Veterinary Surgery
36:156–163, 2007

In Vitro Comparison of Tibial Plateau Leveling Osteotomy with and Without Use of a Tibial Plateau Leveling Jig

KAY INGO SCHMERBACH, Dr Med Vet, CHRISTIAN KONRAD MATTHIAS BOELTZIG, Med Vet, ULLRICH REIF, DVM, Diplomate ACVS & ECVS, JAN CARSTEN WIESER, Med Vet, THOMAS KELLER, Dr Rer Nat, and VERA GREVEL, Dr Med Vet, Diplomate ECVS

Objective—To evaluate the influence of a tibial plateau leveling jig on osteotomy orientation, fragment reduction, and postoperative tibial plateau angle (TPA) during tibial plateau leveling osteotomy (TPLO).
Study Design—In vitro experimental study.
Animals—Large-breed canine cadavers (n = 20).
Methods—TPLO was performed on 40 hindlimbs using 4 methods. Group 1: Jig; dogs in dorsal recumbency with the osteotomy parallel to the distal jig pin. Groups 2–4: No jig; dogs in lateral recumbency with the osteotomy in a vertical orientation (group 2: tibia parallel to the table top; group 3: controlled superimposition of the femoral condyles; group 4: internal rotation of the tibia). Postoperative TPA, fragment reduction, and osteotomy orientation relative to the tibial plateau were compared. Positive or negative values denoted deviation from parallel relative to the tibial plateau.
Results—Postoperative TPA, fragment reduction, and proximodistal osteotomy orientation were not significantly different between groups. Craniocaudal osteotomy orientation was significantly different ($P < .005$) from the tibial plateau. Median deviations were −4.0° (group 1), 11.8° (group 2), 11.2° (group 3), and 0.2° (group 4). Group 1 was not significantly different from group 4.
Conclusions—A jig is not essential for osteotomy orientation, tibial plateau rotation, or fragment reduction. Comparable results were achieved performing a vertical osteotomy with the tibia slightly internally rotated (10°–15°) and parallel to the table surface.
Clinical Relevance—TPLO without use of a jig reduces surgical trauma, is less time consuming, and reduces cost.

INTRODUCTION

CRANIAL CRUCIATE ligament (CCL) rupture, a common disease of the canine stifle joint[1,2] causes hind limb lameness and progressive secondary osteoarthritis.[3–8] A healthy CCL counteracts a biomechanical force called cranial tibial thrust (CTT). In the CCL-deficient stifle, CTT leads to a cranial translation movement of the tibia during weight bearing.[9–11] Tibial plateau leveling osteotomy (TPLO) converts CTT into caudal tibial thrust, and prevents cranial tibial translation during weight bearing.[12,13] During TPLO, after semicircular osteotomy at the level of the proximal aspect of the tibia, the tibial plateau is rotated to achieve an angle of 5° and secured with a bone plate.[14,15] A parallel craniocaudal and proximodistal orientation of the osteotomy relative to the tibial joint surface is critical to prevent limb malalignment. Fragment reduction is also necessary for maximal

From the Department of Small Animal Medicine, Faculty of Veterinary Medicine, University of Leipzig, Leipzig, Germany; Tierklinik Dr. Reif, Böbingen, Germany; and AddStat Statistics, Leipzig, Germany.

Study performed at the University of Leipzig.

Presented at the Resident Forum, 15th Annual Scientific Meeting of the European College of Veterinary Surgeons. Seville, Spain, June 29–July 1, 2006.

Address reprint requests to Dr. Kay Schmerbach, Department of Small Animal Medicine, Faculty of Veterinary Medicine, University of Leipzig, An den Tierkliniken Leipzig, 23 04103, Germany. E-mail: schmerbach@kleintierklinik.uni-leipzig.de

Submitted August 2006; Accepted October 2006

0161-3499/07
doi:10.1111/j.1532-950X.2007.00248.x

stability and to prevent limb malalignment.[16,17] Use of a jig (Tibial Plateau Leveling Jig, Slocum Enterprises Inc., Eugene, OR) developed for osteotomy orientation, connection of the fragments during tibial plateau rotation, and correction of tibial deformities is recommended during TPLO.[17]

Jig use lengthens surgical time. The jig is secured in position by two 3 mm threaded pins which traumatize the tibia, and a second incision wound is needed for distal pin insertion. The pin stabilizing the jig to the proximal fragment can interfere with the pins necessary for tibial plateau rotation and temporary fixation of the fragments, and with the bone screws. Instrument cost is also a disadvantage. To our knowledge, the benefit of using a jig during TPLO has not been shown.

