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Outcome after Tibial Plateau Levelling Osteotomy and Modified Maquet Procedure in Dogs with Cranial Cruciate Ligament Rupture

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Abstract

Objective The aim of this study was to compare outcomes after tibial plateau levelling osteotomy (TPLO) and modified Maquet procedure (MMP) for the treatment of cranial cruciate ligament rupture (CCLR) in dogs using clinical and radiographic evaluation and treadmill-based force plate gait analysis.

Study Design This study was a prospective, randomized, controlled study.

Materials and Methods Sixty-one dogs (76 joints) with CCLR were treated with TPLO ($n = 30$ dogs, 41 joints) or MMP ($n = 31$ dogs, 35 joints) and compared with a control group of 16 healthy Labrador Retrievers. Outcomes after surgery were compared by clinical orthopaedic assessment, radiographic evaluation and force plate gait analysis performed preoperatively, and then at 6 weeks, 3 and 6 months postoperatively. For objective comparison of ground reaction forces, the data were compared with the control group. Major complications were reported.

Results A significant improvement in ground reaction forces was reached in all surgically treated dogs. No significant difference was found between the surgical methods at any postoperative re-examination. With regard to peak vertical force (PVF), there were significantly more patients with TPLO within the reference range of healthy dogs at the 3 months re-examination than dogs with MMP. There was no significant difference in mean value comparisons between TPLO and control groups 6 months postoperatively. Compared with the control group, mean values of 93.9% (PVF) and 85.9% (vertical impulse [VI]) were reached by the TPLO group and 89.4% (PVF) and 79.9% (VI) by the MMP group, 6 months postoperatively. No significant differences were found regarding major complications or progression of osteoarthritis.

Conclusions Although no significant differences were found between the surgical methods, TPLO patients showed superiority with regard to clinical outcome.

Keywords
- cranial cruciate ligament rupture
- tibial plateau levelling osteotomy
- modified Maquet procedure
- force plate gait analysis
- dog

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Introduction

Several surgical methods for the treatment of cranial cruciate ligament rupture have been developed to restore stifle joint function by eliminating tibiofemoral shear forces.[1,2] An investigation by Slocum and Slocum into tibial plateau levelling osteotomy (TPLO) in 1993[2] represented a milestone in dynamic stabilization of the cranial cruciate-deficient stifle joint. The efficacy of this procedure, when compared with other surgical methods, has been documented in several studies.[3–5]

An alternative dynamic technique was developed by Montavon and colleagues[6] in 2002, to neutralize the cranial tibial thrust by tibial tuberosity advancement (TTA). Positive clinical outcomes after TTA have also been reported after subjective evaluation,[7,8] although some studies have demonstrated increased lameness compared with TPLO.[4,9] The modified Maquet procedure (MMP) is an adaptation of the TTA technique and uses a titanium foam wedge[10,11] for cranialization of the tibial tuberosity instead of a cage. The proposed advantages, compared with the original TTA technique, are increased support for the tuberosity provided by the wedge, decreased surgical time and simplification of the surgical technique.[11]

Force plate analysis is an established, objective and reliable method for evaluating limb function after stabilization of cranial cruciate-deficient stifle joints, and is superior to subjective visual gait assessment.[12,13] Peak vertical force (PVF), vertical impulse (VI) and symmetry index are parameters of ground reaction forces (GRF) and are used to accurately assess limb function, especially in dogs with unilateral lameness.[14,15]

The purpose of the study was to compare the outcomes of TPLO and MMP procedures for the treatment of cranial cruciate ligament rupture in dogs using clinical and radiographical assessment as well as objective force plate gait analysis. Comparison was made with orthopaedically normal Labrador Retrievers. The authors hypothesized that there would be a significant improvement in limb function using both surgical methods, with decisive superiority in patients with TPLO.

Materials and Methods

Study Design

A prospective, randomized, controlled study was performed on 61 dogs (76 joints) with cranial cruciate-deficiency which were presented at the Clinic of Small Animal Surgery and Reproduction at the Ludwig-Maximilians-University, Munich, Germany. The joints were treated either by TPLO ($n = 41$) or MMP ($n = 35$). Inclusion criteria were bodyweight between 20 and 35 kg and absence of other orthopaedic or systemic diseases. Written owner consent for their dogs to participate in the study and for the surgical method used was obtained in all cases. The TPLO or MMP was performed alternately, in sequence, on clinical cases with cranial cruciate ligament rupture. In case of bilateral disease, the same surgical method was used in both sides. The surgical methods were compared by means of clinical–orthopaedic evaluation and force plate gait analysis prior to surgery and 6 weeks, 3 and 6 months postoperatively. Parameters included in *orthopaedic examination* consisted of objective lameness assessment (grades $0 - 4$), presence/absence of cranial tibial thrust instability, joint swelling and a pain response during flexion and extension of the stifle joint. For *force plate gait analysis*, the patients were evaluated while walking on a treadmill between 0.9 and 1.2 m/s. The gait velocities were kept constant within the evaluation time point.

