Evaluation of the Triple Tibial Osteotomy. A new technique for the management of the canine cruciate-deficient stifle

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Summary

The triple tibial osteotomy (TTO) is a technique which combines the features of tibial tuberosity advancement and wedge osteotomy for the treatment of complete and partial cruciate ligament injuries in dogs. In this paper, the technique is described and the results of a prospective study of 64 consecutive cases are presented. TTO provided a satisfactory clinical outcome in a very high percentage of cases. The technique is relatively easy to learn and has a low post-operative complication rate.

Keywords

Triple tibial osteotomy, tibial plateau leveling, cranial cruciate ligament, stifle, dog

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Introduction

Complete and partial rupture of the cranial cruciate ligament (CrCL) is the most common cause of lameness in the dog (1). Ever since the condition was first described by Carlin in 1926 (2) numerous papers have been published on all aspects of this condition, the greatest emphasis being on methods of treatment. In 1984, Slocum and Devine described a new approach to treatment with the introduction of the tibial wedge osteotomy (TWO) technique in order to eliminate tibial thrust (3). This concept of treatment was further refined by Slocum and Slocum with the introduction of the tibial plateau leveling osteotomy (TPLO) in 1993 (4).

The rationale behind tibial plateau leveling techniques is to provide functional stifle stability during the stance phase of the gait by eliminating cranial tibial thrust, i.e. the cranially directed force which results from tibial compression that is generated during weight bearing (4). Clinically, cranial tibial thrust can be elicited in CrCL-deficient stifles by performing the tibial compression test (5). In this test, the femur is held in a static position to fix the stifle joint while a force is applied to the foot to flex the hock joint. This results in increased loading of the stifle joint with a total joint force nearly parallel to the Achilles mechanism (6), which is approximately parallel to the functional axis of the tibia as defined by Slocum and Devine (7). Slocum and Slocum (1993) proposed that cranial tibial thrust could be eliminated by performing a radial osteotomy in the proximal tibia and rotating the proximal fragment so that the tibial plateau becomes perpendicular to the functional axis of the tibia (4). This theory was recently supported by a 3-D, 3-segment mathematical model of the canine stifle, however, the results of this analysis also showed that excessive loading of the caudal cruciate ligament occurred following TPLO (8).

Warzee et al. (2001) designed an *in vitro* biomechanical model in an attempt to simulate loading of the stifle joint (9). Their findings showed that the resultant force through the stifle on loading was directed 6.5 degrees more cranially than the tibial functional axis. They concluded that, in order to prevent excessive caudal tibial thrust, the tibial plateau should only be adjusted to an angle of 6.5 degrees. However, this study did not fully duplicate all of the muscle forces which acted upon the stifle. A biomechanical analysis performed by Tepic and others (2002) concluded that the resultant force acting through the load bearing stifle was in a direction more parallel to the patellar ligament and reasoned that shear force on the cranial cruciate can be eliminated by making the tibial plateau perpendicular to the patellar ligament (6). This can be achieved in two ways, either by altering the position of the patellar ligament insertion relative to the tibial plateau, which is the basis of the Tibial Tuberosity Advancement technique (TTA) described by Montavon and others (10), or by altering the alignment of the tibial plateau to the patellar ligament (a modification of the Slocum TPLO technique [4]).

In this paper, we present the results of 64 cases of canine cranial cruciate ligament rupture treated using a technique which

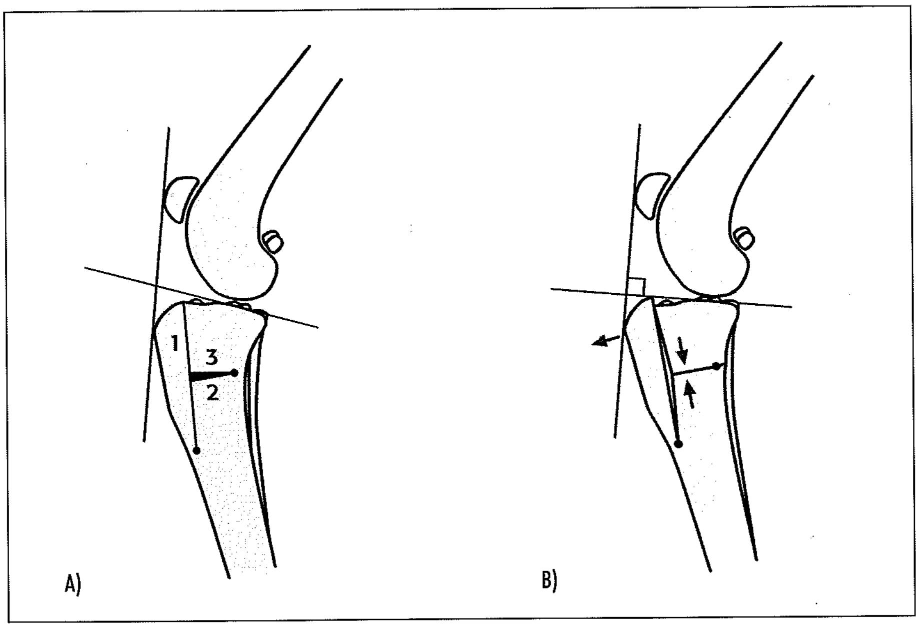

Fig. 1 A) The three osteotomies are depicted. B) Advancement of the tibial tuberosity is depicted as a result of reduction of the wedge ostectomy. Note that the tibial plateau is perpendicular to the straight patellar ligament.

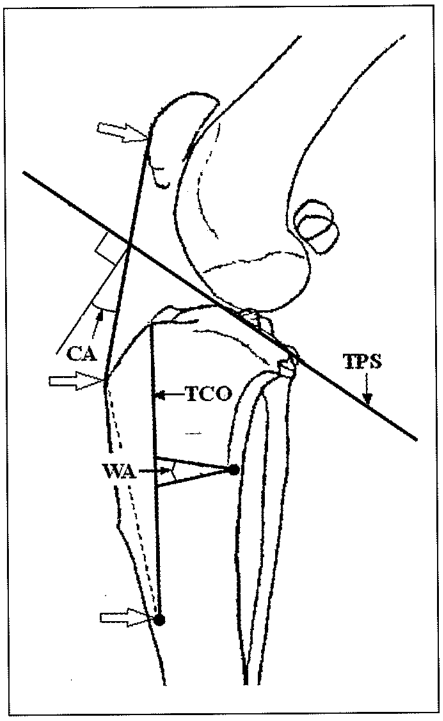

Fig. 2 Diagram illustrating the tibial plateau slope (TPS), correction angle (CA), tibial crest osteotomy (TCO), and wedge angle (WA). The open arrows indicate the length of the patellar ligament and the location of the drill hole at an equi-distant point distally for the TCO.

combines features of both the TTA and TWO techniques to achieve the same outcome, but with less radical angular changes. The triple tibial osteotomy (TTO) is a new technique designed to reduce the tibial plateau slope to an angle perpendicular to the patellar ligament. Three cuts are made in the proximal tibia to create a partial wedge ostectomy caudal to a partial tibial crest osteotomy (Fig. 1A, B). The tibial plateau is made perpendicular to the patellar ligament by rotating the proximal tibial fragment to close the wedge ostectomy and simultaneously advancing the tibial tuberosity.

