Preoperative planning for tibial plateau leveling osteotomy based on proximal tibial width

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ABSTRACT. The purpose of this study was to evaluate the applicability and feasibility of a novel preoperative planning method for tibial plateau leveling osteotomy (TPLO) based on the width of the proximal tibia. All TPLO procedures were performed by the same surgeon. In preoperative planning, the width of the tibial crest to the caudal edge of the medial tibial plateau (W) was measured, and the saw blade size that was closest to the distance between the point of the cranial third W and the intercondylar tubercles was selected. The postoperative tibial plateau angle (TPA), distance of eccentricity (DOE), and minimum thickness of the tibial tuberosity remaining cranial to the osteotomy (tibial tuberosity width; TTW) were documented. Complications in the perioperative and follow-up periods were documented. Thirty-one TPLO procedures were performed in 28 dogs, including both small and large breeds. The postoperative TPA was 8.4 ± 2.0° and the DOE was 3.55 ± 2.88 mm. The ratio of the TTW to the preoperative W was 0.27 ± 0.06. There were no major complications, such as fractures of the tibial tuberosity or implant breakage. This preoperative planning method allowed appropriate planning for TPLO with a clear index that was based on the size of the tibia rather than the breed or weight of the dog. This method should be of benefit to the surgeon, whether an expert or a novice, and contribute to the success of TPLO.

KEY WORDS: cranial cruciate ligament, dog, preoperative planning, tibial plateau leveling osteotomy
cruciate ligaments, and the proximal bone segment should be large enough for adequate implant setting. We have devised a preoperative planning method for selection of a saw blade of adequate size, the position of the osteotomy, and the implant that is based not on body weight but on the size of the proximal tibia of the individual dog. The purpose of this prospective study was to evaluate the applicability and feasibility of our method in dogs undergoing TPLO.

**MATERIALS AND METHODS**

**Case selection**

Dogs that were diagnosed with unilateral or bilateral cranial cruciate ligament rupture and presented for TPLO at The University of Tokyo, Veterinary Medical Center between June 2015 and September 2016 were included in the study. The age, sex, breed, body weight, and operated limb were recorded in all cases. Dogs were excluded if the radiographs obtained preoperatively and immediate postoperatively showed that the mediolateral stifle was not correctly positioned. The position was deemed to be correct if the separation of the superimposed femoral condyles was ≤2 mm on the radiographs [9].

**Preoperative planning**

Mediolateral radiographs were obtained with the stifle and tarsocrural joints each positioned at 90° of flexion. First, the TPA was measured as previously reported [15]. Second, the TPLO saw blade was selected as follows (Fig. 1A). The width of the tibial crest to the caudal edge of the medial tibial plateau (W) was measured and the point of the cranial third W (1/3W) was marked. The distance between the 1/3W and the intercondylar tubercles (R) was measured. The radius of the TPLO saw blade that was closest to R was selected from the 12, 15, 18, 21, 24, 27, and 30 mm sizes, manufactured by Johnson & Johnson K.K. (Depuy Synthes Japan, Tokyo, Japan) or New Generation Devices (Glen Rock, NJ, USA) which was selected either one of devices in random manner.

Next, an osteotomy line with a radius that was the same as that of the selected saw blade was drawn at the middle point of the tibial intercondylar tubercles. Two distances (D1 and D2) were measured as previously reported [18] to determine the intraoperative landmarks. D1 is the distance from the insertion of the patellar tendon to the osteotomy perpendicular to the cranial border of the tibia. D2 is the distance between the insertion of the patellar tendon and the exit of the cranioproximal osteotomy from the tibia (Fig. 1B).

Finally, a maximally sized TPLO plate for placement on the proximal bone segment was selected from the 2.0, 2.4, 2.7, 3.5 mm, and 3.5 mm Broad LCPTM system manufactured by Johnson & Johnson K.K. (Depuy Synthes Japan, Tokyo, Japan) or the 2.5 mm FixinTM mini system manufactured by TraumaVet SRL (Rivolito, Italy).