The treadmill, equipped with four modified Kistler force plates (special elements German Sport University Cologne, Cologne, Germany) was combined with an optical system (Vicon Nexus Vicon Motion Systems Ltd., Oxford, United Kingdom, Quadruped Locomotion Software). The dogs in both treatment groups were compared with a control group, composed of 16 orthopaedically healthy Labrador Retrievers.

Mediolateral and caudocranial stifle radiographs were taken for each patient pre- and postoperatively, as well as at every re-evaluation time point. Progression *of osteoarthritis* (OA) was assessed and graded in four groups (1 = no OA, 2 = mild OA, 3 = moderate OA, 4 = severe OA).[16,17] *Major complications*[18] requiring revision surgery were assessed over the study period.

Surgical Procedures

The same standardized anaesthetic protocol was used for both techniques. The affected stifles were clipped and aseptically prepared for surgery. Orthogonal radiographic projections were taken preoperatively as recommended for the allocated surgical technique.[2,11] Stifle magnetic resonance imaging (MRI) was performed (MAGNETOM Symphony; 1.5 Tesla, Fa. Siemens Healthcare GmbH, Erlangen, Germany) looking specifically for meniscal injury. The following sequences were used: T1-weighted in sagittal plane, proton density weighted with fat saturation (PDF) in dorsal and sagittal planes and T2-weighted in sagittal plane.

Two experienced surgeons (JK, AML) performed all surgical procedures. The TPLO was performed according to the procedure as previously described,[2] but without using a jig. The MMP procedure was performed as described by Ness.[11]

In dogs with medial meniscal injury diagnosed by MRI, a caudomedial mini-arthrotomy was performed prior to TPLO or MMP to partially resect the caudal part of the medial meniscus.[19] Standardized postoperative orthogonal radiographs of the affected stifles were obtained in all cases to evaluate osteotomy and implant positioning.

All patients received the same pain and antibiotic medication peri- and postoperatively, consisting of 15 µg/kg buprenorphine intravenously (Buprenodale ; Fa. Dechra Veterinary Products, GB-Lostock Gralam, Northwich CW9 7UA, UK) three times daily for 1 day, 4.4 mg/kg carprofen orally (Rimadyl; Zoetis GmbH, Germany) once daily for 10 days and 22.5 mg/kg cefalexin intravenously (Cephazolin Fresenius 2 g; Fa. CP-Pharma Handelsgesellschaft mbH, Burgdorf, Germany) every 1.5 hours intraoperatively and 12 hour postoperatively for 1 day, followed by oral administration (Therios, Fa. Ceva Tiergesundheit GmbH, Duesseldorf, Germany) twice daily for 5 days. All limbs were bandaged for 24 hours. Dogs were discharged from the hospital 3 days after surgery.

Data Analysis

Standard statistical software was used for statistical analysis (IBM SPSS 25.0; IBM, Armonk, New York, United States).

Categorical data were displayed as absolute and relative frequencies. Mean and standard deviations were calculated for metric data. Fisher's exact test was used to analyse the categorical parameters (lameness grade, kinetic parameters within or without reference range) for differences between the two methods Chi square test and Fisher's exact test were used. The reference range of the kinetic gait parameters was defined as mean $\pm$ 2 standard deviations[20] of the values of the healthy control dogs. Age, bodyweight and OA score (according to Mager[17]) of the dogs in the TPLO and MMP group were compared using the Mann–Whitney *U* test. In bilateral diseases the stifle joint with less signs of OA were used. The multifactorial generalized linear model was used to compare the kinetic parameters (PVF, VI) of both surgical methods and to compare the control dogs against the TPLO group as well as the MMP group separately at the different time points. The cofactor of bilateral cranial cruciate rupture was considered in comparison of both surgical methods. Cofactors of age and bodyweight of the dogs were considered in comparison of control dogs and treated patients. The multifactorial generalized estimating equations procedure was used to compare the TPLO and MMP groups over time, considering the cofactors of meniscal status, uni- or bilateral cranial cruciate ligament rupture and the pre-surgery OA score. A p-value < 0.05 was considered as significant. Major complications were evaluated as absolute frequencies regarding the number of stifle joints/surgical method and the odds ratio was calculated.

