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Isometry of Potential Attachment Sites for the Iliotrochanteric Suture in Dogs: an *ex vivo* Study

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ABSTRACT

***Background*:** Coxofemoral luxation is the most common traumatic luxation in dogs and the iliotrochanteric suture is one of the surgical treatment options. The orthopedic suture aimed at surgically restoring joint movement should be employed in an isometric manner in order to maintain adequate tension throughout the arc of motion. This study aimed to determine the isometric points for the iliotrochanteric suture in dogs during the joint extension and flexion movements. This evaluation was performed both in the intact hip joint and in the luxation model, establishing the best combination, among the determined points, for the reestablishment of normal joint movement.

***Materials, Methods & Results*:** Radiographic analyses of 12 canine cadaveric hips, both intact and in craniodorsal luxation model, were performed in a neutral position, flexion at 50°, and extension at 150°. In the trochanteric segment, two parallel lines were drawn, creating the central vertical axis and the secondary vertical axis. Three points were then determined on each axis, from proximal to distal, corresponding to 25, 50, and 75% of the height of the axis, and were labelled as T1, T2, and T3 and T4, T5, and T6, respectively. In the iliac segment, a line perpendicular to the longitudinal axis of the ilium was drawn, and 25, 50, and 75% of this height corresponded to points I1, I2, and I3, respectively. The lengths between the points were measured, with the objective of evaluating which combination of points presented less variation in the joint positions. The central location of the iliac and trochanteric segments, determined respectively by I2 and T2, provided smaller variations during the maximal movements of hip flexion and extension.

***Discussion*:** The surgical techniques of iliotrochanteric suture target to maintain the internal rotation of the femoral head inside the acetabulum and abduction of the femur until the soft tissues have healed. The described techniques for the iliotrochanteric suture present a great anatomical variety in the arrangement of the anchor points of the suture. It is known that if during motion, the attachment sites move closer to one another, the suture will become lax and, if the attachment sites move away from one another, the suture will tighten. Therefore, the implantation in isometric sites assists in reducing the variation of the distance between the points of origin and insertion of the suture during joint movement, keeping the suture tension constant and allowing the functional recovery of the joint. This study demonstrates that there are some locations for the origin and insertion of an iliotrochanteric suture that are associated with less length change than others. I2-T2 combination is the point closest to isometry for the iliotrochanteric suture during hip extension and flexion, so that, T2 is the most central point of the greater trochanter, corresponding to 50% of the height of its central vertical axis, as well as I2, which corresponds to the most central point of the ilium, representing 50% of the height of the most caudal portion of its body. The isometric point found by us details the exact location of perforation in all aspects (height and length), both in the ilium and the trochanter. In addition, it is a personalized point created for each patient from its radiographic examination and taking into consideration its anatomical variations, so that there is no damage to the suture during hip extension and flexion movements.

Keywords: canine, coxofemoral joint, hip dislocation, ilio-femoral suture, joint instability, orthopedics.

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INTRODUCTION

Coxofemoral luxation (CFL) is the most common traumatic luxation in dogs [1-3,7,8,17,24] and open reduction is one of the treatment options [8,12,21]. Numerous surgical methods have been described, including capsulorrhaphy [5,22], transposition of the greater trochanter [10], De Vita pinning [4,23], tenodesis of the deep gluteal muscle [18], transarticular pinning [10], replacement of the femoral head ligament [1,4,16,23], excision arthroplasty [15,16] and iliotrochanteric suture [11,13,14,20,21,24].

The iliotrochanteric suture stabilizes the joint by preventing external rotation and adduction of the femur [11,20]. For this suture to provide this support, it is necessary for it to remain under tension when the joint is being loaded. Several techniques have been described and differ mainly in the arrangement of the anchor points of the suture and in the material used [11,13,14,20,21,24].

