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Influence of Kirschner-Wire Insertion Angle on Construct Biomechanics following Tibial Tuberosity Osteotomy Fixation in Dogs

Tyler J. Hawbecker[1] Daniel J. Duffy[1] Yi-Jen Chang[1] George E. Moore[2]

[1] Department of Clinical Sciences, College of Veterinary Medicine, North Carolina State University, Raleigh, North Carolina, United States
[2] Department of Veterinary Administration, College of Veterinary Medicine, Purdue University, West Lafayette, Indiana, United States

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Address for correspondence Daniel J. Duffy, BVM&S(Hons.), MS, MRCVS, FHEA, Dip.ACVS-SA, Dip.ECVS, RCVS and EBVS European Recognized Specialist in Small Animal Orthopedic Surgery, Department of Clinical Sciences, College of Veterinary Medicine, North Carolina State University, 1052 William Moore Dr, Raleigh, NC, 27607, United States (e-mail: djduffy@ncsu.edu).

Abstract

Objectives The aim of this study was to evaluate the effect of Kirschner wire insertion angle on the biomechanical characteristics following tibial tuberosity osteotomy fixation in dogs.

Study Design Twelve pairs of cadaveric tibia were harvested and randomly assigned to two treatment groups. Kirschner wires were placed either transversely (0 degrees) or placed caudodistally (30 degrees) with respect to the tibial tuberosity osteotomy. Each limb acted as its own respective control. Radiographic analysis allowed for the calculation of Kirschner wire insertion angle variance. Constructs were tested to monotonic failure while evaluating yield, peak, and failure forces, construct stiffness, and failure mode.

Results Kirschner wire insertion angles were 1.1 ± 2.2 degrees and 30.5 ± 2.3 degrees, respectively, for 0-degree and 30-degree groups ($p < 0.0001$). Yield ($p = 0.0095$), peak ($p < 0.024$) and failure loads ($p < 0.030$) were all significantly greater for Kirschner wires inserted at an angle of 0 degrees compared with 30 degrees. Construct stiffness did not differ regardless of insertion angle ($p = 0.068$). Failure mode did not differ ($p = 0.87$) with tibial tuberosity avulsion and Kirschner wire pull-out seen in the majority of constructs (67%).

Conclusion Kirschner wires placed transversely (0 degrees) for tibial tuberosity osteotomy fixation were biomechanically superior, increasing yield, peak, and failure forces by 1.6 times, 1.3 times, and 1.4 times, respectively, to those placed in a caudodistal (30 degrees) orientation. Kirschner wire insertion angle is an important consideration following tibial tuberosity osteotomy in dogs, with Kirschner wires placed at 0 degrees conferring increased resistance of the repair to construct deformation.

Keywords
- tibial tuberosity osteotomy
- medial patellar luxation
- canine
- Kirschner wire fixation
- failure mode

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Introduction

A tibial tuberosity transposition is a common procedure performed in the surgical correction of medial patellar luxation in dogs.[1–3] A tibial tuberosity transposition involves the creation of an osteotomy of the tibial tuberosity, lateral transposition, and fixation to counteract the proximally oriented pull of the quadriceps muscles, which allows the patella to sit at a depth of 50% within the femoral trochlear groove.[1,3] Multiple methods for fixation of the tibial tuberosity osteotomy have been described in the veterinary literature including lag screw fixation,[4] use of a single Kirschner wire,[5–7] double Kirschner wires,[1–3,8,9] or locking plate fixation.[10] Prior investigators have proposed that Kirschner wires should be oriented caudoproximally as this has been associated with increased tensile strength,[3,6,9] however, caudodistal angulation is described and routinely performed clinically.[11] One study by Cashmore and colleagues found that the more caudodistally the Kirschner wires were directed, the greater the risk for tibial tuberosity avulsion.[9] Use of a concurrent tension band wire to stabilize the tibial tuberosity transposition has been advocated in larger dogs or those where concern exists over the integrity of the repair.[1,12] Retrospective analysis on the use of a single Kirschner wire showed an approximately 11 times greater risk of tibial tuberosity avulsion and is therefore not currently recommended for use in dogs.[9] This is likely due to diminished resistance of the tibial tuberosity to rotational forces encountered during load application and active weight bearing.[4,9,13] In a recent retrospective study evaluating percutaneous pinning following tibial tuberosity avulsion fractures in immature dogs, it was found that aiming for a lower insertion angle was associated with improved client questionnaire scores regarding patient outcome following surgery.[14] Currently however, there is a paucity of information surrounding the effects of Kirschner wire insertion angle on the effects of construct biomechanics following tibial tuberosity transposition in dogs.[8,9] Information regarding the effect of insertion angle is of use to orthopaedic surgeons to allow informed placement of Kirschner wires which may translate clinically to decrease the occurrence of complications and repair failures in-vivo. The objective of this study was to evaluate the effect of Kirschner wire orientation angle, either placed transversely (0 degrees) or caudodistally (30 degrees) on construct biomechanics and failure mode following tibial tuberosity osteotomy fixation in dogs. Our hypothesis was that Kirschner wire orientated transversely (0 degrees) would be biomechanically superior to those angled caudodistally (30 degrees) to the tibial tuberosity osteotomy. Our secondary hypothesis was that failure mode would not differ regardless of Kirschner wire insertion angle.

