Determination of isometric points for placement of a lateral suture in treatment of the cranial cruciate ligament deficient stifles

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Summary
Complete or partial rupture of the cranial cruciate ligament (CCL) is a common injury of the canine stifle. While numerous techniques have been developed for surgical treatment, extra-articular methods with placement of a lateral suture remain a popular treatment method. The purpose of this study was to determine the potential isometry of the six suture-paired sites; two on the femur and three on the tibia. In six femoro-tibial specimens with intact passive joint restraints, femoral sites adjacent to the proximal (F1) and distal (F2) poles of the fabella, and tibial sites adjacent to the patella insertion (T1), immediately cranial to (T2) and caudal to (T3) the long digital extensor tendon, were identified. A suture from one femoral site to one tibial site was placed under 0 or 5 N of preload, and tension was measured at joint angles of 150°, 130°, 90°, 90°, and 50°. The F2-T3 combination was found to be most isometric. Isometry was reassessed in the same specimens with the suture in the F2-T3 position, and under 5 N, 10 N, and 15 N of preload, and after transection of the CCL. The suture pair retained its isometric pattern in the CCL transected specimens. There was no effect of preload on isometry patterns.

Introduction
Complete or partial rupture of the cranial cruciate ligament (CCL) is a common injury of the canine stifle (1–3). Injury of the CCL allows cranial translation of the tibia resulting in stifle instability and hindlimb lameness (4). It has been demonstrated that dogs with CCL deficient stifles cannot prevent cranial translation of the tibia either by altering hindlimb gait or muscle forces across the stifle (5). As such, conservative treatment of CCL injuries is generally unsuccessful, leading to surgical stabilisation as the preferred method of treatment (6). Numerous surgical techniques have been developed including placement of intra-articular grafts, insertion of suture material or advancement of periarticular structures outside the joint (extracapsular), and tibial osteotomies that alter the joint mechanics (7–9). Although hindlimb function and lameness can be improved with surgical intervention, to date no one technique has been proven to be superior (10, 11). Procedures that require placement of extracapsular sutures are technically less demanding than intra-articular or mechanic-altering techniques, and they remain popular with veterinary surgeons and veterinary practitioners. The optimal extra-articular suture would be one which eliminated abnormal cranio-caudal translation, and was placed so that the distance between the two points of attachment (femur and tibia) did not change through flexion and extension (isometric placement). Our null hypothesis was that the present recommendation for location of femoral and tibial paired sites used for extra-articular reconstruction are isometric. The objectives of this study were to determine the isometry of the five suture-placement sites in the intact and CCL deficient stifle.

Materials and methods
Six cadaver hindlimbs were harvested from male or female dogs that had been euthanatized for reasons unrelated to this study. Dogs were young adults that weighed between 25 to 30 kg, and were determined to have normal stifles as assessed by palpation and observation. Extracapsular soft tissues were removed except for the joint capsule and collateral ligaments. The joint capsule was not entered so as to prevent synovial fluid leakage and articular surface drying. Each specimen was wrapped in a saline moistened towel, then sealed in a plastic bag, and stored at ~80° C until the day of testing. Twenty-four hours prior to testing, each limb was thawed in a refrigerator. The specimen was mounted onto the testing jig by securing the femur to the jig with a series of 24 hours prior to testing, each limb was thawed in a refrigerator. The specimen was mounted onto the testing jig by securing the femur to the jig with a series of

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of end-threaded pins. The pins were placed through external fixation clamps which were rigidly connected to the testing jig. The tibia was not restrained, which allowed cranio-caudal, medial-lateral, and proximo-distal translation as well as axial and varus-valgus rotation. Isometry at three tibial sites (T1, T2, and T3) and two femoral sites (F1 and F2) was determined (Fig. 1).