We evaluated the influence of jig use on postoperative tibial anatomy. Osteotomy orientation, fragment reduction, and postoperative tibial plateau angle (TPA) were determined on hindlimbs without stifle pathology or tibial deformity. Initially, we hypothesized that use of the jig would not improve osteotomy orientation, fragment reduction, and postoperative TPA, and that use of fluoroscopy to ensure femoral condyle superimposition would result in more accurate osteotomy orientation. In a second study, we investigated the influence of internal tibial rotation on the accuracy of osteotomy orientation. We hypothesized that internal tibial rotation during osteotomy would yield comparable results to use of the jig during TPLO.

MATERIAL AND METHODS

Dogs (n = 20; weight, > 23 kg) euthanatized for reasons unrelated to the study were used. Mediolateral and caudocranial radiographic projections of the tibia, centered on the stifle joint, were taken and TPA was measured by the method of Slocum and Devine.[18] There were no radiographic signs of osteoarthritis or tibial deformity. TPLO (described below) was performed on each limb by one person (K.S.) who had experience with > 50 TPLO's before this study.

PART I

Surgical Technique

Initially, 3 methods of positioning for TPLO were studied. Each group had 10 limbs (5 left, 5 right). Method was assigned randomly to a group of limbs by drawing lots.

Group 1: TPLO Using a Jig

Dogs were positioned in dorsal recumbency and the hair was clipped from the tarsal joint to the proximal femur. The unclipped distal limb was wrapped and the dog was draped from the mid-femur. A medial approach to the proximal tibia was performed. A TPL-jig (Tibial Plateau Leveling Jig®, Standard Size, Slocum Enterprises Inc., Eugene, OR) was placed on the tibia and TPLO was completed according to instructions provided in the TPLO course using a 24 mm TPLO-sawblade (TPLO Biradial Sawblade®, Slocum Enterprises Inc.).[17] During osteotomy, the blade was held parallel to the distal jig pin under bi-directional guidance by the surgeon (proximodistal) and the assistant (craniocaudal).

Group 2: TPLO without Jig Use or Control of Femoral Condyle Superimposition

Dogs were prepared as described for group 1, then positioned in lateral recumbency with the procedure limb resting on the table top; the contralateral hind limb was fixed cranially. The sagittal plane of the tibia was positioned parallel to the table top with correct positioning estimated by the surgeon and assistant. The TPL-jig was not applied. Assuming parallel orientation of the sagittal plane of the tibia to the table top, the osteotomy was performed vertically under bi-directional guidance by the surgeon (proximodistal) and the assistant (craniocaudal). Temporary fixation and plate application was performed as described by Slocum and Devine.[17]

Group 3: TPLO without Jig Use but with Controlled Superimposition of the Femoral Condyles

Positioning and draping of the dogs was performed as for group 2. Immediately before performing the osteotomy, superimposition of the femoral condyles was controlled by use of a c-arm (BV 300, Philips Medical Systems, Eindhoven, the Netherlands) with the X-ray beam-oriented perpendicular to the table top and centered on the stifle joint. Patient positioning was adjusted by placing towels under the hip, stifle, or tarsal joint until femoral condyle superimposition was achieved. TPLO was performed as described for group 2.

Measurements

Postoperatively, mediolateral radiographic projections were taken and TPA measured using the method of Slocum.[18] Tibiae were dissected from the hind limbs and all soft tissues removed. Gaps between the proximal and the distal fragment were measured with a caliper at their largest width on the medial and lateral aspect (Fig 1A, B). The bone plate was removed.

Measurements were made on the proximal tibial fragment using a protractor. Two reference lines on the tibial plateau were established.