Results

Signalment and Descriptive Statistics

A total of 61 dogs (76 joints) were treated for cranial cruciate ligament rupture. Labrador Retriever ($n = 20/61$) was the dominant breed in the study and was equally distributed in both groups.

Thirty dogs (41 stifles) were included in the TPLO group with a mean age of 5.9 $\pm$ 2.5 years (2–12.3 years) and a mean body weight of 30.0 $\pm$ 4.64 kg. A primary meniscal lesion was found in 21/41 stifles.

Thirty-one dogs (35 stifles) were included in the MMP group with a mean age of 6.7 years $\pm$ 3.0 (0.9–11.3 years) and a mean body weight of 29.9 $\pm$ 4.8 kg. A primary meniscal lesion was found in 22/35 stifles.

There were no significant differences regarding the signalment between the groups.

All patients were re-examined after an average of 6.2 $\pm$ 0.8 weeks (first re-evaluation), after 3.1 $\pm$ 0.4 months (second re-evaluation) and finally after 6.7 $\pm$ 1.2 months (third re-evaluation).

The control group was composed of 16 healthy Labrador Retrievers with a mean age of 4.1 $\pm$ 1.5 years (1.7–6.7 years) and a mean body weight of 30.5 $\pm$ 5.3 kg.[21]

Clinical Examination

The preoperative subjective gait evaluation revealed a significantly higher degree of lameness in the MMP group ($p = 0.012$) (►**Table 1**).

Table 1 Results of subjective gait analysis (lameness grade 1–4) preoperatively, 6 weeks, 3 months and 6 months postoperatively

Lameness grade	TPLO	MMP	*p*-Value
Preoperatively	**Number of dogs**	**Number of dogs**	
0	0	0	0.012
1	6	0	
2	6	13	
3	10	14	
4	8	4	
6 weeks postoperatively	Number of dogs	Number of dogs	*p*-Value
0	4	4	0.517
1	16	11	
2	8	12	
3	2	4	
4	0	0	
3 months postoperatively	Number of dogs	Number of dogs	*p*-Value
0	16	18	0.321
1	11	6	
2	3	6	
3	0	0	
4	0	1	
6 months postoperatively	Number of dogs	Number of dogs	*p*-Value
0	26	23	0.870
1	2	2	
2	2	3	
3	0	0	
4	0	0	

Abbreviations: MMP, modified Maquet procedure; TPLO, tibial plateau levelling osteotomy.

All patients improved clinically during follow-up. Patients with MMP showed a higher median lameness score 6 weeks postoperatively (median 2, range: 0–3) compared with the TPLO patients (median 1, range: 0–3), although the difference between groups was not significant (►**Table 1**). The re-evaluation 3 and 6 months after surgery revealed a median lameness score of 0 in both groups (TPLO range: 0–2; MMP range: 0–4 3 months postoperatively, range: 0–2 6 months postoperatively). No significant differences were found in other clinical parameters.

Gait Analysis

►**Tables 2** and **3** show the data for PVF and VI of operated dogs. Data for dogs that were within the reference range of the control dogs (group 1) and those that were outside the reference range of the control dogs (group 2) are shown separately.

Table 2 Results of PVF within (group 1), as well as outside (group 2) the reference range, giving the mean values (mean) and standard deviation