The T1 site was located near the insertion of the patella tendon at the tibial crest; T2 represented a site near the joint line located at the bony protuberance 2 mm cranial to the sulcus of the long digital extensor tendon; T3 represented a site near the joint line located at the bony protuberance 2 mm caudal to the sulcus of the long digital extensor tendon. The F1 site was located caudally in the lateral femoral condyle at the level of the proximal pole of the lateral femoral fabella adjacent to the femoral-fabellar ligament. The F2 site was located caudally in the lateral femoral condyle adjacent to the articular cartilage line and 3 mm distal to the articulation of the fabella and femoral condyle. Number-5 polybutylate coated polyester suture served as the material to span the distance between femoral and tibial sites. A 1.6 mm Kirschner pin drilled perpendicular to the femoral surface from lateral to medial at the F1 site, and one drilled perpendicular to the femur from lateral to medial at the F2 site, were used to represent the femoral sites tested. A partially threaded, cancellous bone-screw and washer were used for anchorage of the suture at the tibial sites. A force gauge was secured to the testing jig so that it was in line with the long axis of the femur. The suture was attached to a force gauge clasp using a surgical knot. From the force gauge, the suture passed in line with the long axis of the femur, over one of the pre-placed femoral Kirschner wires (F1, F2), and then to the screw and washer placed at a tibial site (T1, T2, T3). The distance between the force gauge and the tibial site represented a fixed distance. Likewise, the distance from the force gauge to a femoral site (F1 or F2) represented a fixed distance. The joint was moved through its range-of-motion (ROM) (150° extension/50° flexion) and tension was measured at specific angles. Since change in distance could occur between the femoral site (Kirschner wire) and the tibial site (screw and washer), this would cause an increase or decrease in tension at the suture which would then be recorded quantitatively in the force gauge. To control movement through flexion and extension of the joint, an eye screw was placed into the caudal tibial cortex midway between the lateral and medial cortices at the level of the distal prominence of the tibial crest. A guide line was attached to the eye screw and to a motorised reel to produce a consistent movement without manual manipulation of the specimen. Each tibial position and a femoral position were randomly tested as a paired site (F1-T1, F1-T2, F1-T3, F2-T1, F2-T2, F2-T3). Each paired site was tested with the CCL intact to assure normal joint motion through flexion and extension. Each paired site was tested at a preload of 0 N tension in the suture followed by testing at a preload of 5 N tension in the suture. The suture was preloaded along the long axis of the tibia. This was achieved by adjusting the clasp mechanism of the force gauge to which the suture was secured. The assigned preload was applied at 130° of extension and then the specimen placed through its full range-of-stifle-motion. Joint movement was halted at predetermined angles (as measured with a goniometer) and measurements recorded at 130° (normal standing angle), 90° (mid-flexion), 50° (full flexion), 90° (mid-flexion), and 150° (full extension). The force gauge recorded tension (N) in each of the predetermined flexion and extension angles. Stifles were placed through total ROM twice at 0 N preload and twice at 5 N preload. The change in tension was then recorded for each data point. To examine whether isometry patterns were different between joints with the CCL intact and after CCL transection, the paired site determined to be the most isometric with an intact CCL was tested with the CCL transected in the same limbs. After the CCL was transected, each of the six specimens were tested with a preload of 5, 10, and 15 N.

Statistical analysis

The change in force at each joint position was calculated as a proportion of the start-
ing force for each specimen and replication (each test repeated twice), and was the response variable for analysis. The proportional change was the square root transformed to follow a normal distribution. This was verified by failure to reject the null hypothesis of normality at \( p < 0.05 \) using the Shapiro-Wilk test statistic. The fixed effect of degrees ROM on the proportional change was evaluated for each site and starting load for both intact and cut cruciate-specimens using an ANOVA for repeated measures. A significant difference across ROM was considered at \( p < 0.05 \). Failure to find a significant difference across the ROM for a site was the result of interest, indicating the most isometric point. All statistical analyses were performed using commercial software for the analysis.

Results

The F2 site (located in the caudolateral femoral condyle at the level of the distal pole of the lateral fabella) paired with the T3 site (located at the bony protuberance 2 mm caudal to the sulcus of the long digital tendon) was the most isometric paired site when tested at 0 N and 5 N preload with the CCL intact (Fig. 2, Table 1). This finding is verified by failure to find a significant difference in suture tension across the ROM \( (p = 0.19 \) for 0 N preload; \( p = 0.30 \) for 5 N preload). The F1 site (located in the caudolateral femoral condyle at the level of the proximal pole of the fabella) paired with the T3 site was isometric at 5 N preload \( (p = 0.98) \) but not at 0 N preload \( (p = 0.02) \). All other paired sites were not isometric, verified by a significant increase in suture tension across ROM \( (p <0.001) \) at 0 N preload \( (p <0.001) \) and 5 N preload \( (p <0.001) \). The

![Fig. 2](image-url)  
Intact cranial cruciate ligament at 0 N (A and B) and 5 N (C and D) preload.
F1-T2 and F1-T1 paired sites, which represent sites commonly used for suture anchorage (femoral-fabellar ligament to drill hole in tibial crest), were least favorable as the suture tension increased considerably through range of motion. Suture tension at the paired site (F2-T3) remained near isometric when the CCL was transected with the suture preloaded with 5, 10, or 15 N (Fig. 3, Table 2).

