Skin movement during the kinematic analysis of the canine pelvic limb

S. Y. Kim1; J. Y. Kim1; K. Hayashi2; A. S. Kapatin2
1William R. Pritchard Veterinary Medical Teaching Hospital, Davis, California, USA; 2Surgical and Radiological Sciences and Veterinary Orthopedic Research Laboratory, School of Veterinary Medicine, University of California-Davis, Davis, California, USA

Keywords
Canine, skin movement, pelvic limb, kinematics

Summary
Objectives: To determine whether the canine pelvic limb can be considered a linkage of rigid bodies during kinematic analysis.

Methods: The lengths of the femur and tibia based on skin markers were examined throughout gait cycles in six dogs trotting on a treadmill at 2 m/sec. The angular kinematics of the hip, stifle and tarsal joints were calculated based on a conventional stifle marker (CSM) and computed virtual stifle positions (VSP). Based on the CSM and VSP, the kinematic data from the joints were compared and the agreement among them determined. The difference between the CSM and VSP coordinates were illustrated.

Result: The femoral and tibial lengths based on skin markers were not constant throughout a gait cycle and the lengths changed in repeatable patterns in each dog. There was close agreement between the joint angles based on the CSM and VSP in the tarsal joint but not in the hip and stifle joints, where the kinematics based on the CSM tended to calculate smaller angular excursion than the kinematics based on VSP. The pattern of displacement of the CSM was repeatable through a gait cycle.

Clinical relevance: There was skin movement which causes considerable artifact during kinematic analysis of the canine pelvic limb. The skin movement has to be accounted for during canine kinematic analysis.

Introduction
The most common method by which veterinary surgeons diagnose canine orthopaedic injuries, and also assess the success of their treatments, is by subjectively evaluating lameness. However, the human ability to perceive subtle changes during motion is limited, and thus kinematic gait analysis has been used to describe human and animal locomotion quantitatively (1, 2). Information derived from the kinematic analysis of dogs has enabled clinicians and researchers to better understand the characteristics of normal gait patterns and of abnormal gait patterns related to orthopaedic diseases (3–8). Although there are different kinematic analysis systems available, video based motion analysis is the most commonly used in canine kinematics (2).

A computer assisted kinematic analysis protocol for the canine pelvic limb was described by DeCamp et al. and has been widely used to date with minimal modifications (3–7, 9–15). Markers are placed on the skin surface over anatomical landmarks associated with the joints, and the pelvic limb is modelled as a linkage of rigid segments. With these markers in place, the proper gait of a dog is recorded in a calibrated three-dimensional (3D) space. A kinematic analysis system extracts the instantaneous positional data of each marker and calculates the angle, linear and angular velocities, and acceleration of each joint. Assuming the rigid body, the distance between two given markers is considered to remain constant and deformation is negligible. Although 3D kinematics provide more comprehensive information in all directions in the space, sagittal kinematics of limb flexion and extension have been thought most important in normal dogs (7, 12).

The methodological limitations and sources of error in conventional kinematic analysis based on the rigid body have been documented in studies of gait analyses in humans. When markers are accurately placed over anatomical landmarks, the artefact from skin movement is considered to be a major source of error in stereophotogrammetry kinematic analysis (16, 17). The skin artefact is known to result from the effects of inertia and from skin deformation and sliding, which occur mainly around the joints. The effects of the skin artefact on the joint kinematics have been studied in humans and other animals (16–19). While small animal clinicians have adopted the use of kinematic analysis systems, the authors of this study are not aware of any studies of the skin artefact in clinical kinematic analysis of the canine pelvic limb.

This study was performed to investigate if there are artefacts from skin movement over the joints of the canine pelvic limb during the kinematic analysis. A null hyp-
The hypothesis of the study was that the skin deformation of the pelvic limb would be negligible for kinematic analysis while a dog is trotting. To examine the hypothesis, we examined the changes of the femoral and tibial lengths in 3D space throughout a gait cycle on a treadmill. Then, we compared the sagittal joint kinematics of pelvic limbs based on two different stifle positions: a conventional stifle marker (CSM) and the computed virtual stifle position (VSP) of dogs. We also illustrated the difference between the coordinates of the CSM and the VSP.