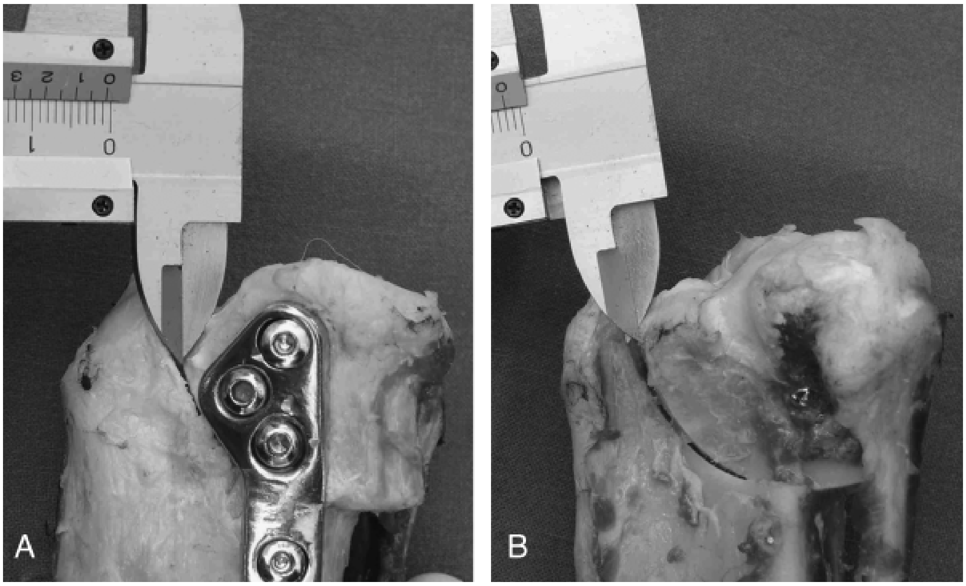

Fig 1. (A) Measurement of a medial gap between the proximal and the distal fragment. A calliper is used to measure the gap at its largest width. A gap of 0.4 mm is present. (B) Measurement of a lateral gap between the proximal and the distal fragment. A caliper is used to measure the gap at its largest width. A gap of 2.0 mm is present.

Reference line 1 (RL1): The connection of the caudal margin of the lateral and medial tibial plateau represented the reference line for measurements in the craniocaudal direction (Fig 2).
Reference line 2 (RL2): The tangential connection of the most distal points of the lateral and medial tibial plateau represented the reference line for measurements in the proximodistal direction (Fig 3).

Parallel orientation of the osteotomy to the reference line (RL1 or RL2) was defined as 0°. Open angles to the lateral aspect were reported as positive, and open angles to the medial aspect as negative values.

(a) Craniocaudal orientation of the osteotomy in relation to the tibial plateau: The caudal margin of the medial and lateral tibial plateau (representing RL1) was placed on the base of the protractor. The protractor arch was aligned with the cranioproximal border of the osteotomy (Fig 2).
(b) Proximodistal orientation of the osteotomy in relation to the tibial plateau: The caudodistal end of the osteotomy zone was placed on the base of the protractor, and the protractor arch was oriented parallel to RL2 (Fig 3).
(c) In group 1, additional measurements were taken. The proximal TPL-jigpin was reinserted in its original hole in the proximal tibia and aligned with the protractor base. The orientation of the pin in relation to RL1 and RL2 was measured as described for the measurement of the osteotomies. The proximodistal and craniocaudal orientation of the pin in relation to the osteotomy was also determined.

Tibiae were number coded. All measurements were repeated in 3 independent measurement cycles by 2 investigators (K.S., C.B.) blinded to the number codes. Means of these 6 measurements were analyzed.

PART II

TPLO was performed on both stifles of 5 additional dogs (group 4) with a modified positioning technique based on results obtained from analysis of groups 1–3.

Surgical Technique in Group 4

Dogs were prepared and positioned as described for group 2. With the hock manually held against the table top, the toes were elevated using a 3-cm pad. Using this position, the tibial length axis was still parallel to the table top but internally rotated by 10°–15°. The osteotomy was performed vertically as described for groups 2 and 3. This modified positioning technique changed craniocaudal but not proximodistal osteotomy orientation with respect to the tibial plateau.

Measurements in Group 4

After osteotomy, all soft tissues were removed from the proximal tibial fragment. The proximodistal and craniocaudal orientation of the osteotomy in relation to

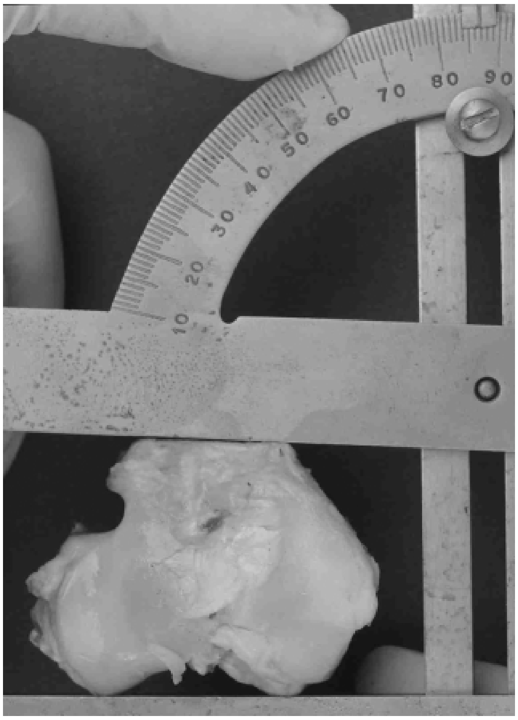

Fig 2. Measurement of the craniocaudal orientation of the osteotomy in relation to the tibial plateau. The caudal ends of the medial and lateral tibial plateau (RL1) are placed on the base of the protractor. The protractor bar is placed on the cranioproximal edge of the osteotomy. Ninety degrees on the protractor are defined as a parallel orientation (0°) of the osteotomy in relation to RL1. An open angle to the lateral of 3.5° is measured.

