

# Computer-assisted gait analysis of the dog: Comparison of two surgical techniques for the ruptured cranial cruciate ligament

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## Keywords:

Tibial plateau levelling osteotomy, capsular-fascial imbrication method, ground reaction forces, joint angles, instrumented treadmill

## Summary:

**Objectives:** To compare the improvement in degree of lameness following surgical repair of cranial cruciate ligament rupture in dogs using computer-assisted gait analysis.

**Methods:** Two groups of 14 dogs were used. One group was treated by a capsular-fascial imbrication method, and the other group by tibial plateau levelling osteotomy (TPLO). All dogs underwent gait analysis prior to surgery, as well as at four days, four weeks, and four months after surgery. Symmetry indices of vertical ground reaction forces as well as vertical ground reaction forces in % body weight, joint angles and certain gait cycle parameters were evaluated.

**Results:** Four months after surgery, the degree of lameness expressed as symmetry

index for peak vertical force for the TPLO group (5.83%) was not significantly different to the capsular-fascial imbrication group (19.05%). Within the TPLO group, there was a significantly increased ability to extend the stifle joint four months after surgery. The stifle motion pattern of the capsular-fascial imbrication group as well as the range-of-motion in both groups showed very little change at the time of the last gait analysis. The complication rate was greater in the TPLO group than in the capsular-fascial group.

**Clinical significance:** In conclusion the results suggest that the TPLO method leads to a faster recovery and improved limb function in comparison to the capsular-fascial imbrication method four months after surgery. Further analyses are needed to determine if the TPLO method is superior concerning long-term joint stability.

The postoperative limb function as well as the morphology of the stifle joint after CCL surgery are usually evaluated by clinical and radiographic examinations. Because of the limitations of the human eye to observe movements of locomotion, surgeons often misjudge the degree of lameness, regardless of their clinical experience (3, 4). Due to this circumstance, computer-based gait analyses have been increasingly used in veterinary medicine to eliminate subjective influences which could bias clinical outcomes. Kinetic measurements provide a non-invasive, objective and quantitative evaluation of ground reaction forces occurring between the foot and the ground during the stance phase of the stride (5). Furthermore, kinematic gait analysis allows an assessment of joint angles and gait cycle parameters during walking or trotting. Previous studies used either force plates or instrumented treadmills to collect kinetic and kinematic data (6–11). Advantages of instrumented treadmills include the possibility to record data-sets of ground reaction forces with minimal variability due to an adjustable constant treadmill velocity. Moreover, treadmills with four integrated force platforms enable one to study all four limbs simultaneously, so for example compensatory effects of lameness can be evaluated (12). Consequently, computer assisted gait analysis is a suitable examination method to assess postoperative lameness improvement after treatment with different surgical techniques.

The selection of a surgical technique for the ruptured CCL has often been based on surgeon preference, which may differ from continent to continent and even from region to region (13). Two common techniques are the tibial plateau levelling os-

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## Introduction

A loss of function of the cranial cruciate ligament (CCL) is the most common condition affecting the stifle joint in dogs (1, 2). The numerous surgical techniques for repair of the ruptured CCL are broadly classi-

fied as intra-capsular ligament replacements, extra-capsular suture techniques, neutralizing dynamic techniques and modified methods. All of these techniques eliminate cranial tibial thrust during weight bearing, but a gold standard has not yet been defined.

teotomy (TPLO) and extra capsular stabilization of the stifle joint (14–16). Advantages of the extra capsular stabilization techniques might be a reduced operation time, less technical demands and therefore less surgery costs. Other authors consider the TPLO to be more suitable to treat CCL rupture, especially in active, athletic dogs (17). However, although results of a number of articles suggested a faster recovery, better function and slower progression of osteophytosis in dogs treated with TPLO, there is no objective study demonstrating that TPLO results in a better improvement in lameness in the first month after surgery than extra-capsular stabilization techniques (18–21).

Thus, the purpose of this study was to objectively analyse changes in lameness improvement over a period of four months in dogs treated for CCL rupture with the TPLO or the capsular-fascial imbrication method, and which did not experience any complications in the postoperative healing process (22). Therefore ground reaction forces, joint angles and gait cycle parameters were analysed. To our knowledge, pre- and postoperative limb function after treatment with the aforementioned surgical techniques has not been analysed with regard to computer-based gait analysis of kinematic and kinetic parameters measured on an instrumented treadmill.

## Material and methods

Originally, 35 dogs of different breeds and ages with unilateral CCL rupture were assigned to two groups in alternating order, depending on order of hospitalization. Due to complications and contralateral CCL rupture, seven dogs were excluded from the study. Once a dog was excluded from the study, the next hospitalized dog was assigned to the group in which the respective complication occurred. In total 28 dogs completed the study, 14 of which had TPLO, and the other 14 underwent a capsular-fascial imbrication.

Prior to surgery, all dogs underwent a physical examination and were diagnosed with CCL rupture by means of the cranial 'drawer' test, the tibial compression test, and radiographic images. The contralateral

limbs were analysed as well to exclude a bilateral CCL rupture. Furthermore for each dog a body condition score was assigned according to a system used by the Nestlé Purina Pet Care Centre (St. Louis, MO, USA)(23). This system describes the body condition of dogs with values between 1 and 9. The value 1 stands for 'emaciated' and 9 for 'obese'. Physical examinations were repeated at four days, four weeks, and four month after surgery.

## Surgical procedure

Acepromazine (0.05 mg/kg)<sup>a</sup> was administered intramuscularly 20 – 30 minutes before induction of anaesthesia. Anaesthesia was induced by intravenous administration of levomethadon (0.6 mg/kg)<sup>b</sup> and propofol (1 – 5 mg/kg)<sup>c</sup> and maintained with isoflurane. In cases where the TPLO method was used, morphine (0.1 mg/kg)<sup>d</sup> and bupivacaine (0.5 mg/kg)<sup>e</sup> were administered epidurally. Cefazolin (22 mg/kg)<sup>f</sup> and carprofen (4 mg/kg)<sup>g</sup> were administered at the time of induction. In case surgery took longer than 90 minutes, a second dose of cefazolin was administered. The limb with CCL rupture was prepared for aseptic surgery. For the TPLO, the distal aspect of the femur and proximal aspect of the tibia were approached caudomedially. A small incision of the skin, superficial fascia and sartorius muscle was carried out caudal to the medial collateral ligament, followed by a transverse incision of the joint capsule as previously described (16, 24). Through this limited approach, the caudal pole of the medial meniscus was identified and extirpated, and then the