Some ligament reconstructions have defined anatomical guidelines for tunnel placement, with the isometry of these sites already studied [6,9,19]. In theory, an isometric reconstruction maintains adequate tension throughout the arc of motion without over-constraining the joint or causing suture stresses. Although it is a widespread technique, the isometric points for the iliotrochanteric suture are unknown, which can be a factor contributing to failures or complications of the procedure.

The aim of this study was to determine, in dog cadavers, points on the ilium and the greater trochanter capable of maintaining isometry during hip extension and flexion. This evaluation was performed both in the intact hip joint and in the luxation model, establishing the best combination, among the determined points, for the reestablishment of normal joint movement.

MATERIALS AND METHODS

This study was conducted with the consent of the Ethics Committee on the Use of Animals (CEUA).

Six canine cadavers (12 hips), consisting of adult, mixed breed dogs, medium-sized males and females that were free of clinical and radiographic evidence of hip arthrosis were used. All of the muscles were dissected from the limbs specimens and the hips were randomly distributed in two experimental groups. In the control group (CG, n = 6 hips), the integrity of the hip joint was maintained, without sectioning of the joint capsule or the ligament of the femoral head. In contrast, in the test group (TG, n = 6 hips), craniodorsal CFL models were simulated by sectioning the joint capsule in the craniodorsal aspect followed by transection of the femoral head ligament. Each cadaver had a hemipelvis in the CG and the contralateral joint in the TG.

The points of the iliotrochanteric suture were determined from radiographic image of the healthy hip joint of each cadaver on lateral projection, which included both the iliac body and the proximal third of the femoral diaphysis. On the greater trochanter, three distinct and equidistant points were marked at the cranial and caudal borders. The points of each border were connected, creating two parallel vertical lines. At the midpoint between these two lines, the central vertical axis (CVA) of the greater trochanter was traced (Figure 1A). From this axis, the trochanteric height was measured, and a perpendicular line was drawn at its midpoint, denoting the central horizontal axis (CHA) of the greater femoral trochanter (Figure 1B).

From the CHA, the length of the greater trochanter was determined, and, at the point corresponding to 25% of this length, a perpendicular axis, called the secondary vertical axis (SVA), was traced (Figure 1C). Then, from the CVA and SVA, the trochanteric points tested in the isometric evaluation were marked. For this, three points, proximal to distal, corresponding to 25, 50, and 75% of the height, were determined on the CVA and SVA. These points were labelled as T1, T2, and T3 on the CVA and T4, T5, and T6 on the SVA, where T1 and T4 were the most proximal points, T2 and T5 were the central points, and T3 and T6 were the most distal points, in relation to the femoral head (Figures 1D-E).

Then, the iliac points were determined by marking two distinct and equidistant points on the dorsal cortex and two on the ventral cortex of the most caudal portion of the iliac body, immediately cranial to the origin of the rectus femoris muscle. The cranial and caudal points, from one cortex to another, were connected, and the midpoint of each line was used to determine the longitudinal axis of the ilium (LAI) (Figures 2A-B). Finally, a line was drawn perpendicular to the LAI that corresponded to the height of the most caudal portion of the iliac body, where 25, 50, and 75% of this height corresponded to the points I1, I2, and I3, respectively (Figures 2C-D).