Materials and Methods

For this study, 24 cadaveric tibias were harvested from 12 skeletally mature, adult dogs euthanized for reasons unrelated to this study using an intravenous infusion of phenytoin and pentobarbital solution (Euthasol, Virbac AH inc, Carros, France). This study was deemed exempt from requiring institutional animal care and use committee approval due the secondary use of cadaveric tissues following euthanasia. Dogs were included within the study when >1 year of age and weighing between 10 and 30 kg. Dogs were excluded if there was any evidence of pathology affecting the femorotibial or femoropatellar joints, or if there was evidence of orthopaedic disease based on a focused orthopaedic examination performed by a board-certified surgeon (D.J.D.). Paired tibiae were serially dissected within 12 hours of euthanasia to remove all soft tissues, ensuring careful preservation of the enthesis of the patellar ligament onto the tibial tuberosity. The patellar ligament was then carefully dissected and a transverse myotomy of the quadriceps contributions was performed using Mayo scissors 2 cm proximal to the patella.[8] All tibias were left whole to aid with specimen fixation. Following collection, specimens were wrapped in moist saline (0.9% NaCl) soaked gauze laparotomy sponges and stored in a thermostatically controlled environment at −20°C until the time of testing.

Tibial Tuberosity Osteotomy

Following a single freeze-thaw cycle at room temperature (21°C) for 10 to 12 hours on the day of testing, tibias were further dissected of all surrounding musculature by one of the study authors (T.J.H.). The infrapatellar fat pad and joint capsular attachments were debrided using a number 10 scalpel blade (MedBlades, Addison, Illinois, United States). A complete osteotomy of the tibial tuberosity was performed using an oscillating saw (Colibri II, DePuy Synthes Vet, West Chester, Pennsylvania, United States) loaded on an orthopaedic drill (Colibri II, DePuy Synthes Vet, West Chester, Pennsylvania, United States). The osteotomy was performed ensuring the medial and lateral malleoli of the distal tibia were held parallel and 90 degrees to the tibial tuberosity. To standardize the osteotomy among constructs, two similar anatomical points were located on the proximal tibia. An osteotomy was performed from the depression immediately cranial to the intermeniscal ligament to a point 10 mm caudal to the enthesis of the patellar ligament, which was measured using a surgical ruler (MediChoice, Owens & Minor, Raleigh, North Carolina, United States) and marked on the periosteal surface using a number 10 blade. A complete, bi-cortical osteotomy was then performed as previously described by Zide and colleagues,[8] with the distal aspect of the osteotomy ending at the level of lesser tibial tuberosity which connected the two aforementioned landmarks. A large point-to-point reduction forceps (Securos Surgical, Sturbridge, Massachusetts, United States) was utilized to hold the osteotomized segment in place before definitive fixation without translation to the osteotomized tibial segment.

