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Learning curve of osteotomy accuracy based on Tibial Plateau Levelling Osteotomy

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Summary

The objective of the study was to assess the learning curve of osteotomy accuracy for a single surgeon based on tibial plateau levelling osteotomy (TPLO). The criterion was the accuracy of achieving a planned osteotomy immediately after surgery compared with that of two experienced surgeons. A literature review was performed, including textbooks, Fossum and Tobias, and journal searches on Google Scholar, ScienceDirect and Pubmed, using the keywords "TPLO", "learning curve", and "training". As of April 2025, it was found that there were no similar studies on the learning curve of osteotomy accuracy. Two studies describe aspects of the TPLO learning curve: one concerns the effect of training on the duration of TPLO, and the other, written by the present author, investigates the learning curve on the basis of TPA. The present study was designed as a retrospective blinded case series with two case controls based on dogs with cranial cruciate ligament disease that had undergone TPLO surgeries (n = 140). Medical records and radiographs for the first 100 TPLO surgeries performed by surgeon A (author) without direct supervision were reviewed, and consecutive numbers from 1-100 were allocated (November 2017-July 2020). Records and radiographs for the last 20 cases of two experienced surgeons B (RCVS Diplomate) (March 2019-June 2020) and C (ECVS Diplomate) (October 2019-June 2020) were used as two comparison groups (further numbers were allocated). Statistics were calculated, and a graph to show the learning curve was created. Improvement in the accuracy of achieving the desired osteotomy position was seen after the first 60 cases. The conclusion and clinical relevance of this study is that to achieve a repeatable outcome in performing osteotomy, a trainee surgeon needs to perform around 60 surgeries.

Keywords: experience, learning curve, surgery, osteotomy, tibial plateau angle, Tibial Plateau Levelling Osteotomy

Cranial cruciate ligament (CCL) disease is the most common cause of hind limb lameness (5, 6). The main treatment options include conservative treatment, extracapsular methods (lateral suture stabilization, Arthrex TightRope, etc.), intracapsular methods and osteotomy techniques (TPLO, tibial tuberosity advancement, CORA-based osteotomy, MMP etc.).

Lateral suture stabilization is the most commonly performed technique for the treatment of CCL disease in veterinary medicine but Tibial Plateau Leveling Osteotomy (TPLO), described in 1987 (13), is one of the most commonly performed surgical techniques in referral centres (7) and can produce the best long-term outcome for the patient (10, 15).

TPLO works by neutralising cranial tibial thrust by changing the tibial plateau angle (TPA). This involves surgical planning, osteotomy, rotation and stabilization of a bone fragment. TPLO is therefore significantly more demanding than extracapsular methods. Unfortunately, the learning process is poorly described (11). Only two studies describe TPLO, and neither focuses on osteotomy itself. One concerns the impact of training on the duration of TPLO, and the other, written by the present author, investigates the learning curve on the basis of TPA (4).

The results of the author's previous study has led to the present one, whose purpose is to describe and assess the learning curve of osteotomy accuracy for a single surgeon based on TPLO. The planned osteotomy was compared with the osteotomy achieved during surgery. These results were compared with those of two experienced surgeons. The hypothesis was that with increasing experience, the osteotomy achieved would be more accurate when compared to the osteotomy planned.

Material and methods

Study design. All surgeries were performed in the same specialist orthopaedic referral practice. Surgeries were performed in the same way throughout the study period. Medical records and radiographs for the first 100 TPLO surgeries performed by surgeon A (author) without direct supervision were reviewed and consecutive numbers from 1 to 100 were allocated (November 2017-July 2020). Records and radiographs for the last 20 cases of two experienced surgeons B (RCVS Diplomate) (March 2019-June 2020) and C (ECVS Diplomate) (October 2019-June 2020) were used as a comparison group (further numbers were allocated).

Inclusion criteria. Dogs were included in the study if they had a confirmed cruciate ligament disease treated by TPLO, complete medical records, as well as pre- and immediate postoperative radiographs. Patients were excluded for incomplete medical records or radiographs.