Discussion

The CCL is a complex structure within which collagen fibers are taught or lax at different angles of flexion or extension. As such, there is no true isometric point, particularly for suture stabilisation outside the joint. Nevertheless, suture tension can be maintained near constant if the femoral and tibial paired sites are near isometric. The results of this study showed that paired sites commonly used for suture placement (F1-T1, F1-T2) have increased suture tension between paired sites through flexion. The most isometric paired site throughout the entire ROM was the F2-T3 paired site. This was true in the CCL intact stifles and CCL deficient stifles with the suture preloaded with 5, 10, or 15 N. Therefore, increasing suture preload (tension to eliminate cranial drawer) did not affect suture isometry at the preloads tested. Although factors such as weight bearing loads and material properties of the suture (stress relaxation) affect breakage and elongation, more isometric sites may help reduce suture tension and thereby, premature suture failure. A recent study showed isometric points different from that determined by this study (12). In that study, the most ideal femoral site was determined to be similar to our findings, but the tibial site was more cranial and distal. With the tibial site located cranial and distal, decreased isometry was noted with increasing flexion. These findings were similar to our results at the tibial sites of T1 and T2. One explanation may be that tibial sites located cranial to the sulcus of the long digital extensor tendon restrain tibial rotation during flexion. As such, increased tension in the suture would occur resulting in less isometry. The referenced study did not examine a tibial site analogous to our T3 tibial site; it is possible that our results would be comparable if both investigations had tested a site caudal to the sulcus of the long digital extensor tendon. Another reason for the different findings between this study and the referenced study may be that the previous study isometric sites were examined in a two-dimensional model with the limb on the table such that varus-valgus and axial rotation was semi-constrained. In the present study, five degrees of freedom of tibial movement was allowed. Although the F2-T3 paired site is more isometric, other factors are important in achieving optimal outcome such as choice of suture material and appropriate postoperative rehabilitation. The forces imposed on a suture used for stabilisation are unknown. As such, the necessary structural strength and stiffness of the suture and the material property of the suture (creep, stress, relaxation) are also not known. Suture breakage or elongation

<table>
<thead>
<tr>
<th>Site</th>
<th>Preload (N)</th>
<th>130°</th>
<th>90°</th>
<th>50°</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1-T1</td>
<td>0</td>
<td>0.41 ± 0.05</td>
<td>5.45 ± 3.10</td>
<td>12.10 ± 6.42</td>
</tr>
<tr>
<td>F2-T1</td>
<td>0</td>
<td>0.41 ± 0.09</td>
<td>2.03 ± 1.54</td>
<td>6.60 ± 3.59</td>
</tr>
<tr>
<td>F1-T2</td>
<td>0</td>
<td>0.41 ± 0.13</td>
<td>4.66 ± 2.61</td>
<td>10.98 ± 4.74</td>
</tr>
<tr>
<td>F2-T2</td>
<td>0</td>
<td>0.38 ± 0.08</td>
<td>1.60 ± 1.05</td>
<td>5.23 ± 3.47</td>
</tr>
<tr>
<td>F1-T3</td>
<td>0</td>
<td>0.38 ± 0.12</td>
<td>0.81 ± 0.82</td>
<td>1.56 ± 2.07</td>
</tr>
<tr>
<td>F2-T3</td>
<td>0</td>
<td>0.41 ± 0.07</td>
<td>0.59 ± 0.68</td>
<td>1.44 ± 1.86</td>
</tr>
<tr>
<td>F1-T1</td>
<td>5</td>
<td>5.18 ± 0.27</td>
<td>14.53 ± 5.15</td>
<td>21.01 ± 7.91</td>
</tr>
<tr>
<td>F2-T1</td>
<td>5</td>
<td>5.04 ± 0.31</td>
<td>7.43 ± 2.17</td>
<td>13.50 ± 4.64</td>
</tr>
<tr>
<td>F1-T2</td>
<td>5</td>
<td>5.23 ± 0.24</td>
<td>13.78 ± 3.63</td>
<td>21.62 ± 6.65</td>
</tr>
<tr>
<td>F2-T2</td>
<td>5</td>
<td>4.93 ± 0.29</td>
<td>6.72 ± 2.27</td>
<td>11.82 ± 4.42</td>
</tr>
<tr>
<td>F1-T3</td>
<td>5</td>
<td>5.07 ± 0.26</td>
<td>5.21 ± 2.71</td>
<td>4.75 ± 4.69</td>
</tr>
<tr>
<td>F2-T3</td>
<td>5</td>
<td>5.12 ± 0.22</td>
<td>4.38 ± 1.74</td>
<td>4.64 ± 3.24</td>
</tr>
</tbody>
</table>