Tibial Tuberosity Fixation

Tibia were randomly assigned to one of two experimental groups ($n = 12$/group) using randomization software (www.randomizer.org, Accessed January 24, 2022). As this was a paired study, each contralateral limb from a single cadaver acted as its control, with equal tibial laterality ensured per group. Two smooth, trocar-tipped Kirschner wires (1.6-mm Kirschner wires, IMEX Veterinary Inc., Longview, Texas, United States) were placed in parallel fashion and proximal and distal to one another in the sagittal plane based on the results of a prior study, regardless of group assignment.[8] Experimental groups consisted of Kirschner wires placed at a 0 degree orientation (transversely) ($n = 12$/group) or caudodistally at a 30 degree orientation ($n=12$/group) with respective angles relative to the osteotomy cut line. During Kirschner wire placement, a medical goniometer (Westcott, Seneca, New York, United States) was utilized to approximate 0 degrees or 30 degrees, respectively, based on the assignment of the limbs according to a randomly generated data sheet. A scored line was etched on the periosteal surface of the proximo-medial tibial metaphysis using a number 10 blade to aid with Kirschner wire orientation during free hand drilling. Kirschner wires were placed using a pin driver attachment (DePuy Synthes Vet, West Chester, Pennsylvania, United States) until each Kirschner wire exited the caudal tibial cortex for a standardized distance of 3 mm. During Kirschner wire insertion, sterile saline (0.9% NaCl) was applied to the tibial tuberosity using a bulb syringe to reduce the effect of osteothermal necrosis. During testing, redirection, retrieval, or replacement of Kirschner wires was not performed in any of the repaired constructs. Following Kirschner wire placement, a 10-French stainless steel suction tip was used to bend each respective Kirschner wire that was then cut to 4 mm using pin cutters (Securos Surgical, Sturbridge, Massachusetts, United States) as would be used in clinical cases by the senior author. All osteotomies and repairs were performed by a board-certified surgeon (D.J. D.) experienced in surgical management of medial patellar luxation in clinically affected dogs. The surgeon was aided throughout testing by a trained assistant (Y.-J.C.).

Pin Variance

Prior to biomechanical testing, orthogonal radiographic projections of each pair of repaired tibia (mediolateral and craniocaudal radiographs) were obtained for assessment of pin insertion angle (►**Fig. 1A–D**). Using commercially available digital radiographic software (eUnity v7.1.1.204, Mach7 Technologies Canada Inc., Waterloo, Ontario, Canada) Kirschner wire insertion angles were calculated by a single investigator (T.J.H.). Briefly, the angle was calculated by creating a line overlying the tibial tuberosity osteotomy. A perpendicular line was then created representing a measurement of 0 degrees (90 degrees to the tibial tuberosity osteotomy) (►**Fig. 1B,D**). Kirschner wire orientation angles were then calculated using a measurement tool in the imaging program (eUnity v7.1.1.204). Kirschner wire orientation angles were then measured and compared with these reference lines representing 0 degrees or 30 degrees, respectively (►**Fig. 1B,D**). The proximal-most Kirschner wire was assigned to be P1, and the distal Kirschner wire assigned to be P2. The variance between Kirschner wires was obtained to allow calculation of a mean ± standard deviation Kirschner wire angle by calculating; ([P1 + P2]/2). (►**Fig. 1B** and **D**)