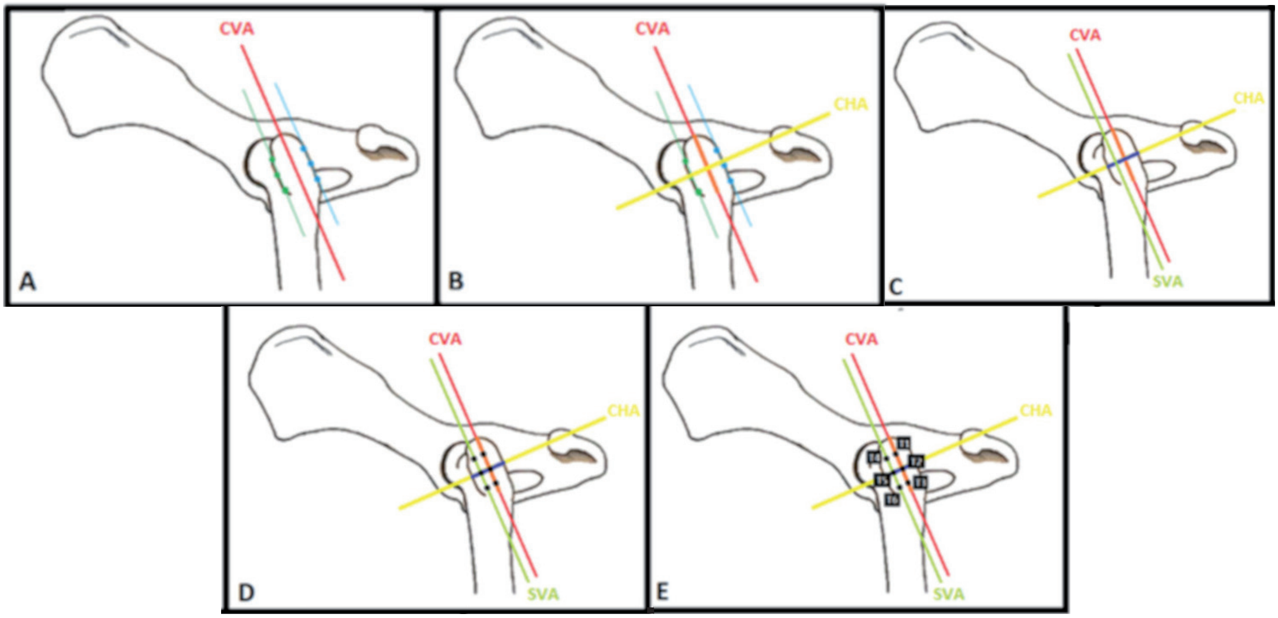

Figure 1. Schematic representation on the lateral projection of the hemipelvis and hip joint of the dog for determination of the trochanteric points. A- Marking of three distinct and equidistant points at the cranial border and the caudal border. The points of each border were connected, giving rise to two parallel vertical lines. At the midpoint between these two lines, the central vertical axis (CVA) of the greater trochanter was traced. B- From the CVA, the trochanteric height was measured, and, at its midpoint, a perpendicular line was drawn that gave rise to the central horizontal axis (CHA) of the greater trochanter. C- From the CHA, the width of the larger trochanter was determined, and, at 25% of this width, a perpendicular axis, called the secondary vertical axis (SVA), was drawn. D- Three points, from proximal to distal, corresponding to 25, 50, and 75% of the height, were determined on the CVA and SVA. E- Marking of T1, T2, and T3 on the CVA and T4, T5, and T6 on the SVA.

