Computed tomographic method for measurement of inclination angles and motion of the sacroiliac joints in German Shepherd Dogs and Greyhounds

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Objective—To develop an in vivo CT method to measure inclination angles and motion of the sacroiliac joints in dogs of performance breeds.

Animals—10 German Shepherd Dogs and 12 Greyhounds without signs of lumbosacral region pain or neurologic problems.

Procedures—CT of the ilium and sacrum was performed in flexed, neutral, and extended hind limb positions. Lines were drawn on volume-rendered images acquired in the flexed and extended positions to measure motion of the ilia relative to the sacra. Inclination angles of the synovial and ligamentous components of the sacroiliac joints were measured on transverse-plane CT images acquired at cranial and caudal locations. Coefficients of variance of measurements were calculated to determine intraobserver variability.

Results—Coefficients of variance of measurements ranged from 0.17% to 2.45%. A significantly higher amount of sacroiliac joint rotational motion was detected for German Shepherd Dogs versus Greyhounds. The cranial synovial joint component had a significantly more sagittal orientation in German Shepherd Dogs versus Greyhounds. No significant differences were detected between breeds for x- or y-axis translational motion or caudal synovial or ligamentous joint component inclination angles.

Conclusions and Clinical Relevance—The small amounts of sacroiliac joint motion detected in this study may buffer high-frequency vibrations during movement of dogs. Differences detected between breeds may be associated with the predisposition of German Shepherd Dogs to develop lumbosacral region signs of pain, although the biological importance of this finding was not determined. Future studies are warranted to compare sacroiliac joint variables between German Shepherd Dogs with and without lumbosacral region signs of pain. (Am J Vet Res 2013;74:1172–1182)
thigh thrust and shear tests, have not been validated. Therefore, it is not known whether sacroiliac joints are a site of pain in dogs. German Shepherd Dogs are predisposed to diseases that cause lumbosacral region pain. German Shepherd Dogs are commonly used as working police and military dogs. These dogs are socially and economically valuable, and lumbosacral region pain in such animals can be career limiting.

Forces from hind limbs are transmitted to the vertebral column through the hip, sacroiliac, and lumbosacral joints. Other authors have proposed that overloading of sacroiliac joints in dogs (caused by activities such as repetitive, intense activity) may lead to instability of those joints. Such instability could lead to secondary disease and development of osteophytes in sacroiliac joints, which could limit motion of the joints and increase loading of adjacent hip and lumbosacral joints. Therefore, it is possible that (in dogs) secondary joint disease could cause pain in the sacroiliac joints or adjacent structures. Alternatively, degenerative changes in sacroiliac joints could develop secondary to diseases of the lumbosacral and hip joints that alter loading of the sacroiliac joints. It is important to understand the biomechanically normal motion of sacroiliac joints before theories regarding sources of sacroiliac joint pain can be determined.

Motion of sacroiliac joints in dogs has been measured in another study, in which soft tissues surrounding sacroiliac joints of canine cadavers were removed with retention of the periarticular and sacrotuberous ligaments; results indicated a mean rotational motion of 7° (range, 4° to 13°). To the authors’ knowledge, no in vivo studies have been conducted to assess motion of sacroiliac joints in dogs. Skin-mounted sensors have been used in in vivo studies to measure motion of sacroiliac joints in horses. In vivo motion studies of humans have been performed by use of roentgen stereophotogrammetry of tantalum implants, and transcutaneous palpation and digitization of anatomic landmarks. Computed tomography is a reliable method for detection of motion in vivo; however, to the authors’ knowledge, no studies have been conducted to directly measure motion between the sacrum and ilium by use of CT in animals of any species.

Inclination angles of the sacroiliac joint are defined as the angle of the axis of the joint relative to a dorso-ventrally positioned reference line, as measured on transverse plane images. The transmission of the force of an animal’s weight through such joints is affected by the inclination angle, which may therefore determine the loading capacity of the joint. Canine sacroiliac joints are aligned close to the sagittal axis. As the alignment of the sacroiliac joints approach the sagittal plane, the direction of loading forces may become closer to parallel with the joint surfaces than it is when the joint is obliquely aligned. Therefore, sagitally oriented sacroiliac joints may have higher shear forces than obliquely oriented joints. German Shepherd Dogs had the most sagitally aligned sacroiliac joints of any breed of dog evaluated in another study. Furthermore, results of that study indicated small-breed dogs have more oblique (ie, less sagittal) orientation of their sacroiliac joints versus large-breed dogs. Sacroiliac joint inclination angles may be related to gait characteristics or body mass. Sacroiliac joint inclination angles have not been measured in active working dogs, to the authors’ knowledge.

