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Preoperative planning using computed tomography in tibial plateau levelling osteotomy: A comparison with conventional radiography

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Abstract

Background: Tibial plateau levelling osteotomy (TPLO) is currently one of the most common surgical procedures for the correction of the stifle joint with a ruptured cranial cruciate ligament. TPLO is based on the preoperative tibial plateau angle (TPA); therefore, it is essential to optimise the consistency and repeatability of TPA measurements.

Objectives: This study aims to compare computed tomography (CT) with conventional radiography in the preoperative planning of TPLO.

Methods: This prospective study included six dogs (12 hindlimbs) and 13 canine cadaveric hindlimbs. In the six beagle dogs, TPAs were measured by three radiologists using digital radiographic and CT images to evaluate the intra- and inter-observer agreement. To evaluate the intra-observer agreement of the TPA before and after surgery, and the intended angle of the postoperative TPA according to the preoperative planning method, 13 cadaveric hindlimbs were evaluated thrice at random by a single radiologist.

Results: The intra- and inter-observer intraclass correlation coefficients (ICCs) of the CT method were higher than those of the radiographic method in normal beagle dogs. The intra-observer ICC of the CT method before and after TPLO was generally higher than that of the radiographic method in the cadaver. However, no significant difference was noted in the evaluation of the intended postoperative TPA according to the preoperative planning method.

Conclusions: The intra- and inter-observer ICCs allowed for easy identification of landmarks required to consistently determine the TPA in the preoperative planning of TPLO based on CT images.

KEYWORDS
computed tomography, dog, tibial plateau angle, tibial plateau levelling osteotomy

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1 | INTRODUCTION

Cranial cruciate ligament (CrCL) rupture is considered one of the most common causes of hindlimb lameness and the development of the degenerative disease of the stifle joint (Hayashi et al., 2004; Innes & Barr, 1998; Johnson & Johnson, 1993; Marshall & Olsson, 1971). Numerous surgical methods have been developed for the correction of the stifle joint with ruptured CrCL (Amiel et al., 1986; Arnoczky et al., 1982; DeAngelis & Lau, 1970; Dickinson & Nunamaker, 1977; Smith & Torg, 1985; Trace, 1982). Many orthopaedic surgical techniques, including the tibial plateau levelling osteotomy (TPLO), have been developed to stabilise the canine stifle, alleviate pain and minimise progressive osteoarthritis (Aragon & Budsberg, 2005; Unis et al., 2010). TPLO, one of the most currently utilised surgical procedures to treat CrCL pathology, is based upon the preoperative tibial plateau angle (TPA); therefore, the determination of an accurate TPA is an important component of preoperative planning (Leighton, 1999; Slocum & Devine, 1983).

To improve the outcomes of TPLO, it is essential to optimise the consistency and repeatability of TPA measurements, as well as the ease of landmark identification (Headrick et al., 2007). However, positioning of the tibia during radiography may affect the appearance of anatomic landmarks used for the determination of the TPA, and observers subjectively select the anatomic landmarks; therefore, measurement variability may be introduced. In veterinary medicine, various studies have reported intra- and inter-observer variability in the measurement of the TPA by radiography (Caylor et al., 2001; Fettig et al., 2003; Reif et al., 2004). Therefore, for accurate TPA measurement, limb positioning on radiographs, and consistent and repeatability landmark identification to determine the TPA is important.

The TPLO procedure is designed to reduce the TPA to approximately 5–6.5° by rotating the proximal portion of the tibial plateau, eliminating cranial tibial thrust and minimising the strain on the caudal cruciate ligament (Slocum & Devine, 1983, 1984; Slocum & Slocum, 1993; Warzee et al., 2001). The amount of tibial plateau rotation required for TPLO is inferred from the degree of TPA measured in the preoperative plan. Preoperative TPA determination is important in TPLO because the recommended rotation of the tibial plateau needs to be performed accurately.

Over-rotation of the tibial plateau may be associated with postoperative caudal cruciate ligament rupture, whereas insufficient rotation is associated with failure to provide a functionally stable stifle joint due to insufficient reduction of the cranial tibial thrust (Reif et al., 2002; Shahar & Milgram, 2006; Slocum & Devine, 1984; Zachos et al., 2002). Therefore, accurate preoperative TPA measurement is necessary to prevent over-rotation or insufficient rotation of the tibial plateau and achieve the desired postoperative TPA (Fettig et al., 2003). However, relative to conventional radiography, there are no published reports of studies that determined or compared TPA measurements using computed tomography (CT).