**Materials and methods**

**Subjects**

Raw data were collected from nine healthy, adult, large breed dogs (body weight: 27.3 ± 2.9 kg) with no lameness and a normal orthopaedic examination performed by the primary author. Before the data collection, all dogs were trained to stand, walk and trot on a treadmill at different speeds (0 – 2.2 m/s) for five sessions. The kinematics of the pelvic limb were examined in dogs while they trotted on a treadmill. All procedures in this study were approved by the Institutional Animal Care and Use Committee of the University of California Davis.

**Kinematic recording**

Using the dynamic linearization process, the 3D space on a treadmill was calibrated for three infrared 200 Hz optical cameras\(^a\) linked to a motion processor\(^b\). Spherical reflective markers measuring 16 mm in diameter were placed on the skin over anatomical landmarks that are conventionally used for kinematic analysis in dogs (Fig. 1) (5, 9, 12). While a dog was standing still on the treadmill, the skin markers were placed over the iliac crest, the greater trochanter of the femur (hip joint), the femoral-tibial joint between the lateral epicondyle of the femur and the fibular head (stifle joint), the lateral malleolus of the distal tibia (tarsal joint), and the distal aspect of the fifth metatarsal bone as previously described (3, 5, 6, 9, 12, 13, 15). The standing posture was recorded in order to measure the lengths of the femur and the tibia (Fig. 1). After the standing posture was recorded, a handler had the dog trot on the treadmill at 2 m/s, and the gait was recorded for 10 seconds. While 3D positional data for each marker were collected with the optical cameras, the motion of each dog was additionally monitored with a 60 Hz digital video camera\(^d\).

The raw positional data were filtered using a low-pass Butterworth filter with 5 Hz as a cut-off. The first five valid gait cycles in each dog were used for data analysis, and each gait cycle was normalized to 100% of the gait cycle. The gait cycle in this study was divided into two parts – a stance phase and a swing phase. The stance phase was defined as initiating when the paw struck the treadmill belt (paw-strike) and terminating when the foot came off the treadmill belt (paw-off). The swing phase was defined as the period from paw-off to paw-strike. The paw-strike and paw-off were visually determined by two observers using the digital video camera.

Because the sagittal kinematics are regarded as a major motion of the canine pelvic limb, the marker positions were expressed with the coordinates on the sagittal plane of the limb (Fig. 1). The horizontal and vertical axes in the sagittal plane were represented by \( X \) and \( Y \) axes respectively. The \( X \) axis was aligned to the movement of the marker on the fifth metatarsal bone and the running direction of the treadmill belt. The segment lengths in the sagittal plane were compared with those in the 3D space during gait using root mean square of the difference. The data from three dogs were excluded from further reduction because the root mean square of the difference exceeded 1.5% segmental length in either the femur or tibia.

The VSP was mathematically derived using the coordinates of the hip joint and tarsal joints and the lengths of the femur and the tibia measured in standing posture (Fig. 1). It was assumed that the stifle joint was located on the distal end of the femur as well as the proximal end of the tibia. In the sagittal plane, the hip and tarsal joints were considered hinge joints. Therefore, the VSP was determined by the intersection of two circles: a circle with its centre at the hip joint \((X_H, Y_H)\) and a radius the length of the femur \(L_{femur}\) and a circle with its centre at the tarsal joint \((X_T, Y_T)\) and its radius the length of the tibia \(L_{tibia}\). The \( L_{femur} \) and \( L_{tibia} \) were measured in the standing posture.

---

\(^a\) Mustang: Kafra AG, Fahrwangen, Switzerland
\(^b\) MX40: Vicon Motion Systems, Centennial, CO, USA
\(^c\) Peak Motus 9.0: Vicon Motion Systems, Centennial, CO, USA
\(^d\) Bosch-LCT610/61: Bosch Security Systems, Inc, Fairport, NY, USA

---

study power was recalculated for data

which did not show significant differences.

A p-value less than 0.05 was considered significant. The positions using paired t-tests. A p-value less

Phase, were compared based on the stifle

angles, as well as the range of motion

lated.

square of the angle difference was calcu-

Data analysis and statistics

The lengths of the femur and tibia in the 3D space were measured throughout gait cycles in the dogs, and the length changes of the femur and tibia from the initially measured lengths were illustrated.