Sacroiliac joint inclination angles have been measured in canine cadavers and symmetric ventrodorsal radiographic images of pelvises of dogs. That radiographic technique involves observation of the sacral wings rather than direct observation of the sacroiliac joint space. The locations of the borders of sacroiliac joint spaces are inconsistent in radiographic images of pelvises of dogs. Although sacroiliac joints have been successfully imaged via CT, that modality has not been used to quantitatively the inclination angles of such joints. The purpose of the study reported here was to develop a novel noninvasive in vivo method for measurement of the motion and inclination angles of sacroiliac joints of dogs by use of CT. Two large performance dog breeds (German Shepherd Dogs and Greyhounds) were selected for evaluation in this study; one of these breeds (German Shepherd Dogs) is predisposed to lumbosacral region pain. We hypothesized that motion and inclination angles of sacroiliac joints would be measurable by use of CT, and differences in rotational and translational motions of sacroiliac joints and inclination angles of such joints would be detected between German Shepherd Dogs and Greyhounds.

Materials and Methods

Animals—This study was approved by the Massey University Animal Ethics Committee, and informed consent of owners was obtained for use of dogs. Ten German Shepherd Dogs from the New Zealand Police Department that had no history of hind limb lameness or performance problems (eg, decreased ability or willingness to jump or enthusiasm for attack training) and were in active work or training were included in the study. These dogs were brought to the Massey University Veterinary Teaching Hospital for evaluation of a clinical problem unrelated to lumbosacral region or hind limb signs of pain or were healthy dogs that were recruited for the study. Twelve racing Greyhounds were recruited for inclusion in the study. These dogs were currently racing and had no history of hind limb lameness or poor performance. Dogs included in the study were free of lumbosacral region signs of pain. Potential causes of hind limb lameness were excluded on the basis of results of orthopedic and neurologic examinations performed by a specialist surgeon (AJW), including evaluation to detect signs of pain of the lumbosacral region (via application of pressure to the dorsal aspect of that region), signs of pain of hip joints (via extension of those joints), or lordosis of lumbosacral joints. After performance of CT, dogs were excluded from the study if transitional vertebrae or degeneration of the lumbosacral intervertebral disk were detected.

CT procedure—A 16-slice multidetector helical CT scanner was used to obtain CT images. The images were obtained via bone and soft tissue algorithms with
1-mm-thick slices that overlapped by 0.5 mm. Computed tomography was performed during anesthesia with either a combination of medetomidine (0.005 to 0.01 mg/kg, IV) and butorphanol (0.2 to 0.3 mg/kg, IV) or propofol (IV to effect), followed by inhalation anesthesia with isoflurane.

Positioning for CT was standardized for all dogs. Positions were intended to achieve the maximum passive physiologic range of motion for hind limb flexion and extension. Dogs were positioned in dorsal recumbency in a padded trough that was placed under the lumbar region of the back and the pelvis. For the flexed position, hind limbs were positioned cranially by use of weights so that they were adjacent to the thorax and the caudal aspect of the pelvis was slightly elevated above the table. This positioning induced complete flexion of the lumbosacral, sacroiliac, and hip joints.

For the extended position, hind limbs were positioned caudally. Pressure was manually applied in a caudo-ventral direction to the proximal aspects of hind limbs until the cranial aspect of the pelvis was slightly elevated above the table. This positioning induced maximum physiologic extension of all motion segments of the caudal aspect of the spinal column. The hind limbs were positioned so that each patella was aligned over the center of the dorsodistal aspect of the femur (without abduction or adduction of the limbs). For the neutral position, femurs were positioned perpendicular to the lumbar aspect of the spinal column, pelvis, and padded trough via flexion of hip, lumbosacral, and sacroiliac joints of dogs in dorsal recumbency. These positions were intended to represent the maximum physiologic extension and flexion of hip, lumbosacral, and sacroiliac joints for each dog (as subjectively assessed).

### Determination of sacroiliac joint motion

- **Rotational and translational motions of sacroiliac joints** of dogs were assessed. For determination of the motion of the ilium relative to the sacrum, translational motion (comprised of components in x- and y-axes) and rotational motion of the ilium relative to the sacrum around an unknown pivot point were calculated. The x-axis was a line along the dorsal sacral spinous processes and the y-axis was a line 90° to the x-axis.

Lines were placed on volume-rendered CT images (constructed with a workstation) of the ilium and sacrum by use of anatomic points that could be accurately and precisely identified on images obtained in flexion and extension of hind limbs (Figure 2). The lines drawn on the sacrum (sacral lines) were positioned to lie between points on the dorsal sacral spinous processes. The lines drawn on each ilium (ilia lines) were typically placed between points on the tuber coxae and the body of the ilium. The lines were placed so that extensions of the ilial and sacral lines would intersect at an acute angle. To compare the rotational and translational motion of the ilium relative to the sacrum between dogs, it was important to ensure identical placement of the sacral and ilial lines between flexed and extended views of each dog. Thus, anatomic points were identical for flexed and extended CT images of each hind limb of each dog. However, the anatomic points used for the lines varied among dogs and between left and right ilia of each dog because of variations in anatomy and CT image lengths. This method allowed selection of the most prominent anatomic points on CT images for each dog.