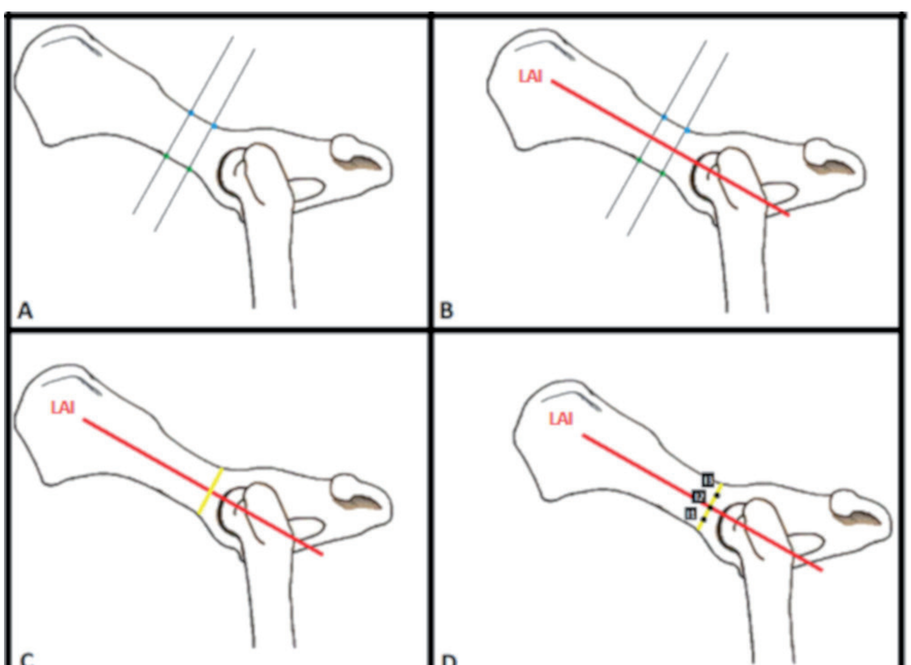

Figure 2. Schematic representation on the lateral projection of the hemipelvis and hip joint of the dog for determination of the iliac points. A- Marking of two distinct and equidistant points on the dorsal cortex and on the ventral cortex of the iliac body. The cranial and caudal points were connected from one cortex to the other. B- The longitudinal axis of the ilium (LAI) was determined from the midpoint of each line. C- A line perpendicular to the LAI was drawn, which corresponded to the width of the most caudal portion of the iliac body. D- 25, 50, and 75% of the width of the caudal iliac body corresponded, respectively, to the points I1, I2, and I3.

The iliac and femoral points were then transcribed to an acetate sheet in real size, which served as a template for the following stage. Subsequently, radiopaque markers were inserted into the hemipelves of each cadaver (CG and TG) at the location corresponding to the iliac and trochanteric points, each one using its respective template. Radiographs were then obtained on the lateral projection of the hip joint in a neutral position, flexion at 50°, and extension at 150°, in both the CG and TG. Then, the distances between the points (lengths) were measured using a digital calliper, with the objective of evaluating which combination of points (between the ilium and the greater trochanter) presented less variation in the joint positions.

The change in length, expressed as a percent of the length measured at neutral position, was calculated for each marker at each position of the hip joint. The mean and standard deviation (± SD) was calculated for the 12 joints using the spreadsheet program.

RESULTS

The percent changes in length between the iliacs and trochanterics markers for angles of flexion and extension relative to the length measured at neutral position were obtained. Measurements of the iliotrochanteric segments resulted in positive and negative values, corresponding to the elongation and shortening of the distance between the points, respectively, referencing the distance in the neutral position as zero. Consequently, values closer to zero, both positive and negative, correspond to lower values of variation, and, therefore, are preferable. In relation to the fixation point I1, the point that obtained the lowest variation in the CG was T3 (1.3%) during extension and T5 (-3.9%) during flexion. In the TG, the lowest variation during extension was observed at T4 (-0.9%), while T2 (-3.0%) demonstrated the lowest variation during flexion. Thus, in both the CG and TG, segment I1 with T1, T4, and T6 showed variations during flexion greater than 15%, whereas variations during extension greater than 6% were observed between I1-T1 and I1-T6 (Table 1).

The results were more homogeneous in relation to the fixation point I2, where T2 obtained the lowest variation during extension and flexion in the CG and TG, with values of -1.3% and -1.2% for the CG and 0.1% and -5.2% for the TG, respectively. The highest percentages of variation were observed between I2 and T1, T3, and T6 during extension and flexion in both the CG and the TG (Table 2).

For the fixation point I3, T2 obtained the lowest variation during extension and flexion in both groups, with values of 2.6% and -3.4% in the CG and 2.6% and -8.2% in the TG, respectively. In association with I3, T4 resembled T2 during extension of the joint in the TG, with a variation equal to -2.6%. The greatest variations, both in extension and in flexion, were obtained by associating I3 with T1, T3, and T6 in both groups (Table 3).