This study aimed to describe a method for obtaining TPA measurement using CT and compare it with the conventional radiographic method in terms of ease of landmark identification, intra- and inter-observer variability and difference in TPA. Our hypotheses were that TPA measurement using CT would be subjectively easier to use for the identification of landmarks and the determination of the TPA than the conventional radiographic technique. Moreover, the CT method would show higher intra- and inter-observer agreement than the radiographic method. Finally, if CT is used in preoperative planning, then the surgical result of the intended angle would be improved.

2 | MATERIALS AND METHODS

2.1 | Study population

Six healthy intact male beagle dogs with a mean age of 8.5 years (range: 8–9 years) and mean body weight of 9.3 kg (range: 7.6–10.3 kg) were included in this study. Physical examination, complete blood count, serum biochemical analysis, radiography, abdominal ultrasound and echocardiography results revealed that all dogs were clinically healthy.

CT examination was performed under general anaesthesia. Anaesthesia was induced with intravenous propofol 0.6 mg/kg (Provive 1%, Myungmoon Pharmaceutical Co., Seoul, Korea) and maintained using 2.0% isoflurane (Terrell solution, Piramal Critical Care Inc., Bethlehem, PA) with 100% oxygen through endotracheal intubation.

Thirteen cadaveric hindlimbs from seven beagle dogs that were euthanised for reasons unrelated to this investigation were used in this study, with the CrCL removed after being used for student practice. The cadaveric hindlimbs were harvested by femoral disarticulation. This study was approved by the Institutional Animal Care and Use Committee of Konkuk University (Approval no. KU21039).

2.2 | Radiographic TPA measurement

The animals and cadavers were placed in lateral recumbency. Mediolateral tibial radiograph (Titan 2000V, Comed Medical Systems Co. Ltd., Seoul, Korea) was centred on the stifle joint, with 90° of stifle and tarsal joint flexion and collimated to include the stifle and tarsal joint. Digital radiographic images were evaluated using the digital imaging and communications in medicine (DICOM) fields and loaded into post-processing software (RadiAnt, Medixant, Pozana, Poland). Radiographs were evaluated to select the appropriately positioned lateral TPLO radiographic images in which superimposition of the femoral condyles was < 2 mm on the mediolateral radiographic projection (Grierson et al., 2005; Slocum & Slocum, 1993). In addition to superimposition of the femoral condyles, radiographs were repeated with the limbs repositioned until superimposition of the femoral and tibial condyles was achieved.

The TPA was determined from each mediolateral tibial radiograph as previously reported (Reif et al., 2004). The tibial long axis was identified by a line connecting a point dividing the intercondylar tubercles of the tibia and the centre of the talus. The tibial plateau axis was

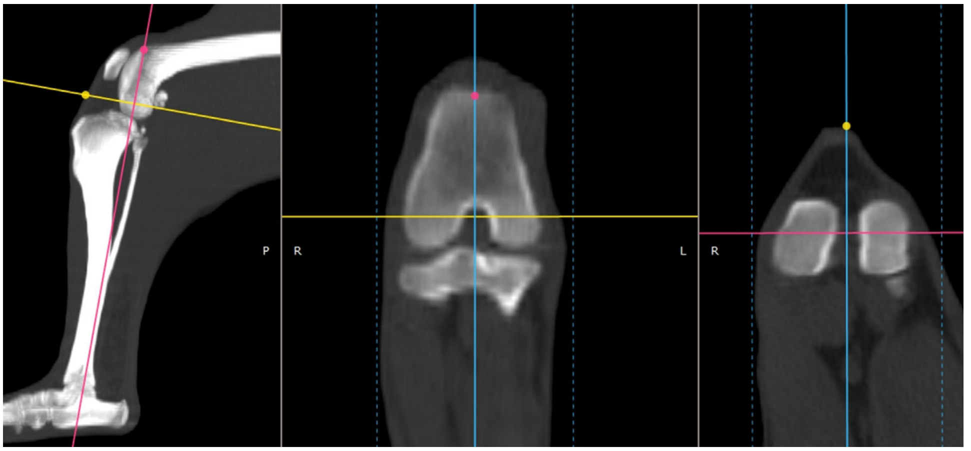

FIGURE 1 Reconstructed computed tomographic image of the tibia using the maximum intensity projection (MIP) technique. The stifle joint is positioned in a true lateral view using multiplanar reformation. Computed tomography (CT) image reconstructed with the MIP technique using digital imaging and communications in medicine software (leftmost image in the above CT image) to reproduce the tibial plateau angle in radiographs