Preoperatively			**1**	**2**	**Total**	***p*-Value**
Operative method	TPLO	*n*	9	21	30	0.360
		Mean ± SD	37.64 ± 3.34	24.68 ± 8.53	28.57 ± 9.47	
	MMP	*n*	5	25	30	
		Mean ± SD	38.67 ± 2.31	26.77 ± 7.79	28.75 ± 8.44	
Total		*n*	14	46	60	
6 weeks postoperatively			**1**	**2**	**Total**	***p*-Value**
Operative method	TPLO	*n*	13	15	28	1.000
		Mean ± SD	40.73 ± 3.84	31.14. ± 4.90	35.59 ± 6.53	
	MMP	*n*	13	16	29	
		Mean ± SD	39.61 ± 2.55	30.94 ± 5.09	34.83 ± 5.99	
Total		*n*	26	31	57	
3 months postoperatively			**1**	**2**	**Total**	***p*-Value**
Operative method	TPLO	*n*	21	8	29	0.035
		Mean ± SD	42.13 ± 4.26	33.11 ± 2.38	38.33 ± 4.23	
	MMP	*n*	13	17	30	
		Mean ± SD	42.13 ± 4.26	33.05 ± 2.70	36.99 ± 5.70	
Total		*n*	34	25	59	
≥ 6 months postoperatively			**1**	**2**	**Total**	***p*-Value**
Operative method	TPLO	*n*	26	4	30	0.063
		Mean ± SD	41.84 ± 5.25	34.75 ± 1.51	41.08 ± 5.50	
	MMP	*n*	17	10	27	
		Mean ± SD	42.35 ± 3.33	33.59 ± 2.52	39.11 ± 5.26	
Total		*n*	43	14	57	

Abbreviations: MMP, modified Maquet procedure; PVF, peak vertical force; TPLO, tibial plateau levelling osteotomy.

There was no significant difference between the number of dogs within the reference range of control dogs (group 1) that had TPLO or MMP, except for dogs with TPLO 3 months postoperatively ($p = 0.035$) (►**Tables 2–4**).

No significant difference in GRF (PVF and VI) was found between the surgical methods at any of the different time points of re-evaluation. Neither age, bodyweight, meniscal lesion nor uni- or bilateral disease influenced the results. Preoperative OA score was the only covariant to influence the results of gait analysis (PVF, $p = 0.002$; VI, $p < 0.001$.

A significant improvement in PVF and VI was noticed in all patients compared with the results of the previous assessment ($p < 0.001$).

The biggest clinical improvement for all patients was seen in the first six weeks after surgery (►**Figs. 1** and **2**).

Comparison of treated patients with the control group revealed a significant difference at every re-evaluation time point ($p < 0.05$), except for PVF of TPLO and the control group 6 months after surgery ($p = 0.144$).

When compared with the control group, mean values of 93.9% (PVF) and 85.9% (VI) were reached by the TPLO group 6 months postoperatively, with 89.4% (PVF) and 79.9% (VI) reached by the MMP group.

Major Complications

Major complications that required revision surgery occurred in 3/41 TPLO joints and 7/35 MMP joints (►**Fig. 3**). The difference between treatment groups was not significant (odds ratio 3.17, $p = 0.105$).

Radiographic Assessment

There was no significant difference in the progression of OA between dogs undergoing TPLO or MMP. At the final recheck, grading of OA had progressed by a median of 0.53 (range: 0.20–1.00) in dogs with TPLO and a median of 0.57 (range: 0.20–1.47) in patients with MMP (►**Table 5**).

Discussion

The results of the study support the hypotheses of significant improvement of limb function after TPLO as well as MMP for the treatment of cranial cruciate ligament rupture. But clinical and radiographic assessment of patients after TPLO and MMP does not reveal an obvious superiority of one of the two surgical methods.

Cranial cruciate ligament rupture in large breed dogs is highly prevalent.[22] In this study, the Labrador Retriever was

Table 3 Results of VI within (group 1), as well as outside (group 2) the reference range, giving the mean values (mean) and standard deviation

Preoperatively			**1**	**2**	**Total**	***p*-Value**
Operative method	TPLO	*n*	14	16	30	0.288
		Mean ± SD	10.77 ± 1.55	5.65 ± 2.40	8.04 ± 3.29	
	MMP	*n*	9	21	30	
		Mean ± SD	10.25 ± 0.91	6.39 ± 2.28	7.55 ± 2.65	
Total		*n*	23	37	60	
6 weeks postoperatively			**1**	**2**	**Total**	***p*-Value**
Operative method	TPLO	*n*	19	9	28	0.585
		Mean ± SD	11.48 ± 1.88	7.15 ± 1.49	10.09 ± 2.69	
	MMP	*n*	17	12	29	
		Mean ± SD	10.66 ± 1.12	7.36 ± 1.02	9.29 ± 1.97	
Total		*n*	36	21	57	
3 months postoperatively			**1**	**2**	**Total**	***p*-Value**
Operative method	TPLO	*n*	25	4	29	0.209
		Mean ± SD	11.36 ± 1.57	8.67 ± 0.27	10.99 ± 1.73	
	MMP	*n*	21	9	30	
		Mean ± SD	10.94 ± 1.63	8.08 ± 0.27	10.08 ± 1.93	
Total		*n*	46	13	59	
≥ 6 months postoperatively			**1**	**2**	**Total**	***p*-Value**
Operative method	TPLO	*n*	26	4	30	$p = 1.000$
		Mean ± SD	11.96 ± 1.84	8.55 ± 0.20	11.51 ± 2.08	
	MMP	*n*	24	3	27	
		Mean ± SD	10.94 ± 1.64	7.47 ± 1.04	10.68 ± 1.84	
Total		*n*	50	7	57	

Abbreviations: MMP, modified Maquet procedure; SD, standard deviation; TPLO, tibial plateau levelling osteotomy; VI, vertical impulse.