**Surgical procedure and postoperative care**

All dogs were induced with intravenous propofol (veterinary propofol injection 1% “Mairan”, MSD Animal Health K.K.,
Tokyo, Japan). General anesthesia was maintained using 1–2% isoflurane (Isofuru®; Zoetis Japan K.K., Tokyo, Japan) in oxygen. For analgesia, 0.25% bupivacaine (Marcaine®; 0.1 ml/kg; Aspen Japan K.K., Tokyo, Japan) was administered for sciatic and femoral nerve block, and ketamine (Ketalar®, 1 mg/kg/hr; Daiichi Sankyo Propharma Co., Ltd., Tokyo, Japan) and fentanyl (Fentanyl Injection 0.5 mg “Janssen”, 10 µg/kg/hr, Janssen Pharmaceutical K.K., Tokyo, Japan) were infused at a constant rate perioperatively. Antibiotic agents were administered intravenously (cefazolin sodium 20 mg/kg; Nichi-Iko Pharmaceutical Co., Ltd., Toyama, Japan) 40 min. before surgery and every 2 hr thereafter during the perioperative period. An oral non-steroidal anti-inflammatory drug, i.e., firocoxib (Previcox®, 5 mg/kg every 24 hr; Boehringer Ingelheim Animal Health Japan Co., Ltd., Tokyo, Japan) or robenacoxib (Onsior®, 2 mg/kg, every 24 hr; Elanco Japan K.K., Tokyo, Japan), was administered for 3–5 days after surgery. Arthroscopy or subpatellar arthrotomy was performed in all cases for debridement of the remnants of the cranial cruciate ligament tissue and injured portion of the meniscus.

The surgical procedure was performed as previously described without an alignment jig [16]. A medial surgical approach to the proximal tibia was used. D1 and D2 were measured, and the positions marked using electrocautery. A TPLO saw, the size of which had been predetermined from the preoperative radiographs, was used for the osteotomy. After the osteotomy, a Steinmann pin (2.0 mm or 2.5 mm in diameter) was placed through the proximal bone segment and used to rotate the proximal segment until the distance required to create a postoperative TPA of 5 degrees was reached. Next, a Kirschner wire (1.0 mm or 1.25 mm in diameter) was inserted through the proximal part of the tibial tuberosity to the proximal bone segment for temporary fixation. The proximal bone segment was stabilized with a predetermined TPLO plate, locking head screws, and cortical screws. After the plate setting, Steinman pin and Kirschner wire were removed.

Radiographic assessment

Using preoperative mediolateral radiographs, the ratio of the width of the tibia at the level of the distal end of the tibial tuberosity (dW) (Fig. 1A) to the width of the remaining proximal bone segment (2/3W) was calculated. The bone cutting point at the proximal tibial surface where no ligaments were attached, i.e., between the caudal attachment of the patellar tendon and the cranial attachment of the cranial tibial ligament of the medial meniscus, was also evaluated. The data were then plotted and the ratio of the bone cutting point to the width of this area was then calculated (Fig. 1C).

Postoperative radiographs of the stifle and tibia were obtained immediately after surgery under anesthesia. The postoperative TPA was measured on these radiographs, and the osteotomy site, apposition, implant position, and limb alignment were evaluated. The accuracy of the osteotomy site was evaluated by measuring the distance of eccentricity (DOE). The intended center of the osteotomy (ICO) was determined as previously described. The actual center of the osteotomy (ACO) was identified using a circular template (as in preoperative planning) that was aligned with the tibial osteotomy. The distance between the ICO and ACO was measured and deemed to be the DOE. The direction of eccentricity was determined by measuring the inaccuracy relative to the cranio-caudal (x-axis; L1) and proximal-distal (y-axis; L2) directions (Fig. 2A). The ratio of the DOE to the preoperative W was calculated to standardize the distance by the bone size. The minimum TTW from the insertion of the patellar tendon to the osteotomy was measured and the ratio of the TTW to the preoperative W was calculated (Fig. 2B). All radiographic measurements

Fig. 2. (A) The actual center of the osteotomy (ACO) was identified during preoperative planning using a circular template that was aligned with the tibial osteotomy. The distance between the intended center of the osteotomy (ICO) and the ACO was measured and defined as the distance of eccentricity (DOE). The tibial mechanical axis (solid line, L1) was identified and a perpendicular line (dotted line, L2) that intersected at the ICO was drawn. Lines L1 and L2 were used as the y-axis and x-axis, respectively. (B) The minimum width of the tibial tuberosity between the insertion of the patellar tendon and the osteotomy was measured. The ratio of the width of the tibial tuberosity to the preoperative width of the tibial crest to the caudal edge of the medial tibial plateau (W) was calculated.
were made by the same observer (HF). Follow-up radiographs were obtained at 6–8 weeks postoperatively and as necessary thereafter to evaluate osteotomy healing and complications.

Complications

Complications in the perioperative period and during follow-up were documented. Complications associated with the surgical procedure were classified as major if reoperation was required and minor if manageable without further surgery.

RESULTS

Thirty-one TPLO procedures were performed by the same surgeon (MH) in 28 dogs (Table 1). The dog breeds included Toy Poodle (n=5), Shiba (n=4), mix breeds (n=4), Jack Russell Terrier (n=2), Border Collie (n=2), and one dog of each of the following breeds: Chihuahua, Bernese Mountain Dog, Cavalier King Charles Spaniel, Beagle, Dogo Argentino, German Shepherd, Rottweiler, Whippet, and Dalmatian. The mean age was 7.6 ± 3.4 (range, 1.6–12.8) years and the mean body weight was 19.2 ± 14.3 (range 3.9–60) kg. The dogs included 10 neutered males, 9 neutered females, 2 males, and 7 females. The operated limb was on the left side in 16 dogs and on the right side in 15.