Thus, considering that the trochanteric point T2 presented the smallest percentage of changes for two iliac points (I2 and I3), we then evaluated which site of the ilium demonstrated less variation in association with T2 (Figure 3). In the CG, the variation in extension was -2.4% for I1-T2, -1.3% for I2-T2, and 2.6% for I3-T2; while in flexion, the variation was 4.3% for I1-T2, -1.2% for I2-T2, and -3.4% for I3-T2. Thus, in the CG, I2-T2 presented the lowest percentage of variation in both extension (-1.3%) and flexion (-1.2%) and, therefore, is considered closest to isometry in the absence of CFL. In addition, in the TG, the variation in extension was -1.4% for I1-T2, 0.1% for I2-T2, and 2.6% for I3-T2; while in flexion, the variation was -3.0% for I1-T2, -5.2% for I2-T2, and 8.2% for I3-T2. Therefore, for the TG, I2-T2 presented the smallest percentage of variation in extension (0.1%), and I1-T2 presented the smallest percentage of variation in flexion (-3.0%).

Table 1. Mean values and standard deviation of the percentage variation of the segments between the first iliac point (I1) and trochanteric points (T1 to T6) in the hemipelves from canine cadavers with intact joints (CG) and after coxofemoral luxation model (TG).

	Ilium 1 (I1)					
	T1	T2	T3	T4	T5	T6
Neutral	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Extension CG	-10.7 ± 3.1	-2.4 ± 1.1	1.3 ±2.9	- 4.4 ± 1.2	3.2 ± 1.3	6.0 ± 1.7
Extension TG	-8.4 ± 1.6	-1.4 ± 0.7	3.3 ± 0.9	- 0.9 ± 0.2	3.0 ± 0.8	8.3 ± 1.5
Flexion CG	23.6 ± 6.00	4.3 ± 1.5	- 8.4 ± 1.0	30.1 ± 3.3	- 3.9 ± 1.6	- 15.4 ± 1.6
Flexion TG	22.4 ± 2.6	- 3.0 ± 1.2	- 14.6 ± 3.2	- 17.8 ± 4.9	- 13.2 ± 2.7	- 21.5 ± 2.3

Table 2. Mean values and standard deviation of the percentage variation of the segments between the second iliac point (I2) and trochanteric points (T1 to T6) in the hemipelves from canine cadavers with intact joints (CG) and after coxofemoral luxation model (TG).

	Ilium 2 (I2)					
	T1	T2	T3	T4	T5	T6
Neutral	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Extension CG	- 8.4 ± 2.7	- 1.3 ± 0.00	5.0 ± 2.2	- 3.9 ± 1.3	4.5 ± 1.9	7.8 ± 2.9
Extension TG	- 6.8 ± 2.8	0.1 ± 0.00	6.2 ± 1.2	- 2.4 ± 1.1	5.7 ± 1.6	11.7 ± 5.5
Flexion CG	21.8 ± 22.2	- 1.2 ± 1.0	- 13.8 ± 1.1	28.6 ± 3.1	- 4.8 ± 1.3	- 19.7 ± 3.0
Flexion TG	18.2 ± 4.7	- 5.2 ± 1.5	- 18.8 ± 2.6	20.3 ± 5.1	- 13.3 ± 2.6	- 24.7 ± 3.1

Table 3. Mean values and standard deviation of the percentage variation of the segments between the third iliac point (I3) and trochanteric points (T1 to T6) in the hemipelves from canine cadavers with intact joints (CG) and after coxofemoral luxation model (TG).

