Tibial anatomy in normal small breed dogs including anisometry of various extracapsular stabilizing suture attachment sites

P. G. Witte
Southern Counties Veterinary Specialists, Hangersley, Ringwood, Hampshire, UK

Keywords
Cranial cruciate ligament rupture, isometry, extracapsular suture, tibial plateau angle, TPA, diaphyseal proximal tibial angle, DPA

Summary
Objectives: To investigate proximal tibial anatomy and its influence on anisometry of extracapsular stabilizing sutures in small dog breeds.

Materials and methods: Mediolateral radiographs of the femora, stifles, and tibiae of 12 small breed dogs were acquired with the stifles positioned at various angles. Measurements taken included tibial plateau angle (TPA), diaphyseal: proximal tibial angle (DPA), patellar tendon angle (PTA), Z-angle, relative tibial tuberosity width (rTTW), and the distance between six combinations of two femoral and three tibial extra-capsular stabilizing suture (ECS) attachment sites. Theoretical strain through stifle range-of-motion was recorded.

Results: The TPA (32° ± 5.8°), DPA (10.2° ± 7.3°), PTA (103.7° ± 6.2°), and Z-angle (70.4° ± 9.0°) were positively correlated with one another (R >0.7), but none were correlated with rTTW (0.93 ± 0.10). The F2-T1 combination of ECS attachment sites had lowest strain for nine stifles. The shortest attachment site separation was at a stifle flexion of 50° for nine stifles. Proximal tibial anatomy measurements could not predict optimal attachment site combination, optimal stifle angle for suture placement, or ECS strain.

Clinical significance: There is individual variation in the optimal attachment site combination and stifle angle for suture placement, which may influence consistency of outcomes with ECS.

Introduction
Cranial cruciate ligament rupture is a common cause of hindlimb lameness in dogs (1). Cranial cruciate ligament rupture results in cranio-caudal translational stifle instability, abnormal cartilage wear and secondary osteoarthritis (2, 3). Various surgical options have been described for stabilization of the cranial cruciate ligament-deficient stifle. Whilst these have typically focussed on the medium, large and giant breeds, only a few studies exist regarding the optimal management of the condition in small dog breeds (4-7). Two primary factors contribute to cranial tibial translation during weight bearing: the joint compressive force (body weight and tension in muscles crossing the joint) and the tibial plateau angle (TPA) (8). Small dog breeds appear to have higher TPA than their larger counterparts (4, 7, 9). Thus, despite their lower body weights, small dog breeds with cranial cruciate ligament rupture may demonstrate high cranial tibial thrust and should theoretically benefit from surgical management.

A recent questionnaire study reporting on the management of cranial cruciate ligament rupture in small dog breeds showed the extra-capsular stabilizing suture (ECS) to be the most common surgical technique, with 63.4% of responding veterinarians employing this technique for this population of dogs (10). Extra-capsular stabilizing sutures are a relatively diverse group of techniques modified from a procedure described by DeAngelis and Lau (11). The ECS technique aims to tether the distal femur and proximal tibia in such a way that cranial translation of the tibia with respect to the femur is resisted by the tethering material. One concern with ECS techniques is a return of instability often linked to a failure to achieve isometric suture placement (12-15). The term “isometry” in ECS technique refers to a situation in which two points, one on the distal femur and one on the proximal tibia, remain at a constant distance apart throughout the stifle range-of-motion. True isometry is not achievable since the canine stifle does not function as a pure hinge joint and the term ‘quasi-isometry’ has been suggested (15-17). Femoral and tibial attachment sites for minimizing anisometry during ECS positioning have been documented (13, 14). These studies have typically found more agreement in the optimal femoral attachment site and less agreement in the tibial attachment site, perhaps suggesting that variation in proximal tibial anatomy may influence...
optimal ECS technique. One study comparing Yorkshire Terriers and Labrador Retrievers has revealed significant differences in various features of proximal tibial anatomy, which may be of significance in ECS planning (18). As a result of anisometry, eventual loosening of an ECS is inevitable and long-term stifle stability following ECS is thought to result from a combination of periarticular fibrosis and adaptation of the muscular stabilizers of the joint (12, 19-23). Loosening may occur by elongation or failure of the prosthetic material, by slippage or failure of the knot or crimp clamp securing the free ends of the prosthesis, by failure of anchors, or by pulling off or through the fabella or fabello-femoral ligament (20, 24). Furthermore, the stifle angle during placement of the suture influences the impact of a failure to achieve isometry on ECS function (12, 15). In a situation of anisometric ECS placement, tying the suture with the stifle in a position at which the distance between the attachment sites is smallest will theoretically result in increased strain on the suture material, limited stifle range-of-motion, or increased femoro-tibial contact forces, or a combination of these. On the other hand, tying the suture with the stifle positioned such that the attachment sites are maximally separated could lead to reduced tension within the material and a failure to resist cranial tibial translation. Previous retrospective studies have reported on the optimal stifle position for placing ECS, but these have not been rigorously confirmed. For example, one recommendation was to place the ligature with the stifle in 90° flexion (12).