After manipulation of the volume-rendered CT images to symmetrically align the ilia, a display image with the ilial and sacral lines but without images of bones was saved (Figure 2). Placement of lines and saving of images was performed 3 times for each hind limb position. Left and right hind limbs of
Dogs were measured and analyzed independently so that comparisons could be made between such images.

The images of sacral and ilial lines were calibrated and measured with a workstation. An angle marker was drawn over the ilial and sacral lines (Figure 3). This marker was used to locate the intersection of any angle between the lines. The distances from the intersection point to the cranial and caudal points of the ilial and sacral lines were measured for CT images obtained with hind limbs in flexion and extension. The lengths of the ilial and sacral lines were calculated to confirm appropriate placement of anatomic points. The ilial line in hind limb flexion was defined as $I_1F$ minus $I_1E$, where $I_1F$ and $I_1E$ are the means of 3 replicated measurements from the intersection of the ilial and sacral lines to the caudal and cranial ends of the ilial line in flexion, respectively. The ilial line in hind limb extension was defined as $I_1E$ minus $I_1F$, where $I_1E$ and $I_1F$ are the means of 3 replicated measurements from the intersection of the ilial and sacral lines to the caudal and cranial ends of the ilial line in extension, respectively. The sacral line in hind limb flexion was defined as $S_2F$ minus $S_1F$, where $S_2F$ and $S_1F$ are the means of 3 replicated measurements from the intersection of the ilial and sacral lines to the caudal and cranial ends of the sacral line in flexion, respectively. The sacral line in hind limb extension was defined as $S_2E$ minus $S_1E$, where $S_2E$ and $S_1E$ are the means of 3 replicated measurements from the intersection of the ilial and sacral lines to the caudal and cranial ends of the sacral line in extension, respectively. All subsequent calculations were performed with mean values of the triplicate measurements (for the variables $I_1F$, $I_1E$, $S_2F$, $S_2E$, $S_1F$, $S_1E$, $\Phi_1$, and $\Phi_2$ where $\Phi_1$ and $\Phi_2$ are the means of 3 replicated measurements of the angle formed by the intersection of the ilial and sacral lines for hind limbs in flexion and extension, respectively).

Measurements were determined with a precision of $0.1^\circ$ and $0.01$ cm with the workstation.

The images of the lines were placed so that the cranial aspect of the sacral lines in CT images acquired in flexion and extension were superimposed, with the ilial lines positioned on the x-axis (Figure 4). Then, the positions of the caudal aspects of the sacral lines were superimposed, confirming that the length of the ilial lines in CT images acquired with hind limbs in flexion and extension were identical. This induced a shift in the position of the extended intersection point along the x-axis ($ds = S_1E - S_1F$, where $ds$ is the amount of change in position [in cm]). This method allowed calculation of coordinates relative to an origin placed at the intersection of the lines in hind limb flexion ($F_0 = 0.0; E_0$ is the intersection of the ilial and sacral lines with a hind limb in flexion). The flexed hind limb position was used as the reference position from which to measure motion between flexed and extended positions. A triangle was drawn for ilial lines with hind limbs in flexion and extension, for which the value of 1 angle ($\Phi_E$) and the length of 1 side ($ds$) were known.

Figure 4—Diagram of lines indicating calculations performed to determine coordinates $(X_p, Y_p)$, relative to the origin of pivot points of ilial lines for hind limbs of dogs in flexed and extended positions. The $x$- and $y$-axis directions are indicated. $(0,0) = \text{Origin of coordinate system placed at the location of the flexed intersection point.} \Phi = \text{Mean of the triplicated measured values (°) of the angle formed by the intersection of the ilial and sacral lines, in the flexed position ($\Phi_1$) and in the extended position ($\Phi_2$).} ds = \text{Shift in the position of the extended intersection point ($E_0$) along the x-axis after the $S_1$ and $S_2$ points were superimposed.} E_0 = \text{The intersection point of the ilial and sacral lines in extension.} I_1 = \text{Mean of the triplicate measured distance (cm) from the intersection point of the ilial and sacral lines to the cranial end of the ilial line, in the flexed position ($I_1F$) and the extended position ($I_1E$).} S_1 = \text{Mean of the triplicate measured distance (cm) from the intersection point of the ilial and sacral lines to the cranial end of the sacral line, in the flexed position ($S_1F$) and the extended position ($S_1E$).} X_p, Y_p = \text{Coordinates of the pivot point of the flexed and extended ilial lines.}
The value of the angle $\Phi_f$ was also known; therefore, on the basis of the law of sines, the other 2 angles of the triangle were calculated ($180^\circ - \Phi_f$) and ($\Phi_f - \Phi_i$). The distance ($d$) from the intersection point of the ilial and sacral lines with a hind limb in extension ($E_0$) to the x- and y-axis coordinates of the cranial point of the ilial line in hind limb extension ($X_{I1E},Y_{I1E}$) was calculated on the basis of the law of sines:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

