-demand functional exercise involving complex joint motion (Durant *et al.*, 2011). Notably, increased FDG uptake was observed in the quadratus femoris, a deep muscle involved in hip extension and external rotation that is difficult to assess using conventional methods such as EMG. Human studies have also reported its activity during dynamic movements and a role in hip stabilization (Semciw *et al.*, 2015), suggesting a similar function in dogs during stair-climbing. Differences in FDG uptake were observed between muscles with similar functions, with the semimembranosus showing higher uptake than the semitendinosus. This finding may reflect their different contributions to hip extension and stifle stabilization during stair-climbing. Interestingly, the relatively low FDG uptake observed in the psoas major and psoas minor muscles is consistent with their primary role as hip flexors and dynamic stabilizers rather than as primary propulsive muscles during stair-climbing. In contrast, propulsion during stair-climbing is predominantly generated by the hip and stifle extensors, which may explain the high FDG uptake observed in the gluteus medius and quadratus femoris (Andriacchi *et al.*, 1980; Protopapadaki *et al.*, 2007). FDG uptake in skeletal muscle reflects glucose metabolism and is influenced by the timing of tracer administration relative to exercise (Richter and Hargreaves, 2013). In human studies, FDG is typically administered during exercise to assess exercise-related uptake (Tashiro *et al.*, 1999; Iemitsu *et al.*, 2000). In this study, FDG was administered immediately after completion of the stair-climbing exercise rather than immediately before or during exercise. Therefore, FDG uptake may not fully reflect glucose metabolism during active exercise, and this methodological limitation should be considered when interpreting the findings. Nevertheless, the effects of vigorous exercise on skeletal muscle FDG uptake have been reported to persist for up to 48 h after exercise (Minamimoto *et al.*, 2025). Therefore, the increased FDG uptake observed in the present study may reflect sustained post-exercise metabolic activity. This sustained metabolic activity is associated with continued glucose uptake during post-exercise recovery to support processes such as glycogen replenishment (Richter and Hargreaves, 2013). The present study has several limitations. The findings are based on a single exercised dog compared with a separate control dog, and inter-individual variability in FDG uptake, including the potential influence of differences in sex and reproductive status, should be considered. In addition, the timing of FDG administration after exercise may have influenced the interpretation of muscle activity. Despite these limitations, FDG PET/CT provided a non-invasive method to evaluate muscle-specific metabolic activity, including deep muscles that are difficult to assess using conventional techniques. The observed muscle activation pattern was biomechanically consistent with the functional demands of stair-climbing, supporting the potential value of FDG PET/CT for assessing exercise-related muscle activity in canine rehabilitation research.

Statement of author contributions: **Heesoo Ahn:** Investigation, Formal analysis, Data curation, Writing–original draft. **Seungho Lee:** Conceptualization, Investigation, Methodology, Formal analysis, Data curation, Writing–review and editing. **Yoocheol Shin:** Investigation, Formal analysis, Writing–review and editing. **Byoungho An:** Data curation, Visualization. **Dongwook Kim:** Formal analysis, Data curation. **Byeong-Teck Kang:** Supervision, Writing–review and editing. **Gonhyung Kim:** Conceptualization, Methodology, Supervision, Writing–review and editing.

Declaration of artificial intelligence use: Generative AI was used solely to assist with English-language editing and sentence refinement. The authors were solely responsible for the study concept, experimental design, data collection, data analysis, interpretation of the results, and final approval of the manuscript.

References

Andriacchi TP, Andersson GB, Fermier RW, Stern D and Galante JO 1980. A study of lower-limb mechanics during stair-climbing. J Bone Joint Surg Am. 62: 749–757.

Baltzer WI 2020. Rehabilitation of companion animals following orthopaedic surgery. N Z Vet J. 68: 157–167.

Berté L, Mazzanti A, Salbego FZ, Beckmann DV, Santos RP, Polidoro D and Baumhardt R 2012. Immediate physical therapy in dogs with rupture of the cranial cruciate ligament submitted to extracapsular surgical stabilization. Arq Bras Med Vet Zootec. 64: 1–8.