The aims of this study were to further investigate optimal ECS attachment sites and stifle joint angle at the time of suture placement in small breed dogs, and to investigate the influence of proximal tibial anatomy on the degree of ECS attachment site anisometry. Hypotheses were: 1) optimal femoral and tibial attachment sites would be consistent with those previously reported and 2) one or more measurements of proximal tibial anatomy would help to predict (a) theoretical strain in ECS or (b) the stifle angle at which the attachment site separation would be minimal, and may therefore be useful in preoperative planning (13, 14).

Materials and methods

Dogs were included in this study if they were less than 15 kg in bodyweight and were presented at the Southern Counties Veterinary Specialists referral centre for orthopaedic conditions other than stifle-related lameness. Absence of cranial cruciate ligament rupture was confirmed by an absence of a stifle effusion in mediolateral radiographs and by absence of a cranial drawer sign on manipulation of the joint. The dogs underwent radiography of one stifle joint (left stifle, unless the dog was affected by left hindlimb lameness, in which case the right stifle was selected). Imaging for the study was acquired, with client consent, while dogs were under sedation or general anaesthesia directly following radiography performed as part of investigations of the causes of lameness. True mediolateral digital radiographs of the tibiae and stifles were acquired at joint angles of 50°, 70°, 90°, 110°, 130° and 150°, with stifle angles measured using landmarks according to the ‘eminence method’ (greater trochanter of the femur, mid-point of the tibial intercondylar eminence and mid-point of the tibiotarsal joint, as previously described) (25).

Measurements of proximal tibial formation were as follows. The TPA was measured as previously described from the views with stifle angle 90° for all dogs (26). The angles between the proximal and diaphyseal tibial longitudinal axes (DPA) were measured from the 90° views (30). Relative tibial tuberosity width (rTTW) (Figure 2) and Z-angle (Figure 3) were measured as previously reported from 90° views (30, 31). All measurements were made three times and the means calculated.

Measurements of ECS attachment site separations were made as follows. Separate...
acetate templates were made for each tibia and each femur by hand-tracing the outlines of the bones, adjusted to anatomical size, directly from the viewing monitor, at the 90° stifle angle. Attempts were made to accurately reproduce specific femoral and tibial landmarks including the extensor groove, point of tibial tuberosity, intercondylar eminence, and distal femoral physeal scar. The acetates were marked with two femoral (F1, F2) and three tibial (T1, T2, T3) attachment sites for ECS positioning. Attachment sites were similar to those previously documented: F1 = the centre of the lateral fabella, representing a circumfemoro-fabellar ligament suture; F2 = the caudal femoral cortex at the level of the distal pole of the lateral fabella; T1 = 2 mm caudal from the point of the tibial tuberosity (distal extent of the patellar ligament insertion, as previously recommended, 12); T2 = 2 mm distal to the femoro-tibial joint surface cranial to the extensor groove; T3 = 2 mm distal to the femoro-tibial joint surface caudal to the extensor groove (Figure 4) (15).