whereby after substitution:

$$d = \frac{ds \sin (180 - \Phi_f)}{\sin (\Phi_f - \Phi_i)}$$

The x- and y-axis coordinates of the pivot point of the ilial lines in flexion and extension ($X_{p},Y_{p}$) were calculated via determination of the change in x-axis and y-axis position of the cranial ($dx_1',dy_1'$) and caudal ($dx_2',dy_2'$) points due to rotation of the ilial line from flexion to extension. $X_{p},Y_{p} = \text{Predicted location of the cranial point of the ilial line if all motion was attributable only to rotation}$. The cranial point of the ilial line if all motion was attributable only to rotation ($X_{I1F},Y_{I1F}$) was assumed to be the net translational motion (including x- and y-axis components). A graph was plotted to help determine the predicted location of the cranial point of the ilial line if motion was attributable only to rotation ($X_{I1F},Y_{I1F}$). The coordinates of that point ($X_{I1F},Y_{I1F}$) were converted to coordinates relative to the original origin by adding or subtracting $X_p$ and $Y_p$ or $X_1'$ and $Y_1'$, depending on the location of $X_1'$ and $Y_1'$ with respect to the pivot point (Figure 6). The x-axis component of the translational motion of the cranial point of the ilial line between hind limb flexion and extension ($dx_f$) was calculated by determination of the difference between these 2 points ($dx_f = X_{I1F} - X_1'$); the y-axis component of that translational motion ($dy_f$) was also calculated ($dy_f = Y_{I1F} - Y_1'$). Similar calculations were performed to determine $dx_c$ (the x-axis component of translational motion of the caudal point of the ilial line between hind limb flexion and extension) and $dy_c$ (the y-axis component of that translational motion) by use of the values $I_{1E}$ ($X_{I1F},Y_{I1F}$) and $X_{I2E}$, ($Y_{I1F}$) around the most cranial point of the ilial line ($X_{I1F},Y_{I1F}$) around the pivot point ($X_p,Y_p$); Figure 5:

$$r^2 = a^2 + b^2$$

whereby $r^2 = dx_r^2 + dy_r^2$, where $dx_r = X_p - X_1'$ and $dy_r = Y_p - Y_1'$. The x- and y-axis coordinates of the cranial point of the ilial line in flexion ($X_{I1F},Y_{I1F}$) were calculated relative to the origin ($X_1 = dx \cos \Phi_f - dy \sin \Phi_f$). The distance ($r$) along the ilial line in hind limb flexion from the pivot point ($X_p,Y_p$) to the x- and y-axis coordinates of the cranial end of the ilial line in flexion ($X_{I1F},Y_{I1F}$) was calculated on the basis of the Pythagorean theorem (the distance $r$ is the radius of rotation of the most cranial point of the ilial line [$X_{I1F},Y_{I1F}$] around the pivot point [$X_p,Y_p$]; Figure 5):

$$r = \sqrt{(X_p - X_1')^2 + (Y_p - Y_1')^2}$$

The ilial line for a hind limb in flexion was rotated around the pivot point ($X_{p},Y_{p}$) until it overlaid the ilial line for the hind limb in extension. This indicated the location on the ilial line in hind limb extension to which the cranial point of the ilial line in flexion ($X_{I1F},Y_{I1F}$) was predicted to move if all motion was attributable to rotation. The x- and y-axis coordinates of the cranial point of the ilial line in flexion ($X_{I1F},Y_{I1F}$) were calculated relative to the pivot point ($X_1,Y_1$) by use of equations ($X_{I1F} = r \cos \Phi_i$ and $Y_{I1F} = r \sin \Phi_i$, respectively). These calculations were repeated for the predicted position of the caudal end of the ilial line in hind limb extension ($X_{I2F},Y_{I2F}$) by use of the values $X_{I1F}$ and $Y_{I1F}$ (where $X_{I1F}$ and $Y_{I1F}$ are the x- and y-axis coordinates of the cranial end of the ilial line in hind limb flexion).