the tibial plateau was measured as described for the groups 1–3.

Statistical Analysis

Data were expressed as median (range). Measurements of body weight, pre- and postoperative TPA, medial and lateral osteotomy gap, proximodistal and craniocaudal orientation were evaluated using Kruskal–Wallis rank sum analysis. Significant differences were analyzed between pairs using Mann–Whitney *U* Test. For analyses within groups, a Wilcoxon-signed rank test was used. A P-value $<.05$ was considered significant. Statistical analyses were performed with software (SPSS for Windows, version 11.0, SPSS GmbH Software, Munich, Germany). The power of the tests was calculated using nQuery Advisor, version 6.01 (Statistical Solutions, Corc, Ireland).

RESULTS

Median dog weight was 33.4 kg (range, 25.3–41.2 kg) with no significant difference between groups ($P = .16$, power 93%).

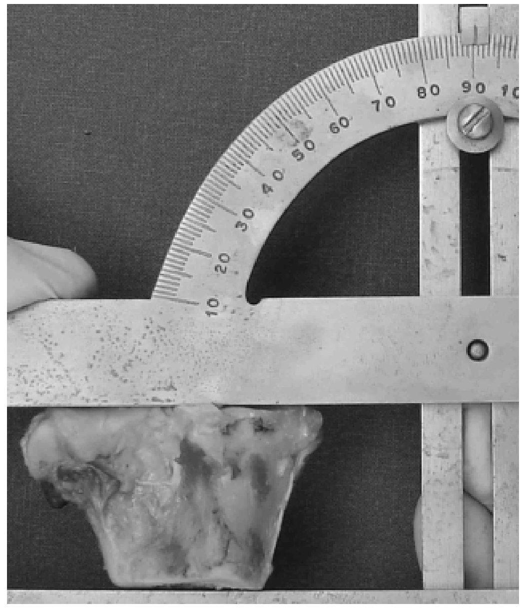

Fig 3. Measurement of the proximodistal orientation of the osteotomy in relation to the tibial plateau: The caudodistal end of the osteotomy zone is placed on the base of the protractor. The protractor bar is oriented parallel to the tangential connection of the most distal points of the lateral and medial tibial plateau (RL2). Ninety degrees on the protractor is defined as a parallel orientation (0°) of the osteotomy in relation to RL2. An open angle to the medial aspect of –0.5° is measured.

Pre- and Postoperative TPA

Median preoperative TPA was 26° (range, 22°–29°) for groups 1–3 with no significant difference between groups ($P = .69$). For groups 1–3, median postoperative TPA was 6.3° (3.0°–9.0°); group 1 = 5.3° (3°–9°); group 2 = 6.8° (3°–9°); and group 3 = 6.6° (3°–8°). These was no significant difference ($P = .52$; Fig 4) between groups (power: 89%).

Gap Between the Proximal and Distal Fragment

For groups 1–3, the gap between the proximal and the distal fragment had a median width of 1.2 mm (0–3.3 mm) laterally, and 0.5 mm (0–1.4 mm) medially. There was no significant difference between groups (lateral: $P = .45$; power 82%; medial: $P = .99$, power 99%), but in groups 1 and 2 there was a significant difference between the medial and the lateral gap with the lateral gap being wider than the medial gap ($P < .0005$). In group 1, median gap was 1.8 mm (0.6–3.3 mm) laterally and 0.5 mm (0.2–1.1 mm) medially ($P < .01$). In group 2, median gap was 1.1 mm (0.4–3.2 mm) laterally and 0.6 mm (0–1.4 mm) medially ($P < .04$). In group 3, median gap was 1.1 mm (0–3.1 mm) laterally and 0.6 mm (0–1.3 mm) medially. In this group, the difference was not significant ($P = .13$; Fig 5).