The mean TPA was 28.3 ± 3.2 (range, 22–36) degrees preoperatively and 8.4 ± 2.0 (range 5.1–12) degrees postoperatively. The following saw blade sizes were selected: 12 mm (n=3), 15 mm (n=10), 18 mm (n=3), 21 mm (n=6), 24 mm (n=3), 27 mm (n=4), and 30 mm (n=2). The size of the TPLO plate used was 2.0 mm (n=2), 2.4 mm (n=4), 2.5 mm (n=4), 2.7 mm (n=6), 3.5 mm (n=13), or 3.5 mm broad (n=2).

The mean dW to 2/3W ratio was 1.24 ± 0.15 (range 0.82–1.59). In all cases, the cutting point at the proximal tibial surface was within the area without any ligaments. The ratio of the bone cutting point to the width of this area was 0.40 ± 0.12 (range 0.08–0.65; Fig. 3).

The mean DOE was 3.55 ± 2.88 mm. In 13 (42%) of 31 TPLO procedures, the ACO was located caudal and distal to the ICO (Fig. 4A). The mean DOE/W was 0.10 ± 0.06 (range 0–0.24) and classified by saw blade size. There were no obvious differences

| Table 1. Summary of Tibial plateau leveling osteotomy (TPLO) procedures and postoperative measurements |
|---------------------------------------------------------------|
| Total number of dogs                                         | 28 |
| Total number of stifles                                      | 31 |
| Age (years)                                                  | 7.6 ± 3.4 |
| Weigh (kg)                                                   | 19.2 ± 14.3 |
| Sex (male/ female/ castrated/ spayed)                        | 2 / 7 / 10 / 9 |
| Pre TPA (degree)                                             | 28.3 ± 3.2 |
| Post TPA (degree)                                            | 8.4 ± 2.0 |
| Operated limb (left/right)                                   | 16 / 15 |
| Ratio of dW to 2/3W                                           | 1.24 ± 0.15 |
| Ratio of the proximal bone cutting point to the area without any ligaments | 0.40 ± 0.12 |
| DOE (mm)                                                     | 3.55 ± 2.88 |
| Ratio of DOE to W                                            | 0.10 ± 0.06 |
| Ratio of TTW to W                                            | 0.27 ± 0.06 |

The data are shown as the mean ± standard deviation or number as appropriate. TPA, tibial plateau angle; dW, tibial width of the diaphysis at the distal end of the tibial tuberosity; W, width of the tibial crest to the caudal edge of the medial tibial plateau; DOE, distance of eccentricity; TTW, tibial tuberosity width.

Fig. 3. The ratio of the bone cutting point to the width of that proximal tibial surface without any ligaments attaching. The ratio was plotted on the line that defined the caudal attachment of the patellar tendon as 0 and the cranial attachment of the cranial tibial ligament of the medial meniscus as 1. The mean ratio was 0.40 ± 0.12 (range 0.08–0.65).
between the groups (Fig. 4B). The mean TTW/W was 0.27 ± 0.06 (range 0.19–0.42).

The mean follow-up duration was 157 ± 85.3 (range 55–413) days. Minor complications occurred in five cases (16.1%) during the perioperative and follow-up periods. These complications included superficial wound dehiscence (n=2), tissue swelling (n=1), fibular fracture (n=1), and patellar tendonitis (n=1). Superficial wound dehiscence caused by self-trauma with skin suture in two cases was successfully treated by wound irrigation and administration of oral antibiotic medication (cefalexin, 20 mg/kg, every 12 hr). In one case, a proximal fibular fracture without fragment displacement was detected on the immediate postoperative radiograph that had healed without treatment by 4 weeks after surgery. In another case, patellar tendonitis was detected 3 weeks after surgery and treated with a prolonged course of oral non-steroidal anti-inflammatory medication (firocoxib, 5 mg/kg, every 24 hr); resolution was achieved by 8 weeks after surgery. There were no major complications, such as tibial tuberosity fracture or breakage of the implant.