	Ilium 3 (I3)					
	T1	T2	T3	T4	T5	T6
Neutral	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Extension CG	-6.2 ± 1.4	2.6 ± 0.9	8.9 ± 2.2	- 3.0 ± 1.5	4.8 ± 2.8	10.2 ± 2.5
Extension TG	- 6.4 ± 2.8	2.6 ± 0.8	9.0 ± 2.7	- 2.6 ± 1.0	3.1 ± 1.2	10.3 ± 2.6
Flexion CG	17.8 ± 2.4	- 3.4 ± 1.0	- 16.6 ± 1.0	25.6 ± 3.7	- 8.5 ± 1.1	- 24.1 ± 3.6
Flexion TG	15.1 ± 4.6	-8.2 ± 1.1	- 22.4 ± 5.1	21.4 ± 5.1	- 14.9 ± 2.3	- 30.0 ± 3.2

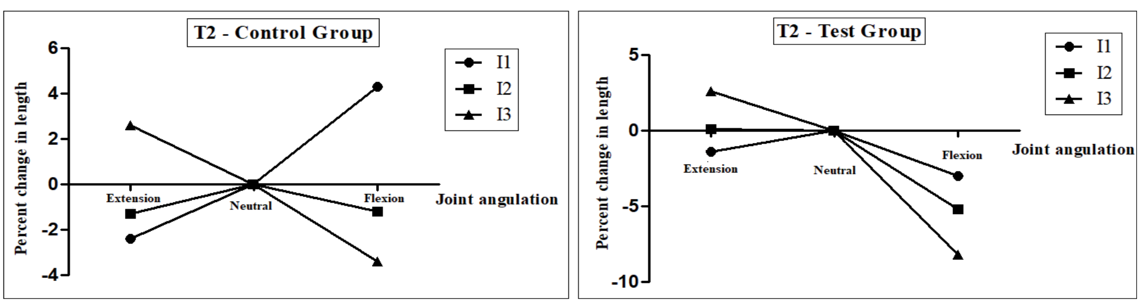

Figure 3. Graphs of the average percent change in length of the distance from the trochanteric marker (T2) to the three iliac markers (I1, I2 and I3), both in control group and test group. The neutral joint position was chosen as the 'zero' point. Values closer to zero, both positive and negative, correspond to lower values of variation.

DISCUSSION

This study determined the points closest to isometry of potential attachment sites for the iliotrochanteric suture in canine cadavers, as a technique for open surgical reduction of craniodorsal CFL. In the CG, where the integrity of the hip joint was maintained, I2-T2 presented the smallest variations in extension and flexion, representing the ideal points. On the other hand, in the TG, where the joint capsule and the femoral head ligament were sectioned, I2-T2 was ideal during extension; however, in flexion, I1-T2 showed more subtle variations than I2-T2. T2 presented the smallest variation in most of the analyses, possibly due to its central location in the trochanteric region, along with I2 when the coxofemoral joint was intact (CG), revealing that the I2-T2 combination is the point closest to isometry for the iliotrochanteric suture during hip extension and flexion.

T2 is the most central point of the greater trochanter, corresponding to 50% of the height of its central vertical axis. As well as I2, which corresponds to the most central point of the ilium, representing 50% of the height of the most caudal portion of its body. Therefore, this combination of points was able to maintain isometry during hip flexion and extension movements. As the iliac and trochanteric points were determined from radiographic images of each cadaver, so the anatomical variations of each specimen were considered in the individual evaluation and revealed that the most central points of each iliac and trochanteric anatomy are the most isometric.

The described techniques for the iliotrochanteric suture present a great anatomical variety in the arrangement of the anchor points of the suture. The anchor points on the ilium and the greater trochanter, respectively, are described as follows by the authors [11,13,14,20,21,24]: 1 to 2 cm cranial to the acetabulum and base of the greater trochanter [11]; insertion tendons of the psoas minor muscle and the gluteus medius muscle [13]; ventral part of the ilium (cranial to the acetabulum) and distal to the insertion of the superficial and middle gluteal muscles [14]; in the origin of the rectus femoris muscle and dorsal aspect of the greater trochanter [20]; at the attachment of the rectus femoris and at the level of attachment of the deep gluteal tendon [21]; and just cranial to the acetabulum and just distal to the insertion of the gluteal muscles [24]. It is observed, therefore, that details are missing about the exact location of the perforation in the dorsoventral aspect (height) of the ilium and there is a great variety of anatomical references in the trochanter.