identified by a line connecting the cranial and caudal extents of the medial tibial condyle. The TPA was measured between a line perpendicular to the tibial long axis and the tibial plateau axis.

2.3 | Computed tomographic TPA measurement

CT data of all hindlimbs of the animals and the cadavers were collected using a 4-channel helical CT scanner (LightSpeed, GE Healthcare, Milwaukee, WI). To obtain the same view as that in radiography, spongy blocks were placed to position the stifle and tarsal joint in a 90° flexion. The image protocol was as follows: 120 kVP, 200 mAs, 1.25-mm slice thickness and bone algorithm. Multiplanar reformation (MPR) images of the hindlimb area were obtained using DICOM software (RadiAnt, Medixant, Pozana, Poland).

The CT images of the stifle joint were positioned close to the true mediolateral view while identifying the anatomical structure using a DICOM viewer and MPR. The images were then reconstructed with the maximum intensity projection technique, which consisted of projecting the voxel on every throughout the volume onto a 2D image (Figure 1) using DICOM software. To identify the landmarks used for TPA measurement, the window level and width were further adjusted in the bone window using DICOM software, and the anatomical structure was confirmed in other cross-sections. The TPA was measured in the same way as that measured in radiographs by creating an image in which the femoral condyle completely superimposed in the mediolateral projection.

2.4 | Surgical technique

TPLO was performed on 13 cadaveric tibias that were divided into two groups: Group A ($n = 6$) underwent TPLO with preoperative planning using radiographic images, as in the conventional surgical method, and Group B ($n = 7$) underwent TPLO with preoperative planning using CT images.

A saw blade of appropriate radius (remaining tibial tuberosity width > 1 cm or more than 25% of the craniocaudal tibial width; Collins et al., 2014; Tan et al., 2014) was selected and centred over the intercondylar tubercles, and the exit of the tibial cortex proximocranially and distocaudally was determined. Three distances were measured for intraoperative landmarks. D1 was the distance from the patellar ligament attachment on the tibial tuberosity to the osteotomy line perpendicular to the cranial border of the tibia. D2 was the distance from the patellar ligament attachment to the osteotomy line along the cranioproximal border of the tibia. D3 was the distance from the most caudal aspect of the medial tibial plateau to the caudal exit of the osteotomy (Woodbridge et al., 2014).

A Slocum TPLO jig (Veterinary Instrumentation, Sheffield, UK) was applied with the proximal Kirschner wire 3–4 mm distal to the tibial plateau, immediately caudal to the medial collateral ligament, and the distal Kirschner wire to the distal end of the tibial diaphysis. D1, D2 and D3 were marked on the medial cortex of the tibia. Osteotomy was performed on the cis cortex of the medial tibia, and the desired distance of rotation was marked on the radial osteotomy line. After the osteotomy was complete, a Kirschner wire was placed on the proximal tibial plateau segment for use as a rotation pin. The TPLO jig was removed after the insertion of a temporary fixation pin through the proximal part of the tibial tuberosity. The osteotomy was stabilised with a TPLO plate (Biortho, Jiangsu, China), locking head screws and cortical screws. The temporary fixation pin was removed after plate application.