Radiography and measurements. Orthogonal radiographs of the affected limbs were obtained with the stifle and hock included in each of them. Radiographs were obtained for preoperative and immediately postoperative measurements. Special attention was taken to superimpose femoral condyles on mediolateral views. All radiographs were calibrated using an orthopaedic ball.

Each pair of pre- and immediate postoperative mediolateral radiographs, free of patients' details, were given a randomly allocated number from 1 to 140 using the randomizer.org website to blind the study. The template of the numbers was hidden. TPA was measured on each radiograph with computer software (DICOM Viewer). The osteotomy was planned by placing a digital template of the TPLO blade with the centre of the radius blade over the intertubercular eminence of the tibia (9). The surgeon selected the blade size according to his preference from 21, 24, 27 and 30 mm blades, ensuring that the saw blade was as big as possible, but remaining tibial tuberosity thickness was not smaller then 10 mm (1). Three different measurements were made:

A – from the tip of the tibial tuberosity to the intended cranial end of tibial osteotomy (16);

B – Tibial Tuberosity Thickness planned (TTT plan) – measurement perpendicular to the cranial straight edge of the tibial crest originating from the tip of the tibial tuberosity to the intended osteotomy (16);

C – Radius planned (rad plan) – from the intertubercular eminence of the tibia to the point where the intended osteotomy transects the caudal tibial cortex (16). This measurement was equal to the blade size used in mm.

The following measurements were obtained from postoperative radiographs:

A post – from the tip of the tibial tuberosity to the cranial end of tibial osteotomy (16);

B post – Tibial Tuberosity Thickness postoperative (TTT post) – measurement perpendicular to the cranial straight edge of the tibial crest originating from the tip of the tibial tuberosity to the osteotomy (16);

C post – Radius postoperative (rad post) – from the intertubercular eminence of the tibia to the point where the osteotomy transects the caudal tibial cortex (16).

Surgical technique. All surgeries were performed in the same manner and without a scrub assistant. After measuring TPA (13), osteotomy position was determined as described by Kowaleski and Woodbridge (9, 16) using tibial intercondylar tubercles and the attachment of the patella tendon as landmarks. An appropriate saw radius was selected from the range of 21-30 mm, ensuring that the saw blade was as big as possible, but the remaining tibial tuberosity was not smaller than 10 mm. Each patient underwent a medial arthrotomy to confirm the initial diagnosis and meniscal examination. The next step was the preparation and identification of the osteotomy site. The sartorius muscle was elevated and a TPLO jig was applied. A hypodermic needle was placed in the intercondylar notch and the patella tendon attachment was located. These two points of reference were used by the surgeon to measure and mark the osteotomy site according to the previous measurements. After performing partial osteotomy, the distance for rotation was marked with a Slocum rotation gauge and a bone scribe. The osteotomy was completed, and the bone fragment was rotated to a new position, using Elis's pin as a rotation device. When the bone fragment was in the correct position, a K wire was placed proximal to the insertion of the patella tendon to the proximal bone fragment as a temporary fixation. Point-to-point reduction forceps were used to compress the osteotomy site and a Synthes locking TPLO plate was used for the final stabilisation of the osteotomy. The wound was flushed and stitched in a routine fashion.

Results and discussion

All cases from groups A and C met the inclusion criteria. Post-operative radiographs for one case from group B were of poor quality due to equipment malfunction, so the next case was included in the study.

Breeds included were Labrador Retriever (n = 43), Golden Retriever (16), Crossbreed (17), Husky (7), English Springer Spaniel (7), Border Collie (6), German Shepherd (5), Dog de Bordeaux (5), Staffordshire Terrier (4), Rottweiler (4), New Foundland (4), Akita (3) and other breeds (29).

The weight of the dogs ranged from 16.6 to 72.2 kg. The TPLO blades used ranged from 21 to 30 mm, with a median of 24 mm.

Statistical analyses

Statistical analyses were performed separately for the TTT value and the radius value.