joint capsule was sutured closed. An osteotomy of the proximal tibia was performed by means of an oscillating saw and the tibial plateau angle was rotated to approximately 5 degrees. A plate<sup>h</sup> was used to stabilize the osteotomy. The wound was then closed sequentially. For the capsular-fascial imbrication method a lateral parapatellar arthrotomy was performed. The ruptured CCL and the caudal pole of the medial meniscus were extirpated. Rotating the tibia in an external direction, the joint was stabilized by two U-shaped sutures in the capsule and the fascia lata respectively<sup>i</sup>. The direction of the first two U-shaped sutures in the joint capsule was from the lateral fabella of the gastrocnemius muscle to the insertion of the patellar ligament at the tibial tuberosity. The direction of the second two U-shaped sutures was proximal of the lateral fabella of the gastrocnemius muscle to the patellar ligament, putting the cranial part of the fascia under the caudal part. The sutures ran at an angle of 45° to the fascial incision. The wound layers were then sutured sequentially.

Beginning 24 hours after surgery, amoxicillin (20 mg/kg)<sup>j</sup> and carprofen (4 mg/kg)<sup>k</sup> were administered orally for ten days. Four days after surgery the patients were discharged. Each dog's activity was restricted to leash walks for six weeks. Dogs were examined four days after surgery and returned for evaluation at four weeks and four months after surgery.

## Kinetic and kinematic evaluation of gait

To evaluate kinetic and kinematic data the subjects of both groups were examined prior to surgery as well as four days, four weeks and four months after surgery on an instrumented treadmill<sup>l</sup>. The treadmill consisted of four separate belts with an in-

<sup>a</sup> Vetranquil® 1%: Albrecht GmbH, Aulendorf, Germany

<sup>b</sup> L-Polamivet®: Intervet Deutschland GmbH, Unterschleißheim, Germany

<sup>c</sup> Narcofol® 10mg/ml: CP-Pharma Handelsgesellschaft GmbH, Burgdorf, Germany

<sup>d</sup> Morphine® 10mg/ml: Hexal AG, Holzkirchen, Germany

<sup>e</sup> Bupivacain-RPR-actavis® 0,5%: Actavis Deutschland GmbH & Co. KG, Langenfeld, Germany

<sup>f</sup> Cefazolin® 2g/ml: Hexal AG, Holzkirchen, Germany

<sup>g</sup> Rimadyl® Injektionslösung: Pfizer GmbH, Berlin, Germany

<sup>h</sup> 3.5 Broad Delta Plate: Eickemeyer, Tuttlingen, Germany

<sup>i</sup> Vicryl 0: Ethicon, Norderstedt, Germany

<sup>j</sup> Amox®: CP-Pharma Handelsgesellschaft GmbH, Burgdorf, Germany

<sup>k</sup> Rimadyl® Kautabletten: Pfizer GmbH, Berlin, Germany

<sup>l</sup> Treadmill, model 4060–08: Bertec Corporation, Columbus, OH, USA

tegrated force plate underneath each of them. This construction allowed a separate measurement of each limb's kinetic data.

For the kinematic measurements, retro-reflective markers<sup>m</sup> were fitted on 16 anatomical landmarks of the hindlimb (8 per side) of each dog using double-sided adhesive tape. The pelvic segment was defined by markers on the ilial crest, ischiatic tuberosity and the greater trochanter of the femur. The marker on the greater trochanter was also part of the femoral segment, which was additionally determined by markers on the fibular head and a marker positioned mid-diaphyseal on the femur. The tibial segment was comprised of the fibular head marker, and markers positioned on the tibia and the lateral malleolus of the distal tibia. The pad segment was determined by the lateral malleolus of the tibia and the distal lateral aspect of the fifth metatarsus. The markers representing the femur and tibia were placed approximately 2 cm cranial to a line connecting the greater trochanter and the fibular head, and another line between the fibular head and the lateral malleolus, respectively.

Four highspeed infrared cameras<sup>n</sup> were used to record the markers of both hindlimbs simultaneously during motion (measurement frequency: 100 Hz). Prior to capturing the motion of the dog's gait on the treadmill, a static and dynamic calibration of the camera system (maximum measurement error for all four cameras: 0.08 mm) was carried out. Both kinetic and kinematic data were simultaneously collected with commercially available software<sup>o</sup>.

For each gait analysis session, the patients were introduced gently to the gait on the treadmill. For data collection, a treadmill velocity of either 0.5 or 0.65 m/s was chosen according to preferred walking gait speed of each dog. During each gait analysis session, two to six trials were recorded, each with a duration of approximately 20 seconds. Treadmill speed was kept constant for

each individual dog for all four different time points of gait analysis. A valid trial included consistent movements and sequential paw strikes of all four paws on the appropriate force plate. Afterwards ten consecutive steps of both the surgically treated and the unaffected limb were analysed with regard to the following parameters: peak vertical force (PVF), mean vertical force (MFz) and vertical impulse (IFz). All vertical forces were normalised by the individual body weight of the dog and expressed as a percentage of body weight (%BW). Additionally, a corresponding symmetry index for the hindlimbs was calculated for the mentioned parameters. The symmetry index was calculated using the following formula (25):

$$SIz (\%) = 100 - [(FI/Fc) \cdot 100]$$

Where SIz = symmetry index of the according parameter (PVF, MFz, IFz), FI = parameter of the lame extremity (% BW of PVF, MFz, IFz), and Fc = parameter of the contralateral extremity (%BW of PVF, MFz, IFz). The dogs were considered to be lame if at least one of the three symmetry indices was greater than six percent.

For a percentual exemplification of lameness improvement in the period of examination, a second graphical analysis was carried out. Therefore symmetry indices of the initial gait analysis were normalized to 100%. The symmetry indices calculated for the following analyses were converted accordingly.

In order to generate the three-dimensional kinematic model of the hindlimb within the software programme, each segment was defined by the three markers as described above. A three-dimensional kinematic model allows for the real determination of segment positions and their relation to each other in three-dimensional space (► Supplementary video: Available online at [www.vcot-online.com](http://www.vcot-online.com)). Within the kinematic model of the canine hindlimb, the angles of the hip and stifle joint were calculated from the position of the respective segments to each other. Due to the limited space on the pad segment, it was only possible to use two markers. Therefore for the hock joint, only a projected flexion and extension angle could be calculated.

