UNIVERSIDAD COMPLUTENSE DE MADRID

FACULTAD DE VETERINARIA

DEPARTAMENTO DE MEDICINA Y CIRUGÍA ANIMAL

TESIS DOCTORAL

Fracturas de la tuberosidad tibial como complicación de la TTA en el perro y tratamiento de las mismas

MEMORIA PARA OPTAR AL GRADO DE DOCTOR

PRESENTADA POR

Ignacio Calvo Bermejo

DIRECTORES

Fidel San Román Ascaso
Paloma García Fernández

Madrid, 2018

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BAJO LA DIRECCIÓN DE LOS DOCTORES

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Madrid, 2015

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CERTIFICAN:

Que **D. Ignacio Calvo Bermejo,** con D.N.I 75754197V, Licenciado en Veterinaria, ha realizado bajo nuestra dirección y supervision el trabajo titulado: **"Fracturas de la Tuberosidad Tibial como complicación de la TTA en el perro y tratamiento de las mismas".**

Revisado el presente trabajo, se considera que reúne a nuestro juicio, la debida calidad y las condiciones de originalidad y rigor metodológico necesarios para su presentación y defensa ante el tribunal correspondiente para optar al título de Doctor Europeo.

En Madrid, a 5 de Octubre de 2015,

Fdo. Paloma García Fernández   Fdo. Fidel San Román Ascaso

A mi padre, mi mayor inspiración

“Más allá de la noche que me cubre, negra como el abismo insondable, doy gracias a cuales dioses fuere por mi alma inconquistable.
En la caida garra de la circunstancia no he gemido ni llorado. Sometido a los golpes del azar mi cabeza sangra, pero está erguida.
Más allá de este lugar de ira y llantos yace sino el horror de la sombra, Y aún la amenaza de los años me halla y me hallará sin temor.
No importa cuán estrecha sea la puerta, cuán cargada de castigos la sentencia, soy el amo de mi destino, soy el capitán de mi alma”

-William Ernest Henley

“De todo jardín hay que salir: a ciegas o con los ojos bien abiertos, oigamos o no la llamada de fuera. Hay que salir para topar consigo mismo. Hay que salir, antes o después, a comenzar la vida. Quizá más adelante, cuando nos hayamos convencido de quiénes éramos, sea posible el regreso. Pero entonces será otro nuestro paso, otra nuestra mirada, otra —completamente otra— la letra de nuestra canción.”

-Antonio Gala

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To all my colleagues, senior surgeons, residents. interns and students at Fitzpatrick Referrals, Glasgow, Dublin and London Universities, because it is good to remember that learning never ends. In particular I would like to thank Mr Mike Farrell and Prof Stuart Carmichael for believing in me.

A mis padres, por su apoyo y amor incondicional, por enseñarme el valor de la honradez, la libertad y la humildad. Por dejarme crecer en un 'jardin'. Sin ellos nada de esto habria sido posible.

To my wife Gillian, because I know I am not the easiest person to deal with, for her patience, support and her inspirational lack of fear and desire to improve and get better.

Y por ultimo a todos esos perros y gatos, pacientes o miembros de mi familia en el pasado o en el presente, por su compañia y cariño, pero sobre todo por dejarme observar su inocencia.

STRUCTURE OF THE PhD THESIS

The PhD thesis entitled **"Fracturas de la Tuberosidad Tibial como complicación de la TTA en el perro y tratamiento de las mismas"** *("Tibial tuberosity fracture as a complication of TTA in the dog and its treatment)* is comprised mainly of four peer-reviewed papers:

• Paper 1: "Tibial tuberosity fracture as a complication of tibial tuberosity advancement". Calvo I, Aisa J, Chase D, Garcia-Fernandez P, San Roman F, Bennett D. Vet Comp Orthop Traumatol. 2014;27(2):148-54. doi: 10.3415/VCOT-13-06-0071.

• Paper 2: Paper 3: "Risk factors for tibial tuberosity fracture after tibial tuberosity advancement in dogs". Nutt AE, Garcia-Fernandez P, San Roman F, Parkin T, Calvo I. Vet Comp Orthop Traumatol. 2015;28(2):116-23. doi: 10.3415/VCOT-14-02-0022.

• Paper 3: "Perioperative risk factors for surgical site infection in tibial tuberosity advancement: 224 stifles". Yap FW, Calvo I, Smith KD, Parkin T. Vet Comp Orthop Traumatol. 2015;28(3):199-206. doi: 10.3415/VCOT-14-09-0141.

• Paper 4: 'Incidence of complications associated with tibial tuberosity advancement in boxer dogs'. Dantas B, Sul R, Parkin T, Calvo I. Manuscript ID VCOT-15-02-0036.R1. ACCEPTED for publication in Vet Comp Orthop Traumatol on 30-Jul-2015.

In addition, the research work conducted during the PhD period has also resulted in several contributions to national and international conferences and meetings:

- Calvo I, Yeadon R, Chase D et al. Tibial tuberosity fracture as a complication of tibial tuberosity advancement: Risk factors and management. Proceedings of the IV World Veterinary Orthopaedic Congress. Pp 89. Bologna 2010.

- Calvo I, Yeadon R and Bennett D. Tibial tuberosity fracture as a complication of tibial tuberosity advancement: Risk factors. Proceedings of the 2011 BSAVA congress. Pp 442. Birmingham 2011.

- Yap FW and Calvo I. Comparison of post-operative infection rates in tibial tuberosity advancement in 197 stifles: post-operative antibiotic treatment versus no post-operative antibiotic. Proceedings of the 2013 ECVS meeting Pp 246. Rome 2013.

- Nutt A, Parkin T, Calvo I. 2014 WVOC & VOS abstracts: Risk factors for tibial tuberosity fracture after tibial tuberosity advancement in dogs. Vet Comp Orthop Tramatol 2014(3):13.

- Brigite de Lima Dantas, Rui Sul, Tim Parkin, Ignacio Calvo. Complications and outcome of tibial tuberosity advancement surgery performed in Boxer dogs. Proceedings of the 2015 BSAVA Congress. Birmingham 2015.

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Resumen

Objetivos:

- Comparar de forma retrospectiva dos subgrupos clínicos de pacientes con fracturas de la Tuberosid Tibial (TT) como complicacion del avance de la tuberosidad tibial (TTA) (fracturas por avulsión incidentales o fractura de configuracion compleja asociada con la aparición repentina de cojera severa) y describir el manejo quirúrgico y el resultado del tratamiento de la fractura de la tuberosidad tibial como una complicación de la TTA.

- Identificar de forma retrospectiva los factores que predisponen a la fractura de la tuberosidad tibial (TT) como complicacion de la TTA.

- Examinar los factores perioperatorios que afectan la tasa de infección post-quirúrgica (IPQ) de la TTA, incluyendo los errores técnicos que predisponen a la fractura de la tuberosidad tibial, como forma de evaluar la asociación entre inestabilidad e infección post-quirúrgica

- Revisar retrospectivamente y describir la incidencia de las complicaciones asociadas con el avance tuberosidad tibial (TTA) cirugías en un grupo de perros boxer y comparar los datos con una población control no boxer.

Métodos

En el primer estudio, se revisaron las historias clínicas y radiografias de 10 perros con fracturas de la TT como complicacion de la TTA. Las complicaciones y el resultado del manejo de las mismas se detectaron a través de exámenes de

seguimiento clínico y radiográfico. La función de la extremidad se evaluó clinicamente entre seis y 12 semanas después de la operación. Los propietarios fueron contactados por teléfono para obtener seguimiento de al menos seis meses después del alta clínica.

En el segundo estudio, las historias clínicas y radiografías de un grupo control de perros (n = 212) a los que se les realizaron 241 TTAs y no sufrieron fractura de la TT y las de 12 perros a los que se les realizaron 13 TTAs y sufrieron fractura de la TT como complicacion de la TTA, fueron evaluadas para determinar el efecto de las caracteristicas del animal, peso corporal y la presencia de errores técnicos en la aparicion de fracturas de la TT. Se realizó una regresión logistica multivariable con la aparición de fractura de la TT como la variable de interés.

Como parte de nuestro tercer estudio, se evaluó la información pertinente a las características del animal, parámetros anestésicos y quirúrgicos, así como la aparición de IPQ. Los perros fueron seguidos durante un mínimo de tres meses tras la operación. La asociación entre los factores perioperatorios e IPQ se evaluó mediante pruebas de Chi-cuadrado y regresión logística binaria.

En nuestro último estudio se realizó un análisis retrospectivo para identificar todas las complicaciones en los perros que se sometieron a cirugía TTA debido a la presencia de enfermedad del ligamento cruzado craneal (LCC). Estos registros se clasificaron en dos grupos: perros boxer y un grupo control formado por el resto de razas. Se realizó una regresión logistica multivariable con la raza como la variable de interés.

Resultados

En el primer studio, cuatro perros requirieron estabilización quirúrgica y seis perros fueron tratados de manera conservadora. En el grupo quirúrgico, todos los casos experimentaron una cojera aguda sin apoyo. En tres de los cuatro casos se hizo un intento para estabilizar la fractura de la TT mientras se mantuvo el avance de la TT. Se encontraron complicaciones postoperatorias en tres de los cuatro casos tratados quirúrgicamente. El resultado funcional se consideró excelente en siete casos y bueno en los otros tres.

Nuestro segundo estudio mostró que las caracteristicas del animal y el peso corporal no estaban asociados con la aparición de fracturas de la TT. Errores técnicos tales como, el tamaño de la osteotomia (p = 0,003), la posición de la placa (p = 0,009), y la posición de la caja (p = 0,039) fueron factores asociados significativamente con la presentación de fracturas de la TT.

En el tercer estudio, la prevalencia de IPQ fue del 5,3% (12/224 TTA). El tiempo quirúrgico (p = 0,02) y el tiempo anestésico (p = 0,03) se asociaron significativamente con la aparición de IPQ. El uso de antibióticos profilacticos post-operatorios (APP) o la presencia de errores técnicos asociados con la presentación de fracturas de la TT no influyeron en la aparición de IPQ (p = 0.719). Los implantes se retiraron en el 1,3% de los casos (3/224 TTA).

De las 307 rodillas incluidos en el cuarto estudio, se registraron 69 complicaciones en 58 articulaciones. La tasa de complicaciones fue significativamente diferente entre los grupos, con el 44,4% de perros boxer desarrollando complicaciones en comparación con 15,5% en el grupo de control no-boxer. Esto corresponde a un OR de 5,8 (IC 1,96-17,02; p <0,001). Los perros Boxer tienen más probabilidades de someterse a una cirugía de revisión y de desarrollar múltiples complicaciones. La incidencia de fracturas de la TT que requirieron reparación quirúrgica (2/36 vs 1/271) y las infecciones incisionales que requirieron tratamiento antibiótico (tres en cada grupo) tambien fueron estadísticamente significativas en el grupo de perros boxer.

Conclusiones

1.La fractura de la tuberosidad tibial es una complicación de la TTA que parece tener un pronóstico favorable, aunque puede resultar en una morbilidad significativa y, en algunos casos la cirugía de revisión puede ser necesaria.

2. La mala posición de la placa, la mala posición de la caja, y la ejecucion de una osteotomia estrecha a nivel distal, están asociados con la aparición de la fractura de la TT como complicación de la TTA. Es de suma importancia prestar especial atención a la técnica quirúrgica con el fin de reducir este riesgo.

3. El aumento de los tiempos quirúrgicos y anestesiscos son factores de riesgo significativos para la ocurrencia de IPQ como complicacion de la TTA. No hay evidencia para demostar que el uso de APP o la presencia de errores técnicos que predisponen a la fractura de la tuberosidad tibial fracturas afecten la tasa de IPQ.

4. Los perros Boxer tienen más probabilidades de desarrollar complicaciones multiples y mas relevantes, tales como fracturas de la TT que requieran estabilizacion y de complicacioines relacionadas con la infección. Recomendaciones especificas del tratamiento mas idóneo de la enfermedad del LCC basada en la raza parece ser un tema digno de mayor consideración.

Abstract

Objectives

1. To retrospectively compare two clinical subsets of dogs suffering tibial tuberosity (TT) fracture (incidental finding or sudden onset severe lameness) as a complication of tibial tuberosity advancement (TTA) and to report the surgical management and outcome of TT fracture as a complication of TTA.

2. To retrospectively identify factors that predispose to tibial tuberosity (TT) fracture after tibial tuberosity advancement (TTA) in dogs.

3. To examine perioperative factors affecting surgical site infection (SSI) rate following tibial tuberosity advancement (TTA) including technical errors that predispose to tibial tuberosity fracture as a way to assess the association between construct instability and surgical site infection.

4. To retrospectively review and describe the incidence of complications associated with tibial tuberosity advancement (TTA) surgeries in a group of boxer dogs (n=36 stifles) and compare the data with a non-boxer control population (n=271 stifles).

Methods

In study 1, the medical and radiographic records of 10 dogs with eleven TT fractures or crest fractures after TTA were reviewed. The outcome and complications were determined from clinical and radiographic follow-up examinations. Limb function was evaluated between six and 12 weeks postoperatively. Owners were contacted by phone for long-term follow-up at least six months after the last examination.

In the second study, medical records and radiographs of a group of control dogs (n = 212) that had TTA surgery (n = 241 procedures) and did not sustain a fracture between 2008 and 2013, and those of 12 dogs that did sustain a fracture (n = 13 procedures) between 2008 and 2013 at two veterinary teaching hospitals were evaluated to determine the effect of signalment, body weight and surgical inaccuracies on TT fracture. Multivariable logistic regression was performed with the occurrence of TT fracture as the outcome variable of interest.

As part of our third study, medical records of dogs that underwent TTA in a single institution were reviewed. Information on signalment, anaesthetic and surgical parameters, as well as occurrence of SSI was recorded. Dogs were followed for a minimum of three months postoperatively. The association between perioperative factors and SSI was assessed using Chi-squared tests and binary logistic regression.

In our last study retrospective analysis of medical records was performed to identify all complications in dogs that underwent TTA surgery due to cranial cruciate ligament (CCL) disease. These records were categorised into two groups: boxer dogs and controls (all other breeds) non-boxers dogs. Multivariable logistic regression was performed with the breed as the outcome variable of interest

Results

In the first study, four dogs required surgical stabilization and six dogs had conservative management. In the surgical group, every case experienced a sudden non-weight-bearing lameness after the initial TTA surgery. In three of the four cases an attempt was made to stabilize the TT and crest fracture while maintaining the TT advancement. Postoperative complications were encountered in three of the four surgically treated cases. Functional outcome was considered excellent in seven cases and good in the other three.

Our second study showed that signalment and body weight were not found to be associated with TT fracture. Of the surgical inaccuracies, osteotomy shape (p = 0.003), plate position (p = 0.009), and cage position (p = 0.039) were factors significantly associated with TT fracture.

In the third study, the prevalence of SSI was 5.3% (12/224 TTA). Surgical time (p = 0.02) and anaesthesia time (p = 0.03) were significantly associated with SSI. The use of postoperative antimicrobial therapy was not significantly associated with lower SSI (p = 0.719). Implants were removed in 1.3% of cases (3/224 TTA).

Of the 307 stifles included in the fourth study, 69 complications were reported in 58 joints. The complication rate differed significantly between groups, with 44.4% boxer dogs developing complications versus 15.5% in the control non-boxer group corresponding to an OR of 5.8 (CI 1.96-17.02; p-value <0.001). Boxer dogs were more likely to undergo revision surgery and to develop multiple complications. The incidence of TT fractures requiring surgical repair (2/36 vs 1/271) and incisional infections requiring antibiotic treatment (three in each group) was statistically higher in the boxer group.

Conclusions

1. Tibial tuberosity fracture is a complication of TTA that seems to have a favourable prognosis, although it can result in significant morbidity and in some cases revision surgery may be required.

2. Poor plate position, poor cage position, and narrow distal osteotomy width are associated with TT fracture after TTA. We conclude that it is of paramount importance to pay careful attention to surgical technique in order to reduce this risk.

3. Increased surgical and anaesthesia times are significant risk factors for SSI in TTA, and that there is no evidence that postoperative prophylactic antimicrobial therapy or presence of technical errors that predispose to tibial tuberosity fracture are associated with SSI rate.

4. Boxer dogs had more major and multiple complications after TTA surgery, higher rate of revision surgery, TT fractures requiring stabilisation and infection related complications than the control non-boxer group. The pertinence and value of breed-specific recommendations for CCL disease appears to be a subject worthy of further investigation.

List of Abreviations

TTA	Tibial Tuberosity Advancement
TTA	Avanzamiento de la Tuberosidad Tibial
TPLO	Tibial Plateau Leveling Osteotomy
TPLO	Osteotomia Niveladora de la Meseta Tibial
TT	Tibial Tuberosity
TT	Tuberosidad Tibial
SSI	Surgical Site Infection
IPQ	Infeccion Post-quirurgica
CI	Confidence Interval
CI	Intervalo de Confianza
OR	Odds Ratio
OR	Razon de posibilidades
CCL	Cranial Cruciate Ligament
LCC	Ligamento Cruzado Craneal
LFS	Lateral Fabellotibial Suture
PAT	Post-operative Prophylactic Antimicrobial Therapy
APP	Antibioticos Profilacticos Postoperatorios
LMI	Late Meniscal Injury
ECVS	European College of Veterinary Surgeons
LPS	Lymphoplasmacytic Synovitis

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<u>Paper 2:</u>

Table 1: Results from multivariate analysis of factors associated with the probability of tibial tuberosity fracture after tibial tuberosity advancement. OR*: odds ratio; OR>1 indicates an increased odds of experiencing a tibial tuberosity fracture, OR = 1 implies no association, and OR <1 indicates decreased odds of having a fracture. CI**: confidence interval.

<u>Paper 3:</u>

Table 1: Definition of surgical site infection (Centers for Disease Control and Prevention).

Table 2: Bacteriology of the surgical site infection. *initial deep tissue swab; † bacteriology from implant after 2 weeks of amoxicillin-clavulanic acid; ‡ after initial course of antimicrobial therapy; MDR = multi-drug resistant, ‘resistant to three or more antimicrobial classes; XDR = extensively drug-resistant, bacterium remains susceptible to only one or two antimicrobial classes.

Table 3: Treatment of the surgical site infection.

Table 4: Association between perioperative risk factors and surgical site infection. CI= confidence interval; PAT = postoperative prophylactic antimicrobial therapy.

Paper 4:

Table 1: Descriptive data of both groups of cases treated with cranial cruciate disease treated with tibial tuberosity advancement procedure.

Table 2*:* Variation in the CCL status at presentation, joint exploration, use of autologous bone graft, surgical and anaesthetic times by group. CCLr = Cranial cruciate ligament rupture; CCL = cranial cruciate ligament.

Table 3: Medical treatment administered intra-operatively, locoregional anaesthetic modalities and prescribed medication at time of discharge from the referral hospital per group. FSNB = Femoral and sciatic nerve block. NSAIDs = Non-steroidal anti-inflammatory drugs.

Table 4: Multivariate logistic regression model describing the association between three explanatory variables and the likelihood of TTA complications. CI= Confidence Interval.

Table 5: Relative frequency of the incidence of major and minor, intraoperative, short and long term complications per group. TT= tibial tuberosity; LMI= late meniscal injury; NWB= non weight bearing; MPL= medial patella luxation; * = statistically significant.

List of Figures

Paper 1:

Figure 1: Medio-lateral radiographic images of the stifle of case 10. A) Prior to revision surgery: fracture of the tibial crest affecting the tine holes and extending caudally to the osteotomy site. B) Immediately following revision surgery: double tension band wire repair with three additional positional Kirschner wires. Note the transarticular external skeletal fixator used to augment the fracture repair and the metallic crimps used to secure the extracapsular prosthesis (C) four weeks post-surgery. The fracture is fully healed.

Figure 2: Medio-lateral radiographic images of the stifle of case 7. A) Fracture of the tibial tuberosity and crest, involving the cranial cage screw and extending through the tine holes. Notice the presence of mineralization within the osteotomy gap consistent with osseous infilling. B) Double tension band wire repair with two additional positional Kirschner wires whilst maintaining the advancement cage.

Figure 3: Medio-lateral radiographic images of the stifle of case 8. A) Prior to revision surgery: fracture of the tibial tuberosity and crest, involving the cranial cage screw and extending through the tine holes. B) Immediately following revision surgery: double tension band wire repair with two additional positional Kirschner wires and two cerclage wires whilst maintaining the advancement cage. C) Six weeks post revision surgery: there are signs of healing. Note the broken pin and fractured tibial tuberosity above the proximal pin.

Figure 4: Medio-lateral radiograph of the stifle of case 1. Incidental finding at the six week follow-up examination. Note the caudal displacement and rotation of the tibial tuberosity and the presence of mineralization at the osteotomy site.tibial tuberosity above the proximal pin.

Figure 5: Medio-lateral radiograph of the stifle of case 9. Fracture through the tines; proximal andcaudal displacement of the fractured tibial crest is obvious.

Figure 6: Medio-lateral radiograph of the stifle of case 5. Small fracture proximal to the advancement cage. Note the increased soft tissue density at the level of the patellar tendon, consistent with significant patellar tendonitis. The cage was improperly placed (upside down).

Paper 2:

Figure 1: Medio-lateral radiograph of a canine stifle showing the anatomical points and landmarks for tibial width measurement. A: Most proximal point of the tibial tuberosity. B: Most caudal point of the tibial plateau. C: Most cranial point of the tibial plateau. D: Most distal point of the tibial tuberosity. E: Cross point of a circle with the centre C and the radius 2 x CD at the cranial border of the tibial cortex. F: Cross point of the circle with the centre C and the radius 2 x CD at the caudal border of the tibial cortex. The common tibial shaft width is defined as the distance between E and F.