Table 4 Results of PVF and VI of the healthy control group

	PVF (% kg BW)	**VI (% kg BW)**
n	16	16
Mean value (M)	43.77	13.40
Standard deviation (SD)	3.69	2.21
Minimum	36.35	7.30
Maximum	50.8	16.75
Low border of the reference range (M – 2 x SD)	36.38	8.98

Abbreviations: BW, body weight; PVF, peak vertical force; VI, vertical impulse.

the most commonly affected breed, justifying the selection of Labrador Retrievers as the control group. With inclusion criteria between 20 and 35 kg bodyweight, larger breeds were not represented.

Concomitant medial meniscal injury is reported in 33.0 to 77.0% of dogs with cranial cruciate ligament deficiency.[23,24] A similar number of dogs were affected in this study with 56.6% having a medial meniscal injury as identified by high field MRI.

With regard to subjective gait evaluation, more than half the patients were considered free of lameness 6 months postoperatively, with no significant difference between the two groups. As described in the literature, a poor agreement is obvious between subjective and objective gait analysis.[25,26] Comparing both surgical techniques objectively, the only significant difference was found in PVF 3 months postoperatively, with 21 dogs with TPLO dogs and 13 patients with MMP reaching the reference range. Regarding the other parameters (VI and mean values), patients with TPLO reached higher values, but without significant difference. The results suggest that the dogs with TPLO reached a slightly better overall outcome. Compared with the control group, all patients achieved significantly lower mean values in PVF and VI up to the 3 months postoperatively. At final recheck only TPLO patients did not show a significant difference in PVF compared with the control group.

There are no studies available which objectively compare MMP with TPLO. Conzemius and colleagues[13] used comparable parameters to qualify limb function before surgery, as well as 2 and 6 months after extracapsular stabilization,