Materials and methods

The patient population consisted of 64 consecutive cases of CrCL injury in 52 dogs referred to the Adelaide Veterinary Specialist and Referral Centre, Adelaide, South Australia and treated by TTO during the period October 2002 to April 2004.

Signalment, body weight, affected limb, and the duration of lameness were recorded. A full orthopaedic and neurological examination was performed on every dog by one of the authors (WJB). Lameness was graded from 0 to 10 (0/10 = sound at all times; 10/10 = continuous, non-weight bearing lameness) (11). Following anaesthesia, cranial draw sign was assessed by assigning a score from 0 to 3, using a semi-quantitative scale whereby 0 = no draw, 1 = mild draw, 2 = moderate draw, 3 = marked draw. Cranial tibial thrust, as determined by the tibial compression test, was assessed as being present (positive) or absent (negative) (5). Thigh circumference and stifle joint range of motion (ROM) was measured in the pelvic limbs using previously described protocols (12).

Medio-lateral and caudo-cranial radiographs of the affected stifle were taken. For the medio-lateral view, the limb was positioned so that the stifle joint was fully extended and the femoral condyles were super-imposed (with <3 mm disparity in any direction). The beam was centered on the tibial plateau and collimated to include the entire tibial length. The tibial plateau slope angle (TPA) was determined using the conventional method (13). The correction angle was defined as the angle between the straight patellar ligament and a line perpendicular to the TPA (Fig. 2). In this series of cases, the wedge angle (WA) was calculated as being two thirds of the correction angle (Appendix).

The patients were pre-medicated with a mixture of acepromazine[a] (0.03 mg/kg i.m.), atropine[b] (0.04 mg/kg i.m.), and morphine[c] (0.8 mg/kg i.m.). Anaesthesia was induced with thiopentone[d] (20 mg/kg i.v.) or propofol[e] (4 mg/kg i.v.) and maintained with a mixture of isoflurane and oxygen. Morphine (0.5 mg/kg s.c.) or buprenorphine[f] (0.01 –0.02 mg/kg s.c.) analgaesia was continued post-operatively for 24 hours as needed. Cephazolin[g] (20mg/kg) was administered once intravenously following anaesthetic induction.

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[a] A.C.P 2, Delvet Pty Ltd, Seven Hills, NSW, Australia.

[b] Atropine Injection, Apex Laboratories Pty Ltd, Somersby, NSW, Australia.

[c] Morphine Sulphate Injection BP, Mayne Pharma Pty Ltd, Mulgrave, VIC, Australia.

[d] Thiobarb Powder, Jurox Pty Ltd, Rutherford, NSW, Australia.

[e] Propofol Sandoz, Sandoz Pty Ltd, North Ryde, NSW, Australia.

[f] Temgesic Injection, Reckitt Benckiser Healthcare (UK) Ltd, Hull, UK.

[g] Cephazolin Sodium, Mayne Pharma Pty Ltd, Mulgrave, VIC, Australia.

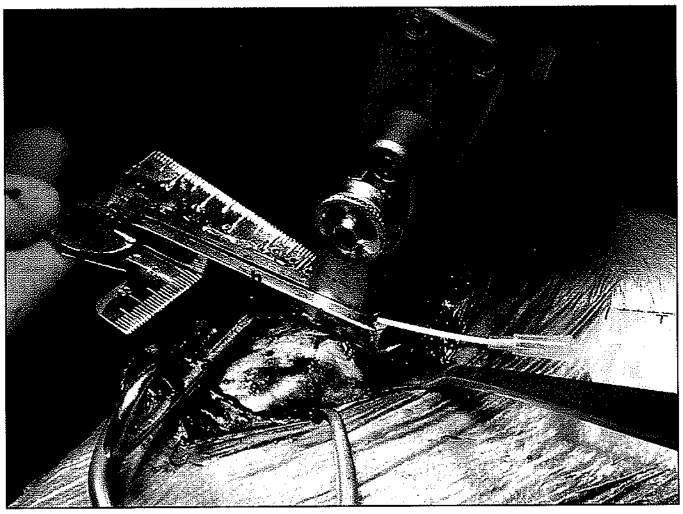

Fig. 3 Intra-operative photograph illustrating the TTO instrumentation. The wedgie (a) is used to lever the tibial crest segment cranially whilst the saw guide (b) and osteometer (c) facilitate accurate bone cuts.

The dogs were positioned in dorsal recumbency and aseptically prepared for surgery. All of the procedures were performed by Warrick J. Bruce. A curvilinear medial para-patellar incision was made which extended from the proximal patella to the medial saphenous vein. Subcutaneous tissues were transected and the medial fascia and medial joint capsule were incised using electrocautery. The patella was subluxated laterally and the cruciate ligaments and menisci were inspected. Ruptured remnants of the CrCL were removed. In cases of partial CrCL rupture, the integrity of the intact portion of the ligament was tested by applying a force using curved haemostats. When the remaining portion of the CrCL was deemed to be sound it was left intact, while the damaged portion was resected. Partial or total meniscectomy was performed where indicated, depending upon the degree of meniscal damage. In cases where there was complete rupture of the CrCL and the medial meniscus was found to be intact, a caudal medial meniscal release was performed by transecting the medial caudal menisco-tibial ligament (14). The meniscus was left intact in cases of partial CrCL. The joint was lavaged and the medial joint capsule and fascia were closed as a single layer using interrupted cruciate pattern sutures of polydiaxanone[h]. A transverse 2.0 mm hole was drilled immediately caudal to the cranial cortex of the tibia at a distance equal to the length of the patellar ligament distal to the patellar ligament insertion (Fig. 2). The tibial crest osteotomy (TCO) was made in the transverse plane parallel to the cranial aspect of the tibial crest. It was initiated at the pre-drilled hole distally and ended proximally caudal to the patellar ligament. The medial crural fascia was undermined subperiosteally to expose the entire medial surface of the proximal tibia and the medial collateral ligament. The tibial crest osteotomy was then wedged open with a specially designed instrument[i] to allow a pre-calculated wedge of bone to be removed from the tibia, caudal to the TCO (Fig. 2). The base of the wedge was located at the exact midpoint of the TCO. In some earlier cases, the apex of the wedge was at the caudal tibial cortex creating a complete ostectomy. However, the technique was later modified to a partial wedge ostectomy; the apex of the wedge was at a pre-drilled 2 mm transverse hole located immediately cranial to the caudal tibial cortex. Care was taken during the entire procedure to retract and protect tissues on the lateral and caudal aspects of the tibia in order to avoid iatrogenic trauma. Approximately half of the cases in this series were performed without the use of any specialised instrumentation. TTO instrumentation[j] was later developed and used to facilitate more accurate saw cuts and cranial retraction of the tibial crest during wedge ostectomy (Fig. 3).