To examine the agreement between the angles of the hip, stifle, and tarsal joints based on the CSM and the VSP, a Bland-Altman test was performed to determine 95% limit of agreement and the root mean square of the angle difference was calculated.

The maximum and minimum joint angles, as well as the range of motion (ROM) during the stance phase and swing phase, were compared based on the stifle positions using paired t-tests. A p-value less than 0.05 was considered significant. The study power was recalculated for data which did not show significant differences.

The statistical tests were performed with standard statistical software.

The grand mean difference of the coordinates between the CSM and VSP from all trials was illustrated throughout a gait cycle.

Result

Stance and swing phases were normalized for each gait cycle and averaged out from a total of 30 gait cycles: five trials from each of six dogs. The stance phase occurred during the first 45% of a complete gait cycle, followed by the swing phase, which occupied 55% of a gait cycle. The femoral and tibial lengths based on the markers were not constant throughout a gait cycle and the changes of the lengths were in repeatable patterns among gait cycles in each dog (Fig. 2). Of the sets of sagittal kinematic data based on the CSM and VSP, the greatest agreement was found to be between the CSM and VSP for the tarsal joint, then for the hip joint, and lastly for the stifle joint, which had the lowest level of agreement (Fig. 3, Table 1).

Table 2 summarizes the ROM as well as the minimum and maximum joint angles during the stance and swing phases. During the stance phase, the ROM based on the CSM was smaller than that based on the VSP in the stifle joint (p <0.01), but there were no significant differences in the ROM of the hip (p = 0.66) and tarsal joints (p = 0.61). The maximum angles based on the CSM was smaller than the maximum angles based on the VSP in the hip (p = 0.05) and stifle joints (p = 0.05) but there were no differences in the maximum angle of the tarsal joint (p = 0.58). There were no significant differences in the minimum joint angles of the hip, stifle, and tarsal joints between the CSM and the VSP but the CSM-based minimum angle tended to be greater in the stifle joint (p = 0.10; 95% CI: −1.17 to 8.10°).

During the swing phase, the ROM based on the CSM were smaller in the hip (p <0.01), stifle (p <0.01), and tarsal joints (p = 0.02) than the ROM based on the VSP. The CSM-based maximum angle was smaller than the VSP-based maximum angle in the stifle (p = 0.04), but there were not any significant differences in the maximum angles of the hip (p = 0.07) and tarsal joints (p = 0.60) between the CSM and the VSP during the swing phase. The CSM generated the greater minimum angles in the hip (p = 0.01) and stifle joints (p = 0.01) than the VSP during the swing phase, but there were not any differences in the minimum angle of the tarsal joint (p = 0.65).

The grand mean difference of the coordinates between the CSM and VSP from all trials was illustrated throughout a gait cycle.

Fig. 2

Average differences in the lengths of the femur (a) and tibia (b) from the lengths measured in standing pose. A black solid line is the grand mean difference while × represents the difference at each time point in each individual trial.

Discussion

The results of this study disproved the null hypothesis and also found that the deformation of the skin occurred in a cyclic pattern throughout gait cycles. The changes of the segment lengths based on the markers during the trot indicate de-
formation of the soft tissue over the anatomic landmarks. Kinematics based on the CSM calculated the smaller angular excursion of the hip and stifle joints than the VSP in a gait cycle. However, in the tarsal joint there was close agreement between angular kinematics based on the CSM and the VSP.

To control variables such as velocity and the direction of the body, and to reduce the variance among data sets in the individual, data were collected from five consecutive gait cycles on the treadmill. Although the joint kinematics on the treadmill were not first compared with the over-ground gait of the dogs, the joint angles based on the CSM in this study grossly agree with those in previous over-ground kinematic studies (Fig. 3) (5, 12). The stifle angular excursion based on the VSP is comparable to the sagittal bone movement of the stifle joint based on the bone fixed markers in a previous study (Fig. 3) (7).

In the human knee joint, the residual inaccuracy after the skin artefact has been optimized ranges from 2.4° to 4.1° (1). The limit of agreement and root mean square of the angle difference in our study indicates the close agreement in the tarsal joint and the lack of acceptable agreement between angles based on the CSM and the VSP in the hip and stifle joints (Table 1).