Besomi M, Hodges PW, Van Dieën J, Carson RG, Clancy EA, Disselhorst-Klug C, Holobar A, Hug F, Kiernan MC, Lowery M, McGill K, Merletti R, Perreault E, Søgaard K, Tucker K, Besier T, Enoka R, Falla D, Farina D, Gandevia S, Rothwell JC, Vicenzino B and Wrigley T 2019. Consensus for experimental design in electromyography (CEDE) project: Electrode selection matrix. J Electromyogr Kinesiol. 48: 128–144.

Bojsen-Møller J, Losnegard T, Kemppainen J, Viljanen T, Kalliokoski KK and Hallén J 2010. Muscle use during double poling evaluated by positron emission tomography. J Appl Physiol. 109: 1895–1903.

Cholewicki J and McGill SM 1996. Mechanical stability of the in vivo lumbar spine: Implications for injury and chronic low back pain. Clin Biomech. 11: 1–15.

Davidson JR, Kerwin SC and Millis DL 2005. Rehabilitation for the orthopedic patient. Vet Clin North Am Small Anim Pract. 35: 1357–1388.

Durant AM, Millis DL and Headrick JF 2011. Kinematics of stair ascent in healthy dogs. Vet Comp Orthop Traumatol. 24: 99–105.

Holler PJ, Brazda V, Dal-Bianco B, Lewy E, Mueller MC, Peham C and Bockstahler BA 2010. Kinematic motion analysis of the joints of the forelimbs and hind limbs of dogs during walking exercise regimens. Am J Vet Res. 71: 734–740.

Iemitsu M, Itoh M, Fujimoto T, Tashiro M, Nagatomi R, Ohmori H and Ishii K 2000. Whole-body energy mapping under physical exercise using positron emission tomography. Med Sci Sports Exerc. 32: 2067–2070.

McLean H, Millis D and Levine D 2019. Surface electromyography of the vastus lateralis, biceps femoris, and gluteus medius in dogs during stance, walking, trotting, and selected therapeutic exercises. Front Vet Sci. 6: 211.

Millis DL and Ciuperca IA 2015. Evidence for canine rehabilitation and physical therapy. Vet Clin North Am Small Anim Pract. 45: 1–27.

Millis DL and Levine D 2013. Canine Rehabilitation and Physical Therapy. 2nd ed. Amsterdam: Elsevier. 508–509 pp.

Minamimoto R, Kato K and Naganawa S 2025. Clinical scenarios of unusual FDG uptake in muscle. Jpn J Radiol. 43: 177–185.

Protopapadaki A, Drechsler WI, Cramp MC, Coutts FJ and Scott OM 2007. Hip, knee, ankle kinematics and kinetics during stair ascent and descent in healthy young individuals. Clin Biomech. 22: 203–210.

Richter EA and Hargreaves M 2013. Exercise, GLUT4, and skeletal muscle glucose uptake. Physiol Rev. 93: 993–1017.

Semciw AI, Freeman M, Kunstler BE, Mendis MD and Pizzari T 2015. Quadratus femoris: An EMG investigation during walking and running. J Biomech. 48: 3433–3439.

Shiozawa H, Ohsawa T, Tsushima Y, Higuchi T, Takagishi K and Chikuda H 2018. Evaluation of muscle activity just after straight leg raising exercise by using ^{18}FDG-PET. J Orthop Sci. 23: 328–333.

Tashiro M, Fujimoto T, Itoh M, Kubota K, Fujiwara T, Miyake M, Watanuki S, Horikawa E, Sasaki H and Ido T 1999. 18F-FDG PET imaging of muscle activity in runners. J Nucl Med. 40: 70–76.

Zink C and Van Dyke JB 2025. Canine Sports Medicine and Rehabilitation. 3rd ed. Hoboken, NJ: Wiley. 577–578 pp.