Figure 2: Medio-lateral view of a tibial tuberosity advancement showing how the osteotomy width is measured. Line A: Drawn parallel to the cranial edge of the cage. Line B: Drawn perpendicular to A and used to measure the osteotomy width at the level of the central point of the distal tine hole.

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Figure 4: Medio-lateral radiographs of three canine stifles immediately post tibial tuberosity advancement demonstrating surgical inaccuracies. A) Poor distal osteotomy width (the level at the distal tine being <25% of the common tibial shaft width), contact between the cranial cage ear and the proximal end of the plate (the plate extending beyond the most proximal aspect of the tibial crest), and poor cage-screw direction (cranial screw angled distally and caudal screw angled proximally). B) No contact between the distal surface of the osteotomized fragment and the tibial shaft, and contact between the cranial cage ear and the proximal end of the plate. C) Poor plate position (the plate is positioned caudal to the region of the tibial crest with the greatest density of cortical bone).

Figure 5: Medio-lateral radiograph of a canine tibia showing a tibial crest avulsion fracture involving all fork holes.

Figure 6: Illustration demonstrating the differences in anatomic shape of the proximal tibia and tibial tuberosity with a high (thick line) versus low (dashed line) patellar ligament insertion point. It can be seen that measurement of the tibial width from tibial tuberosity to the caudal curvature of the proximal tibia is not an accurate method of establishing a common tibial width; a high patellar ligament insertion point gives a wider tibial width (A) than a low insertion point (B). Using the proximal tibia in this way may lead to a distal osteotomy width being calculated as greater than 25% of the tibial width (and thus deemed acceptable) if the tibial tuberosity was low, but less than 25% of the tibial width (and thus deemed poor) if the tibial tuberosity was high.

Figure 7: Transverse computed tomographic image of a canine tibia, illustrating the difference in available cortex for tine engagement between the tibial crest (long arrow) and the area of bone caudal to it (short arrow).

Paper 4:

Figure 1: Boxplot of time to postoperative complications (days) by group of breeds showing the significant difference in the development of complications between dogs from the boxer and control groups.

Introduction

Rupture of the cranial cruciate ligament is one of the most common orthopaedic problems observed in the canine stifle joint (1). Restoration of function is achieved surgically by neutralizing the tibio-femoral shear forces in a cranial cruciate ligament - deficient stifle using either a static, or dynamic surgical procedure (2). Dynamic stabilization is achieved by neutralizing the cranial tibial thrust. Historically this has been achieved by a tibial plateau levelling osteotomy (TPLO), in which a radial osteotomy of the proximal tibia is performed, and rotation of the tibial plateau allows a reduction of the tibial plateau angle (2).

Tibial tuberosity advancement (TTA) was proposed in 2002 as an alternative to tibial plateau levelling osteotomy (3). Tibial tuberosity advancement achieves dynamic stifle stabilization by advancing the tibial tuberosity, thereby altering the direction of the patellar tendon force vector. This results in either a neutral or caudally directed tibio-femoral shear force during the weight-bearing phase of the gait cycle (4).

Tibial tuberosity advancement has become popular over recent years. By comparison with tibial plateau levelling osteotomy, it is claimed that, tibial tuberosity advancement is less invasive and less technically demanding, with a reduced major complication rate (5, 6). However, some reports in the current literature suggest that the complication rates are similar for the tibial tuberosity advancement and tibial plateau levelling osteotomy procedures (1, 2, 6-11). Overall complication rates for the tibial tuberosity advancement range from 19% to 59% which include meniscal tears, infection, medial patellar luxation, chronic poor performance, implant failure, and tibial and tibial tuberosity fractures (1,2, 6-9, 12-15).

Fracture of the tibial tuberosity is considered one of the more serious complications following tibial plateau levelling osteotomy, because of increased patient morbidity and client expense (16); the reported incidence is 3-9% (16). Tibial tuberosity fractures have also been reported after tibial tuberosity advancement, with an incidence ranging from 1- 4 % (1, 2, 6).

The majority of the tibial tuberosity fractures previously reported were incidental avulsion fractures detected on routine radiographic follow-up (1,2,7,8). Although we acknowledge that this is the most common presentation, the author have also recognised the presence of a different clinical subset of animals that are presented with a more complex fracture configuration and sudden onset severe lameness.

The surgical management of three dogs suffering from tibial tuberosity fractures after tibial tuberosity advancement has been mentioned in the literature (1, 2, 7, 8). However, to our knowledge, no previously published studies have specifically compared these two clinical subsets (incidental or sudden onset severe lameness) or has addressed the surgical management and outcome of tibial tuberosity fracture as a complication of tibial tuberosity advancement.

Risk factors for tibial tuberosity fracture after tibial plateau levelling osteotomy are well documented (16) but those for tibial tuberosity advancement are lacking. Possible suggested etiologies for the development of tibial tuberosity fracture after tibial tuberosity advancement include reduced thickness of the osteotomized tibial tuberosity (2, 17, 18), incorrect plate positioning (17, 18), reduced osteotomy contact (18), large preoperative patellar ligament angle (8) and iatrogenic damage to the region during surgical dissection (2). However, to date, statistical data in support of these proposals is only available for preoperative patellar ligament angle, reduced thickness of the osteotomized tibial tuberosity, bilateral single session TTA and reduced osteotomy contact (8, 13, 17, 18).

The prevalence of surgical site infection (SSI) in clean orthopedic surgery in dogs and cats is 2.5 – 4.8% (19-22). Many risk factors for SSI have been identified including prolonged surgical time and pre-anaesthetic clipping (20). Previous studies have reported a SSI rate of 2.6 – 7.2% for TTA surgery (2, 8, 23). A study involving tibial plateau leveling osteotomy (TPLO) and extracapsular lateral suture (ECLS) showed that TPLO has a significantly higher prevalence of SSI (8.4%) when compared to ECLS (4.2%) (P = 0.01) (24). The study has also identified that skin sutures and post-operative prophylactic antimicrobial therapy (PAT) were associated with a lower risk of SSI (24). Other studies in TPLOs found that an increased body weight and being an intact make were associated with increased risk of SSI whereas being a Labrador retriever, the use of post-operative PAT and the application of a locking bone plate were associated with a lower risk of SSI (25-27).

No specific study has examined the peri-operative and post-operative factors of TTA that might be associated with SSI or the association between the use of post-operative PAT and SSI in TTA.

Multiple theories have been proposed to explain particular breed predisposition to cranial cruciate ligament (CCL) disease (28), including ultra-structural differences in the nature of the CCL, anatomical and postural variations (28 -34). To our knowledge no studies have been performed to assess breed-associated variations on the nature and frequency of complications related to TTA surgery. Boxer dogs are a breed commonly affected by CCL disease and a previous study reported a higher complication rate following lateral fabellotibial suture (LFS) when compared to other breeds (35).

Hypothesis and Objectives

The aim of this PhD thesis was the study of the tibial tuberosity fracture as a complication of the tibial tuberosity advancement procedure. Our interest have focused in the management and prevention of this potentially severe complication.

Several hypothesis were created. Firstly, we hypothesized that tibial tuberosity fracture can be a potential serious and challenging tibial tuberosity advancement complication, particularly during the learning curve phase of this surgical procedure that may require revision surgery and extended convalescence.

Secondly we also hypothesized that tibial tuberosity fracture incidence can be reduced by avoiding technical errors and that fracture is associated with incorrect plate position, distal osteotomy width, osteotomy shape, cage position, and cage screw direction, and also the inappropriate presence of cranial cage ear to proximal plate contact, the absence of contact between the osteotomy and the tibial shaft, and body weight.

Thirdly we hypothesized that surgical and anaesthesia time as well as suboptimal osteotomy shape, cage position and plate position were associated with a high rate of surgical site infection and that the surgical rate was not affected by the prophylactic use of antibiotics.

Lastly we hypothesized that there are breed-associated variations on the nature and frequency of complications related to TTA surgery and in particular that boxer dogs have a higher TTA complication rate (including tibial tuberosity fracture).

Several specific objectives were designed to test these hypothesis:

- To describe the surgical management and outcome of tibial tuberosity fracture as a complication of tibial tuberosity advancement.
- To compare two clinical subsets of fracture patients (incidental avulsion fractures or complex fracture configuration with associated sudden onset severe lameness).
- To study different technical errors that may predispose to tibial tuberosity fracture after tibial tuberosity advancement in dogs with cranial cruciate ligament disease.
- To study the technical errors that predispose to tibial tuberosity fracture as a way to assess the association between construct instability and surgical site infection.
- To study peri-operative factors affecting surgical site infection rate following tibial tuberosity advancement.
- To study if boxer dogs have a higher TTA incidence of complications (including tibial tuberosity fractures) compared with a non-boxer population

Published Studies

Tibial tuberosity fracture as a complication of tibial tuberosity advancement

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Keywords

TTA, tibial tuberosity, fracture, dog, stifle

Summary

Objectives: To retrospectively compare two clinical subsets of dogs suffering tibial tuberosity (TT) fracture (incidental finding or sudden onset severe lameness) as a complication of tibial tuberosity advancement (TTA) and to report the surgical management and outcome of TT fracture as a complication of TTA.

Material and methods: The medical records of 10 dogs with eleven TT fractures or crest fractures after TTA were reviewed. The outcome and complications were determined from clinical and radiographic follow-up examinations. Limb function was evaluated between six and 12 weeks postoperatively. Owners were contacted by phone for long-term follow-up at least six months after the last examination.

Results: Four dogs required surgical stabilization and six dogs had conservative management. In the surgical group, every case experienced a sudden non-weight-bearing lameness after the initial TTA surgery. In three of the four cases an attempt was made to stabilize the TT and crest fracture while maintaining the TT advancement. Postoperative complications were encountered in three of the four surgically treated cases. Functional outcome was considered excellent in seven cases and good in the other three.

Clinical significance: Tibial tuberosity fracture is a complication of TTA that seems to have a favourable prognosis, although it can result in significant morbidity and in some cases revision surgery may be required.

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Introduction

Rupture of the cranial cruciate ligament is one of the most common orthopaedic problems observed in the canine stifle joint (1). Restoration of function is achieved surgically by neutralizing the tibio-femoral shear forces in a cranial cruciate ligament-deficient stifle using either a static or dynamic surgical procedure (2). Dynamic stabilization is achieved by neutralizing the cranial tibial thrust. Historically this has been achieved by a tibial plateau levelling osteotomy, in which a radial osteotomy of the proximal tibia is performed, and rotation of the tibial plateau allows a reduction of the tibial plateau angle (2).

Tibial tuberosity advancement was proposed in 2002 as an alternative to tibial plateau levelling osteotomy (3). Tibial tuberosity advancement achieves dynamic stifle stabilization by advancing the tibial tuberosity, thereby altering the direction of the patellar tendon force vector. This results in either a neutral or caudally directed tibiofemoral shear force during the weight-bearing phase of the gait cycle (4).

Tibial tuberosity advancement has become popular over recent years. By comparison with tibial plateau levelling osteotomy, it is claimed that, tibial tuberosity advancement is less invasive and less technically demanding, with a reduced major complication rate (5, 6). However, some reports in the current literature suggest that the complication rates are similar for the tibial tuberosity advancement and tibial plateau levelling osteotomy procedures (1, 2, 6–11).

Fracture of the tibial tuberosity is considered one of the more serious complications following tibial plateau levelling osteotomy, because of increased patient morbidity and client expense; the reported incidence is three to nine percent (12). Tibial tuberosity fractures have also been reported after tibial tuberosity advancement, with an incidence ranging from one to four percent (1, 2, 6). Risk factors for tibial tuberosity fracture have been reported for both tibial plateau levelling osteotomy and tibial tuberosity advancement (12-14).

The majority of the tibial tuberosity fractures previously reported were incidental avulsion fractures detected on routine radiographic follow-up (1, 2, 7, 8). Although we acknowledge that this is the most common presentation, the authors have also recognized the presence of a different clinical subset of animals that are presented with a more complex fracture configuration and sudden onset of severe lameness.

The surgical management of three dogs suffering from tibial tuberosity fractures after tibial tuberosity advancement was mentioned in the literature (1, 7, 8). However, to our knowledge, no previously published studies have specifically compared these two clinical subsets (incidental or sudden onset of severe lameness) or have addressed the surgical management and outcome of tibial tuberosity fracture as a complication of tibial tuberosity advancement.

The objectives of this report are to firstly, describe the surgical management and outcome of tibial tuberosity fracture as a complication of tibial tuberosity advancement, as well as to compare the two clinical subsets of fracture patients (incidental avulsion fractures or complex fracture configuration with associated sudden onset of severe lameness). Our intention is to raise the awareness of a potentially serious and challenging tibial tuberosity advancement complication, particularly during the learning curve phase of this surgical procedure.

Material and methods

Inclusion criteria

The medical records of 10 dogs with eleven tibial tuberosity or tibial crest fractures after tibial tuberosity advancement that occurred within the first 200 consecutive tibial tuberosity advancement surgical procedures performed at Glasgow University and University College Dublin Veterinary Teaching Hospitals were reviewed. For each dog, the information regarding signalment, body weight, time to fracture after tibial tuberosity advancement, lameness score, pertinent medical history, clinical subset (incidental finding or acute onset lameness), type of treatment (conservative or surgical), fracture configuration, presence of new bone at the level of the osteotomy gap, follow-up, other complications, time from fracture detection to resolution, and outcome were all recorded. A detailed clinical examination was used to confirm that a clinically significant abnormality was specifically related to the fracture.

Surgical technique

For the initial tibial tuberosity advancement surgery, a standard medial para-patellar arthrotomy was performed in order to confirm rupture of the cranial cruciate ligament, and to assess meniscal integrity (15). If meniscal pathology was identified, a partial meniscectomy was performed. A standard tibial tuberosity advancement procedure as previously described by others (apart from case 5 where the cage was mistakenly placed upside down) was performed by seven different surgeons (2). Titanium alloy tibial tuberosity advancement implants[a] were used in all cases.

Subsequent patient management

The standard postoperative rest protocol included instructions to enforce strict rest with three or four ten minutes leash walks daily for six weeks. Radiographs were obtained after six weeks, and provided that signs of healing progression were documented, leash exercise was then increased by five minutes per walk on a weekly basis over a four week period. At the end of that month, off-leash exercise was re-introduced over an additional four week period.

Tibial tuberosity fracture repair surgery

The animals were positioned in dorsal recumbency and the affected limb was aseptically prepared for surgery. The animal was then rotated into lateral recumbency leaving the affected limb in contact with the surgery table and a medial approach to the proximal tibia was performed (15). Based on the fracture configuration, the presence of any radiographically apparent signs of osseous infilling of the osteotomy and the surgeon's assessment, a decision was made either to repair the fracture maintaining the cage and therefore the advancement, or to remove all the implants, anatomically reduce and stabilize the tibial tuberosity, and perform an extra-capsular repair to address the cranial cruciate ligament deficiency.

a Veterinary Instrumentation, Sheffield, UK

Preoperative and postoperative radiographic assessment

A minimum of two orthogonal radiographic views, centred on the fracture, were obtained. The preoperative images were used to determine the presence of signs of osseous infilling of the osteotomy gap caudal to the advanced tibial tuberosity, and the number, size and shape of the bone fragments. Radiographs obtained immediately after fracture surgery were evaluated for evidence of tibial tuberosity underadvancement, reduction of the fragments, and the location and type of implants. The presence of complications as well as the progression or completion of healing were assessed with further follow-up radiographs.

Postoperative care

During the first 24 hours after surgery, pain control was achieved with the administration of methadone (0.2 mg/kg by intramuscular injection every four to six hours as needed). On recovery from anaesthesia, meloxicam (0.2 mg/kg subcutaneous injection) was administered and treatment with meloxicam was continued (daily oral dosing at 0.1 mg/kg) for at least four weeks. All dogs were discharged into the owner's care within 48 hours of surgery. Early leash exercise was encouraged but dogs were not permitted free running activity until there was radiographic evidence that bone healing was proceeding – typically at least six weeks after surgery. All implants were left in place unless complications prompted removal or revision surgery.

Conservative management

Instructions were provided to the owners to continue strict rest for at least a further four weeks (depending on clinical progression), including continuation of the non-steroidal anti-inflammatory medication. The importance of avoiding stairs, steps,

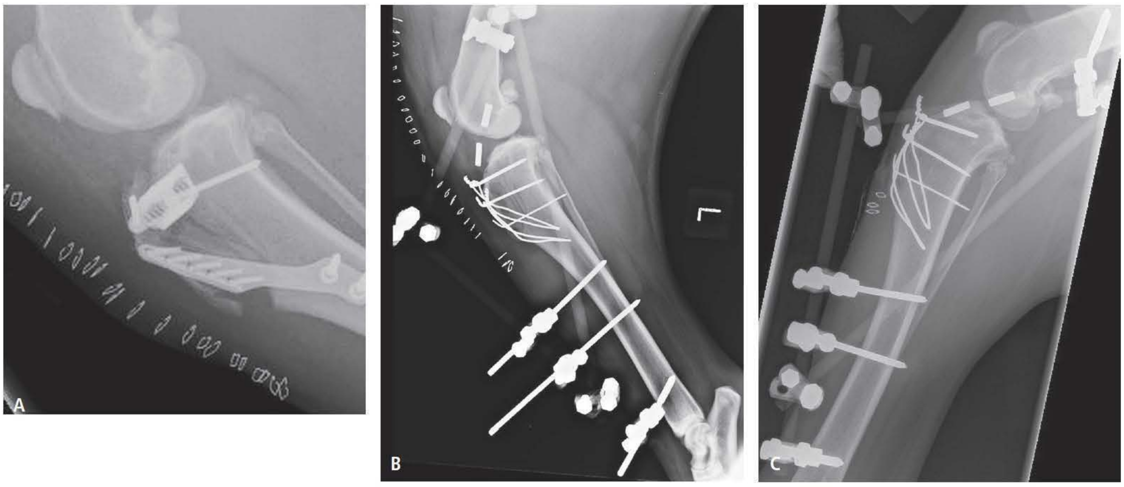

Figure 1 Medio-lateral radiographic images of the stifle of case 10. **A)** Prior to revision surgery: fracture of the tibial crest affecting the tine holes and extending caudally to the osteotomy site. **B)** Immediately following revision surgery: double tension band wire repair with three additional positional Kirschner wires. Note the transarticular external skeletal fixator used to augment the fracture repair and the metallic crimps used to secure the extracapsular prosthesis **(C)** four weeks post-surgery. The fracture is fully healed.

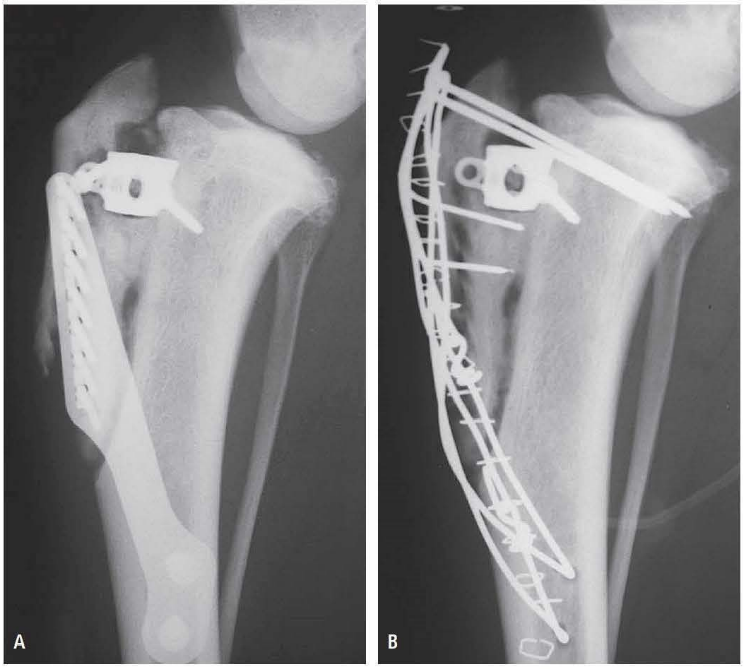

Figure 2 Medio-lateral radiographic images of the stifle of case 7. **A)** Fracture of the tibial tuberosity and crest, involving the cranial cage screw and extending through the tine holes. Notice the presence of mineralization within the osteotomy gap consistent with osseous infilling. **B)** Double tension band wire repair with two additional positional Kirschner wires whilst maintaining the advancement cage.

slippery surfaces, and off-leash exercise was also emphasized.

Post-treatment assessment

The minimum follow-up for the conservatively managed cases included one physical and radiographic examination approximately six weeks after the initial tibial tuberosity advancement surgery, and a telephone conversation with the owner at least six months after fracture diagnosis. Minimum follow-up for the surgically managed cases included physical and radiographic examinations approximately six weeks after revision surgery, and a further physical examination approximately six weeks thereafter, and a telephone conversation with the owner at least six months after fracture surgery. Dogs that were presented for follow-up examinations were evaluated for lameness by observation at the walk and trot. The affected limb was palpated and manipulated for evidence of instability, discomfort, or crepitus, and to evaluate stifle joint motion. A questionnaire was used during the telephone conversation to record the presence of lameness, level of return to activity, and overall satisfaction

(►Appendix 1 – available online at www.vcot-online.com). Functional outcome was defined as excellent when lameness in these dogs was either minimal (less than grade 1/5) or not apparent at the last examination, the patients were able to exercise without restriction, and such activity did not exacerbate lameness or cause subsequent stiffness (as reported by the owners at least 6 months after the last clinical examination). Functional outcome was considered good when lameness in these dogs was either minimal or not apparent at the last examination; the patients were able to exercise without restriction, but heavy exercise exacerbated lameness or caused subsequent stiffness. Functional outcome was considered poor when lameness in these dogs was apparent at the last examination (more than grade 1/5) or the patients were not able to exercise without restriction. Full osteotomy healing was defined as no osteotomy line visible and obliteration at the osteotomy site was obvious. Progression of healing was defined as bone bridging the osteotomy space (increased bone density compared to postoperatively) but with the osteotomy space still clearly visible.