The difference in the coordinates between the CSM and the VSP was characterized in the sagittal plane of which X-axis was aligned to a metatarsal marker (Fig. 4). As the stifle joint was flexed, the CSM movement was directed caudal and distal

### Table 1

<table>
<thead>
<tr>
<th>Joint</th>
<th>RMS of difference (°)</th>
<th>Limit of agreement (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hip joint</td>
<td>4.69</td>
<td>-1.75 – 6.40</td>
</tr>
<tr>
<td>Stifle joint</td>
<td>6.38</td>
<td>-3.77 – 8.21</td>
</tr>
<tr>
<td>Tarsal joint</td>
<td>2.84</td>
<td>-2.91 – 2.79</td>
</tr>
</tbody>
</table>

Key: RMS = Root mean square; ‘Limit of agreement’ indicates 95% confidence interval difference between angles, which ranges from mean difference -1.96 SD to mean difference +1.96 SD.

![Fig. 3](image-url) The grand mean angles of the hip (a), stifle (b), and tarsal (c) joints from 30 gait cycles (from 6 dogs with 5 gait cycles per dog) based on the conventional stifle marker (CSM) (solid line) and the virtual stifle position (VSP) (dotted line). Error bands in the graphs represent the standard deviation. (Dark grey with solid lines: based on the CSM; light grey with dotted lines: based on the VSP).

![Fig. 4](image-url) Time history of the mean difference in coordinates between the conventional stifle marker (CSM) and the virtual stifle position (VSP) through all gait cycles across all dogs. The closed diamond indicates the paw-strike, which is the initiation of the stance phase, and the open diamond indicates the paw-off, which is the initiation of the swing phase. A dotted line indicates the difference of the CSM from the VSP displacement of the CSM during the stance phase, and a solid line indicates the difference of the CSM from the VSP during the swing phase.
Skin movement during canine kinematic analysis

Table 2  Mean ± standard deviation and 95% CI of paired differences of the angular kinematics based on the conventional stifle marker from those based on the virtual stifle position.

<table>
<thead>
<tr>
<th></th>
<th>Paired difference (°)</th>
<th>95% Confidence Interval</th>
<th>p-value</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stance phase</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range of motion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip joint</td>
<td>0.58 ± 3.00</td>
<td>-3.74 – 2.58</td>
<td>0.66</td>
<td>0.07</td>
</tr>
<tr>
<td>Stifle joint</td>
<td>7.60 ± 4.04</td>
<td>-11.84 – -3.36</td>
<td>&lt;0.01*</td>
<td>NA</td>
</tr>
<tr>
<td>Tarsal joint</td>
<td>0.50 ± 2.22</td>
<td>-2.83 – 1.83</td>
<td>0.61</td>
<td>0.07</td>
</tr>
<tr>
<td>Maximum joint angle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip joint</td>
<td>1.71 ± 1.61</td>
<td>-3.39 – -0.02</td>
<td>0.05*</td>
<td>NA</td>
</tr>
<tr>
<td>Stifle joint</td>
<td>5.61 ± 5.33</td>
<td>-11.20 – -0.02</td>
<td>0.05*</td>
<td>NA</td>
</tr>
<tr>
<td>Tarsal joint</td>
<td>0.43 ± 1.81</td>
<td>-2.34 – 1.47</td>
<td>0.58</td>
<td>0.08</td>
</tr>
<tr>
<td>Minimum joint angle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip joint</td>
<td>-1.05 ± 2.93</td>
<td>-4.12 – 2.02</td>
<td>0.42</td>
<td>0.11</td>
</tr>
<tr>
<td>Stifle joint</td>
<td>3.47 ± 4.42</td>
<td>-1.17 – 8.10</td>
<td>0.10</td>
<td>0.35</td>
</tr>
<tr>
<td>Tarsal joint</td>
<td>-0.08 ± 2.12</td>
<td>-2.11 – 2.31</td>
<td>0.93</td>
<td>0.05</td>
</tr>
<tr>
<td><strong>Swing phase</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range of motion</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip joint</td>
<td>-7.24 ± 3.33</td>
<td>-10.73 – -3.75</td>
<td>&lt;0.01*</td>
<td>NA</td>
</tr>
<tr>
<td>Stifle joint</td>
<td>-12.35 ± 3.23</td>
<td>-11.84 – -3.36</td>
<td>&lt;0.01*</td>
<td>NA</td>
</tr>
<tr>
<td>Tarsal joint</td>
<td>-0.81 ± 0.55</td>
<td>-1.39 – -0.23</td>
<td>0.02*</td>
<td>NA</td>
</tr>
<tr>
<td>Maximum joint angle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip joint</td>
<td>-1.60 ± 1.66</td>
<td>-3.34 – -0.15</td>
<td>0.07</td>
<td>0.48</td>
</tr>
<tr>
<td>Stifle joint</td>
<td>-5.14 ± 4.45</td>
<td>-9.81 – -0.47</td>
<td>0.04*</td>
<td>NA</td>
</tr>
<tr>
<td>Tarsal joint</td>
<td>-0.35 ± 1.56</td>
<td>-2.00 – 1.28</td>
<td>0.60</td>
<td>0.07</td>
</tr>
<tr>
<td>Minimum joint angle</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hip joint</td>
<td>5.66 ± 3.57</td>
<td>1.91 – 9.40</td>
<td>0.01*</td>
<td>NA</td>
</tr>
<tr>
<td>Stifle joint</td>
<td>7.07 ± 4.19</td>
<td>2.68 – 11.47</td>
<td>0.01*</td>
<td>NA</td>
</tr>
<tr>
<td>Tarsal joint</td>
<td>0.37 ± 1.93</td>
<td>-1.65 – 2.40</td>
<td>0.65</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Key: * indicates significant paired differences at p < 0.05; NA = Not applicable, the power was not calculated.