2.5 | Imaging evaluation

To evaluate the degree of intra- and inter-observer agreement of the TPA in 12 hindlimbs of normal beagle dogs, digital radiographic and

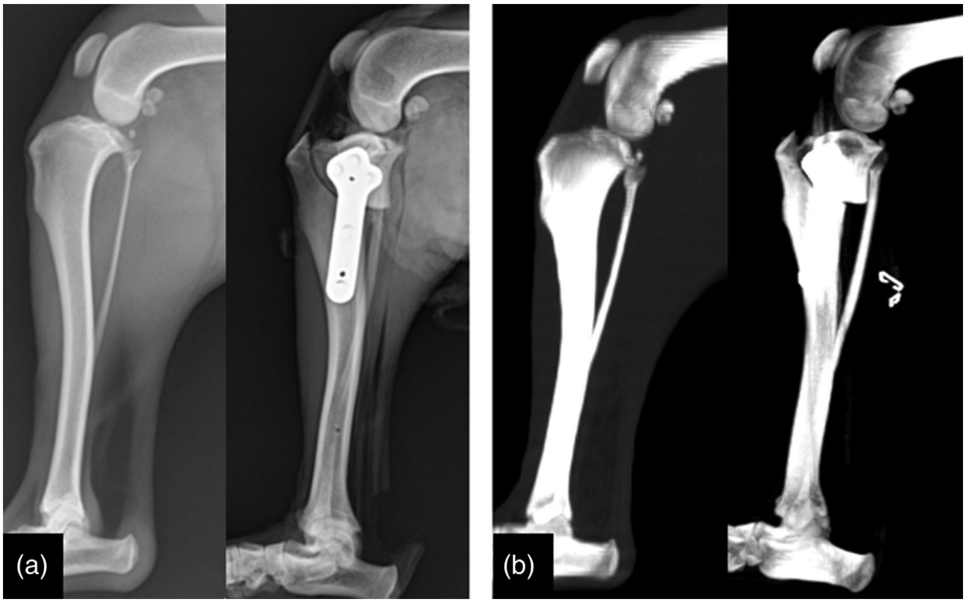

FIGURE 2 Radiographic and computed tomographic maximum intensity projection images of the tibia before and after tibial plateau levelling osteotomy. Radiographic (a) and CT (b) images obtained for tibial plateau angle measurement. Images were randomly measured thrice by a single radiologist

CT images were evaluated by three radiologists with varying levels of experience (Observer 1, master's degree in veterinary surgery and doctoral course in veterinary imaging diagnostics; Observer 2, first year in master's program in veterinary imaging diagnostics; Observer 3, master's degree of veterinary imaging diagnostics). The TPA was randomly measured thrice on each of the images by each observer.

To evaluate the inter-observer agreement of TPA before and after surgery on 13 cadaveric hindlimbs, radiographic and CT images were randomly measured thrice by a single radiologist with expertise in TPLO surgery (Figure 2). Additionally, for each measurement method using radiograph and CT, the intended angle of the two groups of postoperative TPA according to the preoperative planning method was evaluated on the 13 cadaveric hindlimbs.

2.6 | Statistical analysis

Statistical analyses were performed using commercially available software programs (R version 4.0.4., The R Foundation for Statistical Computing, Vienna, Austria). The intra- and inter-observer agreements between the two TPA measurement methods were measured using intraclass correlation coefficient (ICC). A bootstrapping method was used to estimate 95% confidence intervals for ICC. The differences in postoperative TPA according to the preoperative planning method was compared using linear mixed models. For all comparisons, the statistical significance level was set at $p < 0.05$.

3 | RESULTS

TPA measurements were compared between the two different imaging methods in 12 hindlimbs of normal beagle dogs. No significant difference was noted in the measured TPA between the radiographic method (TPA = 24.32° ± 2.5°) and the CT method (TPA = 24.00° ± 2.1°; $p = 0.303$; Figure 3). The intra- and inter-observer ICC of the CT method were higher than those of the radiographic method (Table 1). In addition, a higher intra-observer ICC was identified for both radiographic and CT methods for a more experienced observer than a less experienced observer (Table 1). There was a significant difference in TPA measurement time between the two different imaging