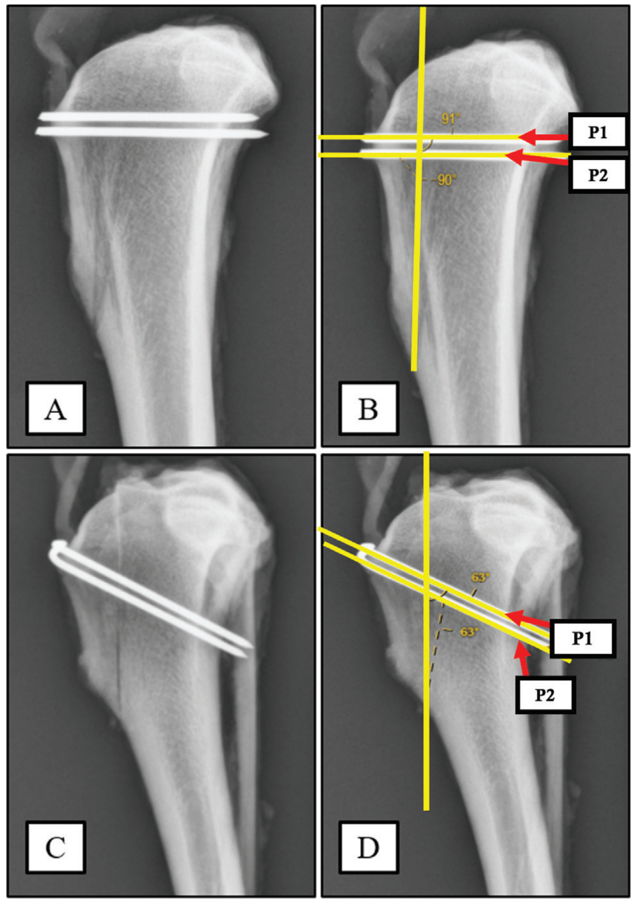

Fig. 1 (**A**) Radiographic mediolateral projection of a representative construct following tibial tuberosity fixation using two vertically positioned 1.6-mm Kirschner wires oriented at 0 degrees (*transversely*) to the tibial tuberosity osteotomy. (**B**) Radiographic mediolateral projection of the same tibia as in (**A**). A perpendicular line was created representing a measurement of 0 degrees (90 degrees to the tibial tuberosity osteotomy) Kirschner wire orientation angles were calculated using a measurement tool in an imaging program (eUnity v7.1.1.204). Kirschner wire orientation angles were then measured and compared with these reference lines representing 0 degrees. The proximal-most Kirschner wire was assigned to be P1, and the distal Kirschner wire assigned to be P2. The variance between Kirschner wires was obtained to allow calculation of a mean ± standard deviation Kirschner wire angle by calculating; ([P1 + P2] / 2). (**C**) Radiographic mediolateral projection of a representative construct following Kirschner wire insertion at 30 degrees (*caudodistally*) relative to the tibial tuberosity osteotomy. (**D**) Same radiographic mediolateral projection as in (C)representing calculation of P1 and P2 respectively.

Mechanical Testing

Testing was performed using a uniaxial material testing machine (Instron Model 5944; Instron, Norwood, Massachusetts, United States) using methodology similar to that as previously described by Zide and colleagues.[8] Respective tibia from each cadaver were secured using a customized bone clamp (SKU No. 1652–1; Sawbones, Vashon Island, Washington, United States) securely mounted to a mechanical vice. A 3.2-mm hole was drilled in the distal tibial diaphysis (equidistant between cranial/caudal cortices respectively) using a 3.0-mm bolt placed transversely through both the clamp and tibia. The patella was secured using a compressive pneumatic clamp (2 kN, Instron, Norwood, Massachusetts, United States) positioned at a measured angle of 135 degrees to the tibia, measured using a medical goniometer. This angle simulated the weight-bearing stance and stifle angle in clinically normal dogs.[8] Following appropriate positioning, constructs were distracted at a rate of 20 mm/s until the point of catastrophic failure. Load and displacement data were collected by the test system software (Bluehill 3, Instron, Norwood, Massachusetts, United States) at a frequency of 100 Hz. Biomechanical load data were generated in newtons (N) and included assessment of yield force, defined as the force at which there was nonlinear deformation >5% of the construct. Peak force was defined as the maximum force measured during each test. Failure force was defined as the load at which tibial tuberosity avulsion, Kirschner wire pull-out, or Kirschner wire pull-through occurred or where a drop in >50% of the applied load occurred during testing. Construct stiffness (N/mm) was defined as the extent to which repaired constructs resisted deformation when load was applied, calculated at 70 to 90% of yield load over the elastic region of acquired load–displacement curves. Mode of construct failure was determined at the time of testing by a single investigator (T. J.H.). Kirschner wire pull-out was defined as Kirschner wires avulsing together with the tibial tuberosity segment, conversely Kirschner wire pull-through was defined as the Kirschner wires pulling through the bone of the tibial tuberosity. Yield, peak, and failure loads and construct stiffness were selected from load–displacement curves using a custom software program (MatLab R2018b, Mathworks, Natick, Massachusetts, United States).