At paw-strike, when the hip joint was flexed and the stifle joint was extended, the CSM was located cranial and distal to the VSP in sagittal plane (i.e. distal to the stifle joint along the femoral axis). At paw-off, when all the joints were extended, the CSM moved proximal to the VSP along the tibia. Because the markers were installed during standing, which mimics a late stance phase, the deviation of the CSM may have been more distinct while the stifle joints were in flexion than extension. This pattern of the CSM displacement is consistent with the patterns of the length changes of the femur and tibia (Fig. 2). The tibial length based on the CSM was longer than the initially measured length from the late stance phase to the early swing phase while the CSM-based length became shorter than the initially measured length as the stifle joints flexed. The femoral length based on the CSM was longer than the initially measured length from the late swing phase to the late stance phase. Although there are general patterns in the length changes, averaged curves tend to obscure the magnitude of length changes among individual trials. In addition, the pattern of the CSM displacement and the length changes can explain why the CSM-based kinematics underestimate the flexion of the hip and stifle joint but still agree with the VSP-based angle in the tarsal joint (Fig. 2, 3 and 4).

The ROM of the stifle joint based on the CSM was smaller than the ROM based on the VSP throughout a gait cycle. In a previous kinematic study, deficiency of the cranial cruciate ligament resulted in more flexion of the stifle joint through a whole gait cycle, and there was approximately a 5° to 14° angle difference (7). In the current study, the ROM of the stifle joint based on the CSM were 7.60 ± 4.04° and 12.35 ± 3.23° less than those based on the VSP during the stance and swing phases respectively. Kinematic data using skin markers is sensitive enough to distinguish abnormal from normal gait. Yet it is important to recognize that skin movement artifact can affect data of tracking bone movements in clinical gait analysis (5). There were also statistically significant differences between the two methods when they were used to determine the ROM of the hip joint and the tarsal joint during the swing phase. While the difference in the hip joint was 7.22 ± 3.44°, the difference in the tarsal joint was 0.81 ± 0.58°, which is small enough to be within the range of systemic error inherent to the kinematic analysis system (1).

During the stance phase, the maximum calculated extension angle of the stifle joint was smaller using the CSM than the VSP. The 95% CI of the difference of the minimum stifle angles was skewed toward positive values, which suggests that the CSM calculated the stifle joint was less flexed than the VSP, though there was no statistical significance (Table 2). The CI and low power indicate that the sample size may have been insufficient to fully evaluate the angle data of the stifle joint. Although there was statistical difference in the maximum angle of the hip joint during the stance phase, the difference may not be big enough to have a clinical meaning. The hip flexed the most at paw-strike during the stance phase, and the minimum angle of the hip joint during this phase did not change between the CSM and the VSP, most likely because the CSM remained close to the femoral axis. The lengths of the femur and tibia, as based on the CSM, changed throughout the stance phase possibly due to skin movement. Recently, inverse dynamics of the canine pelvic limbs have been studied (4, 10, 14). In those studies, powers and work patterns across the joints in the pelvic limb were computed based on the ground reaction forces, angular kinematics, and body segment parameters, in-
cluding the lengths of the segments. The change of the lengths and the joint angles from the skin movement can cause artefacts in inverse dynamics in the dogs.