The wedge ostectomy was reduced (closed) using a pair of large speed-lock fragment forceps. One point of the forceps was placed in the proximal tibia immediately caudal to the TCO; the other point was

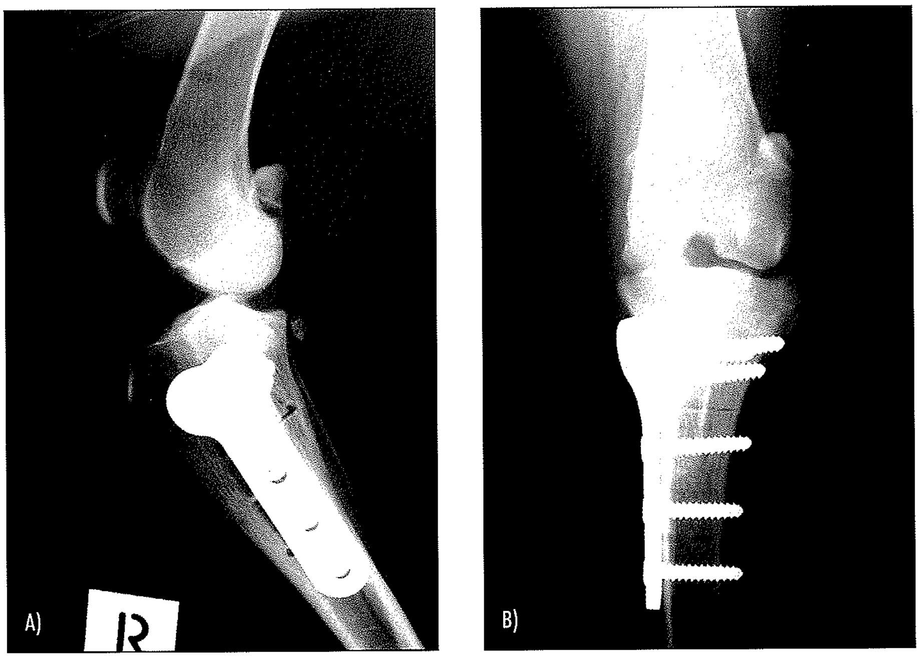

Fig. 4 A) Post-operative medio-lateral view of right stifle illustrating TTO and plate positioning. B) Caudo-cranial radiographic view showing plate positioning. Note the radiolucent line between the distal two screws is the drill hole for the tibial tuberosity osteotomy.

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[h] PDS II, Ethicon Inc, Johnson & Johnson Medical Pty Ltd, North Ryde, NSW, Australia.

[i,j] Veterinary Instrumentation, Sheffield, UK.

Table 1 Stifle compartments and sites used to evaluate osteophyte and enthesiophyte formation.

Compartment	Sites		
1. Femoro-patellar articulation	Proximal trochlear groove	Patellar apex	Patellar base
2. Lateral femoro-tibial articulation	Abaxial surface of lateral femoral condyle	Lateral fabella and popliteal sesamoid	Lateral proximal tibia and fibula
3. Medial femoro-tibial articulation	Abaxial and axial surfaces of the medial femoral condyle	Medial fabella	Medial proximal tibia

Table 2 Results of the owners questionnaire from 48 dogs (61 stifles).

Activities	Normal	Near normal	Mildly abnormal
Walking	41 (85.4%)	7 (14.6%)	
Sitting	31 (64.6%)	16 (33.3%)	1 (2.1%)
Standing	42 (87.5%)	4 (8.3%)	2 (4.2%)
Running	36 (75%)	12 (25%)	
Climbing stairs	38 (79.2%)	10 (20.8%)	
Jumping into car	37 (77.1%)	11 (22.9%)	
Exercise in general	37 (77.1%)	11 (22.9%)	

Normal = No difficulties with activity; Near normal = Occasionally has mild difficulty or impairment; Mildly abnormal = Can perform the activity but frequently has mild difficulty or impairment.

hooked around the jaws of a pair of Kern forceps, which had been secured to the distal tibial crest. The site was stabilized by applying a pre-contoured 3.5 TPLO plate[k] to the medial aspect of the proximal tibia (Fig. 4A, B). Plate size selection was based on body weight (large TPLO plate for dogs ≥35 Kg; medium TPLO plate for dogs <35 Kg). Cancellous bone from the osteotomised wedge was packed into the TCO gap. The cases in which the tibial crest had fractured at its distal attachment during advancement were repaired using a single K-wire and tension-band wire. The tension band wire was placed distally and was looped in a figure of eight between drill holes each side of the fracture; the K-wire was placed proximal to the tibial wedge ostectomy. The medial crural fascia, subcutaneous and sub-dermal tissues were closed in layers using polydioxanone[h] in a simple continuous pattern.

Radiographs were taken immediately post-operatively and were used to determine the post-operative TPA. The actual TPA adjustment was measured by super-imposing the shafts of the tibiae, in the pre- and post-operative radiographs, and measuring the angle between the two tibial plateau slopes.

Robert Jones bandages were applied to all of the dogs immediately post-operatively and the dogs were discharged 24 hours after surgery but were returned for reassessment and bandage removal four- to five days post-operatively. Carprofen[l] (4 mg/kg s.c) was administered immediately post-operatively and orally at 2 mg/kg bid for seven days then at 2 mg/kg sid for seven days. Cephalexin[m] was given orally for five days post-operatively (20 mg/kg). All of the dogs received four injections of pentosan-polysulphate[n] (3 mg/kg) at seven day intervals beginning around day 10 post-operatively. Strict confinement was advised for the first six weeks post-operatively and instructions were given for passive range of motion exercises twice daily.