After labelling all markers of a trial with the proper designation, ten valid foot strikes were marked manually in order to define the stance and swing phase of each limb. Subsequently a spreadsheet in ASCII format was emitted containing the different gait cycle parameters and joint angles of both hindlimbs. In order to better compare the movement pattern of the analysed joints, the step duration was normalized to a value of 100 in all dogs. The joint angles and gait cycle parameters which were considered in this study were the maximum extension and flexion angles as well as the maximum range-of-motion of the hip, stifle and hock. The mean maximum flexion and extension angles as well as the range-of-motion of the respective joints in both examination groups were calculated from the mean joint progression curves of the dogs of each group for all different time points. The mean joint angle progression curves of the aforementioned joints for all of the dogs from the TPLO group as well as that for the capsular-fascial imbrication group were calculated from the mean joint angle progression curves resulting from the 10 strides per dog. In addition, the swing and stance phases of the affected and the contralateral hindlimb were examined. With regard to the gait cycle parameters of the hindlimbs, the support phase was divided into a stance phase in which only the affected or contralateral limb was on the ground and a phase in which the affected and contralateral limbs were on the ground at the same time. All gait cycle parameters were displayed as a percentage of one whole stride.

## Radiographic examination

Prior to surgery, radiographic images were taken of both stifle joints using mediolateral and caudocranial projections to analyse joint effusion. The radiographs were scored for osteophytosis on a five-point discontinuous ordinal (Lickert) scale, with 0 representing 'no osteophytosis' and 4 representing the most severe osteophytosis (18). Furthermore, the affected stifle was radiographed in two planes four weeks and four months after surgery to assess the progression of osteoarthritis. Radiographic

<sup>m</sup> Ø 16 mm reflective markers: Vicon Motion Systems Ltd., Oxford, UK, Germany

<sup>n</sup> MX3+ camera system: Vicon Motion System Ltd., Oxford, UK

<sup>o</sup> Vicon Nexus: Vicon Motion Systems Ltd., Oxford, UK



**Fig. 1**  
Stifle radiographs taken (A) before surgery and at (C) four months after surgery of a dog treated with (B) tibial plateau levelling osteotomy and (D) capsular-fascial imbrication method.

images taken before and four months after surgery are shown for each method in ► Figure 1. To confirm correctness of the TPLO procedure prior to surgery as well as directly after surgery, the tibial plateau angle (TPA) was measured in the dogs of the TPLO-group according to a previously described method (26).

## Statistical analysis

Data were analysed using a one-way analysis of variance (ANOVA) for repeated measures followed by a post-hoc Tukey test. Data are reported as mean  $\pm$  standard error (SEM) and p-values  $<0.05$  were considered significant. An unpaired t-test was used to determine whether body condition score, age and weight were equal between groups.

## Results

### Clinical data

The 14 dogs in the TPLO group consisted of seven females and seven males (► Table 1). In the capsular-fascial imbrication group, eight dogs were female and six were male (► Table 1). Mean age at the time of initial examination was  $4.9 \pm 0.8$  years (median: 4.5 years) for dogs in the TPLO group and  $7.1 \pm 0.7$  years (median: 7 years) for dogs in the capsular-fascial imbrication group. Mean age was not significantly different between groups ( $p > 0.05$ ). Furthermore, there were no significant differences between body weights (TPLO group:  $35.4 \pm 2.3$  kg [median: 35 kg]; capsular-fascial imbrication group:  $32.2 \pm 2.3$  kg [median: 34.1 kg];  $p > 0.05$ ) and body condition scores (TPLO group:  $5.5 \pm 0.17$  [median: 5]; capsular-fascial imbrication group:  $5.4 \pm 0.17$  [median: 5];  $p > 0.05$ ) between both groups. Physical examinations performed on the dogs assigned to the TPLO group prior to surgery revealed positive cranial drawer and positive tibia compression tests in seven dogs each. Within the capsular-fascial imbrication group, 10 dogs had a positive cranial drawer test, and 13 dogs had a positive tibia compression test prior to surgery. During surgery, the status of the CCL

**Table 1** Breed, age, weight and body condition score of all dogs taking part in this study.

Tibial Plateau Levelling Osteotomy					Capsular-fascial imbrication method			
	Breed	Age	Weight	BCS	Breed	Age	Weight	BCS
1	Mixed breed	3	32	5	Mixed breed	11	18.2	6
2	Airedale Terrier	11	36	6	Labrador Retriever	10	32.3	5
3	German Shepherd	7	45	5	Boxer	9	38	5
4	Staffordshire Bull Terrier	1	29	5	Mixed breed	7	32.5	5
5	Australian Shepherd	1	21.5	5	Siberian Husky	9	38.5	7
6	Boxer	6	34	5	Labrador Retriever	6	35.2	5
7	Border Collie	3	22	6	Beagle	7	18.5	5
8	Cane Corso	2	39.1	5	Beagle	6	15	5
9	German Shepherd	9	41	6	Labrador Retriever	9	37.8	6
10	Hovawart	5	40	5	Mixed breed	7	42	6
11	Rottweiler	5	55	7	Boxer	3	40	5
12	Bernese Mountain Dog	4	37.3	6	Mixed breed	6	33	6
13	Mixed breed	3	32	6	Munsterlander	1	32	5
14	Mixed breed	9	32	5	Mixed breed	8	38	5