Tibial tuberosity thickness (TTT). The difference between the intended thickness of tibial tuberosity (TTT plan) and the value achieved (TTT post) was calculated. The absolute value of the difference as well as negative and positive values were analysed separately. Score-based CUSUM (17) analysis was performed to determine whether model parameters changed significantly over time. LOESS analysis, moving graph analysis and ROC curve analysis were performed for the values achieved. For the moving graph analysis, the average of results achieved by surgeons B and C was used as a reference point.

Radius. The absolute value of the difference between rad plan and rad post was determined for each measurement (0 "radius difference"). Score-based CUSUM (17) analysis was performed to determine

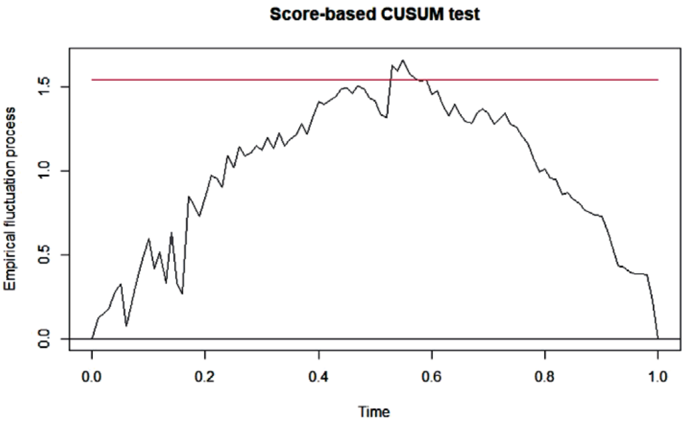

Fig. 1. Learning curve: model fluctuation as a function of time. The corresponding time series OLS-CUSUM process for TTT difference (mm) as the dependent variable

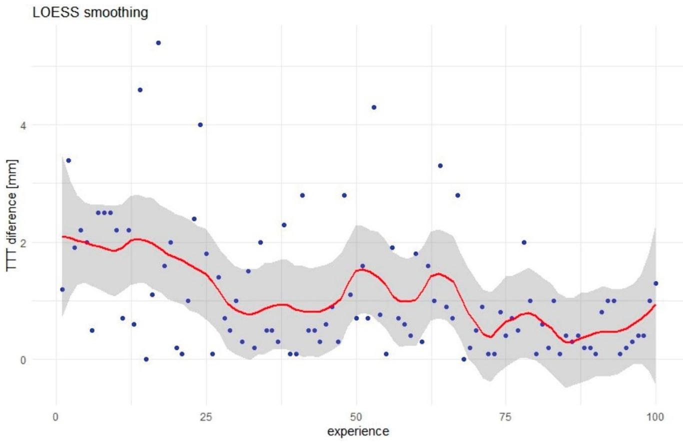

Fig. 2. TTT difference (mm) as a function of time (LOESS method)

whether model parameters changed significantly over time. LOESS analysis, and moving graph analysis were performed for the values achieved. For the moving graph analysis, the average of results achieved by surgeons B and C was used as a reference point.

Many papers describing TPLO suggest that this technique has a steep learning curve. Unfortunately, the learning process is poorly described (11). Only two studies describe TPLO, and neither of them focuses on osteotomy itself. One concerns the impact of training on the duration of TPLO, and the other, written by the present author, investigates the learning curve on the basis of TPA. Some studies show a decrease in surgical complications with the surgeon's increasing experience (2, 8).

Tibial tuberosity thickness

For absolute values, the CUMSUM analysis [f(efp) = 1.66, p = 0.023] showed that the main break time was around case 60 (Fig. 1). The graphical LOESS analysis (Fig. 2) and the moving average graph (N = 5) (Fig. 3) showed stabilisation between cases 60 and 70.

To better understand the dynamics of this parameter and the pattern of changes, a separate analysis was performed for positive values, i.e. thicker tibial tuberosity post osteotomy (n = 57) and negative values, i.e. thinner tibial tuberosity post osteotomy (n = 43). For both values, separate CUSUM analyses were performed.