The dogs were returned approximately six weeks post-operatively (short-term follow-up). Lameness was reassessed and all of the dogs were sedated and the cranial draw sign, tibial compression test, thigh circumference, and stifle joint range were re-measured. Radiographs were obtained to assess bone healing. Owners were instructed to allow a gradual controlled return to normal activities over a six week period.

Long-term reassessment was performed at more than 11 months post-operatively and the same parameters as for the short-term follow-up were re-assessed.

Operated stifles were assigned osteoarthritis (OA) scores using the pre-operative or immediately post-operative radiographs and the radiographs taken at long-term follow-up. Paired sets of stifle radiographs (medio-lateral and caudo-cranial views) were randomly arranged and scored by an experienced veterinary radiologist (AR) who was blinded to the patients' identity, and outcome. The osteoarthritis scoring system used in this study was a modification of a system devised by Vasseur and Berry (1992) (15). Nine sites were evaluated for potential osteophyte or enthesiophyte formation. The stifle joint was divided into three compartments and each compartment was further divided into three sites (Table 1). Osteophyte and enthesiophyte formation was scored on a four point discontinuous ordinal (Likert) scale from 0 to 3 (0 = no new bone formation and 3 = most severe new bone formation). There were neither descriptors nor set limits for the scales, nor was an atlas of disease features provided. All of the scores for each stifle compartment were totaled to give an accumulative OA score.

Owners were asked to complete a questionnaire at long-term follow-up. They were asked to assess their dog's ability to walk, sit, stand, run, climb stairs, jump into the car, and exercise in general by grading it from normal to severely abnormal, using descriptors from a five point scale (Table 2). In addition, they were asked to grade how this procedure had affected their dog's quality of life on a five point scale (from marked improvement to a lot worse), and whether they would have this procedure performed again if they had another dog with the same condition.

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[k] Veterinary Instrumentation, Sheffield, UK.

[l] Rimadyl, Pfizer Animal Health Group, West Ryde, NSW, Australia.

[m] Rilexine Palatable, Virbac Pty Ltd, Peakhurst, NSW, Australia.

[n] Cartrophen Vet, Biopharm Australia Pty Ltd, Bondi Junction, NSW, Australia.

Statistical analyses were performed using the R statistical computer package[°]. The non-parametric Friedman test was used to test for a significant effect of period on thigh difference. A linear model was fitted to test for a significant effect of period on stifle ROM. Ninety-five percent confidence intervals were calculated for the difference in thigh circumference or difference in ROM between the different time periods using Bonferroni adjustment for the multiple comparisons. To test for non-significant decrease in ROM between short-term and long-term follow-up, statistical equivalence was used (16). In summary, in equivalence testing the P-value measures the strength in favour of the hypothesis of a non-significant decrease in ROM, where small values of the P-value correspond to strong evidence in favour of the hypothesis. In this case, the hypothesis was tested using a t-test to test for one-sided equivalence with a margin of 5 degrees. The non-significant increase in OA from surgery to long-term follow-up was tested, again with equivalence testing, by using a non-parametric test, the Wilcoxon sign test, to test for one-sided equivalence with a margin of four.

Results

Fifty-two dogs (64 stifles) were operated on during the study period representing an incidence of 43 stifles / year. Dogs were aged between one and 11 years (mean: 4.82 ± 2.51 years; median: 4 years) and weighed 17.5 to 84.5 kg (mean: 40.96 ± 3.67 kg; median: 40 kg). Thirty-one dogs (60%) were neutered females and 21 (40%) were neutered males. Breeds were Rottweilers and Rottweiler-types (15 dogs), Bull Mastiffs / types (6), Golden Retrievers (4), Labradors (4), Australian Cattle dogs (4), German Shepherd dogs (3), Doberman Pinschers (3), Saint Bernards (2), Maremma Sheepdogs (2), and six other breeds (Gordon Setter, Staffordshire Bull Terrier, Alaskan Malamute, Australian Kelpie, Akita, Standard Poodle) represented by one dog each; there were three cross-breed dogs.

TTO was performed on the right side only in 20 dogs, on the left side only in 20 dogs and bilaterally in 12 dogs. Ultimately, 26 dogs (50%) had bilateral surgery either before entering the study or during the follow-up period of this study. The duration of lameness before surgery ranged from one to 104 weeks (mean: 12.52 ± 20.25 weeks; median: six weeks).

Pre-operative lameness scores ranged from 3/10 to 10/10 (mean: 5.5; median: five). A cranial draw sign was present in all of the dogs and the degree of draw ranged from a score of one to three (median: two). The tibial compression test was positive in 51 cases (79.6%).

Forty stifles (62.5%) had complete CrCL rupture; the remainder had partial ruptures. There were 38 meniscal injuries identified (59.4%); 37 were medial meniscal injuries (27 caudal horn peripheral avulsions, six longitudinal tears, four compression injuries) and one lateral meniscus injury (longitudinal tear) (17). Complete medial meniscectomy was performed in six cases; partial meniscectomy was performed in 32. The caudal medial menisco-tibial ligament was released in 18 cases. The operative time ranged from 50 to 90 minutes (median: 75 minutes).

Pre-operative tibial plateau slope angles (TPAs) ranged from 21° to 51° (mean: 29.1° ± 6.4°; median: 28). The calculated wedge angle was from 6° to 27° (mean: 11.5° ± 3.0°; median: 11°), however, the actual TPA adjustment, which is a measure of the accuracy of wedge resection and reduction, ranged from 9° to 30° (mean: 15.4° ± 3.5°; median: 15°). Post-operative TPAs ranged from 7° to 35° (mean: 16.1° ± 5.5°; median: 15°). The post-operative tibial plateau – patellar ligament angle measured from 89° to 100° (mean: 94.1° ± 3.1; median: 94°)

The total complication rate in this study was 36.0%. Fracture through the distal end of the tibial crest osteotomy (TCO), whilst advancing the tibial crest, was the most common complication and occurred in 15 cases (23.4%). This complication was addressed by pin and tension-band wire repair. The only other intra-operative complication was injury to the popliteal artery in one case.