Results

Patient signalment and history

There were four dogs that were managed with surgical stabilization and six dogs that underwent conservative management. One of the conservatively managed cases had bilateral tibial tuberosity avulsion fractures after a staged bilateral tibial tuberosity advancement. This represents a tibial tuberosity fracture incidence of 5.5%. In the conservative group there were three Golden Retrievers, one Springer Spaniel (bilateral tibial tuberosity fracture), one Border Collie, and one English Mastiff. In the surgical group there were two Rottweilers, one Boxer, and one Labrador Retriever. The mean body weights were 34.6 kg for the conservative group and 42.2 kg for the surgical group. Only case 10 had a history of inappropriate postoperative confinement; the dog was allowed to jump in and out the owner's car. The average additional convalescence was 8.5 weeks after surgical management and 5.14 weeks after conservative treatment. None of the cases had meniscal injury at the time of initial surgery or the revision surgery. The rest of the relevant clinical findings are summarized in ►Appendix 2 (Available online at www.vcot-online.com).

Surgical management

In the surgical group, every case experienced a sudden onset of non-weight-bearing lameness after the initial tibial tuberosity advancement surgery. In three patients, this was within two weeks of the initial tibial tuberosity advancement surgery and five weeks for the fourth. The fracture con-

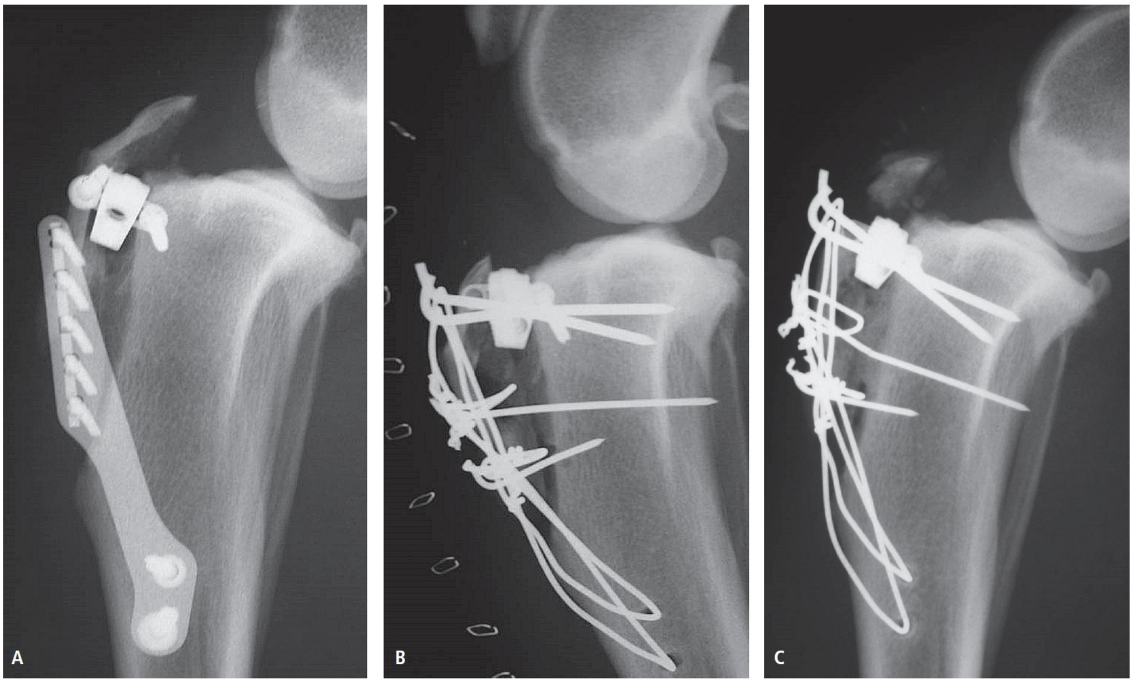

Figure 3 Medio-lateral radiographic images of the stifle of case 8. **A)** Prior to revision surgery: fracture of the tibial tuberosity and crest, involving the cranial cage screw and extending through the tine holes. **B)** Immediately following revision surgery: double tension band wire repair with two additional positional Kirschner wires and two cerclage wires whilst maintaining the advancement cage. **C)** Six weeks post revision surgery: there are signs of healing. Note the broken pin and fractured tibial tuberosity above the proximal pin.

figuration in the surgically managed cases differed slightly amongst patients but could be described as an avulsion fracture that involved all of the fork holes, resulting in proximal and caudal displacement of the tibial tuberosity and crest. The cranial cage screw was still holding in one case (case 10) (▶Figure 1A) and was affected by the fracture in three cases (cases 6, 7 and 8) (▶Figure 2). A moderate degree of comminution was present in case 8 (▶Figure 3). In three of the four cases, an attempt was made to stabilize the tibial tuberosity and crest fracture while maintaining the tibial tuberosity advancement. In these cases, the cranial cage screw, plate, fork and plate screws were removed. The advancement cage and caudal screw were left. The tibial tuberosity was reduced and fixed with two 1.6 mm Kirschner wires and a double tension band (each of the cerclage wires passing through one of the plate screw holes and looped around one of the Kirschner wires) (▶Figure 2B). No additional bone graft was utilized. Two additional Kirschner wires were placed in cases 7 (▶Figure 2B) and 8, and two additional hemicerclage wires were used in case 8 (▶Figure 3). Only in case 10, as part of the first revision surgery, and in case 6, as a result of failure of the first revision surgery, were all the previously placed tibial tuberosity advancement implants removed. In these cases, the tibial tuberosity was anatomically reduced, fixed with two 1.6 mm Kirschner wires and a double tension band wire, and the stifle was stabilized with an extra-capsular technique using an 445 N monofilament nylon prosthesis[a] anchored around the lateral fabella and the proximal Kirschner wire and secured with two metallic crimps. Additionally, in case 10 due to the very active nature of the dog, an additional 1.1 mm Kirschner-wire and a type IA trans-articular external skeletal fixator was placed to augment the fracture repair for four weeks (▶Figure 1) (16).

Postoperative complications were encountered in three of the four surgically treated cases (cases 6, 8, and 10). In case 8, a further asymptomatic tibial tuberosity fracture above the proximal tension band wire pin occurred (▶Figure 3). The rest of the complications are summarized in ▶Appendix 1 (Available online at www.vcot-online.com); however only case six required further surgical intervention due to fixation failure and ongoing tibial tuberosity instability.

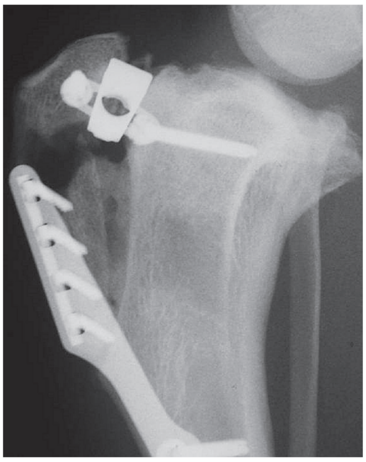

Figure 4 Medio-lateral radiograph of the stifle of case 1. Incidental finding at the six week follow-up examination. Note the caudal displacement and rotation of the tibial tuberosity and the presence of mineralization at the osteotomy site.

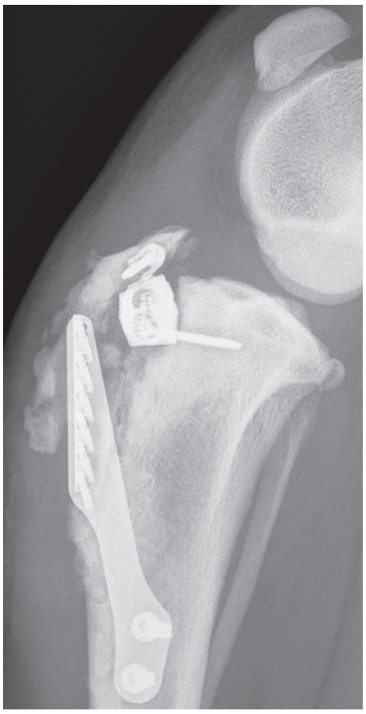

Figure 5 Medio-lateral radiograph of the stifle of case 9. Fracture through the tines; proximal and caudal displacement of the fractured tibial crest is obvious.

Conservative management

In five out of the six conservatively managed cases, the tibial tuberosity fracture was an incidental finding (including the bilaterally affected dog) at the six week routine radiographic follow-up examination, where lameness was not apparent or minimal (less than grade 1/15). Case 5, which was presented at the scheduled six week follow-up appointment, had a lameness score of 3/5 (lameness attributed to secondary patellar tendonitis due to an inappropriately placed cage rather than to the fracture) and conservative treatment was continued for an additional 14 weeks. Two of the six owners reported a transient worsening of the lameness (more lame but still weight bearing) between postoperative weeks two to three that took less than five days to improve.

Five of the seven conservatively managed fractures shared the same fracture configuration: an avulsion fracture where the fracture line (short oblique) involved the most proximal fork hole while the cranial cage screw remained functional, resulting in proximal and caudal displacement of the tibial tuberosity, while still maintaining a degree of tibial tuberosity advancement (▶Figure 4). Case 9 sustained an avulsion fracture that involved all the fork holes resulting in significant proximal displacement of the tibial tuberosity and crest and breakage of the cage ears (▶Figure 5). Case 5 sustained a minimally displaced fracture at the proximal extremity of the tibial tuberosity and cranial cage screw (▶Figure 6).

Radiographic outcome

At the time of the last radiographic follow-up, three of the four surgically treated cases were considered to be fully healed (▶Figure 1C). Mineralisation suggesting bone infilling at the level of the osteotomy was present in all of the conservatively managed fractures (▶Figure 4). Only one of the seven conservatively treated fractures were considered to be fully healed. Bone healing was graded as being progressive in the other six fractures.

Functional outcome

Functional outcome (►Appendix 2 – available online at www.vcot-online.com) was considered to be excellent in seven cases and good in the other three.

Discussion

The increased morbidity associated with tibial tuberosity fractures following tibial tuberosity advancement resulted in extended convalescence of 8.5 weeks after surgical management and 5.14 weeks after conservative management. This outcome was similar to that reported for the tibial plateau levelling osteotomy complicated by tibial tuberosity fracture (12).

The vast majority of the previously reported tibial tuberosity fractures associated with tibial tuberosity advancement were simple avulsion fractures, 23 of these 25 avulsion fractures were incidental findings and were treated non-surgically (1, 2, 7). The remaining two avulsion fractures were treated with a tension band wiring technique, and all cases were reported as having a good outcome, although no specific clinical information was provided. Only one comminuted tibial tuberosity fracture has previously been reported (1). Surgical treatment with a tension band wiring technique while maintaining the cage was reported, however no specific information was provided. We achieved a satisfactory outcome in our case with a comminuted fracture despite the occurrence of a further asymptomatic tibial tuberosity fracture above the proximal tension band wire pin (►Figure 3). A fracture incidence of 5.5% following the tibial tuberosity advancement procedure is the highest yet reported. However five of the 11 fractures occurred within the first 40 cases (14% incidence) leaving an incidence of 3.75% for the 160 subsequent cases. This initial high incidence of tibial tuberosity fracture is probably explained by the lack of surgeon experience. A similar finding was reported with tibial tuberosity fracture after tibial plateau levelling osteotomy, where an initial higher

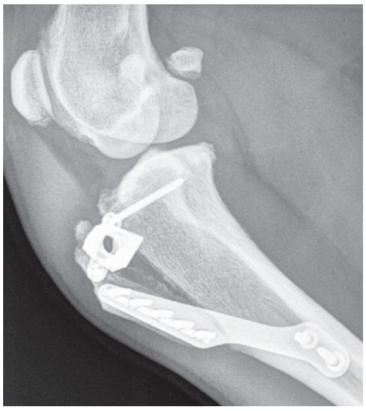

Figure 6 Medio-lateral radiograph of the stifle of case 5. Small fracture proximal to the advancement cage. Note the increased soft tissue density at the level of the patellar tendon, consistent with significant patellar tendonitis. The cage was improperly placed (upside down).

incidence was reported (6.7% for the first 119 cases) (12). A recent study found that the tibial tuberosity advancement learning curve continues for approximately 22 procedures after which mistakes decrease significantly and the overall success rate improves steadily (17). Based on published data reporting complication rates, these authors proposed that an acceptable failure rate (major complication requiring revision surgery) be set at 15% and an unacceptable failure rate at 25%, during the initial learning curve.

Possible suggested aetiologies for the development of post-tibial tuberosity advancement tibial tuberosity fracture include reduced thickness of the osteotomized tibial tuberosity, reduced osteotomy contact, placement of the fork too close to the osteotomy, large preoperative patellar tendon angle, and iatrogenic damage to the region during surgical dissection (2, 6, 8, 13, 14). However, to date, statistical data in support of these proposals is only available for reduced thickness of the osteotomized tibial tuberosity and reduced osteotomy contact (13, 14). Although it was not a primary objective to study the risk factors for tibial tuberosity fracture after tibial tuberosity advancement, technical inaccuracies were identified in 10/11 cases, with the remaining case (case 10) being explained by inappropriate postoperative management. We believe that this complication may be avoidable through careful attention to surgical technique and decision making (13, 14).

Our decision to proceed with either surgical intervention or conservative management was clearly influenced by the severity of clinical signs, particularly the lameness grade, rather than by fracture factors such as configuration and displacement. All four surgically treated cases were presented with a non-weight bearing lameness. Due to the small size of our population, it is not possible to draw any further definitive conclusions. However, the stability of the cranial cage screw may play an important role in the stability of the fractured tibial tuberosity and therefore the associated clinical signs. In six of the seven conservatively managed fractures, the cranial cage screw appeared to be functional. In contrast, the cranial cage screw was involved in the fracture line in three of four surgically managed cases.

In our opinion, repair of the tibial tuberosity fracture whilst maintaining the advancement is a desirable goal, but it could only be achieved in two out of three of our cases. Failure in the third case was probably due to lack of caudal support, thus increasing the stress on the repair and therefore the risk of implant failure or subsequent fracture.

If tibial tuberosity fracture occurs prior to mineralization within the osteotomy gap and the tibial tuberosity advancement implants are removed, one approach is to stabilize the fractured crest fragments in their original anatomic position and perform an extra-capsular repair. However the outcome of such an approach requires long-term evaluation and a larger number of cases.

If the osteotomy gap caudal to the advancement (►Figure 2) was healed, cage removal and stabilization of the crest fragments in their original anatomic position were not possible in two of our cases; therefore an attempt at tibial tuberosity fracture fixation whilst maintaining the tibial tuberosity advancement was made. In cases where the tibial tuberosity bone stock is comminuted, or in exceptional circumstances such as a very active patient, the use of a temporary transarticular external skeletal fixator as described previously could be considered to protect the repair (16).

Although a double tension band construct was used in the surgically managed cases, we acknowledge that there is no biomechanical or clinical data supporting its use. The rationale behind the use of the two individual tension bands was to allow each to tightly conform the wire to each Kirschner wire, minimizing the amount of patellar ligament that was compressed by the wire.

Some degree of tibial tuberosity caudal displacement, and therefore partial loss of the initial tibial tuberosity advancement, was present in all the conservatively managed cases. Although the functional outcome for these dogs was graded as good or excellent, it is possible that the tibio-femoral shear forces were not fully neutralized.

There are several limitations in this study that must be considered when evaluating the data, including a small study population and the lack of long-term physical and radiographic examination. Radiographic examination under sedation for research purposes was not offered since it was considered to be unethical.

In summary, tibial tuberosity fracture is a complication of tibial tuberosity advancement that may have a favourable prognosis although it can result in significant morbidity and in some cases revision surgery may be required. It is a complication that is likely to be avoidable through careful attention to surgical technique and decision making. The severity of clinical signs was the main criterion that determined the treatment option in our cases. Although there are several options for revision surgery, further studies are needed to evaluate the outcome of each approach.

Our findings suggest that major and challenging complications of tibial tuberosity advancement may arise during the learning curve and therefore it is the authors' opinion that tibial tuberosity advancement should not be performed without adequate training and initial supervision.

Conflict of interest

None declared.

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Risk factors for tibial tuberosity fracture after tibial tuberosity advancement in dogs

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Keywords

Dogs, TTA, fracture, complication, tibial tuberosity, tibial tuberosity advancement

Summary

Objective: To retrospectively identify factors that predispose to tibial tuberosity (TT) fracture after tibial tuberosity advancement (TTA) in dogs.

Methods: The medical records and radiographs of a group of control dogs (n = 212) that had TTA surgery (n = 241 procedures) and did not sustain a fracture between 2008 and 2013, and those of 12 dogs that did sustain a fracture (n = 13 procedures) between 2008 and 2013 at two veterinary teaching hospitals were evaluated to determine the effect of signalment, body weight and surgical inaccuracies on TT fracture. Multivariable logistic regression was performed with the occurrence of TT fracture as the outcome variable of interest.

Results: Signalment and body weight were not found to be associated with TT fracture. Of the surgical inaccuracies, osteotomy shape ($p = 0.003$), plate position ($p = 0.009$), and cage position ($p = 0.039$) were factors significantly associated with TT fracture.

Clinical significance: This study provides data to support the hypothesis that poor plate position, poor cage position, and narrow distal osteotomy width are associated with TT fracture after TTA. We conclude that it is of paramount importance to pay careful attention to surgical technique in order to reduce this risk.

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Introduction

Cranial cruciate ligament rupture remains one of the most common causes of hindlimb lameness in dogs. The cause and pathogenesis are still unclear, but mechanical, biological, heritable, degenerative and immunological factors have been suggested (1–8). The resulting changes in tibiofemoral kinematics cause stifle instability, which leads to the development of osteoarthritis (9). Static and dynamic surgical techniques to re-stabilize the cranial cruciate ligament-deficient stifle have been reported; static techniques involve replacement of the cranial cruciate ligament, while dynamic techniques involve an osteotomy to neutralize the tibiofemoral shear force (cranial tibial thrust). The tibial tuberosity advancement is one such dynamic surgical procedure that was first introduced in 2002 (10). It has become one of the most popular choices for cranial cruciate ligament rupture, and many reports on its use are available (10–25). The procedure involves a frontal plane osteotomy of the tibial tuberosity, which is advanced and fixed cranially. This alters the position of the patellar ligament so that it is perpendicular to the tibial plateau slope or, as in more recent studies, the tibiofemoral contact point (10, 17). According to one theoretical model, the joint reaction force is approximately parallel to the patellar ligament, and it can be resolved into a cranially directed shear force and a joint compressive force (10). Advancing the tibial tuberosity in this way will alter the direction of the joint reaction force such that the tibiofemoral shear force is neutralized (10).

Overall complication rates for the tibial tuberosity advancement procedure range from 19% to 59%; complications include meniscal tear, infection, medial patellar luxation, chronic poor performance, implant failure, and tibial fracture. Fracture of the tibial tuberosity postoperatively accounts for complications in 1% – 4.3% of patients, and results in an increased morbidity and client expense (18–25).

Risk factors for tibial tuberosity fracture after tibial plateau levelling osteotomy are well documented, but those for tibial tuberosity advancement are lacking (26). Possible suggested aetiologies for the development of tibial tuberosity fracture after tibial tuberosity advancement include reduced thickness of the osteotomized tibial tuberosity, incorrect plate positioning, reduced osteotomy contact, large preoperative patellar ligament angle, and iatrogenic damage to the region during surgical dissection (19, 22, 27, 28). However, to date, statistical data in support of these proposals is only available for preoperative patellar ligament angle, reduced thickness of the osteotomized tibial tuberosity and reduced osteotomy contact (22, 27–28).

The purpose of this study was to determine factors that predispose to tibial tuberosity fracture after tibial tuberosity advancement in dogs with cranial cruciate ligament disease, and to test the hypothesis that fracture is associated with incorrect plate position, distal osteotomy width, osteotomy shape, cage position, and cage screw direction, and also the inappropriate presence of cranial cage ear to proximal plate contact, the absence of contact between the osteotomy and the tibial shaft, signalment and body weight.

Materials and methods

Case selection

The medical records and radiographs of two groups of dogs identified through the surgical databases of the University of Glasgow Small Animal Hospital and University College Dublin Veterinary Hospital were identified. The first was a group of control dogs obtained consecutively that had tibial tuberosity advancement surgery and did not sustain a fracture between 2008 and 2013. The second group included all the dogs that did sustain a tibial tuberosity fracture as a complication of tibial tuberosity advancement between 2008 and 2013. Data taken from the medical records included breed, age, gender, and body weight at the time of the surgery.