Table 1: Intact cranial cruciate ligament: Suture tension (mean ± standard deviation) for paired sites at 0 and 5 N preload with an intact cranial cruciate ligament. Table shows suture tension beginning at standing angle (130°) and progressing to full flexion (50°).

**Fig. 3**

Transected cranial cruciate ligament, F2-T3 sites.
will occur if the imposed loads exceed the structural or material properties of the suture. Uncontrolled activity postoperatively, may cause excessive tension in the suture used for stabilisation. If this occurs prior to strengthening of secondary restraints, failure and instability are likely to result.

One limitation of the study is that only six paired sites were examined. Sites were chosen because they are readily and consistently identifiable during surgery. Nevertheless, additional studies may identify other medial or lateral sites that are more isometric. Further clinical studies are necessary to determine if the more isometric suture attachment sites noted in this study are more clinically effective than the traditional sites for suture attachment.

## Conclusions

Extra-articular stabilisation is a popular technique for reconstruction of the CCL deficient stifle. One traditional method for the stabilising suture is placement of the suture through the femoral-fabella ligament such that the suture exists at the level of the proximal pole of the fabella to a pre-drilled hole in the tibial crest near the insertion of the patella tendon. These sites closely mimic the F1-T1 or F1-T2 paired sites examined in this study. The results indicate that suture tension increases as one proceeds from extension to full flexion with these two paired sites. If the tension exceeds the material or structural property of the suture, failure by suture breakage or suture elongation may result. The femoral attachment site located at the caudal border of the lateral femoral condyle at the level of the distal pole of the fabella (F2) paired with the tibial attachment site located at the bony protuberance 2 mm caudal to the sulcus of the long digital tendon (T3) resulted in minimal change in suture tension throughout extension/flexion.

## References


### Table 2 Transected cranial cruciate ligament: Suture tension (mean ± standard deviation) for paired sites F2-T3 at 5, 10, and 15 N preload with a transected cranial cruciate ligament. Table shows suture tension beginning at standing angle (130°) and progressing to full flexion (50°).

<table>
<thead>
<tr>
<th>Site</th>
<th>Preload (N)</th>
<th>130°</th>
<th>90°</th>
<th>50°</th>
</tr>
</thead>
<tbody>
<tr>
<td>F2-T3</td>
<td>5</td>
<td>5.30 ± 0.24</td>
<td>4.75 ± 0.24</td>
<td>5.41 ± 2.97</td>
</tr>
<tr>
<td>F2-T3</td>
<td>10</td>
<td>10.10 ± 0.16</td>
<td>9.18 ± 0.16</td>
<td>9.32 ± 3.59</td>
</tr>
<tr>
<td>F2-T3</td>
<td>15</td>
<td>15.04 ± 0.19</td>
<td>14.07 ± 1.67</td>
<td>13.92 ± 3.74</td>
</tr>
</tbody>
</table>
Prevalence of incomplete ossification of the humeral condyle in the limb opposite humeral condylar fracture: 14 dogs