Despite the lack of detail in the description of the techniques, according to the images present in these studies, most of the iliac points are located discreetly more ventral than the point I2. In relation to the location of the trochanteric point, most authors describe at the base of the greater trochanter and, therefore, the description of Tomlinson [21] is closest to the point T2. Thus, the isometric point found by us details the exact location of perforation in all aspects (height and length), both in the ilium and the trochanter. In addition, it is a personalized point created for each patient from its radiographic examination and taking into consideration its anatomical variations, so that there is no damage to the suture during hip extension and flexion movements.

Despite the low complication rate associated with the techniques previously described, some studies [11,20] reported that in most dogs the limb was internally rotated during the first few days after surgery and that, in 28% of the dogs, pain at maximal flexion, extension, and rotation of the affected limb was identified at the time of final clinical evaluation. Due to the fact that this is a preliminary *ex vivo* study and does not yet have clinical results of the isometric application of iliotrochanteric suture, we still do not know if these postoperative results reported by the authors were due to the configuration of the suture at non-isometric points. However, we believe that isometry may improve these results, since isometric reconstruction maintains an adequate tension of the suture throughout the range of motion.

The surgical techniques for reduction of CFL by iliotrochanteric suture target to maintain abduction of the femur and internal rotation of the femoral head inside the acetabulum until the soft tissues have healed with maturation of scar tissue and reformation of the joint capsule, providing the support necessary for the maintenance of the coxofemoral joint reduction [11,20]. However, if during motion in the healing process, the attachment sites move closer to one another, the suture will become lax and the external rotation and adduction of the femur may occur, even, leading to failure of reduction. If the attachment sites move away from one another, the suture will tighten, damage the soft tissues, and may even break early. Therefore, the implantation in isometric sites assists in reducing the variation of the distance between the points of origin and insertion of the suture during joint movement, keeping the suture tension constant and allowing the functional recovery of the joint, since it effectively stabilizes the joint over the full range of motion [9].

There are some considerations in this present study, and more focused studies are encouraged in order to further our understanding about this suture isometry. First, the employ of a bidimensional radiographic technique does not take into account the fact that suture path is not rectilinear from the ilium to the greater trochanter, since the greater trochanter is situated in a more lateral plane than the ilium. Thus, as the joint moves, the suture must slide over the interposed structures, and it is unknown how this affects isometry. Second, the use of single points in the iliac and trochanteric segments does not represent the conventional form of an iliotrochanteric suture in clinical patients, in which iliac and femoral tunnels are used. Usually, the orientation of the perforation in the femoral segment is from caudal to cranial, and in the iliac segment is from lateral to medial [11,14,20,24]. However, the clinical application of the isometric sites found in this study could be achieved using bone anchors. Finally, this study did not consider other hip movements, such as adduction, abduction and rotation, limiting the accuracy of isometry just for hip extension and flexion movements.

Because of the limitations of this study, the perfectly isometric point of the iliotrochanteric suture can not be defined. However, this study revealed the most isometric point for hip flexion and extension movements and, then, the isometry of the suture for the other movements can be evaluated intraoperatively, before tying the knot. Although attachment sites are only one part of the success of CFL treatment with an iliotrochanteric suture, this study shows that, if not placed correctly, tightening and/or loosening of the suture may occur with joint motion.

CONCLUSION

The most central location in the iliac and trochanteric segments, determined respectively by I2 and T2, is that which provides the least variations during hip movement in the maximum degrees of joint extension and flexion.

***Ethical approval*.** This study was approved by the Ethics Committee on the Use of Animals (CEUA) of the University of Franca, under the number 052/11.

***Declaration of interest*.** The authors report no conflicts of interest. The authors alone are responsible for the content and writing of paper.

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