Seven (10.9%) post-operative complications were encountered. There were two fractures through the tibial tuberosity at the level of a proximally placed pin used for intra-operative distal TCO fracture repair. In one case, the tibial tuberosity became displaced and it was repaired using a pin and tension-band wire technique. In the other case, there was not any displacement of the tibial tuberosity and it healed without any surgical intervention. One dog developed an infection around the plate at 11 months post-operatively after self-traumatising the area following excision of a skin lesion. This resolved following plate removal and antibiotic administration. One dog developed an acutely swollen and painful stifle after colliding with a low table 16 months post-operatively. Pseudomonas spps. were isolated from the stifle and antibiotic therapy was initiated. This case was lost to follow-up and eliminated from the study. One dog, a Rottweiler, was euthanatized 22 months post-operatively after developing lameness and radiographic changes consistent with bone neoplasia affecting the proximal tibial metaphysis of the operated limb. Histopathology was not available.

Two dogs (3.1%) required further operations to remove a damaged medial meniscus. One dog with a partial CrCL rupture failed to improve following TTO and it was suspected that this meniscal injury was missed at the time of surgery. The second dog had a meniscal release at the time of TTO but developed a longitudinal tear in the caudal horn of the medial meniscus four months post-operatively. The caudal menisco-tibial ligament was found to be intact in this patient at the time of meniscal surgery. Both dogs recovered uneventfully following partial medial meniscectomy.

Short-term follow-up ranged from six to 12 weeks (mean: 6.9 ± 1.6). Mild lameness (median: 1/10; range: 1 to 4/10) and a cranial draw sign (median: two; range: one to three) were present in all cases. Fifty-seven (89.1%) stifles had a positive tibial compression test. There was a significant increase in thigh circumference measurements between pre-operative and short-term post-operative measurements ($P<0.05$). There was a significant increase in stifle ROM measurements from pre-operative to

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[°] R Development Core Team (2006). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

short-term post-operative follow-up ($P<0.05$). All of the joints had radiographic evidence of bone healing at the closing wedge site and stable surgical implants. Variable degrees of new bone filling the defect caudal to the TCO were present.

Forty-three dogs (55 stifles) returned for long-term evaluation from 11 to 26 months post-operatively (mean: 14.5 ± 3.2 months). Lameness scores ranged from 0 to 1/10 (median, 0/10), cranial draw signs were present in all cases (median score: three; range: one to three) and the tibial compression test was positive in 50 stifles (90.9%). There was a significant increase in thigh circumference between pre-operative and long-term post-operative measurements ($P<0.05$) and a significant increase between short-term and long-term follow-up ($P<0.05$) (Fig. 5). There was a significant increase in stifle ROM from pre-operative to long-term follow-up ($P<0.05$), and there was not a significant decrease in stifle ROM between short-term and long-term follow-up ($P=0.003$) (Fig. 6). There was not a statistically significant increase in OA scores from surgery to long-term post-operative values ($P<0.001$) (Fig. 7).

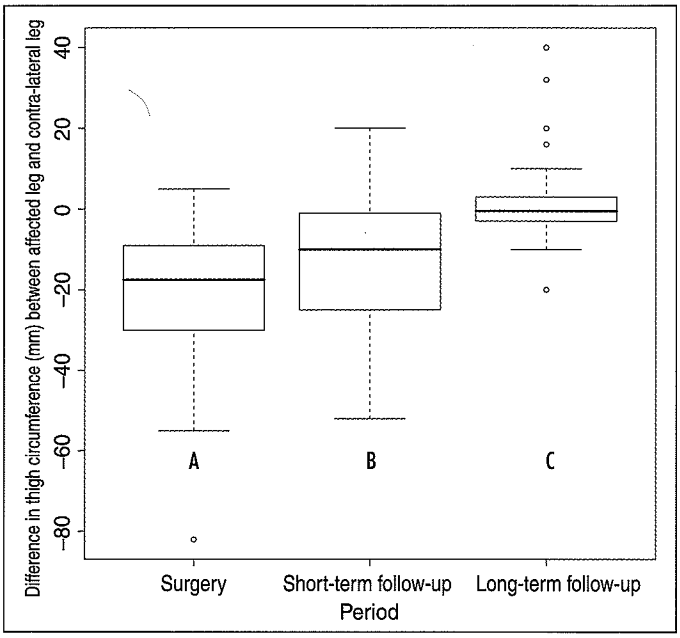

Fig. 5
Boxplots showing the difference in thigh circumference (mm) between the affected limb and the contralateral limb at each time interval. There was a significant increase in thigh circumference from A to both B and C and B to C ($P<0.05$).

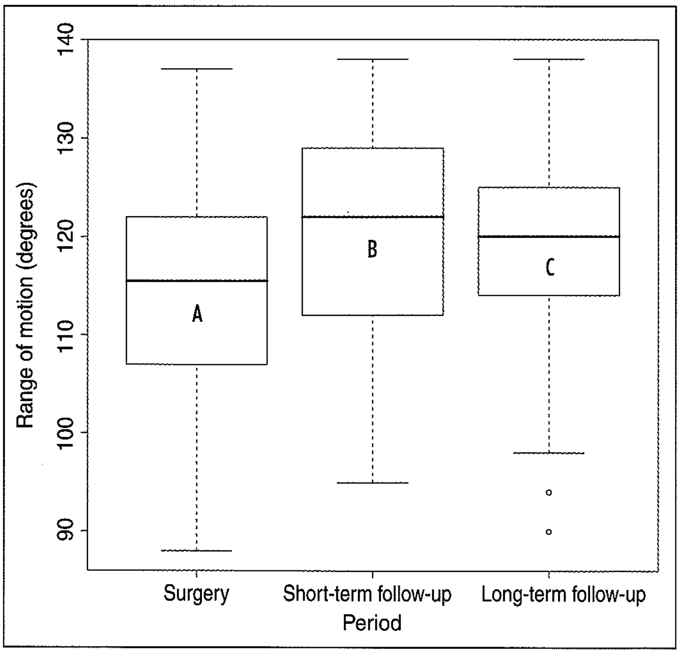

Fig. 6
Boxplots showing the stifle range of motion (degrees) at each time interval. There was a significant increase in stifle ROM from A to B and A to C ($P<0.05$). There was no significant decrease in stifle ROM from B to C ($P=0.003$).

Owners completed questionnaires for 48 dogs (92.3%) at long-term follow-up. Five owners completed the questionnaire over the telephone at more than 12 months post-operatively because these dogs were not available for long-term reassessment. A breakdown of owner assessment of their dog's activities is presented in Table 2. Forty-eight (100%) owners reported that the procedure had resulted in a marked improvement in their dog's quality of life and all (100%) of them indicated that they would have the procedure performed again if they had another dog with the same condition.