**Key:** BCS = body condition score.



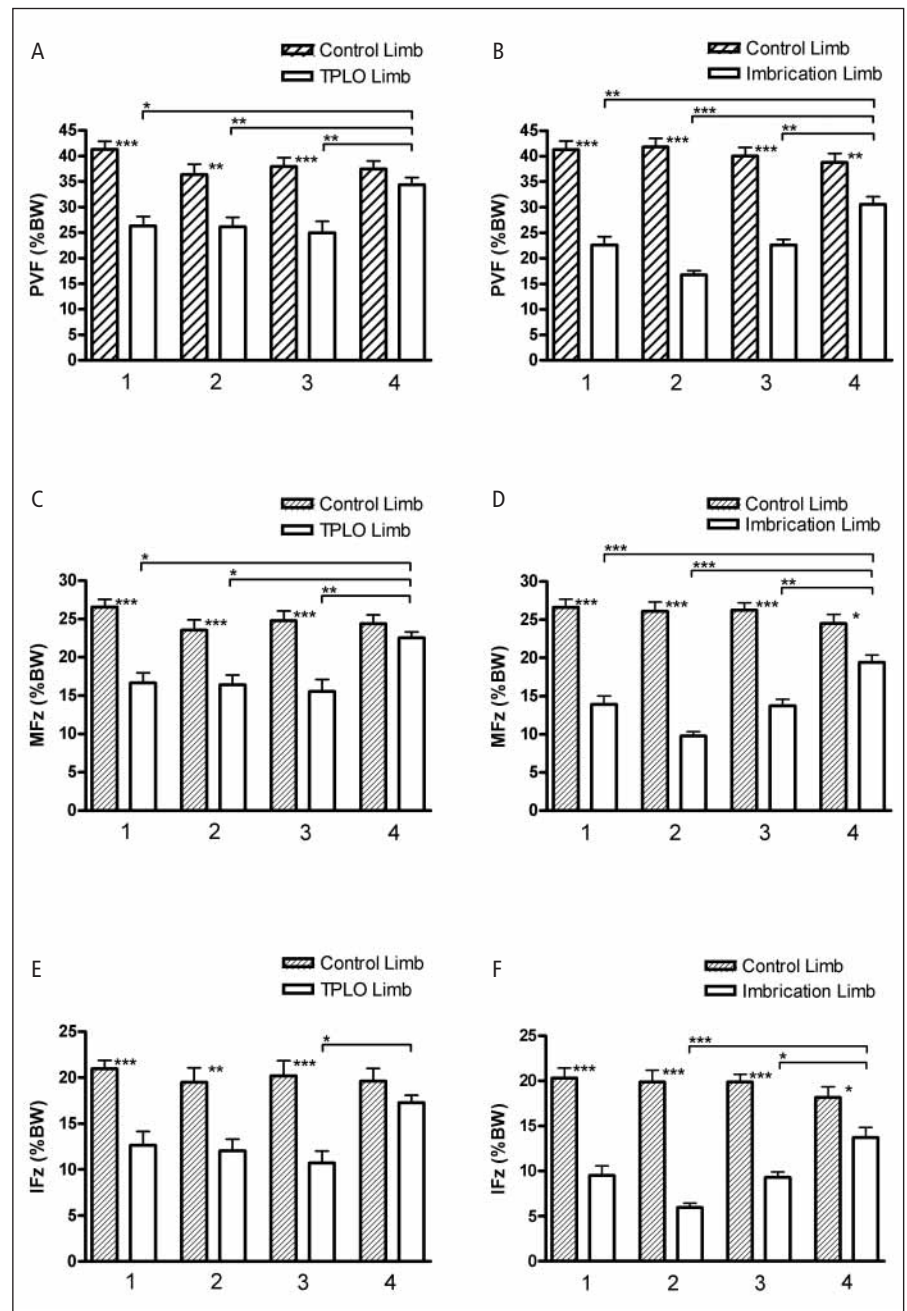
and the medial meniscus could only be evaluated when the capsular-fascial imbrication method was used. Eleven dogs in the capsular-fascial imbrication group had a complete rupture of the CCL and three had a partial rupture of the CCL. Tears of the medial meniscus were present in five dogs whereas the medial meniscus was intact in nine dogs. The status of the CCL could not be evaluated in the dogs in the TPLO group, however medial meniscal tears were present in nine dogs and absent in five dogs. The physical examination confirmed joint stability in the capsular-fascial imbrication group at all time points post-surgery.

### Kinetic data

Mean treadmill speed at all four examination time points of the dogs was  $0.56 \pm 0.08$  m/s in the TPLO group and  $0.54 \pm 0.07$  m/s in the capsular-fascial imbrication group.

In the surgically treated limbs of the TPLO group, a significant improvement of PVF could be observed after four months ( $34.33 \pm 1.42\%$  BW) in comparison to pre-surgery ( $26.3 \pm 1.83\%$  BW;  $p < 0.05$ ), four days after surgery ( $26.17 \pm 1.84\%$  BW;  $p < 0.01$ ), and four weeks after surgery ( $24.96 \pm 2.19\%$  BW;  $p < 0.01$ ) (► Fig. 2A). The PVF of the unaffected limbs in the TPLO group did not change significantly over time with values of  $41.31 \pm 1.56\%$  BW prior to surgery,  $36.31 \pm 2.08\%$  BW at four days,  $37.88 \pm 1.77\%$  BW at four weeks, and  $37.43 \pm 1.54\%$  BW four month after surgery (► Fig. 2A). Significant differences between the PVF of affected and unaffected limbs in the TPLO group were found prior to surgery ( $p < 0.001$ ), four days ( $p < 0.01$ ) and four weeks ( $p < 0.001$ ) after surgery (► Fig. 2A). In contrast, PVF values of the TPLO treated and the unaffected limb four months after surgery were found to be not significantly different (► Fig. 2A).

Improvement of the PVF in the affected limbs four months after capsular-fascial imbrication surgery ( $30.5 \pm 1.59\%$  BW) were significantly different compared to PVF values prior to surgery ( $22.61 \pm 1.64\%$  BW;  $p < 0.01$ ), as well as at four days ( $16.72 \pm 0.85\%$  BW;  $p < 0.001$ ) and four weeks ( $22.6 \pm 1.09\%$  BW;  $p < 0.01$ ) after surgery



**Fig. 2** Peak vertical forces (PVF: A, B), mean vertical forces (MFz: C, D) and vertical impulses (IFz: E, F) of affected and contralateral (control) limbs in the tibial plateau levelling osteotomy and capsular-fascial imbrication groups at the time points prior to surgery (1), four days after surgery (2); four weeks after surgery (3) and four months after surgery (4). Data are displayed as mean  $\pm$  standard error (SEM), significance levels: \* =  $p < 0.05$ , \*\* =  $p < 0.01$ , \*\*\* =  $p < 0.001$ .

(► Fig. 2B). The PVF of the unaffected limbs in the capsular-fascial imbrication group prior to surgery ( $41.29 \pm 1.66\%$  BW) was not significantly different at four days ( $41.81 \pm 1.67\%$  BW), four weeks ( $40.01 \pm 1.71\%$  BW), or four months ( $38.75 \pm 1.76\%$  BW) after surgery (► Fig. 2B). Significant

differences between the PVF of affected and unaffected limbs in the capsular-fascial imbrication group were found prior to surgery ( $p < 0.001$ ), four days ( $p < 0.001$ ), four weeks ( $p < 0.001$ ) and four months ( $p < 0.01$ ) after surgery (► Fig. 2B).

In case of the analysed MFz (► Fig. 2 C & D) and IFz (► Fig. 2 E & F) values a similar improvement pattern could be observed in the TPLO and capsular-fascial imbrication group as described above for the PVF values.