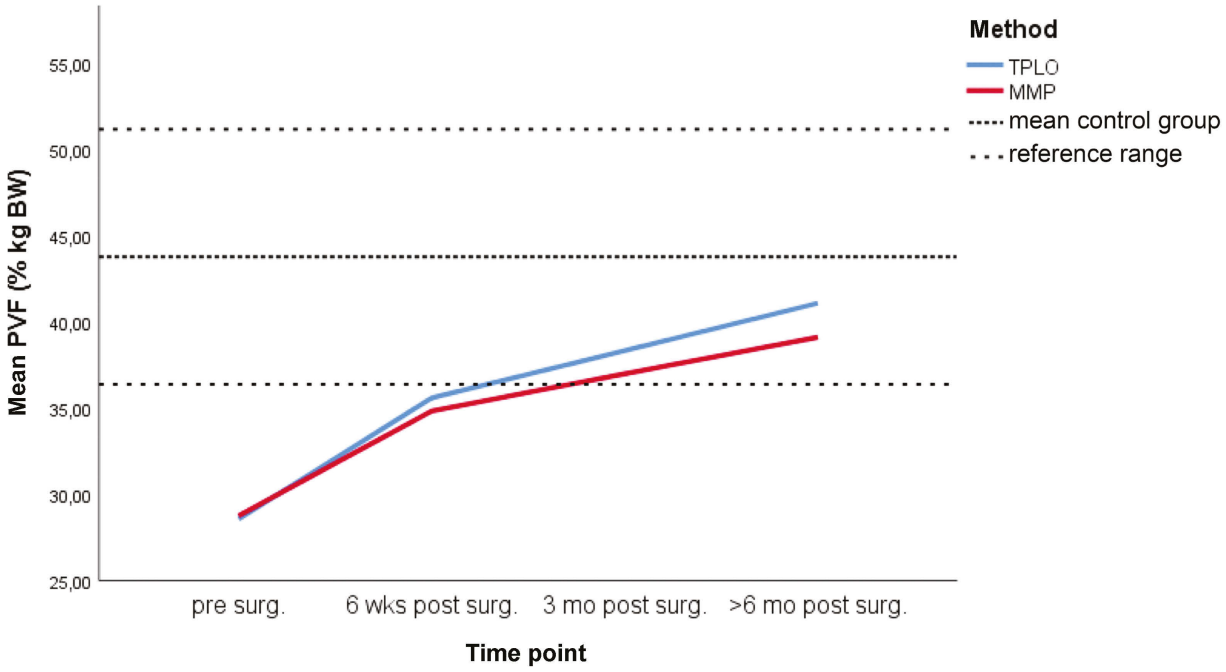

Fig. 1 Results of mean PVF from both surgical methods (TPLO/MMP) at different time points (reference range = dashed line, mean value control group = dotted line). BW, body weight; MMP, modified Maquet procedure; PVF, peak vertical force; TPLO, tibial plateau levelling osteotomy.

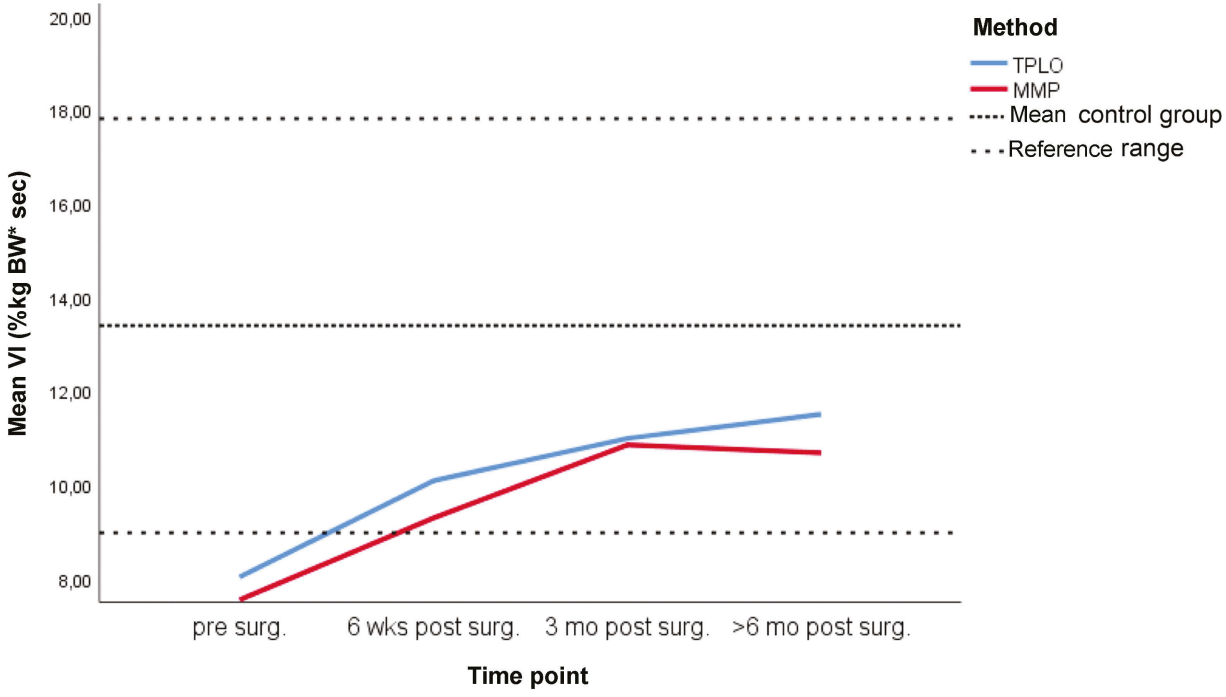

Fig. 2 Results of mean VI from both surgical methods (TPLO/MMP) at different time points (reference range = dashed line, mean value control group = dotted line). BW, body weight; MMP, modified Maquet procedure; TPLO, tibial plateau levelling osteotomy; VI, vertical impulse.

intracapsular stabilization and TPLO. The reported mean values for PVF and VI resemble the results of this study, and only 10.9% of dogs with TPLO could not be distinguished from the healthy dogs 6 months after surgery. Ground reaction forces have been measured after TPLO and in healthy dogs, and no significant difference between the groups was found after a mean of 4 months postoperatively.[12] In a force plate study of dogs that underwent TTA, kinetic values remained significantly lower than controls at 6 months, but eventually returned to 90% of control values.[27] Long-term functional outcomes after TPLO, TTA and extracapsular repair have been reported in a prospective trial,[4] and dogs with TPLO were found to have regained normal limb function after 150 days when walking, as well as when trotting. In contrast, patients with TTA (a biomechanically comparable method to MMP) did not achieve