The separate tibial and femoral acetates were superimposed over each radiographic projection (50°, 70°, 90°, 110°, 130°, and 150°) of the appropriate stifle on the viewing monitor and the femoral and tibial attachment sites marked back onto the digital image views using the point application of the imaging software. The acetates were thought to provide consistency of landmark identification relative to the other landmarks within each bone. Whilst this additional step might have introduced error, it was considered that the accuracy with which the acetate might be placed using the margin of the entire proximal aspect of the bone would be superior to repeat identification of individual landmarks for each measurement. The imaging software was used to measure the distances between the femoral and tibial attachment sites (termed ‘attachment site separation’) giving a total of 36 measurements for each dog (attachment site separation for each of the six combinations of attachment sites [F1-T1, F1-T2, F1-T3, F2-T1, F2-T2, F2-T3] at the six different stifle angles). All attachment site separation measurements were made three times and the means were used for analysis.

**Data analysis**

The TPA, DPA, PTA, rTTW and Z-angle were measured for each stifle. Additionally, the following data were recorded: MIN (the attachment site separation [mm] when the stifle angle was such that this was at its least) and angle\text{\textsubscript{min}} (the stifle angle at which the attachment site separation was at its least). Thus six values of MIN were derived for each stifle (one value for each attachment site combination). Similarly there were six values of angle\text{\textsubscript{min}} for each stifle. Conversely, six values each for MAX (greatest attachment site separation) and angle\text{\textsubscript{max}} (angle at which the greatest attachment site separation was measured) were recorded for each stifle. The difference between MAX and MIN for each of the six attachment site separation combinations (MAX-MIN, mm) was calculated, representing the change in length a theoretical ECS might undergo during a full range of stifle motion. Theoretical strain (strain\textsubscript{t}) was calculated for each combination of attachment sites for each dog. The strain\textsubscript{t} was calculated using the formula strain\textsubscript{t} = MAX-MIN / MIN x 100, giving a figure for the theoretical percent strain through an ECS assuming the suture was placed at the stifle angle resulting in the minimum starting length (e.g. at angle\textsubscript{\text{\textsubscript{min}}}, strain\textsubscript{t} may be considered as a measure of anisometry for each theoretical ECS suture).

The Shapiro Wilk test of normality was performed on measurements of TPA, DPA, PTA, rTTW, Z-angle and strain\textsubscript{t} with significance set to five percent. Descriptive statistics including the range, mean and standard deviation for TPA, DPA, PTA, rTTW and Z-angle were calculated. The range, mean and standard deviation of strain\textsubscript{t} were calculated for each combination of attachment sites.

Visual inspection of scatterplots was performed to confirm the linearity of any correlations between any of the parameters of proximal tibial anatomy (TPA, DPA, PTA, rTTW, Z-angle and strain\textsubscript{t}).
Table 1  Signalment and measurements of proximal tibial anatomy for small breed dogs (n = 12).