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Introduction
Humeral condylar fracture (HCF) in the dog is common (1–4). It has been reported that the primary cause of HCF in adult dogs is secondary to major trauma (5). In skeletally immature dogs that have an open intercondylar physis, HCF can be from minor trauma (e.g. running, climbing or jumping from a height equal or less than one meter) with a peak age incidence at four-months-old (2, 4, 13). However, several manuscripts have reported that HCF occurs secondary to minor trauma in skeletally mature dogs (5–7). It has been suggested that Spaniel breeds are overrepresented and that the fracture is related to incomplete ossification of the humeral condyle (IOHC), which then causes an inherent weakness in the distal humerus (5, 8–10). Although the exact pathogenesis of HCF is unclear, body weight, metabolic disease, conformation of the elbow, intense activity, decreased vascular density, and genetic predisposition in Spaniels have been suggested as predisposing factors (5, 11, 12).

Two separate centres of ossification are responsible for the development of the medial and lateral aspects of the humeral condyle. Early in the ossification process, the two centres are separated by a thin cartilaginous plate (5). Fusion of these two compartments is radiographically detectable at 10 ± 2 weeks of age (5, 8). Dogs with IOHC however have incomplete fusion of these two compartments, and thus the intercondylar separation resembles atrophic nonunion or fibrous tissue (5, 13). This intercondylar separation is visible on standard radiographs as a radiolucent line. This radiolucent line may be missed with standard, properly positioned orthogonal views. Therefore, a 15° cranio-medial-caudolateral view is recommended to more confidently identify the radiolucent line (5). While radiographic diagnosis of IOHC is possible, the sensitivity of a radiographic diagnosis is unknown. Computed tomography (CT) is arguably a more sensitive method of diagnosis. In one study using radiographs, Marcellin-Little et al reported an 86% (12 out of 14 Spaniels) prevalence of bilateral IOHC in Spaniels presenting with unilateral HCF (5). The CT features of IOHC have recently been described in 20 dogs with definitive diagnosis of IOHC (14). In that study, 11 dogs had a history of chronic forelimb lameness and elbow pain, and nine dogs were admitted for chronic forelimb lameness and elbow pain.
with atraumatic HCF. Bilateral CT imaging was performed and 19 of 20 dogs (95%) had either bilateral IOHC, or IOHC with contralateral HCF. All dogs with bilateral involvement were Spaniel breeds, and the only dog affected with unilateral IOHC was a Labrador Retriever.

Both of these manuscripts reported an extremely high incidence of bilateral IOHC in adult dogs; our impression was that the incidence of IOHC in the elbow opposite HCF was not as high as these authors reported. The objectives of this study were to determine the frequency of IOHC in the leg opposite a HCF, and determine the relative sensitivity of radiographic and computed tomography examinations in diagnosing IOHC.

Materials and methods

This protocol was approved by the University of Minnesota Institutional Animal Care and Use Committee. Dogs that had been previously presented to the University and received a diagnosis of a unilateral HCF were recruited for re-examination. In addition, dogs that were presented with a HCF were prospectively recruited for participation. Each dog recruited, or each dog presenting during this period must have sustained the HCF after the age of six months. Owners were contacted and asked if their pets could be re-examined and included in the study. In addition, the owners of dogs that presented to the University for lameness associated with acute (<3 days) HCF were invited to have their pets participate at no additional charge in the study. Cases were excluded if the patient had a history of fracture related to major trauma, or fracture secondary to neoplasia.

Each dog was evaluated by physical examination and imaging. Sedation was performed for all imaging by aseptically placing an intravenous catheter in a lateral saphenous vein using medetomidine (15 mcg/kg IV) and butorphanol (0.2 mg/kg IV). Propofol (4mg/kg IV to effect) was available if chemical restraint was inadequate. Patient information was recorded for electrocardiogram, heart rate, respiration rate, SpO2, and non-invasive blood pressure and temperature while under sedation.

Computed tomography

Images were obtained using a computed tomography scanner. Each patient was positioned in dorsal recumbency with the legs extended cranially over the patient’s head. The legs were secured together with velcro straps and foam wedges to prevent distraction and rotation of the elbows while being scanned.

Two scans were performed for each patient. These scans used an image center of 350 and width of 2000 with the bone reconstruction kernel. The mA was 130 and kVp was 120. The first scan included both elbows, starting from mid-humerus up to including mid-radius and ulna. Using the helical mode, the thickness and image interval was 2 mm. The second scan was of the single unaffected elbow of interest. The same anatomic matrix or anatomic margin was applied, and using an axial mode of 1 mm thickness, slices were collected in a ‘bone’ setting.