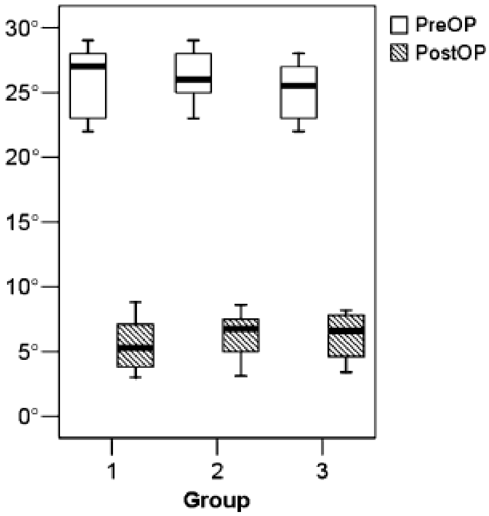

Fig 4. Boxplots representing pre- and postoperative TPA in groups 1–3 (n = 10/group). Neither preoperative ($P = .69$) nor postoperative ($P = .52$) TPA were significantly different between groups.

Craniocaudal and Proximodistal Osteotomy Orientation

The craniocaudal orientation of the osteotomy in relation to RL1 (0°) was significantly different between groups 1–3 ($P < .0005$) The median was −4.0° (−12.2° to 9.2°) in group 1, 11.8° (2.1°–15.3°) in group 2, and 11.2° (4.8°–16.6°) in group 3. There was a significant difference between groups 1 and 2 ($P < .0005$), and between groups 1 and 3 ($P < .0005$).

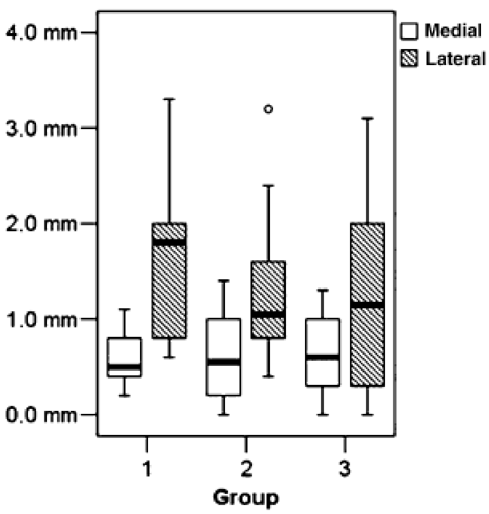

Fig 5. Boxplots representing the lateral and medial gap between the proximal and distal fragment in groups 1–3 (n = 10/group). There was no significant difference between groups in lateral or medial gap (lateral: $P = .45$, medial: $P = .99$), but lateral gap was significantly wider than medial gap in group 1 ($P < .01$) and 2 ($P < .04$).

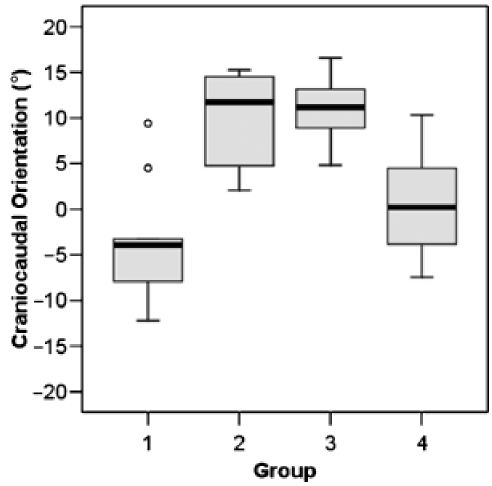

Fig. 6. Boxplots representing the craniocaudal orientation of the osteotomy in relation to RL1 (n = 10/group). There was a significant difference between groups ($P < .0005$). No significant difference could be shown between groups 1 (jig used) and 4 ($P = .12$). In group 1, 2 values were higher than the upper quartile range plus 1.5 times the interquartile range. Therefore they are shown as single dots in the boxplot.

Measurements for groups 2 and 3 indicated craniolateral deviation of the osteotomy. To compensate for this deviation, the tibia was rotated internally during the osteotomy in group 4. For group 4, median deviation of 0.2° (−7.4° to 10.33°) in relation to RL1 was recorded. There were significant differences between groups 2 and 4 ($P = .001$), and between groups 3 and 4 ($P < .0005$). In contrast, between groups 1 and 4, no significant difference was detected ($P = .12$; Fig 6).

Proximodistal orientation of the osteotomy in relation to RL2 (0°) was neither significantly different between groups 1–3 ($P = .71$) nor between the 4 groups ($P = .68$; power 99%). Median deviation from 0° was −2.4° (−6.1° to 3.7°) in group 1, −5.4° (−7.1° to 2.8°) in group 2, −0.8° (−2.1° to 1.7°) in group 3, and −1.0° (−5.8° to 1.6°) in group 4 (Fig 7).