<table>
<thead>
<tr>
<th>Stifle</th>
<th>Age (years)</th>
<th>Breed</th>
<th>Sex</th>
<th>Body weight (kg)</th>
<th>TPA (°)</th>
<th>DPA (°)</th>
<th>PTA (°)</th>
<th>z-angle (°)</th>
<th>rTTW (°)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>JRT</td>
<td>Male entire</td>
<td>9.2</td>
<td>29</td>
<td>7.3</td>
<td>103.2</td>
<td>63.3</td>
<td>0.73</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>JRT</td>
<td>Male neutered</td>
<td>6.8</td>
<td>34</td>
<td>11.7</td>
<td>108.6</td>
<td>65.7</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>Lhasa Apso</td>
<td>Male neutered</td>
<td>11.6</td>
<td>38</td>
<td>10.6</td>
<td>103.6</td>
<td>70.1</td>
<td>0.94</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>Terrier x</td>
<td>Male neutered</td>
<td>12</td>
<td>24</td>
<td>3.8</td>
<td>91.2</td>
<td>63.2</td>
<td>0.71</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>WHWT</td>
<td>Male neutered</td>
<td>8</td>
<td>44</td>
<td>29.8</td>
<td>113.1</td>
<td>89</td>
<td>0.88</td>
</tr>
<tr>
<td>6</td>
<td>2</td>
<td>WHWT</td>
<td>Female neutered</td>
<td>8.4</td>
<td>35</td>
<td>7.5</td>
<td>105.7</td>
<td>79.2</td>
<td>0.8</td>
</tr>
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<td>3</td>
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<td>Male neutered</td>
<td>4.1</td>
<td>24</td>
<td>0</td>
<td>94.5</td>
<td>63.5</td>
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</tr>
<tr>
<td>8</td>
<td>3</td>
<td>Border Terrier</td>
<td>Female neutered</td>
<td>7</td>
<td>30</td>
<td>10.5</td>
<td>103.1</td>
<td>60.1</td>
<td>0.97</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>Shih Tzu</td>
<td>Male neutered</td>
<td>9.8</td>
<td>28</td>
<td>10.6</td>
<td>103.1</td>
<td>72.3</td>
<td>1.04</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
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<td>Female neutered</td>
<td>11.9</td>
<td>30</td>
<td>8.8</td>
<td>102.1</td>
<td>63.3</td>
<td>1.04</td>
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<tr>
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<td>2</td>
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<td>Male neutered</td>
<td>13</td>
<td>36</td>
<td>14.8</td>
<td>104.5</td>
<td>82.2</td>
<td>1.03</td>
</tr>
<tr>
<td>12</td>
<td>8</td>
<td>WHWT</td>
<td>Male neutered</td>
<td>9.9</td>
<td>32</td>
<td>7.5</td>
<td>111.4</td>
<td>72.6</td>
<td>0.94</td>
</tr>
</tbody>
</table>

Mean 2.8
SD 1.9
Range 24–44

JRT = Jack Russell Terrier, Terrier x = crossbred Terrier, WHWT = West Highland White Terrier, TPA = tibial plateau angle, DPA = diaphyseal proximal tibial angle, PTA = patellar tendon angle, rTTW = relative tibial tuberosity width. Mean and standard deviation are given for each parameter.

Table 2  Values for the theoretical strain (max-min/min x 100) for six combinations of femoral and tibial extra-capsular suture attachment sites reported for 12 small breed dog stifles.

<table>
<thead>
<tr>
<th>Stifle</th>
<th>strainT (%)</th>
<th>F1-T1</th>
<th>F1-T2</th>
<th>F1-T3</th>
<th>F2-T1</th>
<th>F2-T2</th>
<th>F2-T3</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>13.5 *</td>
<td>13.7</td>
<td>19.7</td>
<td>13.5 *</td>
<td>22.2</td>
<td>23.4</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>14.5</td>
<td>17.2</td>
<td>16</td>
<td>10.7 *</td>
<td>10.8</td>
<td>16.8</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>16.8</td>
<td>18</td>
<td>13.9 *</td>
<td>19</td>
<td>23.7</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>31.9</td>
<td>28.8</td>
<td>36.4</td>
<td>18.1 *</td>
<td>18.7</td>
<td>28.1</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>4.6</td>
<td>10.2</td>
<td>8.3</td>
<td>3.9</td>
<td>8.7</td>
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<td>10.2</td>
<td>5.4 *</td>
<td>5.6</td>
<td>8.6</td>
<td>7.4</td>
<td>9.7</td>
<td></td>
</tr>
<tr>
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<td>9.2</td>
<td>10.4</td>
<td>11.3</td>
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<td>22.1</td>
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<td>23.9</td>
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<td>9.7</td>
<td>16.2</td>
<td>5.1 *</td>
<td>9.6</td>
<td>13.7</td>
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<tr>
<td>11</td>
<td>20.9</td>
<td>18.7</td>
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<td>11.5</td>
<td>7.7</td>
<td>11.6</td>
<td></td>
</tr>
</tbody>
</table>