Inclusion criteria

For dogs to be included in the study, a clinical diagnosis of partial or complete cranial cruciate ligament rupture must have been made, and the limb must have subsequently been treated only with tibial tuberosity advancement surgery. Additional inclusion criteria were the availability of complete medical records, preoperative and immediate postoperative radiographic projections, and follow-up radiographs at six weeks postoperatively. Dogs were excluded if the radiographic positioning was poor; all radiographs in which the caudal margin of the medial and lateral tibial condyles were separated by more than

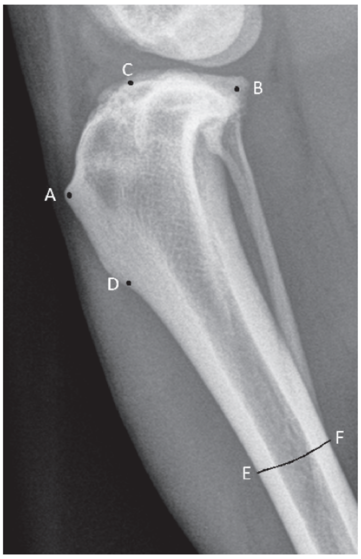


Figure 1 Medio-lateral radiograph of a canine stifle showing the anatomical points and landmarks for tibial width measurement. **A:** Most proximal point of the tibial tuberosity. **B:** Most caudal point of the tibial plateau. **C:** Most cranial point of the tibial plateau. **D:** Most distal point of the tibial tuberosity. **E:** Cross point of a circle with the centre C and the radius 2 x CD at the cranial border of the tibial cortex. **F:** Cross point of the circle with the centre C and the radius 2 x CD at the caudal border of the tibial cortex. The common tibial shaft width is defined as the distance between E and F.

4 mm on the medio-lateral projection were excluded from the study. Radiographs must have included at least the proximal two-thirds of the tibia, and must also have included a radiodense 10 cm radiographic marker to allow calibration of image magnification and linear measurements. Preoperative tibial tuberosity advancement planning was performed on mediolateral stifle radiographs positioned at 135° ± 5° degrees of flexion. The appropriate cage size to obtain a patellar ligament angle of 90° was determined with a transparent overlay using anatomic tibial plateau landmarks.

Cases were omitted from the study if a non-standard tibial tuberosity advancement had been performed, for example Kirschner wires and tension band placement on the tibial tuberosity.

Surgical technique

Initial tibial tuberosity advancement surgery: A standard medial para-patellar arthrotomy was performed in order to confirm rupture of the cranial cruciate ligament, and to assess meniscal integrity (29). If meniscal pathology was identified, a partial meniscectomy was performed. A standard tibial tuberosity advancement procedure was performed in each case by one of seven different surgeons (19). Titanium alloy tibial tuberosity advancement implants[a] were used in all cases.

Subsequent patient management

If clinical progression was considered satisfactory following the surgery, the postoperative protocol included instructions to enforce strict rest with three or four ten minute leash walks daily for six weeks. Radiographs were obtained after six weeks and provided that signs of healing were identified, leash exercise was increased by five minutes per walk on a weekly basis over the next four weeks. At the end of that month, off-leash exercise was re-introduced over an additional four week period. If at any point there was an acute deterioration in weight bearing on the affected limb, the dog would be rested with no further exercise and re-examined as soon as possible.

Radiographic assessment

Medio-lateral radiographs were evaluated either from films (earlier radiographs) or via digital work station with magnification[b]. Three time periods were assessed for all dogs which had had an apparently normal recovery: preoperative, immediately postoperative, and six weeks postoperative. Dogs which developed acute lameness had repeat radiography as soon as possible after onset. The radiographic evaluator (AEN) was blinded to the outcome of each case. On the preoperative radiographs, measurements were made to establish the common tibial shaft width as described previously

a Veterinary instrumentation, Sheffield, UK
b ClearCanvas, Toronto, Ontario, Canada

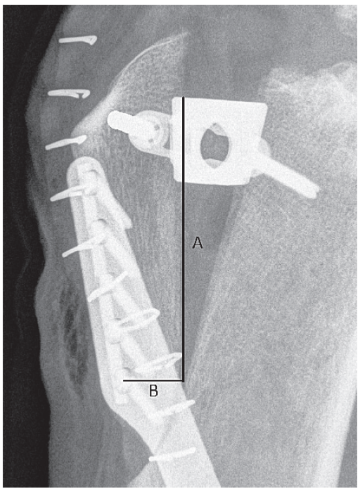


Figure 2 Medio-lateral view of a tibial tuberosity advancement showing how the osteotomy width is measured. **Line A:** Drawn parallel to the cranial edge of the cage. **Line B:** Drawn perpendicular to A and used to measure the osteotomy width at the level of the central point of the distal tine hole.

Figure 3 Medio-lateral radiograph of a canine stifle immediately postoperative showing a tibial tuberosity advancement with no technical errors based on criteria defined in this study.

(►Figure 1) (30). On the immediately postoperative radiographs, the width of the osteotomy was then measured at the level of the central point of the distal tine hole, perpendicular to a line drawn parallel to the cranial edge of the cage (►Figure 2). The cranial edge of the cage was used as a reference line since the shape of the caudal edge of the osteotomy is not always straight. The osteotomy width value was used to calculate the osteotomy width as a percentage of the common tibial shaft width.

Fifteen features were identified on the immediately postoperative radiographs. For the first six, predictors of outcome were recorded as dichotomous variables with the numbers '0' and '1', denoting 'acceptable' or 'poor' respectively (►Figure 3, ►Figure 4):

1. Cage position – the cage must be ≤3 mm distal to the tibial plateau and the cranial cage ear should be proximal to the patellar ligament insertion (not level with or distal to it).
2. Cage screw direction – the cranial screw must angle cranio-proximally.
3. Contact between the cranial cage ear and the proximal plate – there should be no contact. The plate must not extend dorsal to the tibial tuberosity.
4. Plate position – the plate must be positioned on the cranial aspect of the osteotomized fragment, with the proximal pole ≤5 mm, and the distal pole ≤3 mm from the edge.
5. Distal osteotomy width – the width at the level of the most distal tine must not be <25% of the common tibial shaft width.
6. Contact between the distal surface of the osteotomized fragment and the tibia – there must be contact.

Seven further features were measured and recorded as continuous data. The first two relate to distal osteotomy width, whilst features 3–7 relate to plate position. Each measurement was made at the level of the central point of the tine hole, perpendicular to the cage reference line.

1. Absolute osteotomy width at the level of the distal tine
2. Relative osteotomy width at the level of the distal tine
3. Osteotomy width cranial to the proximal tine
4. Osteotomy width at level of the proximal tine
5. Osteotomy width caudal to the proximal tine
6. Osteotomy width cranial to the distal tine
7. Osteotomy width caudal to the distal tine

Two final features recorded were the shape of the osteotomy, that is straight or curved, and also the number of mistakes identified.

Follow-up radiographs were evaluated for signs of fracture of the tibial tuberosity.

Statistical analysis

Dogs were categorized by breed into groups: giant breeds (Mastiff, Newfoundland, Bernese Mountain Dog, Pyrenean Mountain Dog), Retrievers, Rottweilers, other purebreds, and mixed breeds. Sex of the dogs was categorized as female (both entire and spayed) and male (both entire and castrated).

Descriptive statistics were calculated for signalment (age, weight, sex, and breed), obesity (categorised by a bodyweight >30% of the average weight for the breed), cage position, cage screw direction, cranial cage ear-to-proximal plate contact, plate position, osteotomy shape, number of mistakes, distal osteotomy width, and contact between the distal surface of the osteotomized fragment and the tibia (31). Associations between tibial tuberosity fracture and all potential explanatory variables were identified using univariable and multivariable logistic regression. Initially, univariable models were run with each explanatory variable alone in the model against the tibial tuberosity fracture. Those factors that were associated with the outcome at a significance level of ≤0.20 were then included in the multivariable model. A forward stepwise approach was used to identify final multivariable models in which all variables were associated with the outcome ($p < 0.05$). A Hosmer-Lemeshow goodness-of-fit test was used to evaluate the logistic regression model. All analyses were performed using statistical software[c].

c STATA, version 12: StataCorp LP, College Station, Texas, USA

Results

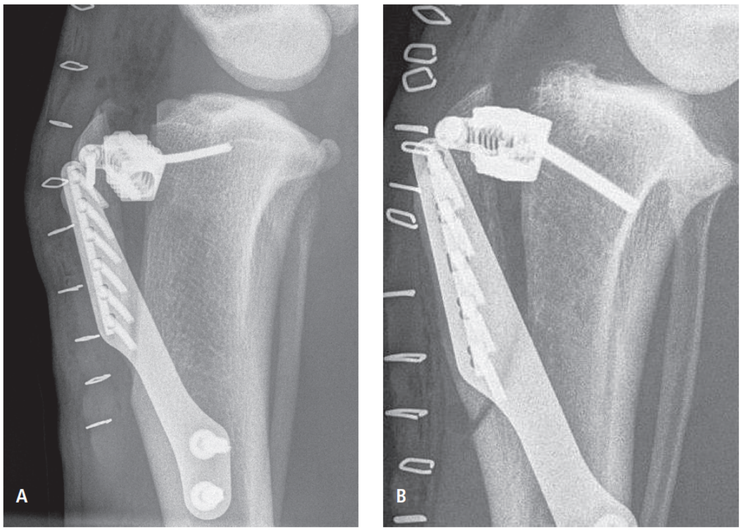
The hospital database search identified 242 dogs that had been treated for cranial cruciate ligament rupture by tibial tuberosity advancement. From this population, 226 dogs had undergone tibial tuberosity advancement surgical procedures, 28 of which were staged bilateral surgical procedures, which met the inclusion criteria giving a total of 254 procedures. Sixteen dogs were excluded due to incomplete medical records (n = 5), incomplete radiographic follow-up (n = 5), and non-standard tibial tuberosity advancement procedures (n = 6). The most common breed overall was the Labrador Retriever (n = 52), followed by the Boxer (n = 26), and the Golden Retriever (n = 26). There were 23 mixed-breed dogs.

The control group consisted of 212 dogs that had 241 tibial tuberosity advancement surgical procedures performed and did not sustain a fracture.

Twelve dogs were diagnosed with thirteen tibial tuberosity fractures at follow-up examination, giving a fracture incidence of 5.12%. Five of these tibial tuberosity fractures were simple tibial tuberosity avulsion fractures through the proximal fork hole with the cranial cage still in place, six were tibial tuberosity avulsion fractures involving all fork holes (►Figure 5), and the other two were comminuted fractures. Three fractures occurred in dogs undergoing staged bilateral operations, and 10 occurred in dogs undergoing unilateral tibial tuberosity advancement. The incidence of fractures by breed was as follows: giant breeds (2/16), Labrador Retrievers (1/52), Golden Retriever (3/26), Rottweilers (2/9), Boxer (2/26), Springer Spaniel (2/16), other purebreds (1/50), and mixed breeds (0/31). The management of 11/13 fractures in our study has been described previously (32).

There were no significant differences in age, weight, or distribution of gender between dogs with or without tibial tuberosity fracture. There were 82 straight cut osteotomies, and 172 curved.

Based on the univariate statistical screening, cage position, cranial cage-screw direction, cranial cage ear-to-proximal plate contact, number of mistakes, plate position, distal osteotomy width, osteotomy-tibial shaft contact, absolute osteotomy width at the level of the distal tine, relative osteotomy width at the level of the distal tine, osteotomy width at level of (and caudal to) the proximal tine, osteotomy width at level of (and caudal to) the distal tine and osteotomy shape (straight or curved), were associated with the occurrence of tibial tuberosity fracture at significance level of $p \leq 0.2$ and thus were included in the multivariable modelling process. In the multivariable model, only risk factors recorded as dichotomous variables remained significant factors associated with tibial tuberosity fracture, and the Hosmer-Lemeshow goodness-of-fit test showed no evidence of a lack of fit. The results indicated that tibial tuberosity advancement with a distal osteotomy width less than 25% of the tibial width had 9.27 higher odds of fracturing (p = 0.003, OR = 9.27, 95% CI = 2.13–40.37). When plate position was suboptimal (proximal pole ≥5 mm and distal pole ≥3 mm from the cranial edge) the odds of a fracture occurring increased 9.47 times (p = 0.009, OR = 9.47, 95% CI = 1.77–50.57), whilst a poor cage position resulted in an increase in odds of 8.28 (p = 0.039, OR = 8.28, 95% CI = 1.11–61.86) (►Table 1).



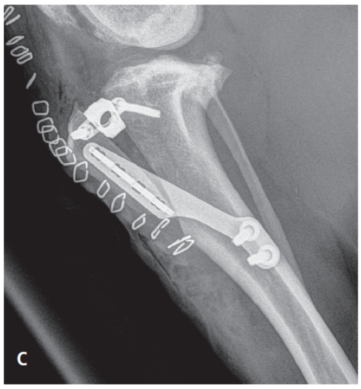


Figure 4 Medio-lateral radiographs of three canine stifles immediately post tibial tuberosity advancement demonstrating surgical inaccuracies. **A)** Poor distal osteotomy width (the level at the distal tine being <25% of the common tibial shaft width), contact between the cranial cage ear and the proximal end of the plate (the plate extending beyond the most proximal aspect of the tibial crest), and poor cage-screw direction (cranial screw angled distally and caudal screw angled proximally). **B)** No contact between the distal surface of the osteotomized fragment and the tibial shaft, and contact between the cranial cage ear and the proximal end of the plate. **C)** Poor plate position (the plate is positioned caudal to the region of the tibial crest with the greatest density of cortical bone).

Figure 5 Medio-lateral radiograph of a canine tibia showing a tibial crest avulsion fracture involving all fork holes.

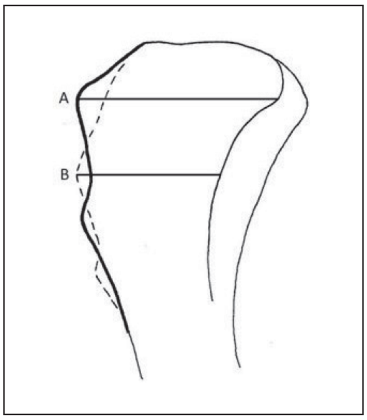


Figure 6 Illustration demonstrating the differences in anatomic shape of the proximal tibia and tibial tuberosity with a high (thick line) versus low (dashed line) patellar ligament insertion point. It can be seen that measurement of the tibial width from tibial tuberosity to the caudal curvature of the proximal tibia is not an accurate method of establishing a common tibial width; a high patellar ligament insertion point gives a wider tibial width (A) than a low insertion point (B). Using the proximal tibia in this way may lead to a distal osteotomy width being calculated as greater than 25% of the tibial width (and thus deemed acceptable) if the tibial tuberosity was low, but less than 25% of the tibial width (and thus deemed poor) if the tibial tuberosity was high.

Discussion

Our study provided data to support the hypothesis that the incidence of tibial tuberosity fracture as a complication of tibial tuberosity advancement could be decreased by careful attention to surgical technique and decision making. Three potential risk factors were found to be significantly associated with fracture of the tibial tuberosity; poor distal osteotomy width (<25% of the common tibial shaft width), poor plate position (proximal pole ≥5 mm and distal pole ≥3 mm from the cranial edge), and poor cage position (>3 mm distal to the tibial plateau).

The fracture incidence rate of our case series is the highest yet reported, however five of the 13 fractures occurred within the first 40 surgical procedures ever performed at the hospitals (14% incidence), leaving an incidence of 3.74% for the remaining 214 surgical procedures. This initial high incidence of tibial tuberosity fracture is probably explained by the lack of surgeon experience. This early learning curve has been documented in previous studies and is reported to continue for approximately 22 procedures, after which time inaccuracies decrease significantly (33).

Age, sex and breed were found not to be significantly associated with tibial tuberosity fracture, though as in previous reports, Retrievers were the most common breed overall, in both the fracture group and the non-fracture group. There was also no association between body weight or obesity, and the occurrence of tibial tuberosity fracture implant size was not related to the occurrence of tibial tuberosity fracture. Analysis for each fracture type was attempted, but due to the small sample sizes, no statistical significance was detected. A previous preliminary study by one of the authors (IC) found the distal osteotomy width to be a significant predictor of postoperative tibial tuberosity fracture, and the findings of our report are similar (p = 0.003) (27–28). The decision to study the distal part of the osteotomy rather than the proximal part was based on the fact that the proximal width of the osteotomy was found to be of adequate size in all dogs (>1 cm at the patellar ligament insertion), whereas the distal osteotomy width was subjectively found to be quite variable. Due to the great anatomical variation in the morphology of the proximal tibia, particularly the patellar ligament insertion point, comparison of the osteotomy width to the proximal tibial width is not useful when trying to draw conclusions about ideal osteotomy shape (30). A high patellar ligament insertion point would give a wider tibial width when measuring from tibial tuberosity to the caudal curvature of the tibia, whilst a low insertion point would give a narrower tibial width (►Figure 6). A previous study identified an anatomical region of the tibia unaffected by breed and so in the preoperative radiographs, measurements were made to establish this common tibial shaft width (►Figure 1) (30). We investigated three potential risk factors for distal osteotomy width. The two recorded as continuous data (absolute distal osteotomy width and relative distal osteotomy width as a percentage of the common tibial shaft width) were not found to be significant, whereas the dichotomously recorded variable (distal osteotomy width <25% common tibial shaft width) was found to be a risk factor. The decision to set the width at which the osteotomy shape was no longer deemed to be acceptable at less than 25% of the common tibial shaft width was based on subjective observation by one of the authors (IC). Whilst the final statistical model indicates that a distal osteotomy width less than 25% of the common tibial shaft width is more likely to result in subsequent fracture, the measures recorded as continuous data did not enable us to recommend a more specific width below which a fracture is more likely to occur. This is probably due to lack of power (frac-

Table 1 Results from multivariate analysis of factors associated with the probability of tibial tuberosity fracture after tibial tuberosity advancement. OR*: odds ratio; OR >1 indicates an increased odds of experiencing a tibial tuberosity fracture, OR = 1 implies no association, and OR <1 indicates decreased odds of having a fracture. CI**: confidence interval.

	OR*	95% CI**	p-value
Distal osteotomy width	9.27	2.13–40.37	0.003
Plate position	9.47	1.77–50.57	0.009
Cage position	8.28	1.11–61.86	0.039

ture case numbers). We theorized that a narrow distal osteotomy may result in poor purchase of the distal tines and overloading of the proximal tines, which could result in increased stress at the proximal part of the osteotomy and potentially lead to fracture. Further biomechanical research is needed to confirm this theory. Nonetheless we recommend careful planning of the osteotomy to ensure that the fragment is not too narrow in the transverse plane, particularly at the distal point. We investigated seven potential risk factors for plate position. Only poor plate position recorded as a dichotomous variable was found to be related to the occurrence of fracture in our study ($p = 0.009$). In relation to this variable, the difference in distance allowance between the proximal and distal aspect of the plate reflects the clinical scenario where the plate is rotated caudally at the proximal aspect to ensure that the plate screws are centred within the tibia. The other six measures detailing exact plate positioning were recorded as continuous data, but none were included in the final statistical model, therefore we are unable to provide recommendations as to the most appropriate position to minimize risk for tibial tuberosity fracture. This again may be due to low fracture case numbers.

We postulate that placement of the plate too far caudally results in placement of the tines in a thinner area of cortical bone, causing a reduced tine holding strength. Repetitive distractive forces of the patellar ligament may cause the tines to 'cheese wire' through the holes, in a similar way to screw toggle as described previously (34). Positioning of the plate as cranial as possible (the cranial border of the plate level with the cranial border of the tibial crest) may provide better cortical bone purchase and therefore reduce the risk of fracture (►Figure 7).

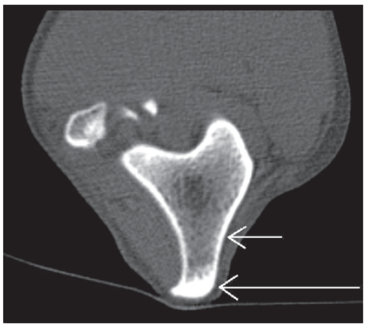


Figure 7 Transverse computed tomographic image of a canine tibia, illustrating the difference in available cortex for tine engagement between the tibial crest (long arrow) and the area of bone caudal to it (short arrow).

Poor cage position was the final significant factor in the final model ($p = 0.033$). Ideal cage position has been reported to be 2–3 mm from the proximal tibial bone margin and with the cranial screw not positioned below the patella ligament insertion; positioning of the cage distal to this has been thought to leave the tibial tuberosity isolated without caudal support (19). However, this was found not to be a risk factor in another study which evaluated the factors predisposing to tibial tuberosity fracture after tibial plateau levelling osteotomy (26). The presence of a screw hole in line with the tibial tuberosity may contribute to cage position being a significant factor for tibial tuberosity fracture because weakened bone in that area could be less resistant to the distractive force of the patellar ligament. We chose to record the predictor of outcome for cage position as dichotomous variables, where 'poor' represented cages that were placed >3 mm below the tibial plateau. None of the cages in our dataset were proximal to the tibial plateau, therefore the consequences of cage position higher than this recommended level were not investigated. Our results suggest that poor cage positioning does increase the risk of tibial tuberosity fracture and therefore we recommend that positioning be planned and executed to the recommended guidelines.

We had reasons for including the other radiographically identifiable potential risk factors in our study. In relation to osteotomy shape, the varied anatomy of the proximal tibia can affect the shape of the osteotomized bone fragment; in some dogs the tuberosity is prominent, whilst in others it is less prominent, meaning despite adequate proximal width, the distal aspect of the osteotomy may become narrow. In order to compensate for this, often during the tibial tuberosity advancement procedure the osteotomy is created with a curve distally to increase the width. We hypothesized that straight-cut osteotomies would be more likely to have a narrower distal width than those which were curved, and thus would be more likely to subsequently fracture. However, osteotomy shape was not found to be significant in our study. This may be because the majority of the straight-cut osteotomies were done correctly on cases with prominent tibial tuberosities, and so were not likely to result in narrow distal widths.