Discussion

The TTO procedure is based on the biomechanical concept, proposed by Tepic and others (2002) of eliminating cranial thrust during weight bearing by making the tibial plateau perpendicular to the straight patellar ligament (6). In the study presented herein, the mean post-operative tibial plateau – patellar ligament angle was 94°, rather than the desired 90°. There are several sources of error that may have contributed to this outcome. The relative contribution of the wedge angle to the total correction angle was proven mathematically to be $WA = 2/3CA$ (Appendix). However, the Appendix illustrates that this formula is only true when point X remains in the same relative position to point Z following surgery (Fig. 8); in other words, the patella position in the cranio-caudal plane relative to the tibia must not change after surgery. In this study it was assumed that (any) cranial movement of the patella, which occurred because the femur was slightly advanced following closing wedge ostectomy, was corrected by the caudal movement of the femur as the stifle was flexed to return it to its pre-operative angle. However this assumption was not always true and the above formula tended to under-

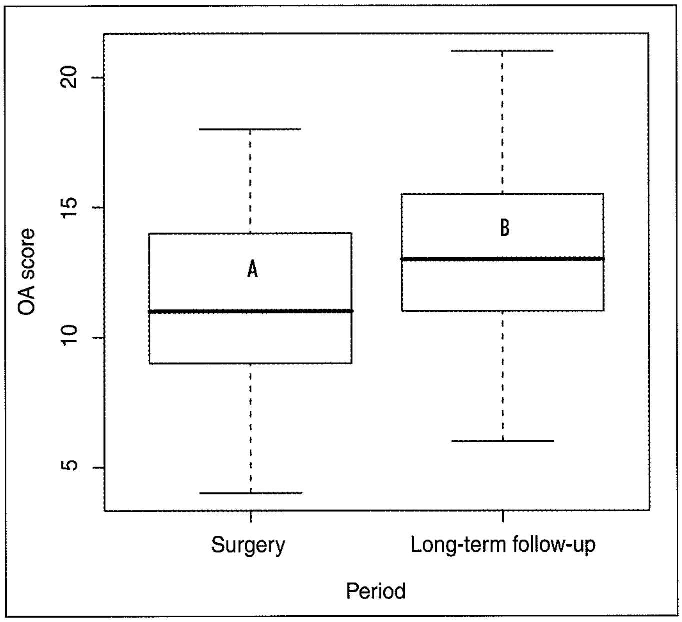

Fig. 7
Boxplots showing the osteoarthritis scores pre-operatively or immediately post-operatively and at long-term follow-up. There was no significant increase in OA scores from A to B (P<0.001).

estimate the wedge angle required in many patients.

Inaccuracies involved in making and reducing the wedge ostectomy may also have been a source of error and have influenced our results. The correct positioning of the wedge ostectomy is critical; the base of the wedge must be located at the exact midpoint of the TCO so that the wedge forms an isosceles triangle with its central axis perpendicular to, and exactly half-way along, the TCO (Fig. 8). The closing wedge ostectomy must also be cut accurately and reduced perfectly. However, inaccuracies involving these technical aspects of the procedure were significantly reduced by the development of specialised instrumentation[i]. Errors may also have occurred due to the difficulties in accurately measuring the TPA (18–20) and the effect of stifle positioning and radiographic technique on the measurement of TPA (13). The patellar ligament angle is strongly influenced by stifle joint position during radiography, particularly the angle of extension, and it was not always possible to obtain identical pre-operative and post-operative stifle joint angles.

The optimal patellar ligament- tibial plateau slope angle required to eliminate cranial tibial thrust *in vivo* is presently unknown. A recent *in vitro* biomechanical study reported that cranial tibial subluxation was neutralised at a patellar tendon angle not significantly different from 90° (21) but the results of our study and one other, on the short-term results of TTA procedures, report good to excellent function with mean post-operative angles of 94° and 95.5°, respectively (22).

Radiographic views of the entire tibial length are not necessary in the TTO technique since the measurement of the TPA and hence the location of the tibial functional axis is not required. They were included in this study so that the post-operative TPA could be measured and compared with other TPLO techniques. Performing a closing wedge ostectomy moves the tibial intercondylar tubercles cranially and thereby advances the tibial functional axis. This results in an increase in the post-operative TPA equal to the angle that the tibial functional axis is advanced (23). In our study, the post-operative TPAs were far greater (as much as 30° in one case) than the optimal 5 to 6.5 recommended for other TPLO techniques to eliminate cranial tibial thrust (9, 24). It is not surprising then that at long-term follow-up, a cranial tibial thrust was detected by the tibial compression test in 91% of cases in our series. This phenomenon could be interpreted as a failure, however, it can be argued that the tibial compression test is not representative of the normal forces acting through the stifle because the joint is not externally braced or fixed during normal weight bearing, as it is during this test (6). The tibial compression test primarily applies a compressive force across the stifle through loading of the Achilles mechanism, however, dynamic stifle joint stability requires the co-contraction of all muscle groups acting around the joint (4, 6). The reason why more stifles with cranial tibial thrust were detected at follow-up than pre-operatively was due to the removal of the intact portion of the CrCL, which was deemed to be unsound, in some cases of partial CrCL rupture.

The overall post-operative complication rate in this study was low and compared favourably with other tibial plateau adjustment techniques (25–29). Complications such as, seroma formation, patellar tendonitis, fibular fracture, injury to the long digital extensor tendon and delayed union, reported by others were not present in this series (25, 27–29). Fracture of the tibial tuberosity was observed post-operatively in two cases and occurred at the level of proximally placed pins. The pins may have acted as a stress riser and similar fractures associated with anti-rotational pins have been observed following TPLO. Other factors such as, age, weight, tibial tuberosity thickness, and single-session bilateral procedures have been reported to increase risk of fracture (30). The two dogs affected in this study were both heavy (>54 kg), unruly dogs whose owners had difficulties controlling them. To avoid this complication it is recommended that an appropriate sized K-wire is placed by hand or by slow-speed power insertion into a pre-drilled pilot hole located more distally in the tibial crest, proximal to the wedge ostectomy.