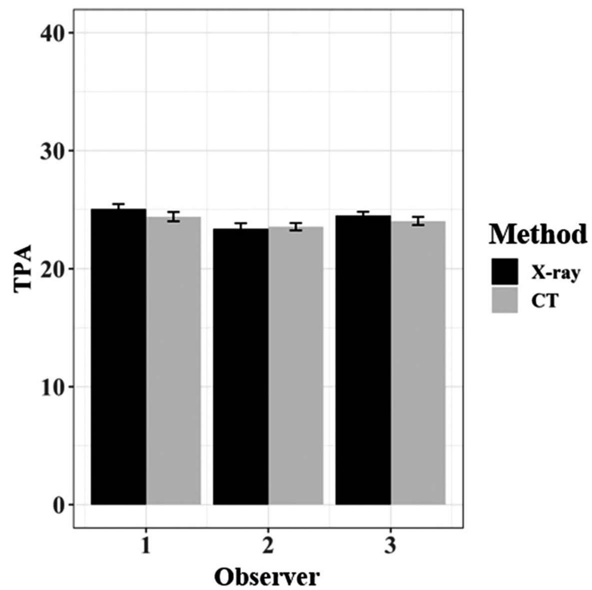

FIGURE 3 Mean tibial plateau angle (TPA) measured by each observer for the radiographic and computed tomographic methods. No significant difference was noted between the two TPA measurements

TABLE 1 Intra- and inter-observer intraclass correlation coefficient (ICC) between two different methods for tibial plateau angle (TPA) measurement

	Intra-observer agreement			
Method	Observer 1	Observer 2	Observer 3	Inter-observer agreement
Radiography	0.903 (0.729–0.961)	0.422 (0.018–0.714)	0.647 (0.227–0.839)	0.561 (0.286–0.766)
Computed tomography (CT)	0.965 (0.900–0.987)	0.872 (0.654–0.944)	0.929 (0.776–0.972)	0.865 (0.679–0.939)

Note: All values are presented as ICC (95% confidence interval (CI)). Observer 1, master's degree in veterinary surgery and doctoral course in veterinary imaging diagnostics; Observer 2, first year of master's program in veterinary imaging diagnostics; Observer 3, master's degree in veterinary imaging diagnostics.

TABLE 2 Intra-observer ICC between two different methods before and after tibial plateau levelling osteotomy for TPA measurement

	Intra-observer agreement	
	Radiography	CT
Pre-operation	0.900 (0.736–0.955)	0.960 (0.897–0.983)
Post-operation	0.878 (0.693–0.952)	0.949 (0.861–0.980)

Note: All values are presented as ICC (95% CI).

TABLE 3 Comparison of postoperative TPA according to preoperative planning using two different methods

	Postoperative TPA deviation from 5°		
Method	Group A	Group B	*p*-value
Radiography	2.53 (1.48)	3.37 (1.58)	0.338
CT	2.30 (1.48)	3.06 (1.44)	0.384

Note: All values are presented as the mean (standard deviation).
$p < 0.05$ is considered significant.

methods for each observer ($p < 0.001$). The TPA measurement time was greater in the CT method (Observer 1, 5.15 ± 0.16; Observer 2, 6.02 ± 0.21; Observer 3, 5.25 ± 0.16 min) than in the radiographic method (Observer 1, 2.07 ± 0.15; Observer 2, 2.68 ± 0.22; Observer 3, 2.36 ± 0.16 min).

TPA measurements between the two different imaging methods were compared before and after TPLO in the 13 cadaveric hindlimbs. The intra-observer ICC of the CT method was generally higher than that of the radiographic method (Table 2). By contrast, in each TPA measurement method, no significant difference was confirmed in the evaluation of the intended angle in the two groups of postoperative TPA according to the preoperative planning method (Table 3).

4 | DISCUSSION

Accurate TPA measurement is the most critical factor in preoperative planning for TPLO because it directly affects the TPLO for the correction of CrCL rupture. Factors influencing the TPA measurement include the radiographic method and technique, presence and extent of degenerative joint disease and determination of landmarks for the measurement location, which is subjective (Caylor et al., 2001; Fettig et al., 2003; Lister et al., 2008). Limb positioning during radiography can have a significant impact on TPA measurements (Caylor et al., 2001; Fettig et al., 2003; Reif et al., 2004), as it causes fluctuations in the shape and position of tibial anatomical indicators used to measure TPA; therefore, incorrect limb positioning can lead to underestimation or overestimation of the measured values (Reif et al., 2004). The cranial medial tibial condyle is easy to identify, but the caudal medial tibial condyle is difficult to identify because of individual anatomical variation and degenerative changes (Caylor et al., 2001; Fettig et al., 2003; Ocal & Sabanci, 2013; Ritter et al., 2007). In addition, the curvilinear shape of the caudal medial tibial condyle makes it difficult to determine and reproduce the point of caudal ligament attachment site (Caylor et al., 2001). Hence, the determination of certain landmarks based on radiography is subjective and may affect the TPA measurement.