Relating to cage screw direction, it has been stated that the proximal cage screw should be directed cranio-proximally, thus maximizing cortical bone purchase (19). To a great extent the holding strength of a screw depends on the integrity of the bone-screw interface (34). As long as the strength of the bone-screw interface (torque) exceeds the applied load, the screw remains stable (35). However if the applied load exceeds the torque, the screw begins to toggle, crushing the bone it contacts and so decreasing the resistance to further toggling. Resistance to toggle depends on the amount of surface area contact between the screw and the bone, as well as the quality of the bone into which is inserted, among other factors (35). Relating this to the tibial tuberosity advancement, if the cranial cage screw is inaccurately placed (poor cortical purchase), it may be possible for the avulsion force of the patellar ligament to exceed the torque of the cranial cage screw, leading to screw toggling and crushing of bone surrounding the cranial cage screw. This area of crushed bone could potentially then act as a stress riser resulting in an avulsion-type fracture or propagate to the plate and fork leading to a more complex fracture configuration. Cage screw direction was not found to be a significant factor associated with tibial tuberosity fracture in our study. This finding may be explained by the theory that the avulsion force applied by the patellar ligament is mainly neutralised by the tension band plate, subjecting the cranial cage screw to small forces that do not exceed its torque even in the presence of poor cortical purchase. Further studies are warranted to ascertain the ideal torque of the cranial cage screw.

Contact between the osteotomy and the tibial shaft was included in the study because it has been proposed that securing the distal end of the plate along the tibial axis without obtaining bone contact at the distal end of the osteotomized tibial crest may lead to implant failure (▶ Figure 4B) (19). The necessity to obtain this second (distal) point of contact in addition to the proximal contact with the cage was emphasized (19). If there were no distal contacts, the resultant compressive vector acting on the osteotomy could cause instability by creating a 'rocking' motion. This could potentially then lead to fracture through the cheesewire and toggling mechanisms described above. In a separate preliminary study by one of the authors (IC), contact was found to be a significant risk factor associated with tibial tuberosity fracture; however it was not a factor in the final model of this report (27). This apparent significance in the preliminary study may have been due to lower case numbers causing a type I statistical error.

There are other factors that may be associated with tibial tuberosity fracture after tibial tuberosity advancement requiring further investigation. These include iatrogenic tissue damage leading to vascular compromise of the tibial tuberosity, and avascular necrosis of the tibial tuberosity secondary to the heat generated from creating the osteotomy.

Limitations of our study include the retrospective nature of the design, and incomplete datasets that resulted in exclusion of dogs from the study. It is possible that dogs which did not return for postoperative evaluation may have had additional, undiagnosed complications including tibial tuberosity fracture. Furthermore, dichotomization of continuous data is a contentious issue. It has been suggested that dichotomizing a continuous variable may result in lost information and reduced power of statistical test (36). However, there is also evidence to suggest that dichotomization of continuous data might improve performance of models when it has biological interpretation, and the authors feel this is the case in our study (37).

In summary, surgical inaccuracies, specifically incorrect positioning of the plate and cage, and creating an osteotomy which is too narrow at the distal point, can play a significant role in the occurrence of tibial tuberosity fractures. These errors during tibial tuberosity advancement are likely to be made in the early learning curve, therefore it is the authors' opinion that the procedure should not be performed without adequate training and initial supervision. We conclude that it is of paramount importance to pay careful attention to surgical technique in order to reduce the risk of tibial tuberosity fracture.

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Perioperative risk factors for surgical site infection in tibial tuberosity advancement: 224 stifles

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Keywords
Tibial tuberosity advancement, TTA, canine cruciate ligament, surgical site infection, prophylactic antimicrobial therapy

Summary
Objective: To examine perioperative factors affecting surgical site infection (SSI) rate following tibial tuberosity advancement (TTA).
Study design: Retrospective case series.
Sample population: 224 stifles in 186 dogs.
Methods: Medical records of dogs that underwent TTA in a single institution were reviewed. Information on signalment, anaesthetic and surgical parameters, as well as occurrence of SSI was recorded. Dogs were followed for a minimum of three months postoperatively. The association between perioperative factors and SSI was assessed using Chi-squared tests and binary logistic regression.
Results: The prevalence of SSI was 5.3% (12/224 TTA). Surgical time (p = 0.02) and anaesthesia time (p = 0.03) were significantly associated with SSI. For every minute increase in surgical time and anaesthesia time, the likelihood of developing SSI increased by seven percent and four percent respectively. The use of postoperative antimicrobial therapy was not significantly associated with lower SSI (p = 0.719). Implants were removed in 1.3% of cases (3/224 TTA).
Conclusions: The findings of this study suggest that increased surgical and anaesthesia times are significant risk factors for SSI in TTA, and that there is no evidence that postoperative prophylactic antimicrobial therapy is associated with SSI rate.

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Introduction

Cranial cruciate ligament rupture is a significant cause of morbidity in dogs, leading to lameness, muscle atrophy and osteoarthritis (1, 2). The underlying aetiologies of cranial cruciate ligament rupture are poorly understood and a myriad of treatment options have been proposed (3-8). There are many surgical procedures described for the management of cranial cruciate ligament rupture, aiming at improving the stability of the stifle. In the last two decades, the attention has shifted from replacement of the cranial cruciate ligament to providing stability through altering the stifle biomechanics by tibial osteotomy. One of the more recently developed surgical techniques, the tibial tuberosity advancement (TTA), has been shown to reduce tibial translation in the cranial cruciate ligament-deficient stifle and provide good clinical outcomes (9).

The prevalence of surgical site infection (SSI) in clean orthopaedic surgical procedures in dogs and cats is 2.5 – 4.8% (10-13). Many risk factors for SSI have been identified including prolonged surgical time and pre-anaesthetic clipping (11). Previous studies have reported a SSI rate of 2.6 – 7.2% for TTA surgery (9, 14, 15). A study involving tibial plateau levelling osteotomy and extracapsular lateral suture showed that tibial plateau levelling osteotomy had a significantly higher prevalence of SSI (8.4%) when compared to extracapsular lateral suture (4.2%) (p = 0.01) (16). The study also found that skin sutures and postoperative prophylactic antimicrobial therapy were associated with a lower risk of SSI (16). Other studies of tibial plateau levelling osteotomy found that an increased body weight and being male were associated with increased risk of SSI whereas the Labrador Retriever breed, the use of postoperative prophylactic antimicrobial therapy and the application of a locking bone plate were associated with a lower risk of SSI (17-19).

In this study, we examined the perioperative and postoperative factors of the TTA procedure that might be associated with SSI in a university teaching hospital. We also examined the association between the use of postoperative prophylactic antimicrobial therapy and SSI in TTA. Our null hypothesis was that the administration of postoperative prophylactic antimicrobial therapy was significantly associated with lower SSI in dogs undergoing the TTA procedure.

Materials and methods

Data collection

Medical records of all dogs that underwent TTA procedures from 1 September 2008 to 30 April 2013 at the Small Animal Hospital at the University of Glasgow, United Kingdom, were reviewed. Dogs that had bilateral TTA were included as two separate

Table 1 Definition of surgical site infection (Centers for Disease Control and Prevention) (20).

Superficial incisional surgical site infection
• Occurs within 30 days after the procedure, *and*
• Involves only skin or subcutaneous tissue of the incision, and
• At least *one* of the following is present: – Purulent discharge from the superficial incision – Positive bacteriology result from an aseptically collected sample – Showing signs of infection, such as pain, tenderness, localized swelling, redness and heat
Deep incisional surgical site infection
• Occurs within 30 days after the procedure if no implant is left in place, or within 1 year if an implant is in place, *and*
• Involves deep soft tissues (such as fascia and muscle layers) of the incision, *and*
• At least *one* of the following is present: – Purulent discharge from deep incision – An abscess or other evidence of infection involving the deep incision is found on direct examination, during revision surgery or by histopathology and radiologic examination – A deep incision spontaneously dehisces or is deliberately opened by a surgeon in cases with pyrexia, localized pain or tenderness, unless bacteriology result of the incision is negative

cases provided that the selection criteria were met. In order to eliminate variables that may have led to an increased risk of SSI, cases that had antimicrobial therapy administration within seven days prior to surgery for other infectious conditions were excluded from the study. Cases that might have infectious processes that were not treated with antimicrobial therapy were not excluded. Cases that had less than three months postoperative follow-up or had traumatic events that could contaminate the surgical site, such as open tibial tuberosity fracture resulting in an opened surgical wound, were excluded from this study.

Information collected from the medical records included age and breed of dogs, affected stifle joint (left or right limb), surgical time, anaesthesia time, anaesthesia induction agent, type of pre- and intra-operative prophylactic antimicrobial therapy used, the interval between first prophylactic antimicrobial therapy dose given and the first skin incision, perioperative nadir body temperature, whether postoperative prophylactic antimicrobial therapy was used, the types of postoperative prophylactic antimicrobial therapy if prescribed, signs of SSI, bacterial culture and sensitivity result from SSI, and the interval between surgery and the development of SSI.

The surgical time was defined as the interval from the first skin incision to the final skin closure. The anaesthesia time was defined as the time from induction to the extubation. The perioperative nadir temperature was defined as the lowest recorded body temperature under anaesthesia and during the immediate recovery period.

Stifles that developed SSI were further categorized into superficial incisional SSI and deep incisional SSI as defined by the Centers for Disease Control and Prevention (► Table 1) (20). All of the samples collected for bacteriology were incubated for at least 48 hours on sheep blood and MacConkey agar prior to bacterial identification and antibiotic susceptibility testing. If an anaerobic bacterium was suspected, the sample was also incubated on horse blood agar.

All the immediate postoperative radiographs were assessed by one of the authors (IC) for any technical errors of the surgical procedures as a way to assess the association between implant instability and SSI. The criteria for assessment of technical errors was adopted from a previous study that assessed the risk factors associated with tibial tuberosity fractures in TTA; these criteria were osteotomy shape, cage position and plate position (21). Cases that had any one or more of the technical errors of undesirable osteotomy shape and cage and plate position were considered to be positive for technical error.

Pre-, peri- and postoperative care

All dogs were premedicated with methadone[a] (0.3 – 0.5 mg/kg) or morphine[b] (0.3 mg/kg) combined with acepromazine[c] (0.01 – 0.02 mg/kg) or medetomidine[d] (2 – 10 μg/kg) intramuscularly. Induction of general anaesthesia was performed using a single anaesthetic agent or a combination of agents; these included propofol[e] (2 – 4 mg/kg), alfaxalone[f] (1 – 3 mg/kg), diazepam[g] (0.1 – 0.2 mg/kg) and midazolam[h] (0.1 – 0.2 mg/kg). Anaesthesia was maintained with isoflurane[i] or sevoflurane[j] in oxygen. A bupivacaine[k] (1 mg/kg) and morphine (0.1 mg/kg) epidural or local nerve block (femoral and sciatic nerves) was administered. Cefuroxime[l] (20 mg/kg IV) or amoxicillin-clavulanic acid[m] (20 mg/kg IV) was administered perioperatively to each case, and was re-administered every 90 minutes intra-operatively. This was discontinued after the surgical site was closed. Postoperative analgesia included the administration of methadone (0.3 – 0.5 mg/kg IM) as required for up to 24 hours, which was followed by buprenorphine[n] (10 – 20 μg/kg)

a Methadone hydrochloride: Eurovet Animal Health B. V., Bladel, The Netherlands
b Morphine sulphate: CP Pharmaceuticals Ltd, Wrexham, U.K.
c Acepromazine maleate: Novartis Animal Health UK Ltd, Surrey, U.K.
d Medetomidine hydrochloride: Eurovet Animal Health B. V., Bladel, The Netherlands
e Propofol: Abbott Animal Health, Abbott Park, Illinois, U.S.A.
f Alfaxalone: Jurox, Worcestershire, U.K.
g Diazepam: Hameln Pharmaceuticals Ltd, Gloucester, U.K.
h Midazolam hydrochloride: Roche Products Limited, Welwyn Garden City, U.K.
i Isoflurane: Merial Animal Health Ltd, Essex, U.K.
j Sevoflurane: Abbott Laboratories Ltd, Berkshire, U.K.
k Bupivicaine hydrochloride: AstraZeneca UK Ltd, Cheshire, U.K.
l Cefuroxime sodium: GlazoSmithKline, Middlesex, U.K.
m Amoxicillin and clavulanic acid: GlaxoSmithKlein, Middlesex, U.K.
n Buprenorphine hydrochloride: Alstoe Limited, York, U.K.

for 6 – 12 hours. Meloxicam[o] (0.1 mg/kg sid per os), firocoxib[p] (5 mg/kg sid per os) or robenacoxib[q] (1 – 2 mg/kg sid per os), was prescribed for seven to 21 days postoperatively. Postoperative prophylactic antimicrobial therapy with cephalexine[r] (15 – 20 mg/kg bid per os) or amoxicillin with clavulanic acid[s] (10 – 20 mg/kg bid per os) was prescribed in some cases for five to 10 days, depending on the preference of the primary surgeon. In general, dogs were hospitalized for one to two days and were re-examined at six to eight weeks postoperatively or when complications occurred.

Surgery

Orthogonal radiographs of the affected stifles were obtained from all dogs under sedation or general anaesthesia prior to surgery as part of the surgical planning. The sedation and anaesthesia protocol used for the stifle radiographs were at the discretion of the individual clinician.

All the surgical procedures were performed as previously described by board-certified diplomates or residents-in-training under the supervision of a board-certified diplomate (9). Titanium alloy TTA plate, fork, cage and screw[t] were used in all cases. The fascia, subcutaneous tissue and skin were closed in layers; the use of skin sutures or skin staples was at the discretion of the primary surgeon.

Table 2 Bacteriology of the surgical site infection.

Stifles	Source of bacteriology samples	Bacterium/bacteria cultured	Drug resistant?	Duration between TTA and SSI (days)
1	Deep wound swab	*Staphylococcus sp.*	No	235
		Bacillus sp.	MDR	
2	Implant culture	*Streptococcus sp. (β-haemolytic)*	MDR	15
3	Peri-implant aspirate	*Staphylococcus sp.*	No	14
4	Deep wound swab	*Staphylococcus saprophyticus*	MDR	42
		Streptococcus sp. (β-haemolytic)	MDR	
5	Wound swab from discharging sinus	*Corynebacterium sp.*	MDR	20
		Staphylococcus pseudointermedius	No	
		Streptococcus sp. (β-haemolytic)	No	
6	Deep wound swab	*Escherichia coli (β-haemolytic)*	MDR	14
7	Synovial fluid	*Escherichia coli (non-haemolytic)*	XDR	7
8	Deep wound swab	*Staphylococcus sp.*	MDR	6
9	Implant culture	*Pasteurella sp.* *	No	14
		Klesiella pneumoniae†	XDR	
10	Synovial fluid	*Staphylococcus chromogenes*	MDR	63
11	Deep wound swab	*Pseudomonas sp.*	MDR	14
		Pseudomonas sp.‡	MDR	
12	Synovial fluid	*Staphylococcus sp.*	No	69

*initial deep tissue swab; † bacteriology from implant after 2 weeks of amoxicillin-clavulanic acid; ‡ after initial course of antimicrobial therapy; MDR = multi-drug resistant, 'resistant to three or more antimicrobial classes (53); XDR = extensively drug-resistant, bacterium remains susceptible to only one or two antimicrobial classes (53).

Statistical analysis

Logistic regression was used to examine associations between clinical data and SSI. Univariable screening of all variables was conducted, including dog identification, as a random effect to account for the clustering of surgical procedures within dogs. All variables with p-values <0.25 from the initial univariable screen were considered to be eligible for inclusion in a multi-level multivariable logistic regression model. A forward selection process was used during the building of the multivariable model and variables were retained within the model if the p-value associated with that variable remained <0.05.

T-tests or Mann-Whitney tests (dependent on evidence of a lack of normality in the data) were used to examine associations between individual clinical variables.

Result

The medical records of 192 dogs with 230 TTA procedures were reviewed. Two hundred and twenty-four stifles from 186 dogs met the inclusion criteria. Six dogs were excluded from the study due to antibiotic administration for a condition unrelated to the TTA within seven days prior to the surgery (n = 3), open fracture of the tibial tuberosity (n = 1), self-trauma from patient which resulted in removal of all skin sutures (n = 1), and death due to septic peritonitis secondary to gastric ulceration 11 days postoperatively (n=1). One hundred and seventeen TTA were performed in male dogs (52%) and 107 TTA were performed in female dogs (48%). The mean age of the dogs at the time of TTA was 5.5 years old (standard deviation: ± 2.73 years). The mean weight of the dogs was 35.3 kg (± 10.7 kg). Thirty-eight dogs had TTA performed bilaterally (20.3%) and the mean interval between the two sur-

o Meloxicam: Boehringer Ingelheim Vetmedica, Berkshire, U.K.
p Firocoxib: Merial Animal Health Ltd, Essex, U.K.
q Robenacoxib: Novartis Animal Health UK Ltd, Surrey, U.K.
r Cephalexine monohydrate: Virbac Animal Health, Suffolk, U.K.
s Amoxicillin and clavulanic acid: Pfizer Animal Health, Kent, U.K.
t TTA plate, cage and fork: Veterinary Instrumentation, Sheffield, United Kingdom

Table 3 Treatment of the surgical site infection.

Stifle	Antimicrobial therapy	Treatment duration (days)	Comment
1	Amoxicillin-clavulanic acid	14	
2	Amoxicillin-clavulanic acid	14	In conjunction with implant removal
3	Amoxicillin-clavulanic acid	28	
4	Enrofloxacin	10	
5	Enrofloxacin	21	
6	Amoxicillin-clavulanic acid	28	In conjunction with open wound irrigation and second intention healing
7	Amoxicillin-clavulanic acid	35	
8	Amoxicillin-clavulanic acid and enrofloxacin	14	
9	Amoxicillin-clavulanic acid and enrofloxacin	14	In conjunction with implant removal
10	Imipenem	7	
	Amoxicillin-clavulanic acid	14	
11	Amoxicillin-clavulanic acid	7	
	Metronidazole	14	
	Cephalexin (after amoxicillin-clavulanic acid was finished)	20	In conjunction with open wound irrigation and second intention healing
12	Amoxicillin-clavulanic acid	28	

gical procedures was 312 days (± 346 days). Overall there were 118 right stifles and 106 left stifles. The median follow-up period was 632 days (range: 90 – 1837 days).

Twelve dogs had SSI giving a prevalence of 5.3%. The breeds of dogs that developed a SSI were: Boxer (n = 4), Labrador Retriever (n = 2), Springer Spaniel (n = 1), Golden Retriever (n = 1), Rottweiler (n = 1), Douge De Bordeaux (n = 1), and Border Collie (n = 1). The Springer Spaniel dog had TTA performed bilaterally with an interval of 183 days between surgical procedures and developed SSI bilaterally. Surgical site infections were found in nine right stifles and three left stifles. The median time from TTA to the development of SSI was 14 days (range 6 – 235 days); seven of the 12 stifles (58.3%) developed SSI within 15 days of the procedure. Mean surgical time in dogs that developed an SSI was 130 minutes (± 39 minutes), which was significantly longer than the dogs that did not develop an SSI (102 minutes ± 25 minutes) ($p = 0.02$).

There were three superficial incisional SSI and nine deep incisional SSI. Of the nine stifles with deep incisional SSI, four stifles had draining sinuses, three had swelling and pain at the surgical sites, two had septic arthritis, one stifle had excessive radiographic signs of periosteal proliferation of the surgical site, and one stifle had signs of radiolucency around the TTA fork.

Seven of the 12 stifles cultured positive for *Staphylococcus* species and three stifles cultured positive for *Streptococcus* species. Bacteriology results for all the SSI are shown in ►Table 2. Two stifles with deep infections or septic arthritis required the removal of the TTA plate and forks; this, together with a TTA cage removal due to cage screw failure, gave an implant removal rate of 1.3%. Five out of the 12 SSI cultured positive for bacteria that were resistant to more than 50% of the antimicrobial agents against which they were tested (multi-drug resistant).

One hundred and eighty-four TTA had propofol as part of the anaesthesia induction or as the sole induction agent; 10 cases with SSI had propofol as the sole induction agent, one SSI had propofol and diazepam for co-induction, and one SSI had alfaxalone as an induction agent. The use of propofol as an induction agent was not significantly associated with SSI ($p = 0.96$). Anaesthetic duration in dogs developing SSI was significantly longer (225 minutes ± 43 minutes) than dogs that did not develop a SSI (197 minutes ± 33 minutes) ($p = 0.03$). Nadir temperature of dogs was available in 213 TTA, the mean was 35.8°C ± 0.87° C. The nadir temperature was not significantly associated with SSI ($p = 0.85$). The mean perioperative nadir temperature was the same in the SSI group (35.8°C ± 0.9°C) and the non-SSI group (35.8°C ± 0.9°C).

The mean interval between first prophylactic antimicrobial therapy dose and first skin incision (available in 211 cases) was 41.5 minutes (±18.4 minutes). Six procedures (2.7%) had the first dose of prophylactic antimicrobial therapy after the initial skin incision (15 minutes ± 8 minutes).

Nine of the 173 stifles in the postoperative prophylactic antimicrobial therapy group developed SSI, and three out of 51 stifles in the non-postoperative prophylactic antimicrobial therapy group developed SSI. There was no significant association between SSI and postoperative prophylactic antimicrobial therapy ($p = 0.75$). The nine dogs in the postoperative prophylactic antimicrobial therapy group that developed a SSI were treated with amoxicillin with clavulanic acid (n = 7) or cephalexin (n = 2). There was no significant association between the surgical (p = 0.91) and anaesthesia times (p = 0.1), and the administration or not of postoperative prophylactic antimicrobial therapy.