The difference between the measured location of the cranial point of the ilial line in hind limb extension ($X_{I1E},Y_{I1E}$) and the predicted location of the ilial line determined for dogs with hind limbs in flexion and extension. The x- and y-axis directions are indicated. $dx,dy = \text{The x-axis and y-axis translational motion}$. All calculations were performed separately for left and right sacroiliac joints.
Determination of sacroiliac joint inclination angles—Sacroiliac joint inclination angles were measured by use of 1-mm-thick transverse CT bone algorithm images acquired with hind limbs of dogs in a neutral position. Neutral position CTs were used to measure inclination angles because hind limbs did not have excessive strain attributable to maximum extension or flexion in that position. The CT images were manipulated with a workstation to align the images to the cranial aspect of the first sacral vertebral segment and to produce a bilaterally symmetric image so that measurements would be standardized. Measurement of inclination angles was performed with the aid of a workstation different than the workstation used to measure sacroiliac joint motion because 1 reference line could be used to measure the inclination angles of all 4 joint components in fewer steps with that software. The inclination angles of the synovial and ligamentous components of the left and right sacroiliac joints of each dog were measured at cranial and caudal aspects of the joints.

The synovial component of a sacroiliac joint was identified via detection of narrowing of the joint space at the ventral aspect, the presence of thick subchondral bone, and the absence of fibrous and adipose tissue in the joint space. The ligamentous component at the dorsal aspect of a sacroiliac joint was identified via detection of a wide joint space and the presence of short tissue fascicles interposed with adipose tissue in the joint space. The cranial location at which measurements were obtained was identified by scrolling through CT images of the sacrum in a caudal direction until the first point at which the synovial component of the ventral aspect of the joint was seen; this appeared as a narrow joint space with high subchondral bone density. The caudal location at which measurements were obtained was found by identification of the ventral deviation of the dorsal foramina of the second sacral vertebral segment from the vertebral canal. A reference line was drawn through the right and left ventral deviations in the dorsal sacral vertebral lamina formed by the junction of the dorsal sacral vertebral lamina with the sacral wings (Figure 7). The inclination angles of the sacroiliac joints were determined via measurement of the inclination angle of the ilial or sacral vertebral bone surface at the margins of the joints. The joint space is of variable width; therefore, bone surfaces were used to measure the joint axis to improve repeatability of the measurements because they formed a flat surface for measurements and removed error associated with measurement of the axis of a joint with variable width. The medial surface of the ilium was selected for measurement of the inclination angle of the ligamentous component of the joint because it was a consistently flat surface. Likewise, the flattest surface for measurement of the synovial component of the joint was the lateral surface of the sacrum. The inclination angle was defined as the angle between the axis of the joint and the reference line in the dorsal plane. Increasing inclination angles indicated a joint axis closer to the sagittal plane (Figure 8). These measurements were performed in triplicate with a precision of 1°.

Statistical analysis—Data were analyzed with statistical software. A mixed linear model that included a random intercepts term for each dog was used to analyze the effects of age, body weight, limb, sex, and breed on the measurements of rotational motion (Φ), translational motions in the x- and y- axes, and inclination angles and their interactions. The mixed model adjusted for repeated measures of left and right hind limbs of each dog was fitted via a restricted maximum likelihood procedure. Values of P < 0.05 were considered significant. Data for each variable were determined in triplicate, and mean values were used for analyses. All measurements were performed by the same observer (FCS), who was unaware of results from previous measurement trials. Intraobserver variability was determined via calculation of the coefficient of variance.
determined for 6 measurements for each variable measured in CT images of 1 dog with hind limbs in flexion and extension. All data were tested for normality via the Anderson-Darling test. Outlier values in the fitted model were identified by examining the plot of standardized residuals versus leverage values. Identification of outlier values was performed via analysis of Cook’s distance. Cook’s distance is used to assess the influence of a value on the set of regression coefficients in a model. Values with high influence can have a disproportionate impact on the model and cause determination of misleading results. Outlier values are influential

Figure 7—Transverse CT images of the cranial (A) and caudal (B) aspects of the right and left sacroiliac joints of a representative dog indicating measurements performed to determine inclination angles of the synovial (S) and ligamentous (L) components of those joints relative to a reference line (R). The inclination angles of the right ligamentous (1), right synovial (2), left synovial (3), and left ligamentous (4) components of the sacroiliac joints are indicated.

Table 1—Values of sacroiliac joint rotational and translational motion for a 32-kg dog adjusted for the effect of body weight on that variable.

<table>
<thead>
<tr>
<th>Variable</th>
<th>German Shepherd Dog</th>
<th>Greyhound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational motion ([°]</td>
<td>2.0 ± 1.5</td>
<td>1.5 ± 0.7</td>
</tr>
<tr>
<td>Estimated rotational motion</td>
<td>2.14</td>
<td>1.28</td>
</tr>
<tr>
<td>x-axis translational motion (mm)</td>
<td>1.0 ± 0.7</td>
<td>1.4 ± 0.7</td>
</tr>
<tr>
<td>y-axis translational motion (mm)</td>
<td>0.6 ± 0.4</td>
<td>0.7 ± 0.4</td>
</tr>
</tbody>
</table>

Data are mean ± SD unless otherwise indicated.