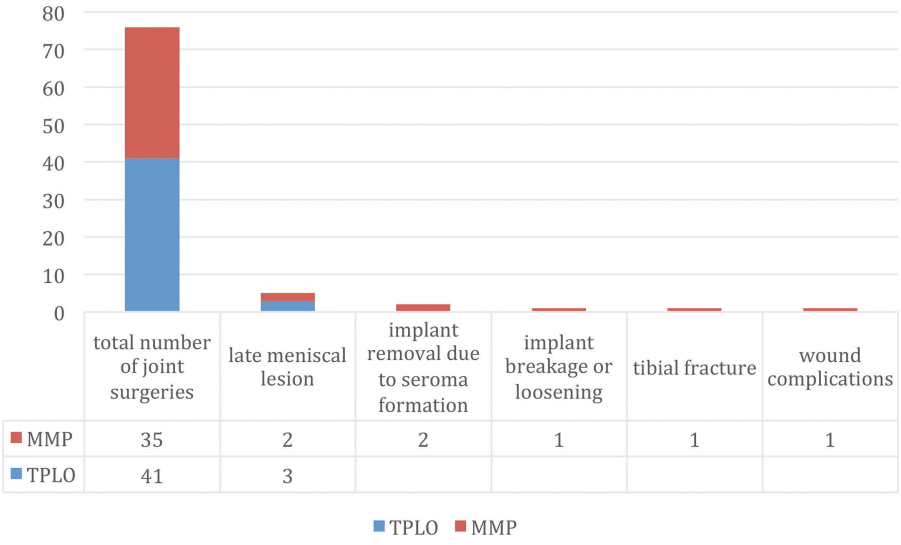

Fig. 3 Major complications. MMP, modified Maquet procedure; TPLO, tibial plateau levelling osteotomy.

Table 5 Score of osteoarthritis (grade 1–4)[16,17] 6 weeks, 3 months and 6 months postoperatively after TPLO and MMP

		TPLO	MMP
	Median value OA score		
Preoperatively	Median Range	1.87 1.27–3.33	1.73 1.27–3.07
	n	30	31
6 weeks postoperatively	Median Range	1.97 1.53–3.73	1.93 1.33–3.33
	n	30	31
3 months postoperatively	Median Range	2.17 1.67–3.80	2.13 1.40–3.33
	n	30	31
6 months postoperatively	Median Range	2.27 1.73–3.87	2.33 1.47–3.40
	n	29	28

Abbreviations: MMP, modified Maquet procedure; OA, osteoarthritis; TPLO, tibial plateau levelling osteotomy.

normal kinematic parameters while trotting at any time point. When walking, no significant difference was found > 300 days postoperatively. In conclusion, these results suggest superior clinical function after TPLO.

The different time points of re-evaluation, as well as the study structure, complicate the comparison of the results of this study with published data. Nevertheless, in the present study, patients with TPLO compared with MMP reached 84.8 and 79.85% of GRF compared with the control group 3 months after surgery and improved up to 89.9 (TPLO) and 84.5% (MMP) 6 months postoperatively. These results resemble published data from long-term outcomes.[13,27] Furthermore, the patients' continuous improvement and the predictions made in the literature suggest a further increase in GRF up to lack of significant difference to healthy control dogs.[5,13,28,29] At final recheck in the present study, only mean values of PVF in TPLO patients showed no significant difference when compared with the healthy group. Longer-term follow-up results would be helpful to evaluate the duration of clinical improvement and to make comparisons with to the control group.

No difference in rehabilitation time was found in the present study comparing TPLO with MMP. A marked increase in GRF was obvious in all patients in the first 6 weeks postoperatively. In the early postoperative period, Krotscheck and colleagues[4] described significantly less lameness in dogs with TTA compared with either TPLO or extracapsular stabilization. Nevertheless, the functional outcome of patients with TPLO was superior to TTA at their re-evaluation 6 to 12 months postoperatively.

Complication rates after TPLO are reported to be between 9.7 and 53.3%.[2,24,30]

Complication rates after MMP are reported at 23% in the only publication currently available.[11] For comparison, the complication rate after TTA ranges between 3 and 53%,[7,8] similar to TPLO.