Mean 15.4
SD 8.5

* denotes the attachment site combination resulting in minimal strainT (theoretical strain) for each stifle. Note stifles 1 and 8 demonstrated two combinations at which strainT was minimal.

PTA, rTTW, Z-angle and between any of these parameters, with strainT or with angle min at each of the six combinations of attachment sites. The Pearson correlation coefficient was calculated to investigate any apparent correlations with significance set to five percent.

Results

Twelve client-owned small breed dogs were included in the study. The ages ranged from one to eight years (mean: 2.8 ± 1.9 years). Breeds included West Highland White Terrier (n = 3), Jack Russell Terrier and crosses (n = 5), and one each of Lhasa Apso, Chihuahua, Border Terrier, and Shih Tzu. Body weights ranged from 4.1 kg to 11.9 kg (mean: 9.3 ± 2.5 kg). The signalment, bodyweight, and proximal tibial anatomy values for the 12 tibiae are reported in Table 1. Normality was confirmed for all parameters apart from DPA.

The percentage values of strainT for all 12 stifles with each of the six different combinations of attachment sites are reported.
Table 2. In seven stifles, the combination giving the lowest strain$_T$ was F2-T1. In a further two stifles, strain$_T$ at F2-T1 was equal lowest alongside F1-T1. For three stifles (stifles 6, 7 and 12), strain$_T$ was lowest for an attachment site combination other than F2-T1. No common feature (breed, bodyweight, anatomical measurements, morphological appearance) was identified to link these three cases or make them different to the other nine cases. Since strain$_T$ was not consistently lowest for any single attachment site combination, the first hypothesis was rejected. To find the attachment site most likely to result in the lowest strain$_T$ for most dogs, the range, mean and standard deviation of strain$_T$ across all dogs for each combination of attachment sites was calculated. These data are given in Table 3. Mean strain$_T$ across all dogs was lowest for F2-T1 (11.7% ± 5.0) and highest for F2-T3 (20.0% ± 9.7).

Among the 12 dogs and various attachment site combinations, all stifle angles were represented as either the angle$_{max}$ or angle$_{min}$ (Table 4). Most ECS (49/72) had an angle$_{min}$ (i.e. the shortest distance between femoral and tibial attachment sites) at the greatest flexion (50°), however, in some cases (13/72) angle$_{min}$ was at the other extreme (150°). For the F2-T1 attachment site combination, angle$_{min}$ was 150° for two stifles, 70° for one stifle, and 50° for nine stifles, while angle$_{max}$ was even more variable, being 150° for five stifles, 130° for four stifles, 110° for one stifle, 90° for one stifle, and 50° for one stifle.

The correlation coefficient for proximal tibial anatomical measurements showed positive correlations for TPA and DPA (R = 0.85), for TPA and PTA (R = 0.79), and for TPA and Z-angle (R = 0.77), but not for TPA and rTTW (R = -0.02). Additionally there were positive correlations for DPA and PTA (R = 0.70) as well as for DPA and Z-angle (R = 0.73), but not for DPA and rTTW (R = 0.01). The PTA and Z-angle were positively correlated (R = 0.60) but PTA and rTTW were not (R = 0.09). However, Z-angle and rTTW were not significantly correlated (R = -0.03).

Correlation coefficients for the anatomical features (TPA, DPA, PTA, Z-angle, rTTW) and strain$_T$ revealed no significant associations for any of the attachment site combinations (F1-T1, F1-T2, F1-T3, F2-T1, F2-T2, F2-T3). Similarly there were no associations between any of the anatomical features and angle$_{max}$. Therefore both components of the second hypothesis were rejected.