Orientation of the Proximal Jig Pin in Group 1

In group 1, the median angle of the proximal TPL jig-pin in relation to RL2 was −2.5° (−6.0° to 2.3°), in relation to RL1 it was −4.1° (−13.3° to 9.3°). The median angle between the jig-pin and the cranial osteotomy border was −0.3° (−1.9° to 1.3°), the median angle to the distal border of the osteotomy was −0.7° (−1.7° to 2.2°). The angle of the pin and the angle of the osteotomy in relation to the tibial plateau were not significantly different in both orientations (craniocaudal: $P = .26$, power 99%, proximodistal: $P = .84$, power 99%). Thus,

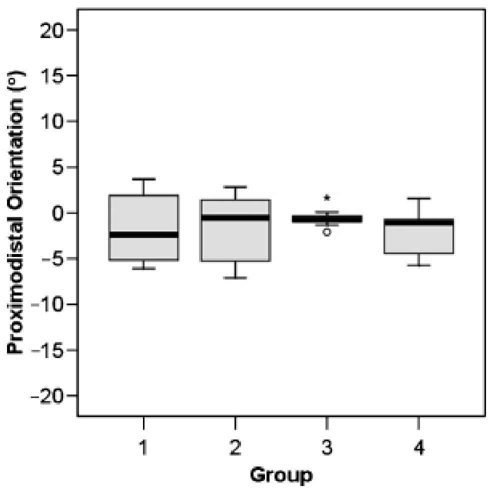

Fig 7. Boxplots representing the proximodistal orientation of the osteotomy in relation to RL2 (n = 10/group). The lowest range is present in group 3. There was no significant difference between groups (*P* = .68).

a parallel orientation of the pin and the osteotomy had been achieved.

DISCUSSION

As an alternative to conventional TPLO in dorsal recumbency (group 1) we positioned dogs in lateral recumbency and performed a vertical osteotomy without a TPL-jig (groups 2–4). Whereas postoperative TPA, fragment reduction, and proximodistal osteotomy orientation was not significantly different between methods, there was a significant difference in the craniocaudal osteotomy orientation. Performing TPLO in lateral recumbency without use of a TPL-jig resulted in a craniolateral deviation of the osteotomy of $\sim 15^\circ$ compared with the conventional TPLO method.

To measure osteotomy orientation, distinct anatomic landmarks were used to determine the 2 reference lines RL 1 and RL 2. These lines connected the most caudal (RL 1) and the most distal (RL 2) points of the medial and lateral tibial plateau. We defined the orientation to be optimal when the osteotomy was parallel to both reference lines. In group 1, dogs were positioned in dorsal recumbency, as recommended by Slocum and Devine.[17] The proximal jig pin was oriented parallel to the estimated rotation axis of the stifle joint. Our results did not show a significant difference between jig pin orientation and osteotomy orientation in relation to the reference lines. Therefore proximal jig pin placement was the most crucial step which determined osteotomy orientation. In the groups where the jig was not used, true lateral placement of the stifle joint was estimated by limb positioning with respect to the table top (groups 2, 4), or by fluoroscopic superimposition of the femoral condyles (group 3). In these groups, perpendicular orientation of the stifle joint rotation axis to the table top was assumed and thus, the osteotomy was performed in a vertical orientation. Clinically, stifle exploration should be performed before TPLO and patient positioning may need to be changed during the procedure. To achieve conditions comparable with a clinical setting, positioning of the leg in groups 2–4 was adjusted after draping.

Only craniocaudal orientation of the osteotomy in relation to the tibial plateau was significantly different between groups 1–3. The conventional TPLO method (group 1) resulted in a median craniocaudal osteotomy orientation of -4.0° (range, -12.2° to 9.2°) which was close to our reference lines. In groups 2 and 3 however, the osteotomies were directed more craniolaterally with a median angle of 11.8° (2.1° to 15.3°) and 11.2 (4.8° to 16.6°), respectively. Thus, performing TPLO in lateral recumbency without use of a jig may lead to a craniolaterally deviated osteotomy orientation with a difference of $\sim 15^\circ$. In group 3, this deviation was detectable despite fluoroscopic evidence of femoral condyle superimposition. This means that controlling femoral condyle superimposition had no advantage over estimating the correct position of the limb on the table top for osteotomy orientation. The most probable explanation is that, even though the femoral condyles are superimposed, some degree of tibia rotation is possible. This means that true lateral positioning of the femur does not lead to a true lateral position of the tibia. In our study, intact stifle joints were investigated.