Statistical Analysis

Based on the results of a prior pilot study, a prospective power analysis was conducted and it was determined that a sample size of 12 constructs ($n = 12$ tibia/group) would have at least 90% power with an α error rate of 5% to detect a mean force difference (±SD) of 50 ± 10 N between treatment groups. Pilot data were not included in the final statistical model. Data were assessed for a parametric distribution using the Shapiro–Wilk test for normality. Continuous variables were assessed using mixed effects linear model with each dog as a random effect to account for each cadaver as a common origin for each respective tibia. Pairwise comparisons of least-square means were performed using Bonferroni adjustment for multiple comparisons. Proportional distributions for the mode of failure were compared among groups using the Pearson Chi-square test. Values of $p < 0.05$ were considered significant.

Results

All constructs were successfully created and biomechanically tested without observed procedural error. No specimens were rejected or excluded with all tibia included within the final statistical model. Mean Kirschner wire angles were 1.1 ± 2.2 degrees and 30.5 ± 2.3 degrees in the 0 degree and 30 degree Kirschner wire groups, respectively, which were significantly different from one another ($p < 0.0001$).

Biomechanical Evaluation

Mean yield ($p = 0.0095$), peak ($p < 0.024$), and failure ($p < 0.030$) loads differed significantly from one another between 0 degree and 30 degree Kirschner wire angle groups, respectively. Yield force for the 0 degree Kirschner wire group was 634.5 ± 145.1 N, and for the 30 degree Kirschner wire group was 401.8 ± 146.9 N. Peak force for the 0 degree Kirschner wire group was 686.9 ± 101.8 N, and for the 30 degree Kirschner wire orientation was 509.8 ± 127.3 N. Failure force for the 0 degree Kirschner wire group was 672.1 ± 115.6 N, and for the 30 degree Kirschner wire group was 493.6 ± 125.2 N. Construct stiffness was 57.4 ± 12.9 N/mm and 53.5 ± 22.7 N/mm for the 0 degree and 30 degree Kirschner wire orientation group, respectively and did not differ between groups ($p > 0.068$; ►**Table 1**).

Mode of Construct Failure

Regardless of experimental group, all specimens demonstrated evidence of construct failure. Failure mode occurred due to tibial tuberosity avulsion with concurrent Kirschner wire pull-out (►**Fig. 2B,C**) or by Kirschner wire pull-through (►**Fig. 2D, E**) with no difference in failure mode seen between groups ($p = 0.87$). Tibial tuberosity avulsion occurred in 92% ($n = 11/12$) and 100% ($n = 12/12$) of constructs in the 0 degree and 30 degree Kirschner wire groups, respectively. Concurrent pull-out of the Kirschner wires was seen in both treatment groups ($n = 8$, 66.67%) and was the predominant mode of failure seen compared with Kirschner wire pull-through ($n = 4$, 33.33%).

Discussion

The results of this study confirm our primary experimental hypothesis and demonstrate that placement of Kirschner wires transversely (0 degrees) was biomechanically superior to those placed in a caudodistal (30 degree) orientation. Kirschner wires placed at a 0 degree orientation had greater overall tensile strength compared with those oriented at

Table 1 Mean ± standard deviation data for yield, peak, failure force (newtons, N) and construct stiffness (N/mm) of tibiae repaired with pins oriented either transversely (0 degrees) or oriented caudodistally (30 degrees) with respect to the tibial tuberosity osteotomy

Repair group	Yield force (N)	Peak force (N)	Failure force (N)	Stiffness (N/mm)
0 degrees (Transversely)	634.5 ± 145.1[a]	686.9 ± 101.8[a]	672.1 ± 115.6[a]	57.4 ± 12.9
30 degrees (Caudodistal)	401.8 ± 148.9[b]	509.8 ± 127.3[b]	493.6 ± 125.2[b]	53.5 ± 22.7

[a, b]Denote significant differences between experimental groups based on Kirschner wire orientation angle ($p < 0.001$); No superscript denotes an insignificant difference between experimental groups.