DISCUSSION

Preoperative planning for TPLO is important to ensure a successful procedure and to reduce the risk of complications. The saw blade size influences the size of the remaining TTW and proximal bone segment. In a previous report, it was shown that the ideal TTW was >10 mm in large dog breeds [2]. In another two reports on small dog breeds, the mean TTW values were 7.7 mm and 5.9 mm with no tibial tuberosity fractures in either study [1, 19]. We typically refer to these TTW values according to body weight and physical constitution when selecting a saw blade size. However, it is difficult to apply these values to all dogs. In this study, we determined the saw blade size based on the 1/3W, preserving the ratio of the width of the tibial tuberosity to the width of the tibia of the individual dog in all cases. Appropriate TPLO procedures were performed and there were no major complications, such as tibial tuberosity fracture. In a report that investigated the risk factors for tibial tuberosity fracture after TPLO, the TTW/W of a group with tibial tuberosity fractures was 0.19 and that of a group without was 0.26 [2]. The mean TTW/W in the present study was 0.27, which is approximately equivalent to the value in the group without tibial tuberosity fracture in the previous report. Therefore, the value of 1/3W used in this study can be considered reasonable.

The advantage of our method is that it is also able to keep the size of the proximal bone segment constant according to the size of the individual dog. One of the important elements of TPLO is to fix the proximal bone segment with suitable implants. If the proximal bone segment is too small, while it is possible to ensure a wide tibial tuberosity, the selection of appropriately sized plates becomes difficult. Using our method, the width of the proximal bone segment was 2/3W and the maximum plate that could span this segment was selected. Therefore, there were no implant-related complications, which indicates that the appropriate implant was able to be selected. The mean dW to 2/3W ratio was 1.24 (range 0.82–1.59). Generally, the implant is selected such that the screw size is <1/3 of the bone width. However, in TPLO, given that two or more screws are inserted in the proximal bone side by side, when determining the screw size from the width of the diaphysis of the tibia, it is difficult to install a plate in a proximal bone segment that is smaller than twice the diaphysis of the tibia. Therefore, our method of taking into account the placement of the plate in the proximal bone segment when selecting the size of the implant is considered clinically acceptable.
When setting the osteotomy line, it is also important not to damage the structures present in the proximal tibial surface, including the patellar tendon, cranial tibial ligament of the medial meniscus, and the attachment of the cranial cruciate ligament. Using our method, the cutting position for the proximal tibia was set in the area without these ligaments in all cases, which allowed for a safe osteotomy. The risk of damage to the attachment of the patellar tendon is more likely if the bone cutting position is close to the cranial edge, and there is also a risk of damage to the cranial tibial ligament of the medial meniscus if the cutting position is close to the caudal edge. In this regard the ratio of 1/3 can be considered reasonable. However, the cutting position was on the cranial side in two of our cases (0.08/0.11), both of which were toy poodles. The shape of the proximal tibia in toy poodles is such that the top of the tibial tuberosity tends to be located proximally, so a more appropriate setting ratio would be required in this breed.

The complication rate in this study was equivalent to that in previous reports and all complications were minor. We also measured DOE using methodology similar to that in earlier reports [6, 18]. The mean DOE in this study was 3.55 mm, which is similar to that reported previously. These findings indicate that a slight gap between the preoperative planning and the actual surgical procedure, which was not associated with serious complications. Furthermore, DOE was standardized by tibial width and classified by saw blade size. Although the number of cases in each group was small, there were no obvious differences between the groups. The DOE/W ratio tended vary more widely when the blade size was larger than when it was smaller.

Our preoperative planning method is simple. When using the conventional method to determine the saw blade size and osteotomy position, some elements should be considered concurrently, including the residual TTW, the center of the osteotomy, the size of the proximal bone segment, and the implants used for fixation of the osteotomy. In contrast, our method proceeds step by step. First, we determine the saw blade size depending on the distance between the 1/3W and the intercondylar tubercles (R). Second, the osteotomy line is drawn at the middle point of the tibial intercondylar tubercles. Finally, a TPLO plate of maximum size is used to cover the proximal bone segment. The simplicity of the preoperative planning should be of benefit to the surgeon, whether an expert or a novice, when devising an appropriate plan and contribute to the success of TPLO.

This study has some limitations. The first is the small number of cases, and future studies should include more cases of various sizes and breeds. The second limitation is that we provisionally applied the value of “one-third” to the ratio of the osteotomy line and TTW. However, the result was that there were no major complications, such as tibial tuberosity fracture or implant breakage. As already mentioned, a ratio of 1/3 can be considered reasonable because it allows a safe bone cutting line to be set. However, the shape of the proximal tibia in dogs depends on the breed. Our impression is that the form of the tibia in Toy Poodle and Pembroke Welsh Corgi are different to that in large breeds (Fig. 5). There is likely to be a more appropriate ratio for these breeds.

In conclusion, our method allows appropriate preoperative planning with a clear index that is not dependent on the breed or weight of the dog but is based on the size of the individual proximal tibia.

CONFLICT OF INTEREST. The authors declare no conflicts of interest related to this report.

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