Following the diagnosis of SSI, six of the nine deep incisional SSI were treated with amoxicillin-clavulanic acid, two with enrofloxacin[u], two with a combination of amoxicillin-clavulanic acid and enrofloxacin, one with imipenem[v] followed by amoxicillin-clavulanic acid and one with a combination of amoxicillin-clavulanic acid and metronidazole[w] followed by cephalexin (▶ Table 3). The choice of antimicrobial agents was based on anecdotal experience while the bacterial culture and sensitivity was pending. The antimicrobial agents were changed subsequently if required, based on the bacterial culture and sensitivity results. One of these dogs underwent two post TTA exploratory arthrotomy procedures (▶ Table 2: stifle 10); the synovial fluid obtained from the first arthrotomy cultured negative for bacteriology, but the synovial fluid from the second arthrotomy cultured positive for a multi-drug resistant *Staphylococcus chromogenes*.

There were three implant removals in the 224 stifles (1.3%). Two of the stifles had implant removal due to implant associated SSI; one stifle had the TTA plate and forks removed while the other stifle had only the TTA forks removed. The implant removal was performed in one dog due to recurrent clinical signs despite prolonged, appropriate antimicrobial therapies. In the second stifle, the TTA plate and forks were removed to prevent further implant movement and irritation of overlying tissue. The TTA forks had loosened, the plate had lifted from the tibial crest and the proximal end of the plate was visible through the skin incision site. These implants cultured positive for a *Staphylococcus* species in the former stifle and *Klebsiella pneumonia* in the later stifle respectively. The stifle with the *Klebsiella pneumonia* SSI was successfully treated with implant removal (TTA cage left in place), open wound management and two weeks of amoxicillin-clavulanic acid and enrofloxacin. The third implant removal was not associated with SSI; the TTA cage with a broken cage screw was removed due to impingement of the patellar ligament.

Table 4 Association between perioperative risk factors and surgical site infection.

Perioperative factors	Odds ratio	95% CI	p-value
Surgical time (minutes)	1.07	1.01 – 1.14	0.02
Anaesthesia time (minutes)	1.04	1.004 – 1.08	0.03
Side of the limb			
• Right (reference)	1		
• Left	0.17	0.01 – 2.02	0.16
Age (years)	0.74	0.46 – 1.19	0.22
Weight (kg)	0.99	0.90 – 1.09	0.80
Nadir Temperature (°C)	1.12	0.34 – 3.70	0.85
Sex			
• Female (reference)	1		
• Male	2.65	0.30 – 23.77	0.38
Technical error			
• No (reference)	1		
• Yes	2.59	0.28 – 23.83	0.40
Postoperative PAT			
• No (reference)	1		
• Yes	0.70	0.07 – 6.64	0.75
Interval between first PAT dose and skin incision (minutes)	1.02	0.95 – 1.10	0.51

CI = confidence interval; PAT = postoperative prophylactic antimicrobial therapy.

Regression analysis

Univariable analysis showed that surgical time was significantly longer in dogs that developed SSI than those that did not (p = 0.02; odds ratio (OR): 1.07; 95% confidence interval (95%CI): 1.01 – 1.14) as was anaesthesia time (p = 0.03; OR: 1.04; 95%CI: 1.004 – 1.08) (▶ Table 4). For every minute increase in surgical time and anaesthesia time, the likelihood of developing SSI increased by seven and four percent, respectively. When comparing two dogs at the 75th (120 minutes) and 25th (86 minutes) percentiles for surgical time, a dog with a surgical time of 120 minutes was 10 times ($1.07^{(120-86)}$) more likely to develop SSI compared to a dog with a surgical time of 86 minutes.

It was not possible to build a model that included more than one variable. Surgical time and anaesthesia time were highly correlated (Spearman correlation coefficient = 0.8) (▶ Appendix Figure 1: available online at www.vcot-online.com) and none of the other variables were statistically significant when either surgical time or anaesthesia time were included as starting points in the multivariable model building process.

Discussion

In this study, we found that surgical time was a significant factor in the development of SSI in this cohort of dogs undergoing TTA surgery. Furthermore we have shown that the use of postoperative prophylactic antimicrobial therapy does not appear to influence the incidence of SSI. As a result, we rejected the null hypothesis.

u Enrofloxacin: Bayer Health Care, Berkshire, U.K
v Imipenem and cilastatin: Merck Sharp & Dohme Limited, Hertfordshire, U.K
w Metronidazole: Pharmvit Ltd, Middlesex, U.K.

The prevalence of SSI in this study was similar to previous reports of post TTA SSI (2.6 – 7.2%) (9, 14, 15). Despite this similarity, interpretation of these results should be performed with caution as the definition and criteria of SSI used in all the other studies were not standardized. In this study, we have used the widely adopted definition outlined by the Centers of Disease Control and Prevention (20). Adaptation of a standardized SSI definition would enable direct comparison of the results between various studies and eliminate this as a limitation.

Staphylococcus species, including multidrug resistant strains, are the most commonly isolated bacteria in reported cases of TTA and tibial plateau levelling osteotomy SSI (9, 14, 17, 22, 23). In dogs and cats, the most common isolates associated with implant-related SSI are *Staphylococcus* species and *Streptococcus* species; *Staphylococcus* species account for 50 - 60% of infections (24). In our study, the most commonly cultured bacteria were *Staphylococcus* species, followed by *Streptococcus* species.

The prevalence of implant removal in our study was 1.3%. To the authors' knowledge, this is the first study reporting the prevalence of implant removal after TTA. In comparison, the reported prevalence of implant removal for tibial plateau levelling osteotomy ranges from 1.3 – 8.5% (17, 22, 23, 25). Two of the stifles had implant removal due to implant associated SSI. The implants from one of these stifles cultured positive for *Klebsiella pneumonia* but it was not possible to determine whether the infection was introduced during or after surgery. *Klebsiella pneumonia* is not a commonly reported pathogen in implant associated SSI.

Surgical site infection is a commonly reported complication in the tibial osteotomy techniques for the treatment of canine cruciate disease (9, 14, 17, 26). Administration of perioperative prophylactic antimicrobial therapy is a common practice for the tibial osteotomy techniques; the types and durations of prophylactic antimicrobial therapy vary greatly between practices and surgeons (18, 27). Two large retrospective studies have shown that postoperative prophylactic antimicrobial therapy after surgical procedures for cranial cruciate ligament rupture significantly reduced the incidence of SSI (16, 17). One of these involved only tibial plateau levelling osteotomy cases while the other involved tibial plateau levelling osteotomy and extracapsular lateral suture equally (16, 17). The significant relationship between postoperative prophylactic antimicrobial therapy and lower SSI rate in these previous two studies may be attributed to the prevention of infection or to the reduction in the identification of SSI in the postoperative period due to postoperative antimicrobial therapy (16, 17, 28). In contrast, our study on TTA did not show a significant relationship between postoperative prophylactic antimicrobial therapy and SSI. Postoperative prophylactic antimicrobial therapy may have protective effects on factors that are applicable to tibial plateau levelling osteotomy but not to TTA, such as the potentially more extensive soft tissue dissection around the proximal tibia, the bulky profile of tibial plateau levelling osteotomy plates and the stainless steel property of the tibial plateau levelling osteotomy plates. These factors may contribute to dead space and may increase the risk of soft tissue complications (29). Titanium implants have been shown to be more biocompatible than stainless steel implants with tissues, and titanium is associated with lower implant associated infection in some studies, but not the others (30-32). As SSI can be augmented by contact necrosis of soft tissue and bone from periosteal compression, the differing degree of area of periosteal compression resulted from the application of bone plate between TTA and tibial plateau levelling osteotomy may also influence the prevalence of SSI and the protective effect of postoperative prophylactic antimicrobial therapy (33). The biomechanical difference between TTA and tibial plateau levelling osteotomy may also explain why postoperative prophylactic antimicrobial therapy may have a protective effect against SSI in tibial plateau levelling osteotomy. The non-locking plate system has been associated with significantly higher SSI in dogs >50 kg; micro-motion and instability at the osteotomy site were suggested to be an important factor in this difference (18). In contrast, micro-motion across the osteotomy may not be as important a factor in TTA as it is in tibial plateau levelling osteotomy. The osteotomy is largely not in contact with implants or adjacent bone. However, further study is warranted to assess the micro-motion at the osteotomy site and bone-implant interface in TTA.

The majority of the published literature in human medicine show that prophylactic antimicrobial therapy after wound closure in a clean surgery is unnecessary, as additional doses have not shown benefit (34-37). A large prospective study in cats and dogs (1010 surgical wounds from multiple types of surgery) also showed the lack of association of postoperative prophylactic antimicrobial therapy and SSI ($p = 0.266$) (11). Concerns with prolonged use of postoperative prophylactic antimicrobial therapy are its limited benefit in the prevention of SSI and its association with emergence of resistant bacterial strains (34, 38). The current recommendation of prophylactic antimicrobial therapy in human orthopaedic surgery is that the first dose of prophylactic antimicrobial therapy begins within 60 minutes before surgical incision and be discontinued within 24 hours of the end of surgery (39).

There was no significant association between timing of first prophylactic antimicrobial therapy dose and SSI shown in our study. This is likely to be a type II statistical error as the number of dogs ($n = 6$) that received the prophylactic antimicrobial therapy after the first surgical incision was small. It is advisable that an appropriate prophylactic antimicrobial therapy effective against the likely encountered organism should be initiated within 60 minutes of the first surgical incision to achieve serum and tissue levels that exceed the minimum inhibitory concentration (39). Interestingly, some studies have found that the administration of intravenous prophylactic antimicrobial therapy four to 30 minutes prior to the time of incision resulted in lower SSI, in contrast to another study showing that the lower SSI was associated with administration of intravenous prophylactic antimicrobial therapy between 30 – 60 minutes prior to skin incision (40-42). Re-administration after two half-lives of the medication is recommended intra-operatively to ensure adequate concentrations of antimicrobial in the serum and tissue during the entire time that the surgical site is open and at risk for bacterial contamination (39, 43).

Half of the SSI occurred within 14 days postoperatively; this finding is similar to those of a previous study on tibial plateau levelling osteotomy (18). The other half of the SSI ranged from 15 days to 235 days postoperatively. The reason behind the biphasic nature of the SSI is unclear, however, the authors speculated that the early SSI could be related to trauma and surgical contamination while the late infections could be the result of trauma, and bacteria contamination that laid dormant for a period of time as well as remote infections (44, 45). Further study is needed to further evaluate the pattern of SSI in canine cranial cruciate ligament surgical procedures and the potential influence of implant material as well as the type of procedures involved.

This study showed a significant association between long surgical and anaesthesia times with SSI in TTA. The finding of significant association between long surgical time and SSI is similar to previous studies in human and veterinary medicine (10, 46-48). Prolonged surgical time is thought to significantly increase SSI through increased environmental contamination of the surgical wound (49). In addition, prolonged surgery is often associated with increased complexity of the surgery or more limited experience of the primary surgeon. Limited surgeon experience may increase the risk of surgical mistakes, which may indirectly affect the mechanical stability of the implants and the risk of postoperative complications, such as SSI. Implant instability has been associated with SSI in tibial plateau levelling osteotomy in dogs (18).

A significant association between perioperative body temperature and SSI is not evident in our study despite published evidence in human medicine showing a significant association between perioperative hypothermia and higher SSI rate, delayed suture removal and prolonged duration of hospitalization (50).

A number of limitations were present in this study. Although we failed to demonstrate any relationship between anaesthesia or surgical time and administration of postoperative prophylactic antimicrobial therapy, the lack of prospective allocation means that other factors that were not recorded may have affected the decision to prescribe postoperative prophylactic antimicrobial therapy, potentially affecting the outcome. Another limitation of this study is the relatively small number of subjects included. However we have reported very similar infection prevalence on both groups with and without prophylactic antimicrobial therapy, which suggests our result retains clinical relevance with the numbers we have reported despite the potential for a type II statistical error. The minimum follow-up period was three months; this might restrict the documentation of some deep incisional SSI cases that occur after three months. According to the Centers for Disease Control and Prevention, deep incisional infection can occur within one year after the procedure if an implant is left in place (20). The lack of speciation of some of the cultured bacteria, especially the *Staphylococcal* species, is also another major limitation. Methicillin-resistant *Staphylococcus pseudintermedius* has been recognized as a significant pathogen in companion animals recently (51). Finally, the absence of an active surveillance for SSI at the hospital may underestimate the prevalence of SSI in the TTA performed (52).

In conclusion, we have shown that postoperative prophylactic antimicrobial therapy does not appear to be a protective factor in TTA and that surgical and anaesthesia times were significant risk factors for SSI in TTA.

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Disclosure Statement

The authors declare no conflict of interest related to this study.

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Incidence of complications associated with tibial tuberosity advancement in Boxer dogs

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Keywords

Boxer dogs, complications, tibial tuberosity advancement, TTA, cranial cruciate ligament disease

Summary

Objective: To retrospectively review and describe the incidence of complications associated with tibial tuberosity advancement (TTA) surgical procedures in a group of Boxer dogs (n = 36 stifles) and compare the data with a non-Boxer control population (n = 271 stifles).

Methods: Retrospective analysis of medical records to identify all dogs that underwent TTA surgery due to cranial cruciate ligament disease. These records were categorized into two groups: Boxer dogs and non-Boxer dogs (controls – all other breeds).

Results: Of the 307 stifles included, 69 complications were reported in 58 joints. The complication rate differed significantly for Boxer dogs (16/36 stifles) and non-Boxer dogs (42/271 stifles), corresponding to an odds ratio of 5.8 (confidence interval: 1.96–17.02; p-value <0.001). Boxer dogs were more likely to undergo revision surgery and to develop multiple complications. The incidence of tibial tuberosity fractures requiring surgical repair (2/36 versus 1/271) and incisional infections requiring antibiotic treatment (three in each group) was significantly higher in the Boxer group.

Clinical significance: Boxer dogs had more major and multiple complications after TTA surgery than the control non-Boxer group; these complications included higher rates of revision surgery, tibial tuberosity fractures requiring stabilization, and infection related complications. The pertinence and value of breed-specific recommendations for cranial cruciate ligament disease appears to be a subject worthy of further investigation.

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Introduction

Described complication rates for tibial tuberosity advancement (TTA) range from 11% to 36% and include late meniscal injury, patellar luxation, bone fracture, infection, haemorrhage, and wound dehiscence (1–10). Multiple theories have been proposed to explain particular breed predisposition to cranial cruciate ligament disease, including ultra-structural differences in the nature of the cranial cruciate ligament and anatomical and postural variations (11–17). To our knowledge, no studies have been performed to assess breed-associated variations on the nature and frequency of complications related to TTA surgery. Boxer dogs are a breed commonly affected by cranial cruciate ligament disease and a previous study reported a higher complication rate following lateral fabellotibial suture when compared to other breeds (18). The objectives of this study were to retrospectively review the incidence of complications of TTA surgery in a group of Boxer dogs, and compare the data with a non-Boxer population. Our null hypothesis was that there would be no difference between the Boxer and non-Boxer population regarding TTA complication rates.

Materials and methods

Medical records were reviewed to identify all dogs that underwent TTA surgery due to cranial cruciate ligament disease between June 2008 and August 2014 at the Small Animal Hospital of the University of Glasgow. A diagnosis of incompetent cranial cruciate ligament was determined based on the physical examination findings of hindlimb lameness and pain localized to the stifle joint, together with positive cranial drawer, tibial thrust or both, and also radiographic evidence of joint effusion. Confirmation of the ligament rupture, partial or complete, was achieved via medial parapatellar mini-arthrotomy of the stifle joint at the time of the TTA procedure. Information extracted from the medical records included signalment, body weight, surgery date, surgeon (resident in training, ECVS diploma holder or board eligible surgeon), affected limb (right or left), status of cranial cruciate ligament at surgery, cranial cruciate ligament treatment (debridement of the remaining fibres), status of menisci at surgery, meniscal treatment, use of autologous cancellous bone graft at the osteotomy site, surgical and anaesthetic times, perioperative medication and use of postoperative bandage, the sizes of the TTA cage plate and fork, complications and further surgical interventions. Case records considered grossly incomplete or where data regarding the six week follow-up was unavailable were excluded. Cases of bilateral cranial cruciate ligament disease where TTA was performed with a minimum interval of eight weeks were included individually and analysed independently. These records were categorized into two groups: Boxer dogs and non-Boxer dogs (all other breeds).

All the complications were recorded and classified as intra-operative, short-term (<15 days postoperative), and long-term (≥15 days). The complications were also categorized as major when the associated morbidity required further medical or surgical treatment or both together, and minor when no additional surgical or medical treatment was required (19).

Data analysis was conducted using two commercially available statistical programs[a,b]. For data not normally distributed, the results were reported as median (mean ± standard deviation; range) and were compared using the Mann-Whitney or Kruskal-Wallis test as appropriate. When data were normally distributed a two-sample T test was used. For categorical data, groups were compared using the Chi-squared (X^2) test for independence. For X^2 tests where the expected frequency in any one cell was less than five cells, a Fisher's exact test was used. Univariable (and multivariable) logistic regression was performed to identify if breed was associated with the likelihood of complications. Clustering within dog was accounted for by including dog as a random effect. A p-value <0.05 was considered statistically significant and the odds ratios calculated and tested for significance with a 95% CI.

a Minitab 17 TM Statistical Software, 2010 (for Windows 8, 2013): Minitab Inc. , State College, PA, USA

b STATA SE 12.1: StataCorp LP, College Station, Texas, USA

Results

The database search identified 32 Boxer dogs and 215 non-Boxer dogs, with 307 eligible stifles (36 and 271 respectively). Eleven non-Boxer dogs were excluded due to incomplete records (n = 2), lack of six week follow-up consultations (n = 8), and death due to gastro-intestinal ulceration and septic peritonitis five days post TTA surgery (n = 1). The following breeds were represented in the non-Boxer group: Labradors (71 stifles), Golden Retrievers (41 stifles), crossbreeds (38 stifles), Springer Spaniels (25 stifles), Rottweiler (15 stifles), Cocker Spaniels (12 stifles), Border Collie (9 stifles), American Bulldog (7 stifles), German Shepherd and Labradoodle (6 stifles each), and five or less of the following breeds: Mastiff, Newfoundland, Dobermann, Bernese Mountain, Dalmatian, Dogue de Bordeaux, Husky, Akita, German Shorthaired Pointer, Staffordshire Bull Terrier, Beagle, Bullmastiff, Great Dane, Northern Inuit, English Pointer, Pyrenean Mastiff, Russian Terrier, and Irish Soft Coated Wheaten Terrier.

There were no significant differences between the Boxer and the non-Boxer groups regarding age, weight, sex distribution, and affected limb (▶Table 1). Four of the Boxer dogs and 56 of the non-Boxer group underwent staged bilateral TTA procedures, with no significant difference between groups (p = 0.17) (▶Table 1).

There were no significant differences between groups for the presence of unilateral or bilateral cranial cruciate ligament rupture at presentation, medial meniscus status (intact or damaged), size of the TTA cages (p = 0.16), size of plate and fork (p = 0.21), use of autologous bone graft, or surgical and anaesthetic times. Overall, complete cranial cruciate ligament rupture was detected in 123/207 stifles and a partial rupture in 84/207 with a similar distribution between groups (p = 0.06) (▶Table 2).

Of the stifles for which information regarding the debridement of the cranial cruciate ligament remnant was available (38%), debridement was performed in 12 Boxers and 94 non-Boxers with no significant difference found between the two groups (p = 0.48). The recorded cranial cruciate ligament debridements were per-

Table 1 Descriptive data of both groups of cases with cranial cruciate disease treated with the tibial tuberosity advancement procedure.

	Boxers	Non-Boxers	p-value
Age (years) *mean (median), range*	5.2 (5.0), 3.0–10.0	5.7 (6.0), 1.0–13	0.28
Weight (kg) *mean (median), range*	32.24 (32.0), 22.0–40.3	34.40 (33.0), 14.4–79.9	0.42
Sex n (%)			
• Male	8 (22.2)	57 (21.0)	0.83
• Male neutered	11 (30.5)	66 (24.4)	0.42
• Female	2 (5.6)	47 (17.3)	0.09
• Female neutered	15 (41.7)	101 (37.3)	0.71
Affected limb n (%)			0.82
• Left	18 (50%)	130 (48%)	
• Right	18 (50%)	141 (52%)	

n = number

formed in stifles with partial cranial cruciate ligament rupture in seven dogs of the Boxers group and 23 dogs of the non-Boxers group. Cranial cruciate ligament debridement was performed with complete cranial cruciate ligament rupture in five Boxer stifles and 57 non-Boxer stifles. In 14 of the non-Boxers where debridement of the cranial cruciate ligament was performed, the status of the cranial cruciate ligament was unknown, and for the same group the remnants of the cranial cruciate ligament were left *in situ* in nine cases of partial rupture and in one of unknown status. In two Boxer stifles, information was unavailable regarding both the status of the cranial cruciate ligament and approach to the ligament remnants. Medial meniscal injury diagnosed at the time of TTA surgery was treated with partial meniscectomy in 91 non-Boxer stifles and eight Boxer stifles (p = 0.40). Complete medial meniscectomy was performed in two Boxer stifles and 15 non-Boxer stifles (p = 0.65) while medial meniscal release was recorded in one Boxer stifle and three non-Boxer stifles (p = 0.33), all with medial meniscal injuries. Injured medial menisci was associated with partial cranial cruciate ligament rupture in four of the 11 Boxer stifles and nine of the 109 non-Boxer stifles and complete rupture of the cranial cruciate ligament in seven out of 11 Boxer stifles and 61 of 109 non-Boxer stifles (▶Table 2).