Animals—One German Shepherd Dog and 2 Greyhounds were removed from the study because of transitional vertebrae in the lumbosacral region. Therefore, 9 German Shepherd Dogs and 10 Greyhounds were included in the study. Data for the left sacroiliac joint of 1 German Shepherd Dog were excluded from analysis of x- and y-axis translation because of a high residual Cook’s distance; exclusion of that data resulted in normally distributed data. German Shepherd Dogs included in this study were 1 to 3 years old or 5.3 to 6.3 years old. Greyhounds included in this study were 2.4 to 5.9 years old. There was a significant (adjusted R² = 0.22; P = 0.02) but small negative association between age and weight in Greyhounds and a significant (adjusted R² = 0.31; P = 0.01) but small positive association between age and weight in German Shepherd Dogs.

Method validation—The CT measurement method for determination of sacroiliac joint motion and inclination angles in this study had low intraobserver variability. The coefficients of variance for joint motion measurements ranged from 0.17% to 1.29% and that for joint inclination angle measurements ranged from 0.55% to 2.45%.

Sacroiliac joint motion—Mean values of sacroiliac joint motion variables were summarized (Table 1). These values were not adjusted for interactions between rotational motion and body weight; an estimated value was determined for rotational motion of sacroiliac joints in a dog with a weight of 32 kg. Estimated values of sacroiliac joint rotational motion and inclination angles determined via the mixed-effects linear regression model were summarized (Table 2). German Shepherd Dogs had significantly (P = 0.047) greater sacroiliac joint rotational motion than Greyhounds. The amount of sacroiliac joint rotational motion decreased (although not significantly; P = 0.067) with increasing body weight for German Shepherd Dogs but not for Greyhounds (P = 0.797). Although mean body weights of each group of dogs were not significantly different, the distribution of body weights seemed to be different between breeds (Figure 9). No significant effect on sacroiliac joint rotational motion was detected for the variables left versus right limb, sex, or age of dogs. The x-axis translation of sacroiliac joints of German Shepherd Dogs was not significantly
(P = 0.105) different from that for Greyhounds; the power for detection of a difference in this variable between dogs of each breed was 0.45. The y-axis translation of sacroiliac joints was not significantly (P = 0.184) different between dogs of each breed; however, the power for detection of a difference in this variable between these groups was only 0.32.

**Sacroiliac joint inclination angles**—The mean inclination angle of the cranial synovial component of the sacroiliac joint was significantly larger (ie, more sagittal in orientation) in German Shepherd Dogs (83.0°) versus Greyhounds (78.5°; P = 0.035; Table 2). Age had an effect on the inclination angle of the cranial synovial component; however, results were not significant (P = 0.087). No significant (P = 0.128) difference was found between German Shepherd Dogs and Greyhounds regarding inclination angles of the caudal synovial components of sacroiliac joints; the power to detect a difference between these groups of dogs for that variable was 0.33. No significant effect of age, weight, limb, or sex was found on inclination angles of the caudal synovial components of sacroiliac joints.

No significant differences were detected between German Shepherd Dogs and Greyhounds regarding inclination angles of the cranial (P = 0.967) and caudal (P = 0.211) ligamentous components of sacroiliac joints. The power to detect a difference between dogs of each breed was 0.41 for the cranial and caudal ligamentous components of sacroiliac joints.

**Discussion**

In the present study, a novel method was used to measure motion and inclination angles of sacroiliac joints in healthy dogs of 2 breeds without signs of lumbosacral region pain. To the authors’ knowledge, this study was the first in which sacroiliac joint motion was measured in vivo and the first in which CT was used to measure sacroiliac joint motion and inclination angles in dogs. Results indicated data obtained via these methods had low intraobserver variability.

In this study, positioning of dogs for CT scans was intended to achieve the full passive range of motion (ie, physiologic range of motion) of hind limbs in flexion and extension. Other authors defined passive range of motion as the motion controlled by a passive stabilization subsystem (eg, vertebrae, intervertebral disks, ligaments, joint capsules, and zygapophyseal joints for dogs in this study) that includes motion at the extremes of the physiologic range whereby motion is induced against substantial resistance. Substantial resistance is defined as the resistance at an extreme of the physiologic range of motion that prevents movement beyond the physiologic limit of tissues. In the present study, the limit of the physiologic range of extension of tissues was identified via observation of elevation of the cranial aspect of the pelvis of dogs off the table (analogous to a fulcrum) when hind limbs were extended caudoventrally. The limit of the physiologic range of motion in flexion was identified via observation of elevation of the caudal aspect of the pelvis off the table (analogous to a fulcrum) when hind limbs were pulled cranially. These movements of the pelvis indicated that the physiologic limits of the range of motion for adjacent structures (lumbosacral, sacroiliac, and hip joints) had been reached. The effect of sedation or anesthesia on range of motion was unknown, but sedation was necessary for performance of CT for the dogs.