### Discussion

The wide range of values for TPA may be due to the differing morphology of the breeds included, and more specific stratification of breeds may be necessary to further clarify the influence of breed on proximal tibial conformation. Nonetheless, the mean TPA was somewhat higher than reported in larger dogs with cranial cruciate ligament disease (32-34). A high TPA has been reported in small dog breeds with cranial cruciate ligament disease (4, 7, 9). The findings of the current study suggests that TPA may be higher in healthy small dog breeds.

The mean DPA for the tibiae in this study (10.2° ± 7.3°) was higher than the DPA in dogs with cranial cruciate ligament rupture (6.0° ± 3.3° and 6.5° ± 2.81°), and also dogs with normal stifles (4.1° ± 2.2°) (27, 28). Dogs in these two other studies were of a wide variety of breeds, but none were below 10 kg. A DPA of >11.23° has been termed ‘proximal shaft deformity’ and was hypothesised to contribute to an increased TPA (4, 35, 36). In one study, all six dogs with such a high DPA also had cranial cruciate ligament rupture (27). A direct correlation between TPA and DPA was demonstrated in medium to large dog breeds and was confirmed in the current population of dogs (27, 28). The three dogs in the current study with a DPA greater than 11.23° were free of cranial cruciate ligament rupture, although future cranial cruciate ligament rupture cannot be excluded. The suggestion that a DPA greater than 11.23° increases the risk of cranial cruciate ligament rupture may be inappropriate in this population of dogs. However, measurement of DPA in these dogs was complicated by the variation in tibial dia-
physiological conformation (from straight to ‘S’ shaped), which hampered the identification of the tibial long axis in the sagittal plane, and may have contributed to the large range and failure of normality of DPA measurements.

In the current study, PTA with the stifle at 130° had a mean measurement value of 103.7° ± 6.2°. A previous study measuring PTA in dogs weighing 21–76 kg showed a similar range of PTA for the few cases measured with the stifle at 130° (30). In another study, the PTA of Yorkshire Terriers measured with the stifle at 135° was 103.7° ± 6.5°, which is almost identical to the findings in this current study (18). The Z-angle defines the orientation of the site of insertion of the patellar ligament relative to the long axis of the tibia. This feature has been investigated in the context of planning for triple tibial osteotomy (31). More precisely, a high Z-angle indicates a proximally positioned tibial tuberosity relative to the centre of the stifle joint, or a broad proximal tibia as measured from cranial to caudal; both of these features might be considered significant in the ECS technique. The Z-angle was reported as a mean value of 61.4° ± 0.11 in the tibiae of dogs weighing 36.5 ± 9.3 kg and was higher in the current population of small breed dogs (31).

The mean rTTW was 0.91 ± 0.18 in healthy dogs and 0.78 ± 0.14 in dogs with cranial cruciate ligament rupture (30). It was suggested that an rTTW of 0.90 or greater may be protective for cranial cruciate ligament rupture. The rTTW in the current study of healthy small dog breeds ranged from 0.71 to 1.10 (mean: 0.93 ± 0.1).

It is not unexpected that there were strong correlations between TPA, PTA, and DPA and Z-angle. Some of these correlations have been reported previously, and these measurements relate to similar aspects of proximal tibial conformation (18). In the current study, none of the parameters showed a correlation with rTTW, although previously this has been shown to correlate with DPA (18). The failure to confirm an association between rTTW and DPA may have been related to the difficulty with measuring DPA in this population of dogs. None of the parameters of proximal tibial anatomy were associated with strain, nor with angle, and therefore they do not appear to aid optimal ECS planning.