With the exception of the examination performed four days post-surgery, the vertical ground reaction force data (in % BW) of affected and unaffected limbs were not significantly different between the TPLO and capsular-fascial imbrication groups at all examination time points ( $p > 0.05$ ).

## Symmetry index

Concerning the TPLO group, the mean symmetry indices of PVF were  $34.85 \pm 5.18$

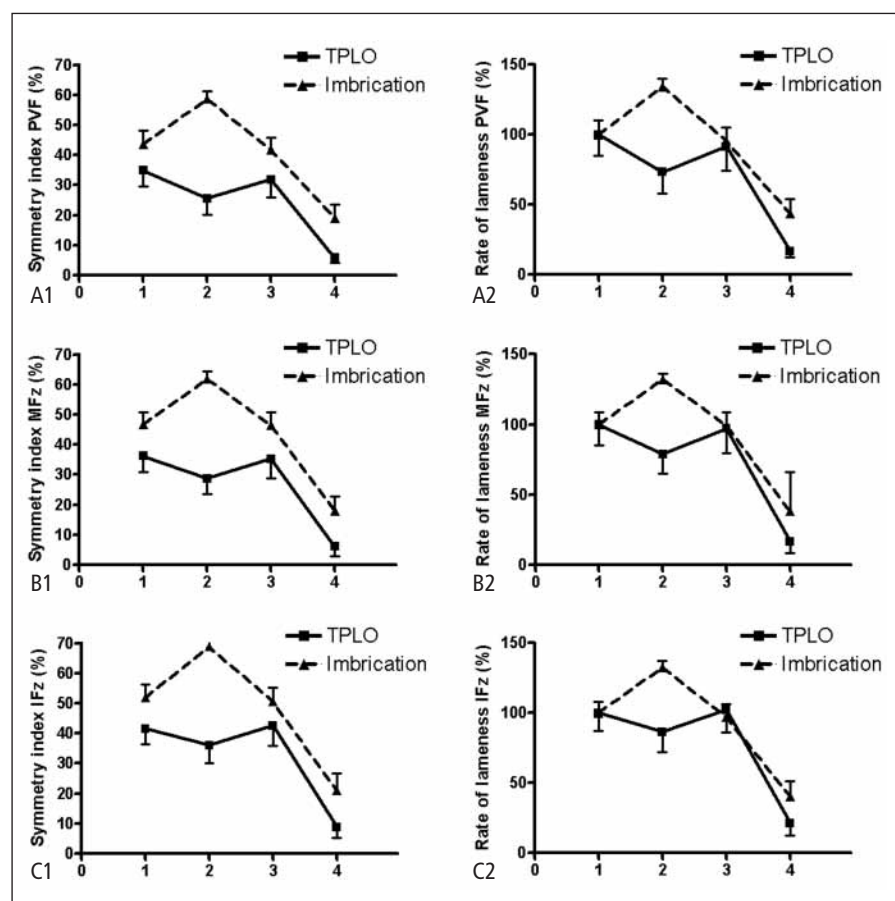
% prior to surgery,  $25.57 \pm 5.33\%$  four days after surgery,  $31.97 \pm 6.09\%$  four weeks after surgery, and  $5.83 \pm 2.31\%$  four months after surgery (► Fig. 3 A1). Mean symmetry indices of MFz (► Fig. 3 B1) ranged from  $36.22 \pm 5.30\%$  (prior surgery), to  $28.66 \pm 5.11\%$  (four days after surgery),  $35.26 \pm 6.45\%$  (four weeks after surgery), and  $6.10 \pm 3.11\%$  (four months after surgery). The values of  $41.64 \pm 5.24\%$ ,  $36.01 \pm 5.89\%$ ,  $42.6 \pm 6.66\%$ , and  $8.83 \pm 3.70\%$  represent the mean symmetry indices of the vertical impulse (► Fig. 3 C1) prior to surgery, and four days, four weeks and four months after surgery. All values decreased significantly from the initial examination to the last examination at four months ( $p < 0.001$ ). There were significant differences seen when comparing the data of examina-

tions at four weeks after surgery with those at four months after surgery (PVF:  $p < 0.01$ ; MFz:  $p < 0.001$ ; IFz:  $p < 0.001$ ).

Regarding the capsular-fascial imbrication group, mean symmetry indices of PVF were  $43.64 \pm 4.50\%$  prior to surgery,  $58.62 \pm 2.51\%$  four days after surgery,  $41.73 \pm 4.12\%$  four weeks after surgery, and  $19.05 \pm 4.50\%$  four months after surgery (► Fig. 3 A2). Mean symmetry indices of MFz ranged from  $46.70 \pm 4.21\%$  (prior to surgery), to  $61.73 \pm 2.60\%$  (four days after surgery),  $46.38 \pm 4.50\%$  (four weeks after surgery) and  $17.86 \pm 5.03\%$  (four months after surgery) (► Fig. 3 B2). The values of  $51.93 \pm 4.31\%$ ,  $68.79 \pm 2.40\%$ ,  $50.49 \pm 6.66\%$ , and  $20.94 \pm 5.77\%$  represent the mean symmetry indices of vertical impulse (IFz, ► Fig. 3 C2) prior to surgery, and at four days, four weeks, and four months after surgery. All parameters showed a significant decrease between the initial and the last examination (PVF:  $p < 0.01$ ; IFz:  $p < 0.001$ ; MFz:  $p < 0.001$ ), and between the examinations at four weeks and at four months (PVF:  $p < 0.05$ ; IFz:  $p < 0.01$ ; MFz:  $p < 0.01$ ). Comparing the methods, there only were significant differences seen between data of the fourth day examinations ( $p < 0.001$ ). Differences between data at four months after surgery were not significant ( $p > 0.05$ ).