**Table 2**—Estimated values and SEs of various variables of rotational motion and inclination angles of the cranial synovial components of the sacroiliac joints in 9 German Shepherd Dogs and 10 Greyhounds determined via a mixed-effects linear regression model.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimated value</th>
<th>SE</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotational motion (°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>8.32*</td>
<td>1.78</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Breed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>German Shepherd Dog</td>
<td>Reference</td>
<td>Reference</td>
<td>Reference</td>
</tr>
<tr>
<td>Weight</td>
<td>−0.22†</td>
<td>0.06</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>Inclination angle of the</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>cranial synovial component (°)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>73.25†</td>
<td>3.3</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Age</td>
<td>1.5†</td>
<td>0.8</td>
<td>0.087</td>
</tr>
<tr>
<td>Breed</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>German Shepherd Dog</td>
<td>Reference</td>
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*The baseline value of rotational motion for a Greyhound without the effect of body weight. †The amount of rotational motion for a German Shepherd Dog relative to a Greyhound during baseline conditions without the effect of body weight (ie, rotational motion for a German Shepherd Dog was 9.18° [8.32° + 0.86°]). ‡Indicates value by which body weight for Greyhounds would be multiplied for determination of rotational motion with the effect of weight (amount of rotational motion [°] for a Greyhound = 8.32° − (body weight × 0.22)). §The baseline inclination angle of the cranial synovial component of the sacroiliac joint for a Greyhound. ¶The value by which inclination angles would increase for each 1 year of age for Greyhounds or German Shepherd Dogs (ie, the effect of age was 1.5°/y for both breeds). ∥The sacroiliac joint inclination angle for German Shepherd Dogs relative to Greyhounds; the inclination angle (°) of the cranial synovial component of the sacroiliac joints of German Shepherd Dogs adjusted for age = (73.2° + 5.6°) + (1.5 × age of dog).
Results of this study indicated sacroiliac joints of dogs had only a small amount of rotational and translational motion. The main component of translational motion was along the x-axis (along the dorsal spinal processes of the sacrum), with very little motion detected in the y-axis perpendicular to the dorsal sacral spinal processes. The amount of sacroiliac motion measured in dogs in the present study was less than that determined for cadavers of dogs in another study. Results suggested sacroiliac joints have much less motion than adjacent high-motion lumbosacral and hip joints; the small amount of motion detected in sacroiliac joints indicated that they are still joints. High-frequency vibrations are better absorbed by joints than they are by direct bone connections. If the sacrum and ilium were fused, they would have high efficiency for transmission of forces during a gait but would have low ability to buffer forces. Bone-to-bone connections may be more susceptible than joints to degenerative changes because of transmission of high amounts of vibration.

The higher amount of sacroiliac joint rotational motion in German Shepherd Dogs versus Greyhounds detected in the present study may be associated with the predisposition of German Shepherd Dogs to lumbosacral region pain, either as a direct cause of sacroiliac joint pain or via transfer of physiologically abnormal loads to adjacent structures (eg, lumbosacral joints). Further studies may be warranted in which sacroiliac joint motion is measured in German Shepherd Dogs and with and without signs of lumbosacral region pain to assess this potential association. Currently, identification and localization of sacroiliac joint signs of pain in dogs is difficult, and it is possible that sacroiliac joints are not typically involved in the development of lumbosacral region pain.

Rotational motion has been measured in sacroiliac joints of canine cadavers following removal of surrounding soft tissues. Substantially less sacroiliac joint rotational motion was detected in dogs in the present study versus cadavers of dogs in that other study. The higher amount of motion found in that other study could have been attributable to removal of soft tissues (which have important roles in restricting motion in vivo) and potential changes in tissue dynamics following freezing and thawing of cadavers; alternately, differences in results may have been attributable to differences in the magnitude of loading forces applied to joints and the use of different methods in the studies.

The distributions of body weights of dogs in this study varied between groups. The range of body weights for German Shepherd Dogs was 26 to 38 kg and that for Greyhounds was 28 to 34.5 kg. Although light German Shepherd Dogs seemed to have higher sacroiliac joint rotational motion than heavy German Shepherd Dogs, none of the Greyhounds had body weights similar to those at the extremes of the range for German Shepherd Dogs. Therefore, comparisons between groups for dogs with high or low weights were difficult. To determine the effects of breed and body weight on sacroiliac joint rotational motion, further studies would be necessary in which dogs of a broader range of body weights were included.