In a cruciate deficient stifle, rotational instability is even more pronounced.[19] Hence there is greater risk of incorrect patient positioning in a clinical setting. Additionally, with a draped patient it is more difficult to estimate tibial rotation than estimating a parallel position of the tibia length axis to the table top which increases the risk for a craniocaudal osteotomy deviation. To correct the difference in craniocaudal osteotomy orientation we added a fourth group in the second part of the study. After patient positioning in lateral recumbency, the tibia was rotated internally 10°–15° and kept in this position during osteotomy by use of a support (3 cm pad) under the foot while the hock remained on the table top. The osteotomy was oriented vertically. The median craniocaudal osteotomy orientation with respect to the reference line was 0.2° (range, -7.4° to 10.33°) for group 4; a significant difference to group 1 was not detected. Thus, if the TPLO is performed in lateral recumbency with the saw blade oriented vertical, the tibia should be slightly internally rotated.

The proximodistal orientation of the osteotomy relative to the tibial plateau was not significantly different between groups. The least deviation from the reference line was achieved when superimposition of the femoral condyles was adjusted under fluoroscopic control. However, a similar range, lack of significant measurement difference (groups 2 and 3), and lack of an advantage for craniocaudal osteotomy orientation, argue against use of fluoroscopy, mitigating radiation exposure, time, and expense.

It was recently reported that incorrect osteotomy orientation with respect to the tibial plateau will cause tibial malalignment and that fragment reduction may play a greater role in inducing deformities than osteotomy deviation.[16] The precision of fragment reduction can be quantified by measuring the width of a remaining lateral or medial gap between the fragments. In groups 1–3, fragment reduction was measured, and no significant difference was detected. Thus, use of a jig did not prevent gap formation between fragments. In groups 1 and 2, the osteotomy gap was significantly wider laterally than medially. TPLO is performed from the medial side and the lateral aspect of the osteotomy is not observed. Although fragment reduction on the medial side can be observed by the surgeon, there was an overall median gap of 0.5 mm. Plate contouring to the modified shape of the proximal tibia after tibial plateau rotation may play a role in gap formation. After rotation of the proximal fragment, the narrow cranial part of the tibia has to be fixed to the broader caudal part. Even if the step between the fragments is lessened or the proximal fragment is pulled medially, the fragments are not anatomically reduced. Additionally, in the cranial osteotomy zone, cancellous and cortical bones are rotated against each other because of the triangular cross-section of the proximal tibia. Bone plate application may push the stronger cortical bone into soft cancellous bone leading to a gap formation on the opposite side. We measured the gap at its largest width, which was always on the most cranioproximal part of the osteotomy. In this location, it is difficult to assess the osteotomy because of overlying soft tissue (patellar tendon insertion, joint capsule, retropatellar fat pad, periosteum). Also, in this region a temporary fixation pin is placed which could distract the osteotomy in its cranial aspect.

Osteotomy distraction may also result from the tibia compression mechanism which tends to force the proximal fragment in a caudodistral direction, leading to compression in the caudodistal and distraction in the cranioproximal part of the osteotomy. After TPLO, the distal part of the osteotomy was completely reduced in all specimens. It is unlikely that a cranioproximal gap <2 mm, and a difference between the lateral and the medial gap <1 mm, as occurred in most specimens leads to a clinically noticeable malalignment.

Jig use lengthens surgical time and its application causes patient trauma. During jig application, the surgeon has to subjectively estimate the stifle joint flexion-extension-axis, place a pin parallel to this axis, and finally orient the osteotomy parallel to a second pin placed distally through the jig into the tibia. Vertical saw blade orientation with the dog in lateral recumbency without use of a TPL-jig presumes correct patient positioning, in particular parallel orientation of the tibia to the table top. We believe that jig application is more demanding and, especially for surgeons not experienced with the method, more prone to error than the positioning technique described, which is similar to the positioning used during radiography to obtain mediolateral TPLO projections. Surgeons not experienced with TPLO might have less difficulty achieving correct osteotomy orientation when the patient is in a fixed position and when the saw is aligned with vertical objects in the surgical room.

In our dogs, jig application had no advantage on postoperative TPA, fragment reduction, and proximodistal osteotomy orientation. The craniocaudal osteotomy deviation in groups 2 and 3 could be compensated by internal rotation of the tibia during osteotomy. In patients with tibial varus, valgus, and rotational deformities the TPL-jig may be beneficial because limb alignment can be evaluated and performed while the position of the fragments is secured. Because we excluded dogs with tibial malalignment, this potential advantage of using a TPL-jig was not evaluated.