## Kinematic data

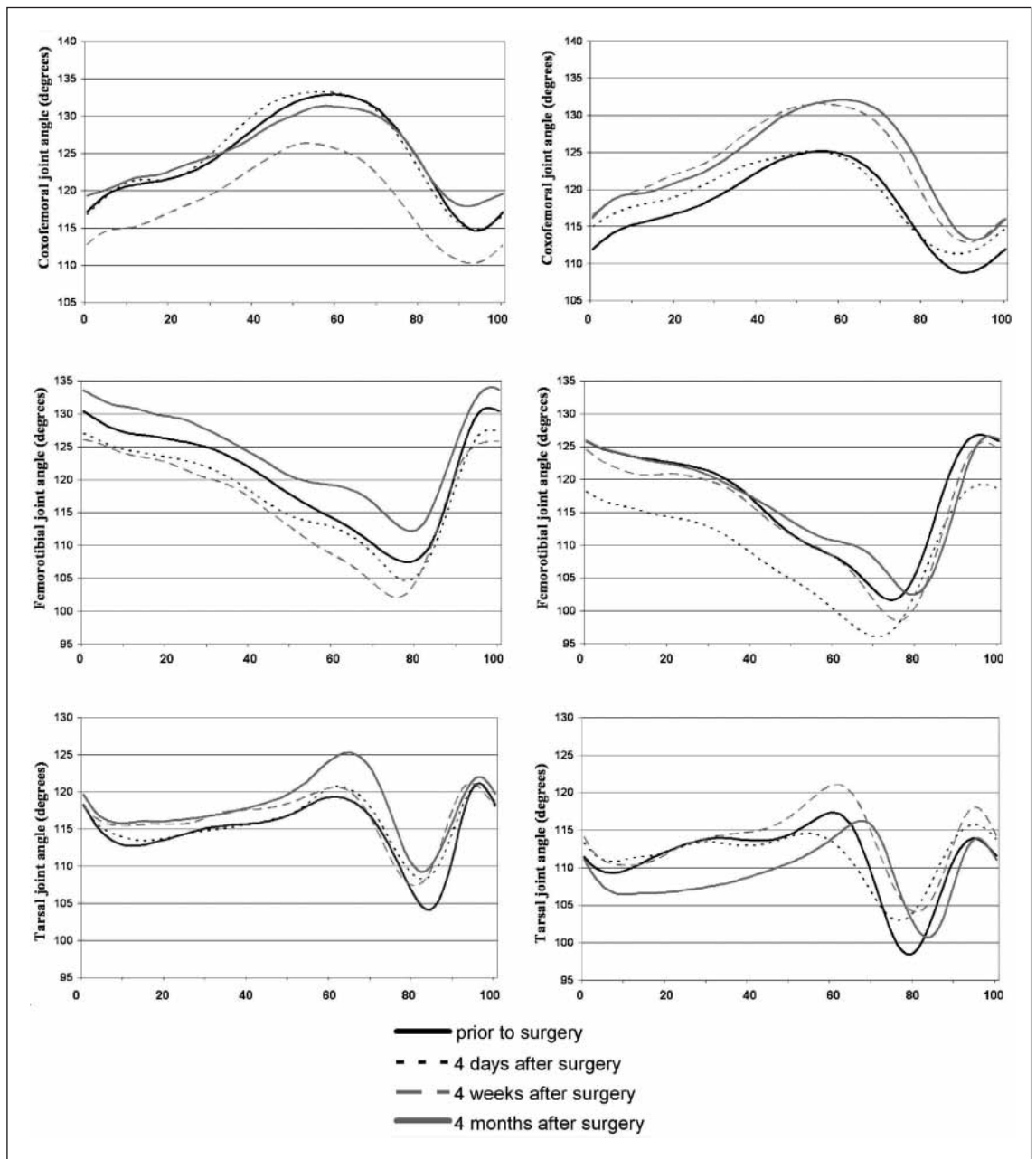
The data depicting the mean coxofemoral, femorotibial and tarsal joint angle progression in both groups are illustrated in ► Figure 4. Maximum flexion and extension angles of the different joints were calculated from the respective mean joint angle progression curves. All joint angle values showed high variances (*not shown in* ► Fig. 4). Compared with prior to surgery values, four months after surgery the maximum flexion and extension angles were significantly higher with regard to the femorotibial and tarsal joint angles in the TPLO group ( $p < 0.01$ ). Changes in coxofemoral joint angles prior to and at four months after surgery showed no significant differences. On the contrary, subjects of the capsular-fascial imbrication group showed significant differences in maximum coxofe-



**Fig. 3** Left side (A1, B1, C1): Comparison of the development of the three symmetry indices of the TPLO group with those of the capsular-fascial imbrication group (A1 = symmetry index of PVF; B1 = symmetry index of MFz; C1 = symmetry index of IFz). Right side (A2, B2, C2): Symmetry indices of the initial gait analysis were defined as 100 %. The symmetry indices calculated for the following analyses were accordingly converted. The graphs demonstrate the improvement of lameness during evaluation period (error bar = standard error of the mean).

**Fig. 4**

Comparison of mean angular change patterns of hip, stifle and tarsal joint. **Left side:** Dogs treated with tibial plateau levelling osteotomy. Extension of the stifle and tarsal joint increased significantly at four months after surgery in comparison to pre-surgery. **Right side:** Dogs treated with the capsular-fascial imbrication method show significant changes in angular patterns of the hip and tarsal joint. The abscissa for each graph is displayed as percentage of gait cycle.



moral ( $p < 0.001$ ) flexion and extension angles ( $p < 0.001$ ) between examinations prior to and four months after surgery. In the capsular-fascial imbrication group, the maximum femorotibial angles showed no significant differences prior to and four months after surgery. Analysis of the range-of-motion showed no significantly different values for all analysed joints in both groups at four months after surgery in comparison to prior to surgery. In the TPLO group, the range-of-motion had de-

creased at four months after surgery in comparison to prior to surgery in the coxofemoral and tarsal joints, whereas a slight improvement could be found for the range-of-motion of the stifle joint (all joints:  $p > 0.05$ ). In the capsular-fascial imbrication group, the range-of-motion of the hip joint was increased at four months after surgery, whereas the range-of-motion of the stifle joint had remained constant and the range-of-motion of the hock joint had decreased at four months after surgery in

comparison to prior to surgery (all joints:  $p > 0.05$ ).

Gait cycle parameters of both groups showed an improvement to equal values between affected and contralateral hindlimbs four months after surgery: an increase from pre-surgery to four months after surgery was evaluated for the stance phase of the affected hindlimb and for the swing phase of the contralateral hindlimb. Accordingly, the stance phase of the contralateral hindlimb as well as swing phase of

**Table 2** Comparison of the gait cycle parameters stance and swing phases of the affected and contralateral limbs. With regard to only the hindlimbs, the stance phase is divided into a phase in which only affected or contralateral limb are in stance and a phase in which affected and contralateral limb are in stance. This table shows the data of the affected and the contralateral hindlimbs as percent of gait cycle  $\pm$  standard deviation.