It is accepted that minimizing anisometry is desirable in the interests of mimimizing ECS strain, maintaining joint range-of-motion and minimizing joint stresses. However, true isometry is not achievable; indeed, the cranial cruciate ligament does not have isometric origin and insertion sites (37). Anecdotally, sites F1 (lateral fabella) and T1 (tibial tuberosity) are the most common sites for placement of ECS since these closely represent a suture encircling the lateral fabello-femoral ligament and a bone tunnel in the cranial aspect of the tibial tuberosity, as previously described (11, 12, 20, 38). In the current study, true isometry would theoretically result in zero strain (i.e. no change in attachment site separation throughout stifle range-of-motion, or MAX = MIN). No combination of femoral and tibial attachment sites fulfilled this criterion, confirming that true isometry was not possible using the attachment sites studied. The F2-T1 combination resulted in the lowest mean strain. Therefore, in this study this combination most closely approached isometry. The F2 femoral attachment site has been shown to be preferable in studies of large dog breeds (13, 14, 24). However, the reported best tibial attachment site of T1 in this study differs from previous reports showing T1 to be least isometric and either T2 or T3 to be superior (13, 14). The femoral attachment site appears to be consistent across studies (including the current study), while the optimal tibial attachment site has varied. The methods for measuring isometry were different across the studies. Roe and colleagues performed measurements similar to those in the current study on seven cadaveric stifles from medium sized dogs while Hulse and colleagues and Fischer and colleagues used strain gauges attached directly to ECS on cadaveric stifles from dogs weighing 25–30 kg and 20–55 kg respectively. Differences in the methods may have resulted in the conflicting results.

The findings of the current study might suggest that the optimal attachment site combination is not universal for all dogs. Although mean strain, was lowest for F2-T1, three dogs demonstrated minimal strain with a combination other than F2-T1. Unfortunately, no feature was found to identify dogs for which the optimal combination was different from F2-T1. Further investigations are indicated to confirm that the optimal attachment site combination varies for different dogs and how the optimal combination may be predicted for each individual dog. Human surgeons employ various methods for intra-operative assessment of isometry in anterior cruciate ligament reconstruction, where anisometry is recognized as one of the largest complicating factors, and are increasingly guided by computer-aided navigation (39). Intra-operative assessment of isometry may prove to be superior to pre-operative planning. One additional factor in achievement of isometry is the surgeon’s ability to consistently place an ECS as planned. There are no studies to document the accuracy with which planned femoral and tibial attachment sites may be identified and utilized intra-operatively. There were no apparent correlations between strain, or angle, and any of the measurements of proximal tibial anatomy. The results of these components of the study do not provide any evidence that measurements of various previously described features of proximal tibial morphology should influence planning of ECS surgery.

It has been reported that most surgeons hold the stifle in extension while tightening the ECS ligature, but that a 90° angle may be optimal since this achieves the ‘tightest’ suture (12, 40). Fischer and others suggested ECS placement with a stifle angle of 100° to avoid a ‘peak’ in tension apparent in their data when tightening was performed at 90°. The purpose of the measurements of angle and angle was to investigate whether there was a particular stifle angle at which ECS placement would consistently result in predictable suture tension. The question of whether ECS placement with the stifle at angle (i.e. the ‘tightest’ possible suture) is, in fact, appropriate was not addressed in this study. In this study, angle varied with the attachment site combination (as might be predicted), but also between stifles for the same attachment sites combinations (for the F2-T1 attachment site combination, angle was...
50° for 9/12 stifles). The optimal stifle angle for ECS placement may not be the same for all dogs. Further investigation is required to clarify this component of the ECS technique.