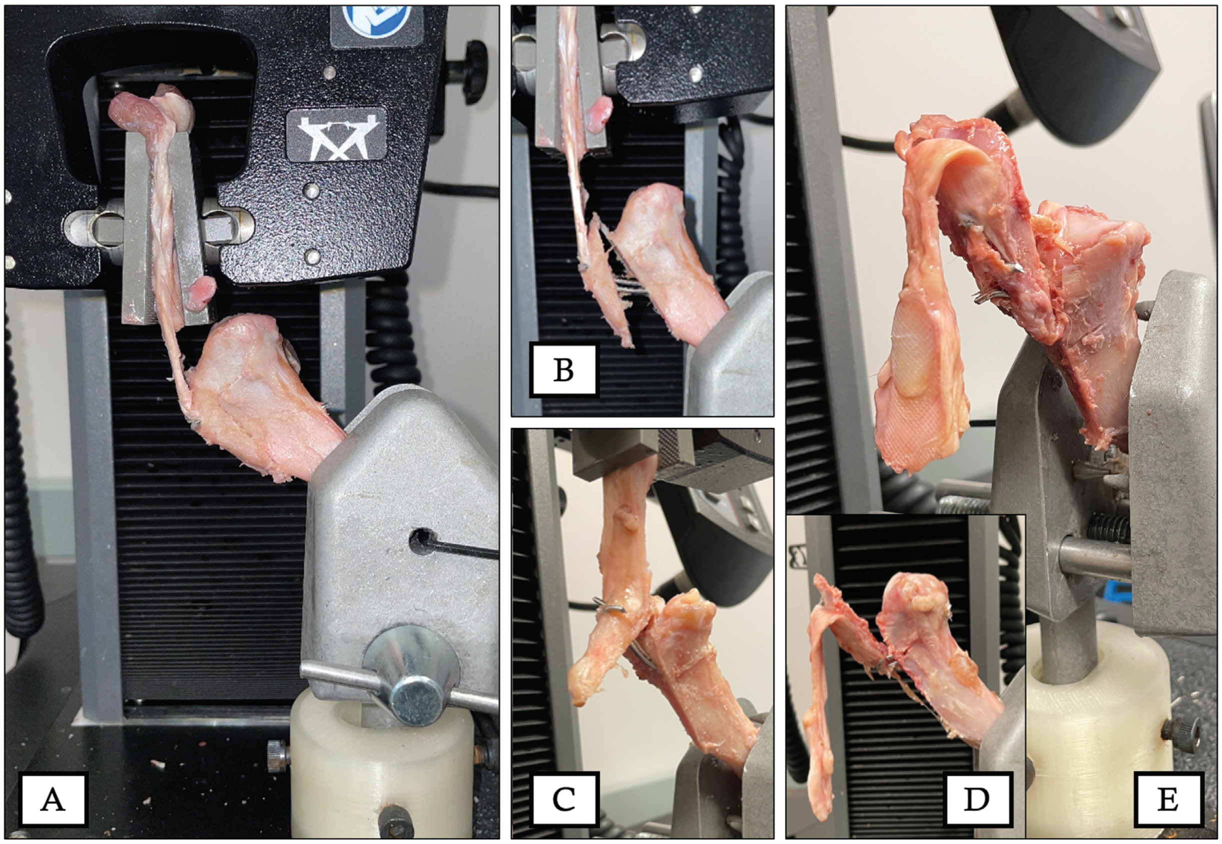

Fig. 2 (**A**) Photographic image depicting repaired tibial tuberosity osteotomy held within custom testing apparatus prior to load application. The tibia is secured in with the patellar ligament oriented at a measured angle of 135 degrees relative to the longitudinal axis of the tibia. (**B**) Construct failure with tibial tuberosity avulsion with concurrent evidence of Kirschner wire pull-out (*mediolateral view*) in a specimen with an insertion angle of 30 degrees (**C**) Construct failure with tibial tuberosity avulsion with evidence of Kirschner wire pull-out (*mediolateral view*) in a specimen with an insertion angle of 0 degrees. Bending of the Kirschner wires can be seen in the image. (**D**) Failure by avulsion with evidence of Kirschner wires pulling-through the tibial tuberosity (*mediolateral view*) in a specimen with an insertion angle of 0 degrees. Note the proximal translation of the tibial tuberosity in the image. (**E**) Mediolateral photograph showing Kirschner wire pull-through showing the proximal change in the position of the osteotomized tibial tuberosity bone segment.