The two infections reported in this series may not have been related to the TTO procedure since they occurred more than 11 months post-operatively and were associated with other factors such as trauma and surgical intervention in the area of the plate. Latent infection secondary to surgical site trauma or implant loosening are also possibilities although there was not any gross evidence of implant loosening when the plate was removed in one case. Similarly, the one unconfirmed case of suspect bone neoplasia in this series may not have been related to the procedure since it occurred in an 'at risk' breed at a common predilection site (31).

There are conflicting reports in the literature as to whether there is any association between TPLO surgery or implants and bone neoplasia (32, 33).

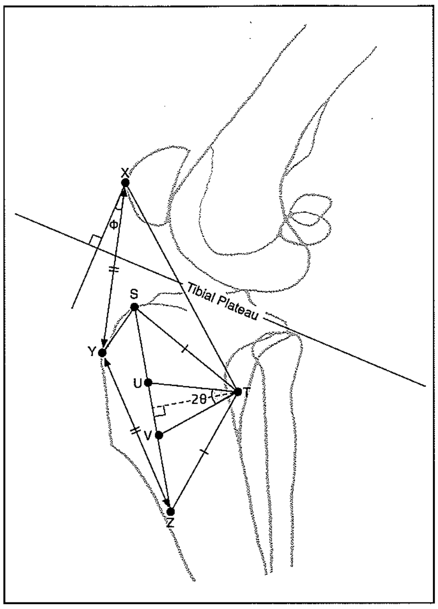

Fig. 8 Stifle joint with associated reference points and angles.

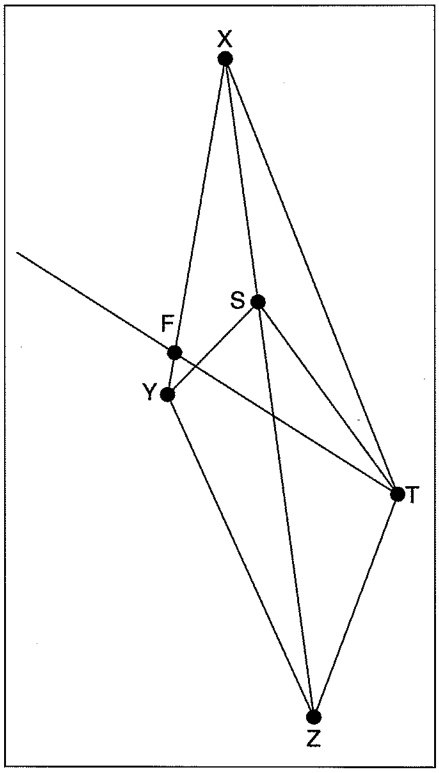

Fig. 9 Diagram illustrating reference points before surgery. TF represents a line parallel to the tibial plateau.

There were two cases of post-operative meniscal injury, which required repeat stifle surgery in this series. In one of these, a caudal medial menisco-tibial ligament release had been performed. This procedure has been shown to be effective in protecting the caudal pole of the medial meniscus from further injury (34). It is interesting to note the menisco-tibial ligament was found to be intact in this case. This suggests the menisco-tibial ligament was not completely transected at the time of meniscal release or the ligament had healed and hence predisposed the meniscus to re-injury. In the second case the meniscal injury was thought to have been missed at the time of TTO surgery, since complete inspection of the medial meniscus was not possible as this was a case of a partial cruciate ligament rupture. This dog had a pathological TPA (51°) and adopted a crouched stance with a flexed stifle joint, which is a common feature of this condition (35). Studies in dogs and humans have shown that the distance between cranial and caudal poles of the meniscus is reduced in stifle flexion (34, 36). Therefore, careful inspection of the menisci for injury in patients with pathological TPAs is essential as they are predisposed to entrapment of the caudal pole of the medial meniscus.

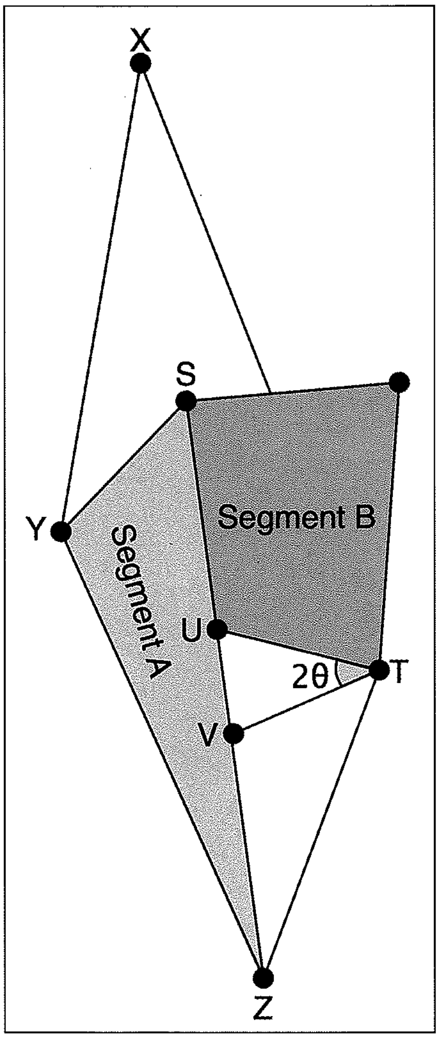

Fig. 10 Diagram illustrating the two segments of bone mobilised in the TTO procedure.

The major intra-operative complication was fracture of the bone at the distal end of the TCO during advancement of the tibial crest. This was repaired with a pin and tension-band wire. Distal TCO fractures were more likely to occur in older dogs, in dogs with pathological TPAs where larger wedges are removed, or where technical errors were made in the placement of the distal TCO hole. The incidence of this complication has reduced significantly as the authors have become more experienced in the placement of the distal TCO hole and the cranial retraction of the tibial crest segment using specialised TTO instrumentation during wedge ostectomy and reduction.

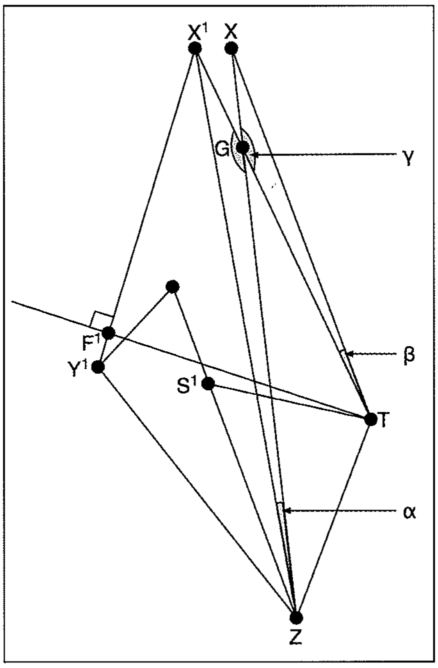

Fig. 11 Diagram illustrating new reference points and angles after surgery. TF1 represents a line parallel to the tibial plateau.