In the present study, a total of 10/76 surgeries (13.2%) suffered a major complication; however, the risk of requiring surgical revision was 3.17 times higher in MMP patients. In both groups, postoperative medial meniscal injury was the most common major complication, as described in the literature (0.7–13%[24,29,31] after TPLO and 3.6–27.8% after TTA[7–9]). A published comparison of TTA and TPLO describes a three times higher risk of a secondary meniscal lesion after TTA compared with TPLO.[9] In the present study, revision surgery to treat a meniscal lesion was performed in three patients with TPLO (3/41) and in two dogs with MMP (2/35). The results are within the described rates of meniscal injury after surgery, and there is no suggestion of superiority of either one of the tested surgical methods. Nevertheless, postoperative meniscal lesions are still an unresolved problem, and one that is also influenced by effective meniscal assessment at the time of presentation. The risk of undetected primary meniscal lesions or remnants of injured meniscal tissue could be the reason for persistent lameness and meniscal complications.[32] Although

arthroscopy is considered to be the gold standard for assessment of intraarticular stifle joint structures,[33] the sensitivity and specificity for the diagnosis of meniscal lesions using high-field MRI, as used in the current study, are described as 90 and 96% respectively.[34] Blond and colleagues[35] concluded that high-field MRI is a reliable method to assess medial meniscal injuries, avoiding the need for arthrotomy or arthroscopy.

The remaining three major complications occurred in the same patient with MMP and were related to tibial fracture. Ness[11] reported a tibial fracture in two dogs (8%) with MMP, which was associated with mal-positioning of the cerclage wires. The positioning of drill holes was subsequently changed in the surgical guidelines, and no further tibial fracture was documented as a major complication. The tibial fracture that occurred after MMP in this study developed despite following the revised recommendation for the placement of the cerclage wires. However, the owner of the affected dog reported severe trauma at time of tibial fracture. Implant removal of the cerclage wires was subsequently required due to bone reaction, seroma formation or implant failure. The 'User Guide for MMP surgical procedure' was updated in 2014 and instead of cerclage wires, bone clamps are currently recommended for fixation[10] to reduce the risk of cerclage wire-associated complications.

There was no difference in the progression of OA between the treatment groups. This finding supports the statement that progression of OA after dynamic stabilization of cranial cruciate ligament rupture is thought to occur at a low level.[2] Lazar and colleagues[36] defined the risk of OA after extra-articular stabilization for cranial cruciate ligament rupture as 5.78 times higher compared with TPLO.

There are several limitations of the present study that need to be considered. The patient population included dogs with unilateral as well as bilateral cranial cruciate ligament rupture. Although the GRF of the hindlimbs were not compared with the contralateral side but to a healthy control group instead, a load shift to the frontlimbs may have affected the results. Previous publications report the incidence of bilateral cranial cruciate disease at presentation to be between 21 and 61.3%,[23,37] confirming that it is very difficult to evaluate only unilaterally-affected patients in clinical studies. Most of the published studies which include unilaterally diseased dogs have lower case numbers.[38] In the present study, a comparable breed was used in the control group to ameliorate any possible error.

Gait evaluation was performed with the dogs walking rather than trotting. Evans and colleagues[39] documented that the results of gait analysis during walking correlate very well with those when trotting, and that it is much more difficult to acquire representative values while trotting in clinically affected dogs.

In conclusion, the results support the hypothesis that there was a significant improvement in limb function using both surgical methods.

The minor differences observed within the force plate gait analysis may give rise to the assumption that the functional outcome might have been better in the TPLO group. Nevertheless, no significant clinically relevant differences could be found between the two surgical procedures, and the hypothesis that there would be decisive superiority in patients with TPLO was not supported. The MMP represents an alternative to the well-established TPLO in evaluated breeds between 20 and 35 kg bodyweight.

Further objective gait analysis is required to monitor the long-term outcomes of both surgical methods.

Authors' Contributions

Julia Knebel and Andrea Meyer-Lindenberg contributed to the conception of study, study design, acquisition of data and data analysis and interpretation. Daniela Eberle and Stephanie Steigmeier-Raith contributed to the acquisition of data and data analysis and interpretation. Sven Reese contributed to the study design and data analysis and interpretation. All authors drafted, revised and approved the submitted manuscript.

Conflict of Interest

Dr. Reese reports grants from Gesellschaft zur Förderung Kynologischer Forschung e.V. (GKF), during the conduct of the study.

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