Radiographs

Radiographic images were obtained using a digital radiology system. The fractured and contralateral elbows were evaluated with orthogonal views in a craniocaudal and a mediolateral direction. In addition, a craniocaudal 15° oblique was performed on the non-fractured elbow.

Reviewing images

Radiographic and computed tomographic images of the non-fractured limbs were placed in random order with all patient information deleted. Two board-certified radiologists independently evaluated for the presence or absence of IOHC. We used CT as a gold standard for the diagnosis of IOHC. Therefore, in cases where both radiologists agreed that IOHC was present on the CT image, it was concluded to be an affected case. All other cases were deemed unaffected. Similarly, for a radiographic diagnosis of IOHC, both radiologists had to agree to conclude radiographic diagnosis of IOHC. Radiographic diagnosis of IOHC was defined as complete or incomplete radiolucency between the humeral condyles, where ‘complete’ is from the joint surface to the supratrochlear foramen. Incomplete IOHC is defined as an area of high attenuation (sclerosis) adjacent to the hypointensitating area that does not communicate completely from the joint surface to the supratrochlear foramen. The findings for the CT and radiographic examination were compared to establish the sensitivity and specificity of radiographs as a diagnostic test for IOHC. Any disagreement between radiologists resulted in a final radiographic diagnosis of no IOHC. The level of agreement between radiologists was also determined for both imaging techniques.

Dogs presenting with humeral condylar fracture

Computed tomography and radiography were performed for each participant as described in the Methods section prior to surgery for the HCF. Standard of care for surgical correction of the humeral condylar fracture was provided based on fracture type and surgeon preference.
Data analysis

Descriptive analysis was used for all variables using VassarStats software. This programme was utilised for sensitivity, specificity and confidence interval calculations. Positive and negative predictive values and the Kappa coefficient were calculated between the two radiologists for the radiographic diagnosis of IOHC. Confidence intervals were calculated using a 95% cutoff, and proportions included a continuity correction in their calculation.

Results

Of the 31 cases presented during the five-year period that were available for recruitment (the patient was alive and had not moved from the area), nine owners elected to have their pet participate in the study. An additional five cases presented with HCF and were included for a total of 14 dogs evaluated.

Of the 31 mature dogs available for recruitment, 21 were male (CI: 0.49–0.83) and 10 were female (CI: 0.17–0.51) (male:female 2.1:1). Of the 14 participants, eight were male (CI: 0.30–0.81) and six were female (CI: 0.19–0.70) (male:female 1.3:1). The breeds varied with Spaniel breeds having the greatest representation. Eight participants were of Spaniel breed: Cocker Spaniel (n = 4), Cavalier King Charles Spaniel (n = 3), English Springer Spaniel (n = 1). The remaining breeds included an English Setter, Toy Poodle, Soft Coat Wheaten Terrier, Jack Russell Terrier, German Shepherd and a Boston Terrier. Dogs were aged from seven months to eleven years, and weighed 5.2 to 33 kg at time of presentation. All humeral condylar fractures were reported by the owners to have occurred during normal activities. All humeral condylar fractures occurred after six months of age. Of the 14 dogs evaluated, eight had lateral condylar fractures, five had intercondylar (Y or T), and one had a medial condylar fracture.

Computed tomography findings

Evidence of IOHC in the contralateral limb to the fractured limb was identified in six of 14 cases (43%; CI: 0.19–0.70) by CT. Fifty percent (4/8) of the Spaniel breeds and 33% (2/6) of the non-Spaniel breeds had IOHC. Of these six cases with IOHC, incomplete IOHC (the radiolucency between the condyles did not communicate from the joint surface to the supratrochlear foramen) was diagnosed in three cases. In effect, only three of the 14 (21%; CI: 0.06–0.51) dogs had complete IOHC; two of these dogs were of Spaniel breed and one was a non-Spaniel breed (Fig. 1). There was perfect agreement between the radiologists for interpretation of the CT.