The difference between number of TTA procedures in the two groups performed by surgical residents in training and ECVS diploma holders and board eligible surgeons was not significant (p = 0.31).

There was no significant difference found between the groups in terms of medication received from the time of surgery until discharge (▶Table 3). Approximately a quarter of the stifles in each group did not have a bandage applied and the remaining cases had a modified Robert Jones applied overnight, with no significant difference found between groups (p = 0.64) (▶Table 3).

Of the 307 stifles included in this study, 69 complications (51 major, 12 minor, and six intra-operative) were reported in 58 joints. The complication rate differed significantly between groups (p <0.001).

Table 2 Cranial cruciate ligament status at presentation, joint exploration, use of autologous bone graft, surgical and anaesthetic times by group.

	Boxers	Non-Boxers	p-value
CCLr at presentation (n stifles)	**36**	**271**	**0.59**
• Unilateral • Bilateral	29 7	228 43	
CCL status (n stifles)	**34**	**173**	**0.06**
• Partial rupture • Complete rupture	19 15	108 65	
Medial meniscus (n stifles)	**36**	**271**	**0.26**
• Intact • Damaged	25 11	162 109	
Bone graft (n stifles)	**34**	**250**	**0.27**
• Autologous bone • None	15 19	111 139	
Surgical time (min)			**0.43**
• Median (range) • Mean ± SD	120 (48–190) 117 ± 29	115 (45–192) 116 ± 26	
Anaesthetic time (min)			**0.90**
• Median (range) • Mean ± SD	205 (100–300) 199 ± 39	200 (120–315) 200 ± 34	

n = number; min = minutes; CCLr = cranial cruciate ligament rupture; CCL = cranial cruciate ligament.

Table 3 Details regarding the intra-operatively administered medical treatment, locoregional anaesthetic modalities, and prescribed medication at time of discharge from the referral hospital per group.

	Boxers (n stifles)	Non-Boxers (n stifles)	p-value
Locoregional anaesthetic modalities			
Epidural FSNB Other	23 / 36 10 / 36 3 / 36	136 / 271 124 / 271 11 / 271	0.15 0.05 0.22
Medication intra-operatively			
Antibiotic medication • Amoxicillin-clavulanic acid • Cefuroxime	 11 / 30 19 / 30	 123 / 264 141 / 264	0.30
Analgesia • NSAID received • NSAID avoided	 33 / 35 2 / 35	 261 / 270 9 / 270	0.51
Medication prescribed at discharge			
Antibiotic medication NSAID	24 / 36 34 / 36	152 / 271 260 / 271	0.22 0.69

FSNB = femoral and sciatic nerve block; n = number; NSAID = Non-steroidal anti-inflammatory drugs.

Table 4 Multivariate logistic regression model describing the association between three explanatory variables and the likelihood of TTA complications.

Variable		Odds ratio	CI	p-value
Breed	Non-Boxer dogs	1		
	Boxer dogs	5.78	1.96–17.02	0.001
Surgeon	Resident	1		
	Senior	2.25	1.08–4.70	0.03
Status of medial meniscus	Damaged	1		
	Intact	2.63	1.16–5.94	0.02

CI = confidence interval.

Boxers had a postoperative complication rate of 44.4% (16/36 stifles) while the non-Boxer group developed complications in 15.5% of the cases (42/271 stifles). Multivariable logistic regression identified that Boxer dogs were 5.8 times (95% CI: 1.96–17.02; p-value <0.001) more likely to have complications than non-Boxer dogs (►Table 4). Multiple complications occurred in 11 stifles, of which seven belonged to the Boxer group, which was significant (p = 0.006). Four Boxer dogs developed both major and minor complications. Five (two Boxers, three non-Boxers) sustained two major complications and two others (one of each group) had two minor complications. Having the surgery performed by a diploma holder and having an intact medial meniscus at the time of the TTA surgery were variables identified as being significantly associated with the odds of complication in the multivariable model (►Table 4). Senior surgeons were 2.25 times more likely to have cases with complications. Dogs with an intact medial meniscus at the time of presentation had a 2.63 times higher risk of developing complications compared to dogs with a damaged meniscus detected at the time of the TTA surgery (►Table 4).

Weight, age and gender were also included in the final multivariable models to identify any potential confounding effect of these explanatory variables which had minimal effect on the associations between the significant variables in the final model (►Table 4).

Eighteen of all complications recorded (26%) were infection related (eight in Boxer dogs, 10 in the non-Boxer group) with no significant difference between the dogs that were treated with a course of antibiotic medication following surgery and the ones that only had antibiotic medication intra-operatively (p = 0.87). Binary logistic regression showed that Boxer dogs were 7.46 times more likely to develop an infection related complication than the non-Boxer dogs (95% CI 2.72 – 20.4; p ≤0.001).

An equal number of intra-operative complications were recorded in both groups (n = 3 each). In the non-Boxer group, one of each of the following complications were recorded: breakage of a drill bit while drilling the caudal cage screw and it was not possible to retrieve, breakage of the cranial ear of the cage, and breakage of the the cranial cage screw which could not be retrieved. In the Boxer group minor complications were recorded as one of each: stripping of the cranial cage screw, breakage of the cranial cage ear, and lack of

Table 5 Relative frequency of the incidence of major and minor, intra-operative, short- and long-term complications per group.

Complications	Boxer group	Non-Boxer group	Fisher's exact p-value
Major *n incidences / n stifles (%)*	**14 / 36 (38.9 %)**	**37 / 271 (13.6 %)**	**<0.001***
Tibial tuberosity fracture	2	1	0.03 *
Tibial tuberosity fracture repair failure	0	1	1
Late meniscal injury	4	22	0.52
Incisional infection	3	3	0.02 *
Deep infection & marked limb swelling	1	0	0.12
Incisional infection & dehiscence	0	1	1
Implant associated infection	2	5	0.19
Septic arthritis	1	2	0.31
Persistent non-weight bearing lameness	1	0	0.12
Medial patellar luxation	0	2	1
Minor *n incidences / n stifles (%)*	**6 / 36 (16.7 %)**	**6 / 271 (2.21 %)**	**0.003***
Tibial tuberosity fracture	0	4 / 6	1
Patellar tendonitis	1 / 6	1 / 6	0.22
Seroma	1 / 6	0	0.12
Stifle periarticular swelling	2 / 6	0	0.01 *
Implant loosening	2 / 6	0	0.01 *
Lick granuloma	0	1 / 6	1
Timing of complications n incidences / n stifles (%)	**23 / 36 (63.9 %)**	**46 / 271 (17.0 %)**	**<0.001***
Intra-operative	3 / 6	3 / 6	0.02*
Short-term	4 / 8	4 / 8	0.037*
Long-term	16 / 55	39 / 55	0.001*

n = number; * = statistically significant.

contact between fork and plate with application of cerclage around the tibial tuberosity.

Fifty-one of the 69 complications registered were classified as major and are presented in ▶Table 5. Boxer dogs had a significantly higher incidence of tibial tuberosity fractures (2/36 compared to 1/271) requiring surgical repair and incisional infections requiring antibiotic treatment (three in each group). In the Boxer group, one of the fractures developed through the fork holes and cranial cage screw and another developed through the fork holes only. Both cases required surgical reduction with pins and tension band wire. In the non-Boxer group, one fracture through the fork holes was recorded ten days following surgery (8). In this dog, the TTA plate and fork and screws were removed, the tibial crest fracture was then reduced with two pins and subsequently reduced distally to the tibial diaphysis with pins and a tension band wire.

In the Boxer group, the incisional infections were caused by one of each: *Pasteurella sp* resistant to clindamycin, beta-haemolytic *E. coli* resistant to clindamycin, and *Corynebacterium sp* resistant to cephalexin which were successfully treated with amoxicillin-clavulanic acid. Incisional infections on the non-Boxer group were caused by *Staphylococcus sp* in two of the three cases with resistance to ampicillin, clindamycin and pradofloxacin and treated with amoxicillin-clavulanic acid and enrofloxacin. In the third case, *in vitro* culture was negative despite presence of purulent discharge associated with the surgical wound. Revision surgery (n = 36) was required in 35 stifles, 28 out of 271 stifles within the non-Boxer group and the remaining eight out of 36 stifles in Boxer dogs. The majority of the revision surgeries were exploratory stifle medial mini-arthrotomies to address late meniscal injury (26/36), followed by stabilization of tibial tuberosity fractures (3/36), wound debridement and flushing (1/36), implant removal (4/36), trimming of the cranial cruciate ligament remnants (1/36) and second revision surgery (transarticular external skeletal fixator repair) (1/36). Boxer dogs had a significantly higher proportion of surgical revision procedures than the dogs in the non-Boxer group group (p = 0.04) (▶Table 5).

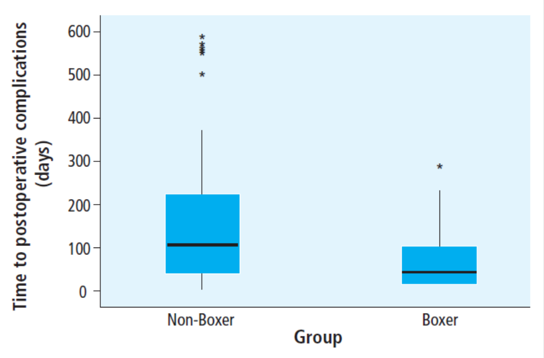

Figure 1 Boxplot of time to postoperative complications (days) by group of breeds showing the significant difference in the development of complications between dogs from the Boxer and non-Boxer groups.

Regarding the time frame, eight of the 69 registered complications were short term and 55/69 were long-term complications with the remaining six being intraoperative. The time to developing complications was significantly different between groups (p = 0.02) with the Boxer dogs sustaining these earlier than non-Boxers. The time to complications was 13.5 days (77.4 ± 81.6; range: 13–289 days) in the Boxer group and 106 days (166.9 ± 177.7; range: 6–588 days) in the non-Boxer group (▶Figure 1).

Discussion

The four major retrospective TTA studies predating 2014 had a combined major complication rate of 12.3% (2, 4–6). Our overall rate of major complications was 16.6% (51/307), which is higher than the average rate from those studies. Of these four studies, only two mention the participation of residents in training, in another all TTA procedures were performed by three specialist surgeons only, and in the remaining one no specific information was available (4–6). The 307 TTA surgeries in our study were performed by seven residents and seven ECVS boarded or board eligible surgeons. The number of surgeons involved could explain the slightly higher overall major complication rate, although care must be used when comparing previous results in the literature due to variable definitions of major complications. More complications were recorded in cases where the surgery was performed by an ECVS diploma holder or eligible surgeon which could be explained by the natural attribution of the more challenging cases to senior surgeons and not the residents in training or due to type I statistical error.

Contrary to the null hypothesis, Boxer dogs undergoing TTA surgery had a significantly higher overall complication rate (44.4%) than the non-Boxer dogs (15.5%). In our study Boxer dogs were 5.8 times more likely to have complications than the non-Boxer group and it followed that Boxer dogs are also at higher risk of developing multiple complications. Levien and colleagues reported that Boxer dogs have a higher overall rate of complications associated with lateral fabellotibial suture compared to other breeds with an odds ratio of 5.12, which is in agreement with our data regarding TTA surgery (18). Dogs which had an intact medial meniscus at the time of the TTA surgery were 2.63 times more likely to develop complications. This finding was somewhat expected as although our overall incidence of late meniscal injury was 8.47%, which is within the reported range following TTA, it accounted for 37.7% of all the postoperative complications (1–3, 5, 6).

It has been suggested that Boxer dogs have a significantly higher incidence of partial cranial cruciate ligament disease, contrary to our results (18). Treatment of partial cranial cruciate ligament disease remains highly controversial, particularly regarding the decision to debride or to preserve the ligament remnants (18). Early stabilization without debridement of a partially ruptured cranial cruciate ligament has been associated with good functional outcome and slow progression of joint disease as assessed by second look arthroscopy (20). However in a different study, two Boxers were persistently lame six weeks after tibial plateau levelling osteotomy and lameness resolved after revision surgery for cranial cruciate ligament remnant resection and debridement (21). In our study, one Boxer dog with intact menisci at the time of initial surgery developed acute persistent non-weight bearing lameness at 92 days post TTA. The lameness resolved completely following debridement of the cranial cruciate ligament remnants during a second arthrotomy which failed to reveal meniscal injury. The presence of non-debrided cranial cruciate ligament remnants was not detected as a risk factor for postoperative complications in our study although it might have been underpowered to detect such association.

Tibial tuberosity fracture was diagnosed in seven stifles representing an overall incidence of 2.3%. The two cases documented in Boxer stifles required surgical revision leading to their classification as major complications according to the current definitions applied in this study (19). The same kind of fracture was recorded in five non-Boxer cases with only one requiring further treatment. The incidence of major tibial tuberosity fractures was significantly more common in the Boxers group ($p = 0.03$) although the number presented here is small. Incisional infection-inflammation was the most common complication in the largest previously published study on TTA (7.6%) (5). However, the higher incidence of superficial infections in Boxers (22%) compared with non-Boxer dogs (3.7%) found in our study was an unexpected finding. A study examining risk factors for development of surgical site infections revealed that four of these 12 dogs were Boxers corresponding to 33% of the surgical site infection cases (22). No difference was encountered between groups in terms of surgical and anaesthetic time, body weight, surgeon experience, and perioperative medication (including the use of antibiotics) which could potentially explain this. Similarly, when evaluating the overall infection-related complications which accounted for 26% of all instances, Boxer dogs had a 7.46 times higher risk of developing this type of complication than the non-Boxer dogs. This greater odds ratio was not associated with the use of antibiotic medication at discharge from hospital.

The timing of postoperative complications was significantly shorter for dogs in the Boxer group. The only other study where Boxer dog complications were highlighted did not offer information regarding the time at which they developed, and thus we have no means of comparison (18). One could speculate that Boxers are naturally very active and highly energetic dogs and perhaps more challenging to restrict during the recovery period. Furthermore, when considering that eight out of 14 (57%) major complications recorded in the Boxer dogs were infection-related, it could be expected that these would develop relatively soon following surgery. In fact all of these in the Boxer group developed during the first 2.5 months, which is in agreement with previously reported time frame for surgical site infection in tibial plateau levelling osteotomy and lateral fabellotibial suture cases (23).

Contrary to what was reported by Steinberg and colleagues, we did not find any association between the development of complications and body weight nor cage size between groups (6).

Our surgical revision rate was 11.7%, which is within the previously reported range of 6.19% to 14.3% (2, 3, 5, 6). Boxer dogs were 2.58 times more likely to require revision surgery with a proportion of 22.2% for the Boxer group and 9.96% for the non-Boxers. We believe this is a relevant issue which should be discussed preoperatively with owners of Boxer dogs with cranial cruciate ligament rupture. Although several studies have investigated TTA complications, none have identified differences between breeds. This probably resulted from the small number of Boxer dogs included in these studied samples. Amongst the larger studies investigating TTA complications between 2006 and 2014, fewer than 13 Boxer dogs have been included out of 1123 dogs (1–7).

Boxers have been reported as a breed particularly prone to lymphoplasmacytic synovitis (24). Although the clinical relevance of lymphoplasmacytic synovitis in dogs with cranial cruciate ligament rupture and the true incidence of this phenomenon in Boxers is yet to be defined, it has been proposed that cell-mediated immune responses have a role in cranial cruciate ligament rupture in dogs (25, 26). Lymphoplasmacytic synovitis has also been proposed to contribute to poor postoperative function following correction of medial patella luxation, and perhaps it may also contribute to their higher degree of postoperative complications (27).

Although suggesting Boxer-specific recommendations regarding the adequacy of the available surgical techniques is beyond the scope of this paper, our Boxer TTA complication rate (44.4%) warrants further studies, ideally of prospective nature to draw further conclusions. It is important to remember that other factors may play a crucial role when providing specific recommendations on how to treat cranial cruciate ligament disease. Biological, mechanical, conformational, anatomical, and clinical factors must be considered on an individual basis.

The limitations in this study mostly stem from its retrospective design and must be considered when evaluating the data presented here. Information present in the medical records may have been incomplete. All the cases included in the study were referred from general practitioners and some postoperative complications may have been detected by them without our knowledge. This would most likely have happened for minor complications as one would not expect referring colleagues to deal with major complications following TTA. The number of surgeons may have influenced the occurrence of complications positively or negatively due to learning curves and differences in perioperative care. The follow-up time of six months may have excluded a number of potential long-term complications therefore lowering the overall complication rate. The lack of long-term physical and radiographic examination as well as objective outcome assessment did not allow us to comment on the outcome of these procedures.

Conclusion

We rejected the null hypothesis and concluded that Boxer dogs had more complications after TTA surgery than the non-Boxer population. In Boxer dogs, major and multiple complications were more frequent, surgical revision was more often required, and the time to complication development was shorter when compared to the non-Boxer population. Although beyond the scope of this study, the pertinence of breed-specific recommendations for cranial cruciate ligament disease is a factor worthy of further investigation.

Conflict of interest

The authors have not declared any conflicts of interest for this paper.

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Discussion

The increased morbidity associated with tibial tuberosity fractures following tibial tuberosity advancement resulted in extended convalescence of 8.5 weeks after surgical management and 5.14 weeks after conservative management. This outcome was similar to that reported for the tibial plateau levelling osteotomy complicated by tibial tuberosity fracture (16).

The vast majority of the previously reported tibial tuberosity fractures associated with tibial tuberosity advancement were simple avulsion fractures (1, 2, 7), 23 of these 25 avulsion fractures were incidental findings and were treated non-surgically. The remaining two avulsion fractures were treated with a tension band wiring technique, and all cases were reported as having a good outcome, although no specific clinical information was provided. Only one comminuted tibial tuberosity fracture has previously been reported (1). Surgical treatment with a tension band wiring technique while maintaining the cage was reported; however no specific information was provided. We achieved a satisfactory outcome in our case with a comminuted fracture despite the occurrence of a further asymptomatic tibial tuberosity fracture above the proximal tension band wire pin (fig 3, paper 1).

A fracture incidence of 5.12% following the tibial tuberosity advancement procedure is the highest yet reported. However 5 of the 13 fractures occurred within the first 40 cases (14% incidence) leaving an incidence of 3.74% for the 214 subsequent cases. This initial high incidence of tibial tuberosity fracture is probably explained by the lack of surgeon experience. A similar finding was reported with tibial tuberosity fracture after tibial plateau levelling osteotomy, where an initial higher incidence was reported (6.7% for the first 119 cases) (16). A recent study found that the tibial tuberosity advancement learning curve continues for approximately 22 procedures after which mistakes decrease significantly and the overall success rate improves steadily (23). Based on published data reporting complication rates, these authors proposed that an acceptable failure rate (major complication requiring revision surgery) be set at 15% and an unacceptable failure rate at 25%, during the initial learning curve.

Our decision to proceed with either surgical intervention or conservative management was clearly influenced by the severity of clinical signs, particularly the lameness grade, rather than by fracture factors such us configuration and displacement. All four surgically treated cases were presented with a non-weight bearing lameness. Due to the small size of our population, it is not possible to draw any further definitive conclusions. However, the stability of the cranial cage screw may play an important role in the stability of the fractured tibial tuberosity and therefore the associated clinical signs. In 6/7 of the conservatively managed fractures the cranial cage screw appeared to be functional. In contrast, the cranial cage screw was involved in the fracture line, in 3/4 surgically managed cases.

In our opinion, repair of the tibial tuberosity fracture whilst maintaining the advancement is a desirable goal but it could only be achieved in 2/3 of our cases. Failure in the third case was probably due to lack of caudal support, thus increasing the stress on the repair and therefore the risk of implant failure or subsequent fracture.

If tibial tuberosity fracture occurs prior to mineralisation within the osteotomy gap and the tibial tuberosity advancement implants are removed, one approach is to stabilize the fractured crest fragments in their original anatomic position and perform an extra-capsular repair. However the outcome of such an approach requires long term evaluation and a larger number of cases.

If the osteotomy gap caudal to the advancement (fig 2, paper 1) is healed, cage removal and stabilization of the crest fragments in their original anatomic position was not possible in two of our cases; therefore an attempt at tibial tuberosty fracture fixation whilst maintaining the tibial tuberosity advancement was made. In cases were the tibial tuberosity bone stock is comminuted or in exceptional circumstances such as a very active patient the use of a temporary transarticular external skeletal fixator as described previously could be considered to protect the repair (36)

Although a double tension band construct was used in the surgically managed cases, we acknowledge that there is no biomechanical or clinical data supporting its use. The rationale behind the use of the two individual tension bands was to allow each to tightly conform the wire to each Kirschner wire, minimising the amount of patellar ligament that was compressed by the wire.

Some degree of tibial tuberosity caudal displacement and therefore partial loss of the initial tibial tuberosity advancement was present in all the conservatively managed cases. Although the functional outcome for these dogs was graded as good or excellent, it is possible that their tibio-femoral shear forces were not fully neutralised.

Our study equally provides data to support the hypothesis that the incidence of tibial tuberosity fracture as a complication of tibial tuberosity advancement could be decreased by careful attention to surgical technique and decision making. Three potential risk factors were found to be significantly associated with fracture of the tibial tuberosity; poor distal osteotomy width (<25% of the common tibial shaft width), poor plate position (proximal pole ≤ 5mm and distal pole ≤ 3mm from the cranial edge), and poor cage position (>3mm distal to the tibial plateau).

Age and sex were found not to be significantly associated with tibial tuberosity fracture, though as in previous reports, in both the fracture group and the non-fracture group. There was also no association between body weight or obesity and the occurrence of tibial tuberosity fracture implant size was not related to the occurrence of tibial tuberosity fracture. Analysis for each fracture type was attempted but due to the small sample sizes no statistical significance was detected.