30 degrees to the tibial tuberosity osteotomy. Avulsion of the tibial tuberosity was the most common mode of failure and did not differ between groups. This information is of use to small animal orthopaedic surgeons as Kirschner wire orientation is an important consideration during tibial tuberosity transposition in dogs with Kirschner wires placed at 0 degrees conferring significantly increased strength to the repair.

Yield, peak, and failure forces were all significantly increased when Kirschner wires were orientated transversely (0 degrees) compared with those oriented caudodistally (30 degrees) to the tibial tuberosity osteotomy. In support of these findings, prior studies have demonstrated an increase in the occurrence of tibial tuberosity avulsion and complications following stabilization using Kirschner wires angled in a caudodistal orientation.[3,9,15] An abstract by Cashmore and colleagues, demonstrated a 3.2 to 6.5 times increase in construct strength by orienting Kirschner wires caudoproximally.[15] Our study found an increase in yield, peak, and failure forces by 1.6 times, 1.3 times, and 1.4 times, respectively, for transversely orientated Kirschner wires compared with those placed caudodistally. It should be noted that this aforementioned study did not evaluate canine bone, instead using Derlin acetal homopolymer blocks and different test methodology which may account for the magnitude of differences seen between studies. The findings of our study are in agreement with a prior biomechanical study evaluating Kirschner wire fixation methods in dogs.[8,16] In an ex-vivo study by Zide and colleagues, failure forces were 555.5 ± 113.8 N for vertically oriented Kirschner wires.[8] Although this study differed with respect to the biomechanical variables analyzed, tibial tuberosity fixation in this study was performed utilizing Kirschner wires oriented in parallel fashion and proximal and distal to one another in a sagittal plane with similar failure forces.[8] In our study, construct stiffness did not differ between groups. These findings are likely attributable to the skeletal maturity of the dogs enrolled with all constructs failing by tibial tuberosity avulsion. Given the ex-vivo nature of this study, further evaluation is necessary to elucidate the clinical relevance of these findings.

Our findings may be attributed to the direction of applied loads exerted on the Kirschner wires, as would occur during proximal contraction of the quadriceps muscle.[17] These forces may be even greater when quadriceps muscle contracture occurs with the femorotibial joint positioned in partial flexion. In humans, tibial tuberosity avulsion fractures occur predominantly in athletic adolescents associated with powerful quadriceps contraction or forceful flexion of the knee during concurrent quadriceps contraction.[17] We postulate that Kirschner wires oriented in a caudodistal direction are biomechanically inferior as they are inherently less resistant to forces aligned along or around their axis (tension and rotation). A study by Sahar and colleagues demonstrated that the force exerted by the quadriceps muscle in a dog at a walk is approximately 95% of a patient's body weight.[18] Based on mathematical calculations, this would equate to forces of 115 to 290 N at a walk based on the weights of similar dogs to those used in this study. Yield, peak, and failure forces of all repaired constructs in this study exceed this theoretical force exerted by the quadriceps. It should be noted, however, that the effect of juxta-articular muscle contributions during periods of exercise or strenuous physical activity is currently unknown and remains an area for future investigation. These activities would likely exert greater force on the repair.