TPLO relies on subjective estimation of correct osteotomy orientation and cannot be objectively performed. To have comparable conditions during surgery in all groups all procedures were performed by the same surgeons, the instructions by Slocum and Devine were closely followed in group 1, and all procedures were performed with every step observed bi-directionally.[17] Also, measurements were repeatedly taken by the same observers. Because we only used limbs without stifle pathology, measurement points for TPA and osteotomy orientation were not obscured by osteoarthritic changes.

Therefore, despite its subjective character, our study led us to conclude that the TPLO jig is not needed to achieve correct osteotomy orientation, tibial plateau rotation, and fragment fixation in dogs without tibial deformities. However, lateral patient positioning in combination with a vertical osteotomy should be adjusted by internally rotating the tibia $\sim 15^\circ$ to obtain similar results to the method of Slocum.

REFERENCES

1. Paatsama S: Ligament injuries of the canine stifle joint. A clinical and experimental study. Thesis, Helsinki, Finland, 1952.

2. Marshall JL, Olsson SE: Instability of the knee. A long-term experimental study in dogs. J Bone Joint Surg Am 53: 1561–1570, 1971
3. Flo GL, DeYoung D: Meniscal injuries and medial meniscectomy in the canine stifle. J Am Anim Hosp Assoc 14:683–689, 1978
4. Bennett D, May C: Meniscal damage associated with cruciate disease in the dog. J Small Anim Pract 32:111–117, 1991
5. Korvick DL, Pijanowski GJ, Schaeffer DJ: Three-dimensional kinematics of the intact and cranial cruciate ligament-deficient stifle of dogs. J Biomech 27:77–87, 1994
6. Bellenger CR: Knee joint function, meniscal disease, and osteoarthritis. Vet Q 17(Suppl 1): S5–S6, 1995
7. Smith GN, Mickler EA, Albrecht ME, et al: Severity of medial meniscus damage in the canine knee after anterior cruciate ligament transection. Osteoarthritis Cartilage 10:321–326, 2002
8. Liu W, Burton-Wurster N, Glant TT, et al: Spontaneous and experimental osteoarthritis in dog: similarities and differences in proteoglycan levels. J Orthop Res 21:730–737, 2003
9. Henderson RA, Milton JL: The tibial compression mechanism: a diagnostic aid in stifle injuries. J Am Anim Hosp Assoc 14:474–478, 1978
10. Slocum B, Devine T: Cranial tibial wedge osteotomy: a technique for eliminating cranial tibial thrust in cranial cruciate ligament repair. J Am Vet Med Assoc 184:564–569, 1984
11. Slocum B, Devine T: Cranial tibial thrust: a primary force in the canine stifle. J Am Vet Med Assoc 183:456–459, 1983
12. Reif U, Hulse DA, Hauptman JG: Effect of tibial plateau leveling on stability of the canine cranial cruciate deficient stifle joint: an in vitro study. Vet Surg 31:147–154, 2002
13. Warzee CC, Dejardin LM, Arnoczky SP, et al: Effect of tibial plateau leveling on cranial and caudal tibial thrusts in canine cranial cruciate deficient stifles: an in vitro experimental study. Vet Surg 30:278–286, 2001
14. Slocum B, Devine T: Tibial plateau leveling osteotomy for repair of cranial cruciate ligament rupture in the canine. Vet Clin North Am Small Anim Pract 23:777–795, 1993
15. Slocum B, Devine T: Tibial plateau leveling osteotomy for cranial cruciate ligament rupture, in Bojrab MJ (ed): Current Techniques in Small Animal Surgery (ed 4). Philadelphia, PA, Williams & Wilkins, 1998, pp 1209–1215
16. Wheeler JL, Cross AR, Gingrich W: In vitro effects of osteotomy angle and osteotomy reduction on tibial angulation and rotation during the tibial plateau-leveling osteotomy procedure. Vet Surg 32:371–377, 2003
17. Devine T, Slocum B, Boulay J, Gores B: *TPLO - Surgical technique*. TPLO Seminar Course documents, Eugene, OR, 2003.
18. Devine T, Slocum B, Boulay J, Gores B: *Tibial plateau measurement*. TPLO Seminar Course documents, Eugene, OR, 2003.
19. Arnoczky SP, Marshall JL: The cruciate ligaments of the canine stifle: an anatomical and functional analysis. Am J Vet Res 38:1807–1814, 1977