		Stance phase (affected) [%]	Stance phase (contralateral) [%]	Stance phase (affected + contralateral) [%]	Stance phase (contralateral + affected) [%]	Swing phase (affected) [%]	Swing phase (contralateral) [%]
Prior to surgery	TPLO	27.06 $\pm$ 2.71	32.36 $\pm$ 4.94	40.18 $\pm$ 6.72	40.95 $\pm$ 6.66	33.03 $\pm$ 5.86	26.92 $\pm$ 2.27
	Imbrication	28.87 $\pm$ 3.31	37.33 $\pm$ 4.99	33.50 $\pm$ 6.76	34.49 $\pm$ 7.36	37.66 $\pm$ 5.19	28.29 $\pm$ 3.75
4 <u>days</u> after surgery	TPLO	28.02 $\pm$ 3.84	36.70 $\pm$ 6.52	31.27 $\pm$ 7.11	35.16 $\pm$ 8.18	36.64 $\pm$ 6.32	28.19 $\pm$ 3.74
	Imbrication	27.31 $\pm$ 3.80	39.69 $\pm$ 6.57	32.63 $\pm$ 8.99	32.88 $\pm$ 9.40	41.05 $\pm$ 6.85	27.93 $\pm$ 4.15
4 <u>weeks</u> after surgery	TPLO	28.09 $\pm$ 5.84	36.04 $\pm$ 4.17	35.90 $\pm$ 7.44	35.94 $\pm$ 7.31	36.44 $\pm$ 4.80	28.03 $\pm$ 6.20
	Imbrication	27.51 $\pm$ 3.33	34.12 $\pm$ 5.56	38.28 $\pm$ 7.59	38.68 $\pm$ 7.14	34.41 $\pm$ 5.57	27.35 $\pm$ 3.10
4 <u>months</u> after surgery	TPLO	29.88 $\pm$ 4.37	31.36 $\pm$ 4.21	38.92 $\pm$ 7.77	39.03 $\pm$ 7.89	31.30 $\pm$ 4.23	29.77 $\pm$ 4.52
	Imbrication	29.75 $\pm$ 3.85	34.16 $\pm$ 4.99	36.05 $\pm$ 8.12	35.89 $\pm$ 7.81	34.29 $\pm$ 5.48	30.08 $\pm$ 4.01

Key: TPLO = Tibial plateal levelling osteotomy method; Imbrication = capsular-fascial imbrication method.

the affected limb decreased (►Table 2). However, neither between examinations nor between both groups were the differences significant.

## Complication rate

The overall complication rate ( $n = 5$ ) in the TPLO group (originally  $n = 19$ ) was 26.3%. These dogs were excluded from the study. The following six complications were observed (some dogs had multiple complications): fracture of the tibial tuberosity, fibular fracture, screw loosening, infection with multi resistant *Staphylococcus pseud-intermedius* (3 dogs), suture dehiscence (3 dogs), and bone lysis.

Two dogs in the capsular-fascial imbrication group (originally  $n = 16$ ) were excluded because of a contralateral CCL rupture.

## Radiographic examination

During the preoperative examinations, joint effusion was present in all affected stifle joints but not in the contralateral limbs of both groups. At the same time point, the osteophyte score of the affected stifle in the TPLO group was 1 for 10 dogs, 2 for two dogs and 3 for two dogs. The osteophyte score at the final examination

time had increased in one dog from 1 to 2. In the capsular-fascial imbrication group, the preoperative osteophyte score of 11 dogs was 1, and three dogs had an osteophyte score of 2. Four months after surgery there was an increase of osteophyte score in the stifles of two dogs from 1 to 2. Prior to surgery, the osteophyte score in the unaffected stifles in the TPLO group and the capsular-fascial imbrication group was 0 in eight dogs, 1 in four dogs, and 2 in two dogs. The TPA was  $21.72 \pm 6.32^\circ$  prior to TPLO surgery and  $10.97 \pm 3.47^\circ$  directly after surgery.

## Discussion

The aim of this study was to objectively analyse which surgical technique for the repair of the ruptured CCL would result in improved limb function regarding ground reaction forces, joint angles, and gait cycle parameters within the first four months following surgery. Our results suggested that the TPLO method leads to a faster recovery and better limb function in comparison to the capsular-fascial imbrication method within the examination period of four months after surgery.

For improved comparability, the dogs in the two treatment groups had a similar body weight, BCS and age. However, clinical studies always suffer from variables such as different breeds, duration of CCL rup-

ture, pre-existing arthritis, concurrent diseases, as well as postoperative exercise, which makes standardization within the study difficult. On the other hand, outcomes of experimental studies possibly cannot be transferred into clinical cases (27). The owners of the dogs were not asked to fill out a questionnaire regarding the postoperative development of their dogs so that the objectivity of this study would not be lost. Consequently, the results of this study only represent limb function and improvement, respectively, at the different time points of gait analysis. Changes in these parameters occurring after a longer period of recumbency or physical stress were not considered. As compensation for hindlimb lameness is usually carried out by the contralateral hindlimb, gait analysis of the forelimb was not performed in this study (28, 29).

Alt found that the therapeutic outcomes in dogs with CCL rupture were not negatively influenced by partial resection of the intact meniscus after a six month follow-up time period (30). These results were supported by a study of Ertelt et al. comparing different surgical procedures for CCL rupture and consequent meniscal injuries in dogs (16). The most successful results concerning lameness reduction six months after surgery were obtained in the patients in which the stifle joints were explored using a medial arthrotomy for partial re-



moval of the medial meniscus (16). Thus, in this study a partial meniscal resection was performed, although one recent study in cadaveric dog stifles reported that partial meniscectomy results in significant changes of load transmission within the stifle joint which might result in osteoarthritis (31). As these examples show, the optimal treatment of the medial meniscus in context with CCL rupture has not yet been decided upon and requires further investigation.