The age distribution of dogs varied between the 2 breed groups in the present study. The age ranges of dogs included in this study were deliberately small to minimize the effects of age and maximize the ability to detect breed differences. However, the differences in age distributions between groups decreased the ability of the model to detect the effects of age on the evaluated variables. Results indicated an effect of age on the inclination angles of the cranial synovial components of sacroiliac joints, although results were not significant (1.5%\(; P = 0.087\)). Age was left in the mixed-effects model for the inclination angle of the cranial synovial component because of the potential effect it may have had on this variable. It would be worthwhile to investigate this effect with a larger sample size. Age had no significant effect on other variables; however, effects of age may have been masked by the differences in age distributions of dogs in each group. In addition, weight may have been a confounding variable. A moderate association between age and weight was detected for both German Shepherd Dogs and Greyhounds. Further studies including dogs of a wider range of ages may be warranted to determine the effects of age on sacroiliac joint variables.

Sacroiliac joint inclination angles have been determined for dogs in another study via measurement of the dorsal and ventral transverse diameters between sacral wings in radiographic images of cadavers. Sacroiliac joint spaces can be directly observed in CT images of dogs, allowing measurement of the axis of the joint space. For some dogs in the present study, differences between the inclination angles of the ligamentous and synovial components of sacroiliac joints were detected. For this reason, these components of joints were evaluated separately to improve accuracy of inclination angle measurements. Cranial synovial components of sacroiliac joints were more sagittally oriented in German Shepherd Dogs than they were in Greyhounds in this study. No significant differences between breeds were found for inclination angles of other sacroiliac joint components. The importance of the difference in cranial synovial components between breeds is unknown. Sacroiliac joint inclination angles may be related to the risk of development of lumbosacral region signs of pain in German Shepherd Dogs. Further studies to compare inclination angles between German Shepherd Dogs and without lumbosacral region signs of pain would provide further information regarding relationships between inclination angles and lumbosacral region pain in such animals.

The finding that there were no significant differences between variables for left and right sacroiliac joints of Greyhounds in this study was interesting. Repeated racing in 1 direction on a track leads to asymmetric adaptive remodeling of lower aspects of limbs in dogs. Results of another study indicate there are differences in bone mineral density of central tarsal bones between left and right hind limbs in racing Greyhounds. Therefore, asymmetric forces may not be transferred through sacroiliac joints in Greyhounds during racing or asymmetric forces may not cause changes in sacroiliac joints in such dogs.

In the present study, sacroiliac joint motion of dogs was calculated via measuring changes in positions of 2 lines that were drawn by use of arbitrary anatomic land-
marks that could be clearly identified on CT images acquired with hind limbs in flexion and extension. The anatomic landmarks that were chosen varied because of differences in anatomy and CT image lengths among dogs. However, because lines used for measurements were arbitrarily chosen reference lines, the important aspect of the method was that the same points were chosen in CT images obtained with hind limbs in flexion and extension for each dog; it was not important for anatomic landmarks to be identical among dogs. The coefficients of variation for sacroiliac joint motion measurements had a range of 0.17% to 1.29%; this finding suggested that selection of identical anatomic landmarks in CT images obtained with hind limbs in flexion and extension was accurate and that the method was appropriate for measurement of sacroiliac joint motion. For some dogs, the intersection point of the ilial and sacral lines was a short distance from 1 end of the ilial line; therefore, there was high variation in the length of this line among dogs. Because low coefficients of variation were determined for this method, this variation in line length did not have a substantial effect on the results.

Computed tomographic images in which ilial anatomic points could be placed further from the intersection point of the ilial and sacral lines had lower variation in measurements versus CT images in which such anatomic points were closer to that intersection; therefore, this method could be improved for future studies.

The power of the present study to detect differences in variables between dogs of each breed ranged from 0.32 to 0.45. Those powers were not strong and may have reduced the ability of the study to identify small differences in values as significant; however, such small differences in values may not be biologically important. Another limitation of the study was that we did not determine interobservervariability in measurements. This variable should be determined in future studies.

A novel CT method for noninvasive in vivo measurement of sacroiliac joint motion and inclination angles in dogs was used in the present study. These variables were measured for dogs of 2 working breeds that did not have signs of lumbosacral region pain. Results of the study indicated German Shepherd Dogs had higher sacroiliac joint rotational motion than Greyhounds. The cranial synovial components of sacroiliac joints in German Shepherd Dogs were oriented closer to a sagittal plane than they were in Greyhounds. These breed differences may be related to the predisposition of German Shepherd Dogs for development of lumbosacral region signs of pain, although whether sacroiliac joints are typically involved in lumbosacral region signs of pain in dogs is, to the authors’ knowledge, unknown. Further studies are warranted to measure sacroiliac joint motion and inclination angles in German Shepherd Dogs with and without signs of lumbosacral region pain.

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