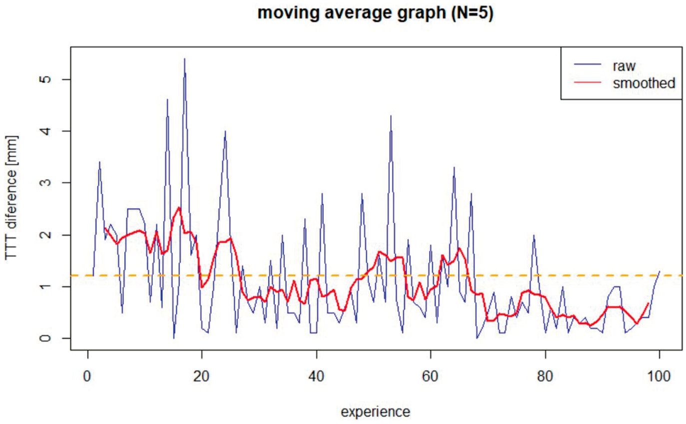

Fig. 3. The error level for TTT difference (mm) as a function of time (moving average method). The yellow line on the graph indicates the average error for an experienced surgeon

For the positive values f(efp) = 1.22, p = 0.273, and for the negative values f(efp) = 1.10, p = 0.298. Unfortunately, neither positive nor negative values were statisticaly significant. This is most likely due to the small number of cases in each group. However, the graphical LOESS analysis (Fig. 4) and the moving average graph (Fig. 5) showed interesting dynamics.

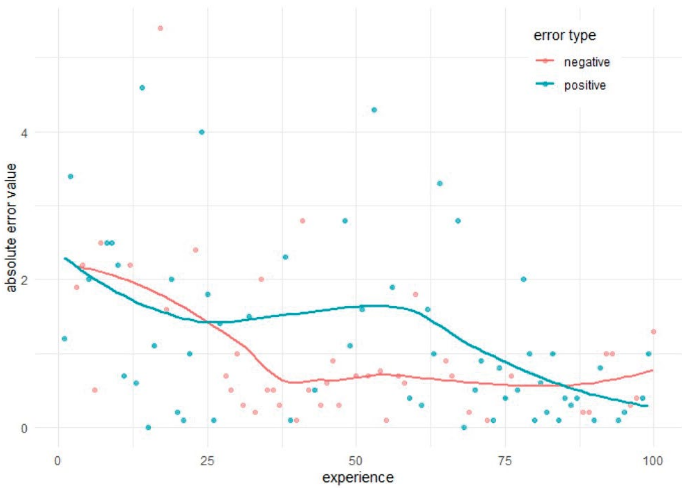

Fig. 4. The error level for TTT difference [mm] as a function of time in interaction with the error type (LOESS method)

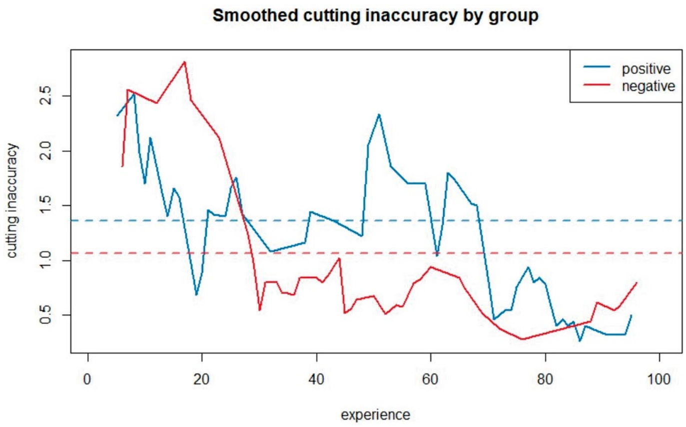

Fig. 5. The error rate for TTT difference [mm] as a function of time in interaction with the error type (moving average method)

The negative values stabilised relatively quickly (around the 40th surgery), whereas for positive values, stabilisation occurred around case 70.

Radius

The graphical LOESS presentations (Fig. 6) and the moving average graph (N = 5) (Fig. 7) show stabilisation around case 60, and at this stage the results of the inexperienced surgeon are similar to those of an experienced surgeon.