The symmetry index allows a simple illustration of lameness, therefore, it is well-suited for assessing improvement of limb function (25). In this context, it is important that the unaffected limb is not worsening during the entire examination time to make sure that the symmetry index reflects the actual lameness condition and that it does not represent lowered values due to a diseased contralateral limb. In cases with CCL rupture, 59% of dogs with bilateral stifle radiographs showed evidence of osteoarthritis in the contralateral joint without having shown any clinical signs. There is a risk of the contralateral CCL rupture subsequently (32). Consequently, a sub-clinical contralateral CCL rupture or another orthopaedic disease in the same limb may influence the results of the symmetry index. Therefore, changes in the diagnostic findings of the contralateral limbs during the examination period were ruled out by analyses of the vertical ground reaction forces prior to surgery as well as at four days, four weeks and four month after surgery. The fact that contralateral limb function did not change significantly over time in both groups is likely to indicate that any contralateral stifle condition did not result in a clinically relevant gait change. Nevertheless there always remains an uncertainty regarding true limb symmetry in clinical patients due to possible mild or undiagnosed concurrent orthopaedic diseases. Keeping the limitations of the symmetry index in mind, the analysis method leads to easily interpretable values. Especially for the comparison of the lameness improvement after two different surgical techniques, the symmetry index was considered as an adequate method.

Regarding the symmetry index of the vertical ground reaction forces certain facts are evident: The TPLO group shows a

better approximation to the symmetry index of six percent and therefore better symmetrical weight bearing of the hindlimbs four months after surgery than the capsular-fascial imbrication group. Although dogs of the capsular-fascial imbrication group had a higher degree of lameness before surgery, dogs in the TPLO-group showed on average a more obvious improvement of lameness (►Fig. 2, 3). Four days after surgery, the symmetry index of both groups diverged remarkably. The higher degree of lameness in the capsular-fascial imbrication group as well as the increase in symmetry index four days after surgery might be related to a higher number of complete CCL ruptures and therefore more severe joint pain in this group.

A direct comparison of the results of this study with those of previous studies was difficult. To the best of our knowledge, there were only a few studies which evaluated limb function after capsular-fascial imbrication (22). Allgoewer et al. reported a good limb function in 93% of his cases, but the time of assessment varied from three to 36 months after surgery (22). The assessment was carried out by orthopaedic examinations and measurements of muscle circumference, and ground reaction forces were not determined. Seven to ten months after surgery with a modified retinacular technique, Budsberg et al. found an excellent improvement of all vertical ground reaction forces in the affected limbs (34). In contrast to this study, which had a convalescence period of only four months, the improvement reported by Budsberg et al. might also be the result of an extended convalescence period (34). In a study by Ballagas et al., PVF and VI were analysed for dogs treated with TPLO (33). The final gait analysis was performed 4.5 months after surgery. Symmetry indices were 9.73 and 15.8 and resemble the values obtained in this study. Other studies comparing surgical techniques deal solely with data of the treated hindlimb while symmetry index were not considered (21). However, especially with regard to the ground reaction forces, results of this study are in agreement with those of Conzemius et al. who did not find any significant difference between TPLO and capsular-fascial imbrication method six months after surgery (21).

In the kinematic gait analysis study reported here, a comparison of the maximum flexion and extension angles as well as the range-of-motion was carried out for the joints of the affected hindlimbs. There were evident differences regarding stifle angles of both groups. In contrast to the TPLO-group, there was no significant increase in flexion and extension angles between the initial and the final gait analysis in the femorotibial joint of dogs treated with the capsular-fascial imbrication method. We assume that these findings in the capsular-fascial imbrication group might be induced by the tissue tightening resulting from the surgical procedure. Changes of the coxofemoral motion pattern may also be compensatory. Another possible explanation for the demonstrated different movement patterns of the stifle joints is that small misplacements of markers, along with muscular contractions and skin, tendon and ligament movements could also affect the surface marker position and thus the kinematic data could be significantly affected. Although we placed a special emphasis on precise marker positioning, no significant changes in the range-of-motion between pre-surgery and at four months after surgery were detectable, which supports this hypothesis. On the other hand it is possible that only severe lameness can result in significant changes in the range-of-motion of affected joints. Assessing the range-of-motion after modified retinacular technique and TPLO in a cadaver model, Chailleux et al. observed a significantly decreased range-in-motion in stifles treated by modified retinacular technique; however, investigators suggested this restriction was a direct consequence of the non-isometric placement of the prostheses (35). In this context it has to be kept in mind that changes in passive range-of-motion as demonstrated in cadaveric experiments might not necessarily influence joint excursions during motion. Kinematic gait analysis has been shown to be suitable in quantitating limb function (6). From our own results, we conclude that using kinematic analysis in a clinical research setup for the quantification of lameness improvement remains challenging and still needs to be improved further.

Although the overall complication rate is not main issue of this study, it represents the most obvious difference between both groups and supports the results of previous studies: TPLO are associated with a higher number of complications than other CCL stabilization methods (36). The two most recent studies dealing with this topic reported complication rates of 17.4 and 14.8% in more than 1000 TPLO cases (14, 15). In two older studies, complication rates of 18.8 and 28% were reported, which is similar to the results of our study (17, 37). Studies regarding other invasive orthopaedic procedures using implants and screws have also reported similar complication rates (37). Concerning the capsular-fascial imbrication technique, Allgoewer et al. reported a complication rate of 5.45% in 110 cases (22). Beside joint infection and non-infectious arthritis, meniscal lesions were mainly observed. Metelman et al. documented an incidence of 13.8 % for meniscal lesions, which required a second arthrotomy and meniscectomy (38). Therefore, absence of complications in the capsular-fascial imbrication group may be due to the performed partial meniscal resection and the smaller number of patients.

In addition to the kinematic and kinetic gait analysis, the progression of osteoarthritis was evaluated for both groups. There was not a significant difference found in the osteophyte score between the capsular-fascial imbrication and TPLO groups at four months after surgery, which is consistent with the results of a study by Lazar et al. (39). Another recent study did not find any significant differences in osteoarthritis progression between dogs with CCL rupture treated with TPLO and an extra-capsular fixation technique (40). However, the design of our study, especially the short examination period of four months after surgery, is not optimally suited for assessing progression of osteoarthritis.

In summary, the results of this study provide objective information about improvement of limb function using TPLO or the capsular-fascial imbrication method. Most of the evaluated parameters did not show any significant differences between methods. However, the small number of patients per group and the clinical variables (e.g. different lameness status prior to sur-

gery, unknown status of CCL in TPLO group) may have resulted in an inability to detect differences in the outcome between the groups. Indeed, four months after surgery, vertical ground reaction forces of dogs treated with TPLO achieve slightly more symmetrical weight bearing of the hindlimbs. Nevertheless, the higher complication rate using TPLO represents a disadvantage of this method. Otherwise the TPLO might be superior concerning the long-term joint stability. This hypothesis has yet to be tested by further long-term analyses.

### Conflict of interest

None declared.

### Online supplementary material

A video of the three-dimensional kinematic model is available online at: <http://www.vcot-online.com>.

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