In our study, all constructs failed by tibial tuberosity avulsion with concurrent Kirshner wire pull-through or pull-out during loading of the repaired construct. Between the 0 degree and 30 degree Kirschner wire groups, there was no difference in the way these constructs failed, with the majority of constructs failing by Kirschner wire pull-out. Without a tension band wire to counteract the force placed on the constructs, smooth Kirschner wires are held by friction alone and, therefore, are inherently less resistant to bending forces encountered during testing, leading to inadequate compression of tibial tuberosity, resulting in tibial tuberosity avulsion. The addition of a tension band wire has been shown to reduce the incidence of tibial tuberosity avulsion during medial patellar luxation surgery and may be an important consideration in reducing the incidence of tibial tuberosity avulsion in clinical cases.[9] Our results are in agreement with prior studies where the mode of construct failure was tibial tuberosity avulsion with pull-out of Kirschner wires, regardless of orientation.[8,9,16] Clinically, a partial tibial tuberosity osteotomy is often preferred by surgeons, thus preserving distal bone stock or periosteal attachments to act as a hinge to avoid the need for a tension band wire. We performed a complete osteotomy; however, preservation of these distal attachments may have altered the biomechanical properties or mode of failure of repaired constructs. The use of smooth Kirschner wires in this study may account for Kirschner wire pull-out seen as the predominant mode of failure. One study found that divergent placement and use of negatively threaded Kirschner wires reduced complication rates compared with the use of smooth pins following percutaneous pinning of tibial tuberosity avulsion fractures in immature dogs.[14] The addition of a hybrid external fixation system to a double Kirschner wire construct has also been described for stabilization of tibial tuberosity avulsion fractures and may provide an alternative method of tibial tuberosity osteotomy fixation, especially in immature dogs where concern exists for premature closure of the tibial apophysis or where substantial growth potential remains.[16] Postulated reasons for concurrent pull-through of the Kirschner wires in our study may include younger dogs with more compliant cortical bone, area moment of inertia of the Kirschner wires used, or biomechanical methods of destructive testing used.

This study has several inerrant limitations related to its ex-vivo design which may not accurately replicate the complex forces encountered by the repair during different phases of the canine gait cycle. Our study only evaluated progressive loading in a single controlled orientation, rather than cyclical loading that would likely better represent the physiologic forces encountered clinically. Loading was applied at a controlled angle of 135 degrees to mimic a weight-bearing stance in the dog and to replicate the methodology of prior biomechanics studies.[8] Smooth Kirschner wires used in this study (1.6-mm Kirschner wire) were all of the same size and may not be appropriate in larger or smaller dogs, respectively. Given that a tension band wire has been found to increase the strength of the construct by approximately 1.8 times,[8] we recognize that the use of a tension band wire may significantly change our results and represent an area for further study. A tension band wire was not included due to the paired nature of our study design. Cadavers ranged from 10 to 30 kg and therefore may not be representative of canine demographics clinically affected by medial patellar luxation. Based on the patient population of prior veterinary studies, approximately 61% of dogs presenting for medial patellar luxation were considered small breeds weighing <14 kg.[19,20] To compare the strength of our constructs and allow meaningful comparisons between studies, the tibial tuberosity was not laterally translated as would be performed in clinical cases. A 3D-printed drill guide could have been used to ensure greater standardization of the tibial tuberosity osteotomy and Kirschner wire orientation angles among constructs; we elected to drill Kirchner wires free hand to simulate what is performed during clinical cases. In our study, tibias were held securely within a mechanical bone clamp instead of being potted within fiberglass resin as previously described.[8] Distal specimen fixation may play a role in the biomechanical stability of these specimens and, therefore, direct comparison between studies should be interpreted with caution. Lastly, we only evaluated two methods of Kirschner wire orientation, transversely (0 degrees) and caudodistally (30 degrees); further studies are warranted to determine the effect of different insertion angles and determine the optimal orientation for Kirschner wire placement for tibial tuberosity osteotomy fixation.

In conclusion, placement of Kirschner wires at an angle of 0 degrees (transversely) was biomechanically superior to those placed at 30 degrees (caudodistally), with the majority of constructs failing by tibial tuberosity avulsion. Kirschner wire insertion angle is an important consideration during tibial tuberosity osteotomy in dogs with Kirschner wires placed at 0 degrees conferring increased strength to the repair. Further studies are warranted to evaluate optimal Kirschner wire insertion angle, evaluation in an in-vivo model, and the effects of tension band wire augmentation on construct biomechanics and failure mode.

Authors' Contributions

T.J.H. contributed towards acquisition of study data, biomechanical testing, drafting of the manuscript, and final approval of submitted manuscript. D.J.D. contributed towards design of study, construct repair, data acquisition and analysis, interpretation of the data, writing and drafting of final manuscript, revision of the work, and final approval of submitted manuscript. Y-J.C contributed towards specimen collection and dissection, assistance during biomechanics testing, interpretation of data and final approval of the submitted manuscript. G.E.M. contributed towards statistical analysis of data, interpretation of data, and final approval of the submitted manuscript.

Conflict of Interest

None declared.

Acknowledgments

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