A previous preliminary study by the author (IC) found the distal osteotomy width to be a significant predictor of postoperative tibial tuberosity fracture (17, 18), and the findings of our report are similar (p=0.003). The decision to look at the distal part of the osteotomy and not at the proximal part was based on the fact that the proximal width of the osteotomies were found to be of adequate size in all dogs (>1cm at the patellar tendon insertion), whereas the distal osteotomy widths were subjectively found to be significantly variable. Due to significant anatomical variation of the proximal tibia, particularly the patellar ligament insertion point, comparison of the osteotomy width to the proximal tibial width is not useful when trying to draw conclusions about ideal osteotomy shape (37). A high patellar tendon insertion point would give a wider tibial width when measuring from tibial tuberosity to the caudal curvature of the tibia, whilst a low insertion point would give a narrower tibial width (figure 6, paper 2). A previous study identified an anatomical area of the tibia unaffected by breed (37) and so in the preoperative radiographs, measurements were made to establish this common tibial shaft width (figure 1, paper 2). We investigated three potential risk factors for distal osteotomy width. The two recorded as continuous data (absolute distal osteotomy width and relative distal osteotomy width as a percentage of the common tibial shaft width) were not found to be significant, whereas the dichotomously recorded variable (distal osteotomy width <25% common tibial shaft width) was found to be a risk factor. The decision to set the width at which the osteotomy shape was no longer deemed to be acceptable at <25% of the common tibial shaft width was based on subjective observation by the author (IC). Whilst the final statistical model indicates that a distal osteotomy width <25% of the common tibial shaft width is more likely to result in subsequent fracture, the measures recorded as continuous data did not enable us to recommend a more specific width below which a fracture is more likely to occur. This is likely due to lack of power (fracture case numbers). We hypothesize that a narrow distal osteotomy may result in poor purchase of the distal tines and overloading of the proximal tines, which could result in increased stress at the proximal part of the osteotomy and potentially lead to fracture. Further biomechanical research is needed to confirm this. Nonetheless we recommend careful planning of the osteotomy to ensure that the fragment is not too narrow in the transverse plane, particularly at the distal point.

We investigated 7 potential risk factors for plate position. Only poor plate position recorded as a dichotomous variable was found to be related to the occurrence of fracture in our study (p-0.009). In relation to this variable, the difference in distance allowance between the proximal and distal aspect of the plate reflects the clinical scenario where the plate is rotated caudally at the proximal aspect to ensure that the plate screws are centred within the tibia. The other 6 measures detailing exact plate positioning were recorded as continuous data, but none were included in the final statistical model, therefore we are unable to provide recommendations as to the most appropriate position to minimize risk for tibial tuberosity fracture. This again may be due to low fracture case numbers.

We postulate that placement of the plate too far caudally results in placement of the tines in a thinner area of cortical bone, causing a reduced tine holding strength. Repetitive distractive forces of the patellar tendon may cause the tines to 'cheesewire' through the holes, in a similar way to screw toggle as described previously. Positioning of the plate as cranial as possible (the cranial border of the plate level with the cranial border of the tibial crest) may provide better cortical bone purchase and therefore reduce the risk of fracture (Figure 7, paper 2).

Poor cage position was the final significant factor in the final model (P = 0.033). Ideal cage position has been reported to be 2-3mm from the proximal tibial bone margin and with the cranial screw not positioned below the patella ligament insertion (2); positioning of the cage distal to this has been thought to leave the tibial tuberosity isolated without caudal support. However, this was found not to be a risk factor in one paper which evaluated the factors predisposing to tibial tuberosity fracture after tibial plateau levelling osteotomy (16). The presence of a screw hole in line with the tibial tuberosity may contribute to cage position being a significant factor for tibial tuberosity fracture because weakened bone in that area could be less resistant to the distractive force of the patellar ligament. We chose to record the predictor of outcome for cage position as dichotomous variables, where 'poor' represented cages that were placed >3mm below the tibial plateau. None of the cages on in our dataset were proximal to the tibial plateau therefore the consequences of cage position higher than this recommended level was not investigated. Our results suggest that poor cage positioning does increase the risk of TT fracture and therefore we recommend that positioning be planned and executed to the recommended guidelines.

We had reasons for including the other radiographically identifiable potential risk factors in our study:

In relation to osteotomy shape, the varied anatomy of the proximal tibia can affect the shape of the osteotomized bone fragment; in some dogs the tuberosity is prominent, whilst in others it is less prominent meaning despite adequate proximal width, the distal aspect of the osteotomy may become narrow. In order to compensate for this, often during the tibial tuberosity advancement procedure the osteotomy is cut with a curve distally to increase the width. We hypothesized that straight-cut osteotomies would be more likely to have a narrower distal width than those which were curved, and thus would be more likely to subsequently fracture. However, osteotomy shape was not found to be significant in our study. This may be because the majority of the straight cut osteotomies were correctly done so on cases with prominent tibial tuberosities, and so were not likely to result in narrow distal widths.

Relating to cage screw direction, it has been stated that the proximal cage screw should be directed in a cranio-proximally, thus maximizing cortical bone purchase (2). To a great extent the holding strength of a screw depends on the interlocking of the bone-screw interface (38). As long as the strength of the bone-screw interface (torque) exceeds the applied load, the screw remains stable (39). However if the applied load exceeds the torque, the screw begins to toggle, crushing the bone it contacts and so decreasing the resistance to further toggling. It is important to remember that the resistance to toggle depends (among other factors) on the amount of surface area contact between the screw and the bone, as well as the quality of the bone into which is inserted (39). Relating this to the tibial tuberosity advancement, if the cranial cage screw is inaccurately placed (poor cortical purchase), it may be possible for the avulsion force of the patellar ligament to exceed the torque of the cranial cage screw, leading to screw toggling and crushing of bone surrounding the cranial cage screw. This area of crushed bone could potentially then act as a stress riser resulting in an avulsion-type fracture or propagate to the plate and fork leading to a more complex fracture configuration. Surprisingly cage screw direction wasn't found to be a significant factor associated with TT fracture in our study. This finding may be explained by the theory that the avulsion force applied by the patellar ligament is mainly neutralised by the tension band plate, subjecting the cranial cage screw to small forces that don't exceed its torque even in the presence of poor cortical purchase. Further studies are warranted to ascertain what the ideal torque of the cranial cage screw is.

Contact between the osteotomy and the tibial shaft was included in the study because it has been proposed that securing the distal end of the plate along the tibial axis without obtaining bone contact at the distal end of the osteotomized tibial crest may lead to implant failure (2) (figure 4b, paper 2). The necessity to obtain this second (distal) point of contact in addition to the proximal contact with the cage was emphasized (2). If there were no distal contact the resultant compressive vector acting on the osteotomy could cause instability by creating a 'rocking' motion. This could potentially then lead to fracture through the cheesewire/toggling mechanism described above. In a separate preliminary study by the author (IC), contact was found to be a significant risk factor associated with TT fracture (17); however it was not a factor in the final model of this report. This apparent significance in the preliminary study may have been due to lower case numbers causing a type I statistical error.

We hypothesized that the presence of contact between the cranial cage ear and the proximal plate may create screw-tine clustering. This would reduce the bone stock and cause a rise in stress, thus increasing the risk of fracture. However, this factor was not significant in multivariate analysis.

There are other factors which could not be evaluated in our study and yet may be associated with TT fracture after TTA. These include iatrogenic tissue damage leading to vascular compromise of the TT, and avascular necrosis of the TT secondary to the heat generated from creating the osteotomy. Further investigation into these factors related to the TTA is needed.

In this study we have also identified that surgical time is a significant factor in the development of SSIs in this cohort of dogs undergoing TTA surgery. Furthermore we have shown that the use of post-operative PAT does not appear to influence the incidence of SSIs. As a result, we have rejected the null hypothesis.

The prevalence of SSI in this study was similar to previous reports of post TTA SSIs (2.6 – 7.2%) (2, 8, 23). Despite this similarity, interpretation of these results should be performed with caution as the definition and criteria of SSI used in all the studies were not standardised. In this study, we have used the widely adopted definition outlined by the *CDC* (40). Adaptation of a standardised SSI definition will enable direct comparison of the results between various studies and eliminate this as a limitation of the study.

Staphylococcus species, including multi-drug resistant strains are the most commonly isolated bacteria in reported TTA and TPLO SSIs *(2, 8, 25, 41, 42)*. In dogs and cats, the most common isolated associated with implant-related SSIs are Staphylococcus species and Streptococcus species; Staphylococcus species accounting for 50 - 60% of infections (43). In our study, the most commonly cultured bacteria were Staphylococcus species, and followed by Streptococcus species.

The prevalence of implant removal in our study was 1.3%. To author's knowledge, this is the first study reporting the prevalence of implant removal after TTA. In comparison, the reported prevalence of implant removal for TPLO ranges from 1.3 – 8.5% (10, 25, 41, 42). Two of the stifles had implant removal due to implant associated SSI. The implants from one of these stifles cultured positive for Klebsiella pneumonia but it was not possible to determine whether the infection was introduced during or after surgery. Klebsiella pneumonia is not a commonly reported pathogen in implant associated SSI.

SSI is a commonly reported complication in the tibial osteotomy techniques for the treatment of canine cruciate disease (2, 8, 25, 44). Administration of peri-operative PAT is a common practice for the tibial osteotomy techniques (26, 45); the types and durations of PAT vary greatly between practices and surgeons. Two large retrospective studies have shown that post-operative PAT after cruciate ligament surgeries significantly reduced the incidence of SSI (24, 25). One of these involved only TPLO cases (24) while the other involved TPLO and ECLS equally (25). The significant relationship between post-operative PAT and lower SSI rate in the retrospective TPLO and ECLS studies stated above maybe attributed to the post-operative PAT truly prevented infection or it reduced the identification of SSI in the post-operative period (46). In contrast, our study on TTA did not show a significant relationship between post-operative PAT and SSI. Post-operative PAT may have protective effects on factors that are applicable to TPLO but not to TTA, such as the potentially more extensive soft tissue dissection of the proximal tibia, the bulky profile of TPLO plates and the stainless steel property of the TPLO plates. These factors may contribute to dead space and may increase the risk of soft tissue complications (6). In contrast to stainless steel implants, titanium implants have been shown to be more biocompatible with tissues and are associated with lower implant associated infection in some studies (47,48), but not the others (49). As SSI can be augmented by contact necrosis of soft tissue and bone from periosteal compression (50), the differing degree of area of periosteal compression resulted from the application of bone plate between TTA and TPLO may also influence the prevalence of SSI and the protective effect of post-operative PAT. The biomechanical difference between TTA and TPLO may also explain why post-operative PAT may have a protective effect against SSIs in TPLO. Non-locking plate system has been associated with significantly higher SSIs in dogs >50kg; micro-motion and instability at the osteotomy site were suggested to be an important factor in this (26). In contrast, micro-motion across the osteotomy may not be as important a factor in TTAs as it is in TPLOs. The osteotomy is largely not in contact with implants or adjacent bone. However and although no relation was found between technical errors and SSI further study is warranted to assess the micro-motion at the osteotomy site and bone-implant interface in TTAs.

Majority of the published literature in human medicine show that PAT after wound closure in a clean surgery is unnecessary, as additional doses have not shown benefit (51-53). A large prospective study in cats and dogs (1010 surgical wounds from multiple types of surgery) also showed the lack of association of post-operative PAT and SSI (P = 0.266) (54). Concerns with prolonged use of post-operative PAT are its limited benefit in the prevention of SSI and its association with emergence of resistant bacterial strains (51, 55). The current recommendation of PAT in human orthopedic surgery is that the first dose of PAT begins within 60 minutes before surgical incision and be discontinued within 24 hours of the end of surgery (56).

In our study, six stifles (3.0%) received first dose of PAT after the first surgical incision. There was no significant association between timing of first PAT dose and SSI shown in our study. This is likely to be a type II statistical error as the number of dogs received the PAT after the first surgical incision was small. It is advisable that an appropriate PAT that is effective against the likely encountered organism should be initiated within 60 minutes of the first surgical incision to achieve serum and tissue levels that exceed the minimum inhibitory concentration (56). Interestingly, some studies have found that the administration of intravenous PAT 4 – 30 minutes prior to the time of incision resulted in lower SSI (57, 58), in contrast to another study showing that the lower SSI was associated with administration of intravenous PAT between 30 – 60 minutes prior to skin incision (59). Re-administration after two half-lives of the medication is recommended intra-operatively to ensure adequate concentrations of antimicrobial in the serum and tissue during the entire time that the surgical site is open and at risk for bacterial contamination (56, 60).

Half of the SSIs occurred within 14 days post-operatively, this is similar to a previous study on TPLO (26). The other half of the SSI ranged from 15 days to 235 days post-operatively. The reason behind the biphasic nature of the SSI is unclear, however, the authors speculated that the early SSIs could be related to trauma and surgical contamination while the late infections could be the result of trauma, bacteria contamination that laid dormant for a period of time as well as remote infections (61, 62). Further study is needed to further evaluate the pattern of SSIs in canine CCL surgeries and the potential influence of implant material as well as the type of procedures involved.

This study showed a significant association between long surgical and anaesthesia times with SSI in TTAs. The finding of significant association between long surgical time and SSI is similar to previous studies in human and veterinary medicine (63-66). Prolonged surgical time is thought to significantly increase SSI through increased environmental contamination of the surgical wound (67). In addition, prolonged surgery is often associated with increased complexity of the surgery or more limited experience of the primary surgeon. Limited surgeon experience may increase the risk of surgical mistakes, which may indirectly affects the mechanical stability of the implants and the risk of post-operative complications, such as SSI. Implant instability has been associated with SSIs in TPLO in dogs (26).

A significant association between peri-operative body temperature and SSI is not evident in our study despite published evidence in human medicine showing a significant association between peri-operative hypothermia and higher SSI rate, delayed suture removal and prolonged duration of hospitalization (68).

Contrary to the null hypothesis boxer dogs undergoing TTA surgery had a significantly higher overall complication rate (44.4%) than the non-boxer dogs (15.5%). In our study boxer dogs were 5.8 times more likely to have complications than the non-boxer group and it followed that boxer dogs are also at higher risk of developing multiple complications. Levien et al (2013) reported that boxer dogs have a higher overall rate of complications associated with LFS compared to other breeds with an OR of 5.12 and which is in agreement with our data regarding TTA surgery. Dogs which had an intact medial meniscus at the time of the TTA surgery were 2.63 times more likely to develop complications. This finding was somewhat expected as although our overall incidence of LMI was 8.47%, which is within the reported range following TTA (1, 2, 7, 8, 14), it accounted for 37.7% of all the postoperative complications.

It has been suggested that Boxer dogs have a significantly higher incidence of partial CCL disease (35), contrary to our results. Treatment of partial CCL remains highly controversial, particularly regarding the decision of debriding or preserving the ligament remnants. Early stabilisation without debridement of a partially ruptured CCL has been associated with good functional outcome and slow progression of joint disease as assessed by second look arthroscopy (69). However on a different study, two Boxers were persistently lame six weeks after TPLO and lameness resolved after revision surgery for CCL remnant resection and debridement (25). In our study one boxer dog with intact menisci at the time of initial surgery developed acute persistent non weight bearing lameness at 92 days post TTA. The lameness resolved completely following debridement of the CCL remnants during a second arthrotomy which failed to reveal meniscal injury. The presence of non-debrided CCL remnants was not detected as a risk factor for postoperative complications in our study although we might have been underpowered to detect such association.

TT fracture was seen in seven stifles representing an overall incidence of 2.3%. The two cases documented in boxer stifles required surgical revision leading to their classification as major complications according to the current definitions applied in this study (70). The same kind of fracture was recorded in five non-boxer cases with only one requiring further treatment. The incidence of major TT fractures was statistically more common in the boxers group (p= 0.03). Although the number presented here is small and makes difficult to ascertain why boxers are more prone to experience a tibial tuberosity fracture as a complication of tibial tuberosity advancement, we hypothesize that since boxer dogs are known to have a naturally narrow tibia with a no very prominent tibial tuberosity crest, we believe technical errors such as thin osteotomy are more likely to be present.

Incisional infection and inflammation was the most common complication in the largest TTA study currently published (7.6%) (8). However the higher incidence of superficial infections in Boxers (22%) compared with non-boxer dogs (3.7%) found in our study was an unexpected finding. No difference was encountered between groups in terms of surgical and anaesthetic time, body weight, surgeon's experience and perioperative medication (including the use of antibiotics) which could potentially explain this. Similarly when looking at the overall infection-related complications which accounted for 26% of all instances, boxer dogs had 7.46 higher risk of developing this type of complication than the non-boxer dogs. This greater odds ratio was not associated with the use of antibiotics at discharge from hospital.

The timing of postoperative complications was statistically shorter for dogs in the boxer group. The only other study where boxer dogs complications were highlighted did not offer information regarding the time at which they developed (35) and so we have no mean of comparison. One could speculate that boxers are naturally very active and highly energetic dogs and perhaps more challenging to restrict during the recovery period. Furthermore when considering that 8/14 (57%) major complications recorded in the boxer dogs were infection-related it could be expected that these would be developing relatively soon following surgery. In fact all of these in the boxer group developed during the first 2.5 months which is in agreement with previously reported time frame for surgical site infection in TPLO and LFS cases (24).

Contrary to what was reported by Steinberg et al (2011) we found no association between the development of complications and body weight nor cage size between groups. None of the remaining signalment variables were identified as risk factors for complications in none of the breeds included in our study.

Thirty-six revision surgeries were performed in 35 stifles with one Springer spaniel dog in the non-boxer group requiring two revision surgeries due to boisterous exercise in the early postoperative period. Our surgical revision rate was of 11.7% which is within the previously reported range of 6.19% to 14.3% (2, 7, 8, 14). Boxer dogs were 2.58 times more likely to require revision surgery with a proportion of 22.2% for the boxer group and 9.96% for the non-boxers. We believe this is a relevant issue which should be discussed preoperatively with owners of boxer dogs with CCLr. Although several studies have investigated TTA complications none has identified differences between breeds. This is likely to result from the small number of Boxer dogs included in these studied samples. Amongst the larger studies investigating TTA complications between 2006 and 2014 *(1, 2, 8, 12, 14, 15)* fewer than 13 boxer dogs have been included out of 1123 dogs.

Boxers have been reported as a breed particularly prone to lymphoplasmacytic synovitis (LPS) (71). Although the clinical relevance of LPS in dogs with CCL rupture and the true incidence of this phenomenon in Boxers is yet to be defined, it has been proposed that cell-mediated immune responses have a role in CCL rupture in dogs (72,73). LPS has also been proposed to contribute to poor postoperative function following correction of medial patella luxation (74), and perhaps it may also contribute to their higher degree of postoperative complications.

Although suggesting Boxer-specific recommendations regarding the adequacy of the available surgical techniques is beyond the scope of this paper our boxer TTA complication rate (44.4%) warrants further studies, It is important to remember that other factors may play a crucial role when providing specific recommendations on how to treat CCL disease. Biological, mechanical, conformational, anatomical and clinical factors must be considered on an individual basis.

Conclusions

1. Tibial tuberosity fracture is a complication of tibial tuberosity advancement that may have a favourable prognosis although it can result in significant morbidity and in some cases revision surgery may be required.

2. The severity of clinical signs was the main criterion that determined the treatment of choice (conservative Vs surgical).

3. Surgical inaccuracies, specifically incorrect positioning of the plate and cage, and creating an osteotomy which is too narrow at the distal point, play a significant role in the occurrence of TT fractures.

4. Errors during TTA are likely to be made in the early learning curve, therefore it is author's opinion that the procedure should not be performed without adequate training and initial supervision.

5. There is a significant association between long surgical and anaesthesia times with surgical site infection in TTA.

6. The prevalence of implant removal in our study was 1.3%

7. Prophylactic antimicrobial therapy and the presence of technical errors associated with tibial tuberosity fracture didn't influence the surgical site infection rate.

8. In boxer dogs, major and multiple complications (including tibial tuberosity fracture) were more frequent, surgical revision was more often required and the time to complication development was shorter when compared to the non-boxer population.

Conclusiones

1. La fractura de la tuberosidad tibial es una complicación de la TTA que suele tener un pronóstico favorable aunque en ocasiones puede causar una morbilidad significativa y en algunos casos la cirugía de revisión puede ser necesaria.
2. La gravedad de los signos clínicos es el criterio principal que determina el tratamiento de elección (conservador vs quirúrgico).
3. Errores técnicos, específicamente posicionamiento incorrecto de la placa y la caja, al igual que la creación de una osteotomía que es demasiado estrecha en el punto distal, juegan un papel significativo en la aparición de fracturas de la TT como complicacion de la TTA.
4. Errores técnicos en la ejecucion de la TTA se realizan mayoritariamente durante la curva de aprendizaje, por lo que es recomendable que el procedimiento no se realice sin una formación adecuada y supervisión inicial.
5. Existe una asociación significativa entre los largos tiempos quirúrgicos y de anestesia con la infección post-quirúrgica en la TTA.
6. La prevalencia de la extracción de implantes en nuestro estudio es del 1,3%
7. El tratamiento antibiótico profiláctico y la presencia de errores técnicos asociados con la fractura de la tuberosidad tibial no influye la tasa de infección post-quirúrgica.
8. En los perros boxer, complicaciones mas graves y múltiples (incluyendo fractura de la tuberosidad tibial) son más frecuentes, la revisión quirúrgica es a menudo más necesaria y el tiempo para desarrollar una complicacion es más corto en comparación con la población no-boxer.

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