Extensive discussion of the mechanical properties of materials commonly used for ECS was considered outside the scope of this study, but is of importance. Ideally the stress-strain dynamic of a functioning ECS will remain within the elastic range of the material throughout a full range of stifle motion such that plastic deformation is avoided (preventing elongation and permanent accumulation of damage over time). True isometry is not achievable, and the data in the current study suggest that no optimal technique to universally minimize anisometry shall be found. Therefore, materials used for ECS should incorporate the need for a potentially unpredictable degree of elasticity. Minimum strain in the best combination of attachment sites recorded in the current study had a mean value of 11.7% ± 5.0. Therefore, materials with a yield strain above approximately 12% should theoretically tolerate cycling through a full range of stifle motion without the accumulation of permanent deformation. However, this concept is complicated by the significance of the stiffness of the material. A stiffer material will resist much greater forces prior to significant deformation, but may have a lower yield strain (i.e. its mechanical properties may deteriorate with less deformation). Consequences of increased material stiffness in a situation of poor isometry include increased joint contact forces, limited range of stifle motion, or greater forces on the material. A stiffer material will resist much greater forces prior to significant deformation, but may have a lower yield strain (i.e. its mechanical properties may deteriorate with less deformation). Consequences of increased material stiffness in a situation of poor isometry include increased joint contact forces, limited range of stifle motion, or greater forces on the mechanisms of anchoring or securing the material. The ideal ECS material should provide the optimal balance between stiffness and tolerance of deformation, among other considerations.

There are several limitations to this study. The number of stifles investigated was relatively small making extrapolation of conclusions to larger populations of dogs less reliable. It is also possible that, despite an attempt to investigate dogs from a specific population (dogs <15kg), the variety of breeds included may still be a complicating factor. The breeds represented in this study encompass variable degrees of chondrodystrophy and miniaturism, and this morphological diversity may have limited the capacity to find true associations. Investigations concentrating on specific breeds alone may result in improved reliability of conclusions by reducing the variability in anatomy. Additionally, dogs in this study were unaffected by cranial cruciate ligament rupture at the time of the study. This criterion was selected to ensure that stifles used in the study moved through a normal range-of-motion. Unfortunately, the application of this criterion resulted in a set of data derived from a population of dogs unaffected by a disease for which the data is relevant. Furthermore, the range-of-motion of a cruciate ligament-deficient stifle is not normal; there is no evidence that ECS restores a normal stifle range-of-motion, and there is no evidence that restoration of a normal stifle range-of-motion is critical to re-establishment of clinical function following ECS (41). Data derived from joints with a normal stifle range-of-motion may give misleading information. Serial two-dimensional radiographs fail to account for the three-dimensional structures over which an ECS must pass and for intertibial rotation through the stifle range-of-motion. True measurements of strain, as reported previously, are likely to be more appropriate to the clinical situation (14, 15). Studies of true strain comparing larger groups of dogs, stratified according to breed or anatomical type, may help to determine which modifications of ECS technique are appropriate for different populations.

Recent studies have shown improved outcomes with tibial osteotomy procedures, specifically tibial plateau levelling osteotomy, in comparison with ECS (43, 44). Tibial plateau levelling osteotomy has been reported in small breed dogs (7, 9). Extracapsular stabilizing suture remains a popular treatment for cranial cruciate ligament rupture in this population, however, the current study suggests a degree of unpredictability with performance of the technique (10). A true evaluation of the efficacy of ECS in treating cranial cruciate ligament rupture requires that the technique be performed optimally.

Conclusions

In this population of small dog breeds, the TPA, DPA, Z-angle and rTTW were higher than those previously reported for larger dogs. The F2-T1 combination of ECS attachment sites achieved minimal theoretical strain for three quarters of the stifles, however, in the remaining stifles other combinations were closer to being isometric. The shortest distance between attachment sites was most consistently recorded with a stifle flexion of 50° in this population of dogs, however, for the F2-T1 combination, this was not the case in a quarter of the stifles. There appears to be individual variation in the optimal combination of ECS attachment sites and in the optimal stifle angle for suture placement, which is as yet unpredictable and has not been previously recognised. This variation may be significant in achieving consistent outcomes with this technique.

Conflict of interest

The author does not have any conflicts of interest which pertain to this work.

References


P. G. Witte: Extracapsular suture isometry in a small breed dog