Achieving the desired osteotomy position is a very important part of TPLO. A distal centring of the osteotomy leads to a craniodistal translation of the tibial plateau, and post-operative TPA is greater than expected (9). When placed more proximally, the space for safe implant placement is minimised.

Another aspect is a change in the tensile force of the quadriceps and gastrocnemius after TPLO when the centre of the osteotomy is located on the intercondylar eminence (12). This could lead to patellar tendinitis and increase the risk of tibial tuberosity fracture. Benefits of a precise osteotomy in the reduction of tibial tuberosity fractures have been confirmed by many research papers, such as Collins or Bergh (1, 3).

The analysis shows that the values stabilised after around 60 surgeries, and at that point, tibial tuberosity differences and radius differences became similar to those for experience surgeons. The quicker stabilisation of negative results for TTT post was an interesting finding. It is most likely due to the known risk of tibial tuberosity fracture with a thicker fragment (1). A less experienced surgeon may consciously try to perform the surgery more safely. A similar pattern was noted by Tan (14), where 79% of osteotomies were positioned distal and caudal.

There are several limitations to this study, including its retrospective nature. Only one inexperienced surgeon was involved. He also performed other similar surgeries, such as CCWO, during the study period, which may have positively influenced the results.

Another criticism of the study is that it focused exclusively on the number of osteotomies and ignored other factors. Hopefully, further studies will provide more in-depth knowledge about other factors that influence the learning curve for TPLO.

Despite its shortcomings, this study has determined a learning curve for achieving the desired placement of osteotomy during TPLO. This may be useful in the training of surgical residents. Further analyses for a larger number of surgeons should be considered in the future.

Ethical statement

According to the local legislation and institutional requirements, ethical approval for studies involving animals was not required, because of the retrospective nature of this study. No patients or clients are identifiable. Written informed consent was not obtained from the owners for the participation of their animals in this study because it was not required due to the retrospective nature of the study.

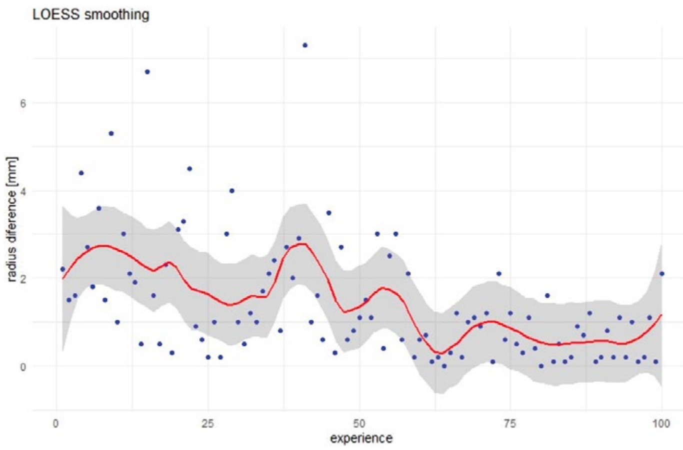

Fig. 6. Radius difference as a function of of time (LOESS method)

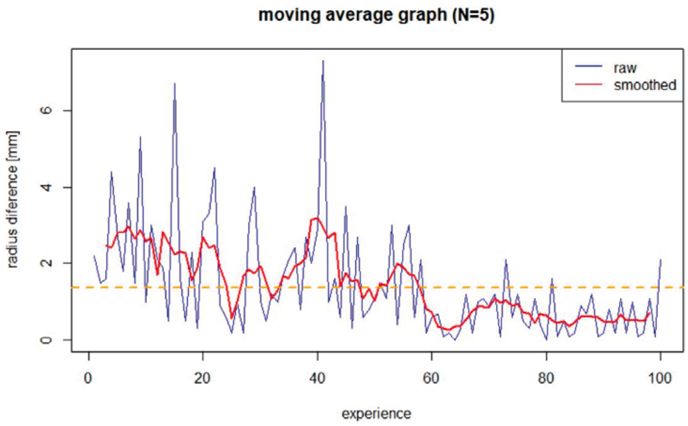

Fig. 7. The error rate for radius difference as a function of time (moving average method). The yellow line on the graph indicates the average error rate for an experienced surgeon

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