Radiographic findings

A diagnosis of IOHC was identified in the limb opposite the HCF in five of 14 cases (38%; CI: 0.14–0.65) by plain radiography. One case was a false negative by both radiologists. It is important to note that there was disagreement on two cases between the radiologists. As detailed in the Methods section, these were given a ‘no IOHC’ diagnosis. The positive predictive value for radiologist 1 was 71% and the negative predictive value was 86%. Radiologist 2 had a positive predictive value of 100% and a negative predictive value of 89%. When compared to CT as the diagnostic gold standard, plain radiographs had a sensitivity of 0.83 (95% CI: .36 to 0.99) and a specificity of 1 (95% CI: .60 to 1) for the diagnosis of IOHC. The Kappa coefficient was 0.714 when assessing agreement of radiographic diagnosis of IOHC between radiologists. This is considered substantial agreement (18). One final consideration is that the one case where IOHC was missed via radiographs (Fig. 2 and 3): the case had a diagnosis of incomplete IOHC via CT (Fig. 4). In effect, the sensitivity and specificity of complete IOHC was 100% between the radiologists.

Discussion

We report the frequency of IOHC in the contralateral limb in 14 dogs with unilat-
eral HCF. To ensure that a definitive diagnosis could be made in the contralateral limb, we elected a minimum age of six months at the time of fracture. The intercondylar physis may close by four months of age, however to increase the likelihood that it would be closed in our study population, we elected to study only dogs older than six months, as recommended by Carrera et al (14).

To improve the probability of correct radiographic diagnosis of IOHC, both board certified radiologists had to agree that a case was affected, otherwise the case was considered unaffected. This agreement method was elected because prophylactic surgery has been reported for IOHC without fracture displacement (15–17). We elected a conservative diagnostic approach since there is little scientific evidence that prophylactic surgery is necessary.

Several reports suggest that IOHC creates an area of stress concentration predisposing the humeral condyle to fracture. To support this hypothesis, mechanical testing comparing the dog’s elbows with and without IOHC is necessary. Since this mechanical study had not been performed, it seems reasonable to provisionally diagnose IOHC in mature dogs presenting with a HCF associated with normal day-to-day mechanical loads. A biopsy of the intercondylar region of a dog undergoing surgery for HCF could be performed to support the diagnosis; this information may be useful for an owner of a dog that has IOHC on the opposite leg and the owners are deciding if prophylactic surgery should be performed. However, if only bone were found on the biopsy, a diagnosis of IOHC could not be ruled out because the area biopsied may not have been affected (in the case of incomplete IOHC), or the cartilage or fibrous tissue may be removed from the trauma. Regardless, these current and previous data provide only enough information to suggest that HCF is related to pre-existing IOHC (5, 13, 16).

It is important to note that only nine of the 31 dogs that had been treated historically for HCF participated in our study. This introduced significant recruitment bias to our study population as we did not have a random selection of the entire HCF study population. While it seems likely that any breed of dog is vulnerable to HCF, if one considers data from all manuscripts, it appears that Spaniel and Terrier breeds are predisposed to IOHC and HCF, and that there is low representation of larger breed dogs such as Labradors, German Shepherds and Rottweilers (14, 15, 21). However, to our knowledge, no population study has yet been performed.

Although the aetiology is uncertain, IOHC can be bilateral like many other developmental orthopaedic diseases. In our study population we found a much lower incidence, approximately 43%, than that reported in two previous reports (5, 14). However, it is important to note that our findings were similar to one earlier report of a heterogeneous population of dogs where only two out of seven dogs imaged via CT had bilateral IOHC (10). In addition, our findings of a reduced incidence of IOHC in the limb opposite HCF included the Spaniel breeds. We found only 50% of spaniels with HCF had IOHC on the opposite limb. This is in contrast to two previous reports that suggested an 86% and 100% incidence of IOHC (14). Our findings lend some support to data reported by Fitzpatrick where only one out of five Spaniels had IOHC opposite a HCF (16). Regardless, it is important to note that one should not assume that a Spaniel with a HCF has IOHC on the opposite limb. Study differences can simply be explained by differences in the sample of the breed population as none of the studies evaluated a large number of dogs.