Previous studies have reported significant intra- and inter-observer differences in TPA measurements using radiography (Caylor et al., 2001; Fettig et al., 2003). One of the major factors affecting TPA measurement is the difference in the understanding and selection of anatomical landmarks for TPA measurement by each observer (Headrick et al., 2007). In the present study, the mean TPA measurement obtained using the CT method was not significantly different from that obtained using the radiographic method, but the CT method showed higher intra- and inter-observer agreement than the radiographic method. In addition, according to three different radiologists with varying degrees of experience, the identification of anatomical landmarks for TPA measurement with the CT method was subjectively easier than with the radiographic method. In particular, the MPR imaging technique could clearly confirm the anatomical structure and easily identify the landmarks, thereby increasing the reproducibility of measurement and minimising subjective factors between the observers. However, the TPA measurement time with the CT method was longer than with the radiographic method. When using the CT method, the process of positioning the image of the stifle joint in the true mediolateral view using DICOM software is added, and the process of identifying landmarks in multiple cross-sections using MPR is added, which may reduce the efficiency in terms of time. However, the time difference between the two different imaging methods was only less than 5 min. In the present study, the preoperative planning method using radiography and CT was not significantly different from the surgical outcome of the intended TPA. In addition to the preoperative planning, postoperative TPA is suspected to be affected by various factors, including the degree of rotation, eccentric distance and direction and movement during plate application (Leitner et al., 2008; Tan et al., 2014).

The disadvantage of measuring TPA using CT in clinical practice is that it may require general anaesthesia. However, unlike the radiographic method, the CT method does not require multiple scans until the correct limb position is achieved. Moreover, the CT images obtained using the MPR technique are considered to be of sufficient value because they provide a multi-dimensional plane that allows for easy identification of anatomical structures and accurate limb positioning. Another disadvantage of TPA measurement using CT is that metal artefacts due to implant after surgery can be identified in the medial condyle of the tibia, which is one of the landmarks used for TPA measurement. However, according to the radiologist who made the measurements in the present study, even if metal artefacts were identified in the medial condyle of the tibia, the window level and width were adjusted more in the bone window using DICOM software (Link et al., 2000; White & Buckwalter, 2002), and the anatomical structure was also confirmed in other cross-sections. Therefore, there was little difficulty in measurement. However, postoperative measurements were performed by a single radiologist; therefore, further studies with other observers' evaluations are necessary. Additionally, metal artefacts can be minimised if a metal artefact reduction sequence is used for CT scans (Joemai et al., 2012; Yu et al., 2009).

There are some limitations to this study. First, the number of cases used in the present study was small. To investigate the clinical relevance of the CT method in the preoperative planning of TPLO, including TPA measurement, further studies are needed on the relevance of various breeds and the presence or absence of CrCL disease. Second, it is necessary to evaluate whether similar results would be derived by applying our technique to clinical cases in the future. Finally, in preoperative and postoperative studies that used cadavers, all measurements were performed by a single radiologist, and hence further studies with inter-observer evaluation are necessary.

In conclusion, the present study described the technique of using CT for TPA measurement, which allows for easy identification of anatomic landmarks required to consistently determine the TPA. Compared with the radiographic method, TPA measurement using CT was subjectively easier for the identification of landmarks and determination of the TPA and also showed higher intra- and inter-observer agreement. The preoperative planning method using the two methods was not significantly different from the surgical outcome of the intended TPA. The results of the present study suggest that the CT method may be beneficial for the accurate determination of TPA in the preoperative planning of TPLO.

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ETHICS STATEMENT

The authors confirm that the ethical policies of the journal, as noted on the journal's author guidelines page, have been adhered to and this study was approved by the Institutional Animal Care and Use Committee of Konkuk University (Approval no. KU21039).

AUTHOR CONTRIBUTION

Jayon Kim: Conceptualization, Data curation, Writing original draft, Writing review & editing; **Jaeeun Ko**: Data curation; **K. Eom**: Supervision, Writing review & editing; **Jaehwan Kim**: Conceptualization, Supervision

CONFLICT OF INTEREST

The authors declare no conflict of interest related to this report.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1002/vms3.716

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