Appendix

In order for the tibial plateau to be made perpendicular to the straight patellar ligament, the proximal tibia must be adjusted by an angle of $\varnothing$ (the correction angle) by removing a bone wedge of size 2θ (Fig. 8). For this study, the relationship between 2θ and $\varnothing$ was determined to be $2\theta = 2/3\varnothing$. The justification of this formula is based on the trigonometry detailed below.

The angle XFT is the angle made between the patella ligament XY and the tibial plateau TF (Fig. 9). This angle is $90 + \varnothing$ degrees before the surgery. During TTO surgery, the bone wedge UVT is removed and the bone segment B (Fig. 10) is rotated 2θ degrees anticlockwise around point T. Assuming bone is non-compressible, this results in the rotation of line TF by 2θ degrees around T to become the line TF^1 (Fig. 11).

Consider the triangle STZ. The length ST is equal to the length TZ making STZ an isosceles triangle (Fig. 8). This means that the angle TSZ is equal to the angle TZS. After the rotation of segment B, the point S slides down bone segment A to become point S^1 (Fig. 11). The length TS^1 is equal to TZ and so TS^1Z is an isosceles triangle. As the angles in a triangle sum to 180 degrees and the angle STZ decreases by 2θ due to the rotation, then the angle TZS must increase by θ to become the new angle TZS^1. This means bone segment A rotates $\varnothing$ degrees anticlockwise around point Z and so the line ZY rotates θ degrees anticlockwise around Z to become ZY^1.

Consider the triangle ZYX, the length ZY equals the length YX and so ZYX is an isosceles triangle. This means the angle YZX is equal to the angle ZXY. After rotation the angle XZY increases by θ (as shown above) to become the angle XZY^1. If the point X moves relative to Z and T to point X^1, and we denote the angle XZX^1 as α (Fig. 11), then the angle XZY increases by $\theta - \alpha$ degrees to become angle X^1ZY^1. As the triangle X^1ZY^1 is an isosceles triangle this means the angle ZX^1Y^1 increases by $\theta - \alpha$ degrees.

Consider the triangles TGX and ZGX^1, the angles XGT and X^1GZ are equal, denote this angle as γ (Fig. 11). Also denote the angle XTX^1 as β. As the angles in a triangle sum to 180 degrees then:

$$TXZ + \gamma + \beta = 180,$$
$$TX^1Z + \gamma + \alpha = 180.$$

Rearranging this gives:

$$TX^1Z = TXZ + \beta - \alpha$$

This means the angle TXZ increases by $\beta - \alpha$ degrees following rotation to become the angle TX^1Z, where β is the rotation of X anticlockwise around T to the point X^1, and α is the rotation of X anticlockwise around Z to the point X^1. By a similar argument it can be shown that $ZX'Y = ZXY + \alpha - \delta$, where δ is the angle XYZ' caused by the rotation.

Finally, consider the triangle TFX and its change to the triangle TF^1X^1 after surgery. The angle TXF increases by $\theta + \beta - \alpha - \delta$ degrees to become the angle TX^1F^1, and the angle XTF increases by 2θ degrees to become the angle XTF^1, but the line XT is rotated β degrees anticlockwise to X^1T. This means the angle XTF increases by $2\theta - \beta$ degrees to become the angle X^1TF^1. As the angles in a triangle sum to 180 degrees, the angle XFT decreases by $\theta - \alpha + \beta - \alpha + 2\theta - \beta = 3\theta - \alpha - \delta$ degrees to become the angle X^1F^1T.

To achieve the surgical goals this decrease is to be the correction angle $\varnothing$.

Equating gives:

$$\varnothing = 3\theta - \alpha - \delta \rightarrow \varnothing/3 + \alpha/3 + \delta/3 = \theta$$

Rearranging this gives:

$$2\theta = \frac{2\varnothing}{3} + \frac{2\alpha}{3} + \frac{2\delta}{3}$$

In this study, we made the assumption that point X remained in the same relative position to point Z, Therefore $\alpha = \delta = 0$ and we arrive at the formula:

$$2\theta = 2/3\varnothing.$$

Clinical assessment of cases at long-term follow-up revealed lameness scores of 0/10 or 1/10. There was a significant increase in thigh muscle mass post-operatively. Fig. 5 shows the mean difference in muscle mass between the operated and contra-lateral limb approached zero. This finding further supports the clinical lameness assessment of near normal limb use. The four outlying results illustrated in the boxplot at long-term follow-up (Fig. 5) with positive thigh circumference values were dogs that had developed contra-lateral CrCL injuries. There was an expected increase in stifle joint ROM at short-term follow-up since removing a wedge of bone from the proximal tibia effectively advances the distal tibia and therefore results in an increase in the maximum stifle joint extension angle. No significant reduction in stifle ROM between short-term and long-term follow-up was observed, which might be expected with capsular fibrosis or progression in osteoarthritis (37).

There was not any significant increase in OA scores at long-term follow-up in this study. Prevention of the progression in OA is one of the purported goals of surgical treatment of CrCL injuries, but it is unlikely that any surgical technique will achieve that goal long-term.

However, the analyses of the results of this study, in which a large number of the patients completed the long-term follow-up, are encouraging; a high percentage of cases having a satisfactory outcome. In the more recent modification of the technique the tibial osteotomy is incomplete and the proximal tibia is re-shaped and stabilized with a rigid T-plate. There were not any incidences of implant failure in the present series of cases or in the subsequent 300 cases performed by the authors. The TTO technique is relatively easy to learn and the additional equipment, although not essential, does make the operation more precise. It takes slightly longer than the TTA technique (10) but does not require special implants or spacers, nor does it require a specialised jig or a dedicated saw like the Slocum TPLO technique (4).

Every effort was made in the design of this study to minimise any subjectivity in assessment of the patients. However, this still remains a major limitation to the study and further research using force plate gait analysis is necessary to complement our findings with more objective data. Biomechanical analysis of TTO on cranial and caudal tibial thrust and retropatellar forces would also be useful to enable direct comparison of this method of tibial plateau adjustment with other techniques. The relationship between CA and WA is complex and requires further study to investigate the effect, if any, of variables such as, the size of dog, TPA, and stifle standing angle.

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