The diagnosis of IOHC is primarily made through imaging with radiographs as the primary modality using an orthogonal views and a 15° craniomedial-caudolateral view. Incomplete ossification of the humeral condyle has also been diagnosed via CT, magnetic resonance imaging (MRI), arthroscopy and histopathology (5, 10, 15). Computed tomography and MRI provide observation of the elbow joint without the superimposition of bony structures, and while they may be imperfect, they are arguably more sensitive and specific to make a diagnosis of IOHC. In our opinion, until MRI is more reliably tested as a diagnostic tool for this condition, CT remains the gold standard for diagnosis of IOHC. Incomplete ossification of the humeral condyle can be observed either as complete hypoattenuation through the humeral condyle, from the articular surface to the supratrochlear foramen, or as incomplete (14). Incomplete IOHC may be very difficult to observe with plain radiographs. In our review we observed one false negative, or misdiagnosis, of IOHC in one elbow by plain radiographs. This elbow was determined to have partial IOHC by CT findings. The confidence intervals in our report demonstrate the low power of this study. Our findings should be interpreted with this understanding as well as other studies with low case recruitment. To our knowledge, the only other report where IOHC was not observed with radiographs, but was instead identified via CT, was in a study by Fitzpatrick, where IOHC was identified in two out of 13 elbows; for one patient in this study, IOHC was observed via arthroscopy (10, 16). Thus, in the majority of cases reported in patients with atraumatic HCF or lameness where IOHC is suspected, elbow radiographs are sufficient to diagnose IOHC in the opposite limb. However, the sensitivity of plain radiographs may be decreased if IOHC is not suspected because the radiologist may not be specifically looking for IOHC as they were in this study. It is important to note that we are not suggesting that CT does not provide for im-

![Fig. 4](same elbow as shown in Figure 2. This is an example of incomplete ossification of the humeral condyle. Notice the intercondylar hypoattenuation with surrounding sclerosis.)
proved visualisation of the intercondylar region, only that the improved view may not be necessary to make a diagnosis of IOHC. In our hospital, we no longer perform CT solely to investigate for the presence of IOHC.

The sensitivity of diagnosing IOHC, especially a partial IOHC, becomes more important if one believes that elbows with IOHC should have prophylactic surgery to prevent HCF. Obviously, IOHC can be clinically silent (10). In the six dogs in this study that were found to have IOHC in the contralateral leg, on re-examination, three dogs were found to show signs of elbow pain. Those three dogs had surgery for their IOHC with transcondylar lag-screw fixation. However, it is important to note that IOHC may persist even after transcondylar lag-screw placement. It has been reported that the lag screw can mechanically fail and HCF can still occur after prophylactic lag-screw placement (22). Inclusion of an autogenous transcondylar graft along with compression from a screw has also been reported to enhance healing of the intercondylar separation (17). For the remaining dogs where IOHC was present, but signs of elbow pain could not be elicited, nonsurgical management was recommended because we were uncertain of the relative risk of fracture when IOHC is present, and because prophylactic surgery is not necessarily successful. One could argue we made an ill-informed recommendation if one were to read the report by Marcellin-Little where he found a high rate of HCF with conservative management of IOHC; three out of seven condyles (43%) with partial IOHC, and one out of 12 condyles (8%) with complete IOHC fractured 11 days to 18 months after identification of IOHC (5). Certainly owner communication of the relative benefits, risks and costs is of paramount importance when a decision for prophylactic surgery is made. We will continue to follow the patients included in our study to see if clinical signs develop.

A major objective of this study was to identify frequency of IOHC in the contralateral humerus of mature dogs with traumatic HCF. We reported a low frequency, which was as we expected. This is, in part, due to a mixed population of Spaniels and non-Spaniel breeds. However, a more important factor may be due to the low number of dogs enrolled in this study. This significantly decreases the power in regards to conclusions drawn as evidenced on the large confidence intervals reported. Therefore, when interpreting our conclusions, specifically in regards to frequency of IOHC and the sensitivity of radiographs versus CT, one should keep in mind the low number of dogs evaluated. Unfortunately, this is a common problem in the literature related to this topic.

Conclusion

We report findings of IOHC in the limb opposite atraumatic HCF in 14 dogs. The proportion of observed LCF was equal to that of ICF in the population of dogs studied. The estimated prevalence of IOHC in the opposite limb in this population was 43%, which is less than what has been previously reported for a similar population of dogs. While CT allows for a greater sensitivity and specificity in the diagnosis of IOHC, appropriate radiographs are of sufficient accuracy in most cases.

References