The displacement of the CSM and the change of tibial length occurred in greater magnitude during the swing phase than the stance phase (Fig. 2 and 4). Consequently, the CSM-based kinematics underrated not only the extension and flexion of the stifle joint but also flexion of the hip joint. The maximal extension of the hip took place immediately after paw-off. The difference in the maximal hip angle was relatively small and this could be because the markers were installed in the standing posture which mimics late stance phase.

Interaction between the 3D space and the sagittal plane has been described using a linkage model (20). Projected lengths become shorter than lengths in the 3D space and generate less flexed joint angles than real flexion if the motion is not parallel to the sagittal plane, or if the joint is abducted, adducted, or rotated. In the current study, the lengths of the femur and tibia in the sagittal plane were compared with the lengths in the 3D space and the data from three dogs were excluded from analysis to avoid significant errors from the interaction. Because the VSP was calculated using the constant sagittal lengths of the femur and tibia measured during a stance pose, the interaction between the space and the plane could have caused erroneously flexed joint angles based on the VSP. The VSP generated greater maximum extension angle of the hip and stifle joints than the CSM which would result from skin movement rather than the interaction between the space and the plane. The interaction between the space and the plane with the VSP, if any, would cause more flexed angles of all joints, but there was no any difference in the maximal flexion angle of the tarsal joint based on the CSM and VSP (p = 0.65, power = 0.07). Adduction of the stifle joint during the trot has been recently investigated by using a joint coordinate system (21). In that study, the stifle joint was adducted while the stifle joint flexed during the swing phase and this adduction indicates possible interaction between the space and the sagittal plane in the dogs. However, the mean adduction angle of the stifle joint was not greater than 10° which can cause only 1.6% projection error in the lengths. In the current study, there was the substantial displacement of the CSM which is not fully explained by the interaction. Although interaction may exist between the space and the sagittal plane, the difference of angles in this study could be mainly due to skin movement.

Certain limitations are associated with characterizing the skin movement based on the VSP. The authors of this study considered the stifle joint as a hinge joint in the sagittal plane and calculated the VSP from initial marker placement in a standing pose. A previous study indicates that the centre of rotation of the normal stifle joint is located around lateral condylar ridge, which is close to the location of a stifle marker in the current study (22). However, the instantaneous centre of rotation of the canine stifle joint has not been studied yet during active gait. Therefore, the authors placed all makers as described in previous kinematic studies (3, 5, 6, 9, 12, 13, 15). Nevertheless, possible misplacement of the marker over the stifle joint could lead to incorrect VSP calculation. In addition, the authors computed the VSP based on the lengths of the femur and tibia as well as instant positions of the hip and tarsal joints according to the assumption of a rigid body. As a consequence, the result from the methodology suggests that the stifle joint is the only source of artefact while it disproves the null hypothesis of the study. In humans and horses, soft tissue movement of the hip joint is also considered to be a major source of artefact due to the profound musculature of those two species (17, 19). The movement of a marker over the hip joint could have effects on computing the VSP. Because of this limitation, the difference of coordinates of the CSM from the VSP cannot characterize the skin movement over the stifle joint. However, the result in this study shows strong evidence that the skin over the joints in the pelvic limb deforms in a certain pattern throughout a gait cycle. Comprehensive characterization of the skin movement over the bone would require a reliable segmental coordinate systems such as bone fixed coordinate systems in each bone (1, 8, 16, 23, 24).

The results of this study show that skin movement occurs in a pattern during kinematic analysis of the canine pelvic limb and can affect sagittal kinematic analysis when skin markers are used. Skin movement over the pelvic limb has to be accounted for during kinematic analysis. Further studies to comprehensively characterize skin movements in canine kinematics are necessary. Knowing skin movement patterns can lead to development of improved surface marker systems that optimally capture bone movement.

Conflict of interest
None declared.

References