

Extracorporeal shock wave therapy improves short-term limb use after canine tibial plateau leveling osteotomy

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Abstract

Objective: To determine the influence of postoperative extracorporeal shock wave therapy (ESWT) on hind limb use after tibial plateau leveling osteotomy (TPLO).

Study design: Randomized, prospective clinical trial.

Animals: Sixteen client-owned dogs, 2 to 10 years old weighing 18 to 75 kg.

Methods: Dogs were randomly assigned to treatment cohorts, TPLO with ESWT (ESWT, $n = 9$) or TPLO without ESWT (control, $n = 7$). Treatment consisted of 1000 pulses at 0.15 mJ/mm^2 immediately and 2 weeks after surgery. Subjective pain, stifle goniometry, stifle circumference, peak vertical force (PVF) and vertical impulse (VI) were measured before surgery, prior to ESWT, and 2 and 8 weeks after surgery. Measures were compared between treatments at each time point and among time points for each treatment ($P < .05$).

Results: The PVF ($5.5 \pm 1.0 \text{ N/kg}$, mean \pm SD) and VI ($0.67 \pm 0.14 \text{ N-s/kg}$) of surgically treated limbs in the ESWT cohort were higher 8 weeks after surgery compared with preoperative ($3.8 \pm 1.1 \text{ N/kg}$, $P < .0001$ and $0.47 \pm 0.21 \text{ N-s/kg}$, $P = .0012$, respectively) values. In the control cohort, PVF ($2.9 \pm 1.3 \text{ N/kg}$, $P = .0001$) and VI ($0.33 \pm 0.20 \text{ N-s/kg}$, $P = .0003$) 2 weeks after surgery and VI ($0.42 \pm 0.2 \text{ N-s/kg}$, $P = .0012$) 8 weeks after surgery were lower ($4.59 \pm 2.33 \text{ N/kg}$ and $0.592 \pm 0.35 \text{ N-s/kg}$, respectively) than before surgery. Other parameters did not differ between groups.

Conclusion: Weight bearing increased faster after TPLO in dogs treated with postoperative ESWT.

Clinical significance: This study provides evidence to consider adjunct ESWT after TPLO.

1 | INTRODUCTION

The content of this study was presented at the annual conference of the American College of Veterinary Surgeons; October 24-27, 2018; Phoenix, Arizona.

Cranial cruciate ligament (CrCL) rupture is the most common orthopedic condition requiring surgical treatment in dogs.¹

The tibial plateau leveling osteotomy (TPLO) is among the most frequent surgeries performed to stabilize canine CrCL deficient stifles.^{2,3} As with most stifle stabilization surgeries, recovery is between 8 and 12 weeks, and pain management may consist of nonsteroidal anti-inflammatory drugs (NSAID) and opioids.^{4,5} Complications of asymmetrical gait associated with postoperative pain include decreased stifle joint range of motion, muscle atrophy, and increased loading of other limbs.⁶⁻⁹ Use of NSAID to control postoperative pain can be limited by potential side effects and patient comorbidities.^{10,11} Controlled drug regulations complicate opioid availability and administration, and the efficacy of oral administration in dogs has recently been questioned.^{4,12} A mechanism to enhance standard pain management strategies and reduce postoperative discomfort may help restore normal gait, reduce postoperative complications, and improve patient outcomes.

Extracorporeal shock wave therapy (ESWT) is a therapeutic modality in which high pressure and velocity acoustic waves are applied to tissues to accelerate healing and/or reduce pain and inflammation.¹³⁻¹⁷ Various mechanisms of action, including upregulation of cytokines, increased vascular density of treated tissues, and altered nerve conduction, have been reported.¹⁸⁻²⁰ Published information suggests that ESWT may improve limb use in dogs with chronic osteoarthritis (OA) pain. Dogs with stifle OA that were treated with ESWT did not show the same increase in lameness or decrease in stifle joint range of motion as control (untreated) dogs.²¹ In addition, ESWT subjectively reduced shoulder pain due to various orthopedic pathologies in 64% to 85% of treated dogs.^{22,23}

Based on published evidence that ESWT may alleviate musculoskeletal pain, this study was performed to quantitate the effects of ESWT in conjunction with standard pain management on limb function after elective canine TPLO. The tested hypothesis was that dogs treated with postoperative ESWT in addition to standard pain management would have greater hind limb ground reaction forces, greater stifle joint range of motion, and lower subjective pain scores in the surgically treated limb after TPLO compared with those that received only standard pain management.

2 | MATERIALS AND METHODS

2.1 | Study design

The study was a randomized, controlled clinical trial approved by the Louisiana State University Institutional Animal Care and Use Committee prior to study initiation. Dogs evaluated for CrCL insufficiency during the study recruitment period that met inclusion criteria were invited to

participate. Complete physical and orthopedic examinations were performed by a board-certified surgeon in all dogs to confirm the presence of CrCL insufficiency. Owner education about TPLO and ESWT was presented, and consent for surgery, data collection, presentation, and publication were obtained prior to enrollment. Inclusion criteria were (a) body weight ≥ 18 kg; (b) radiographic evidence of closure of proximal tibial physes; (c) body condition score ≤ 4 of 5; (d) no evidence of lameness in other three limbs; and (e) no, minimal, or moderate radiographically evident degenerative joint disease in the affected stifle. Enrolled dogs were randomly assigned to one of two treatment groups, TPLO with ESWT (ESWT) or TPLO without ESWT (control) by using a random number generator in Excel (Microsoft, Redmond, Washington).

Caudocranial and lateral radiographs of the affected stifle in full extension and flexed 90° were performed (EDR 6; Sound-Eklin, Carlsbad, California) with dogs heavily sedated (0.2 mg/kg butorphanol and 2.5-5 mcg/kg dexmedetomidine, both intravenously [IV]). Radiographic evidence of OA was scored by a board-certified radiologist preoperatively as none, mild (periarticular osteophytes), moderate (periarticular osteophytes, bone sclerosis), or severe (periarticular and intra-articular osteophytes, bone sclerosis, subchondral bone lysis).²⁴ Only dogs with no, mild, or moderate OA were enrolled in the study. Dogs were sedated in a similar manner to obtain the same radiographic views 8 weeks postoperatively. Radiographic evidence of healing of the osteotomy at 8 weeks was scored by a board-certified radiologist according to a previously published scale.²⁵ Complications throughout the study period were classified as either major (requiring surgical intervention) or minor.

2.2 | Outcome measures

Subjective pain was quantitated with the Glasgow Composite Pain Score short form before and 24 hours, 2 weeks, and 8 weeks after surgery by a trained member of the small animal surgery service unaware of treatment. Directly after surgery, stifle range of motion and circumference were measured three times each with the dog in lateral recumbence on the unaffected limb. Joint angles with the joint in full extension and flexion were measured by placing the center of the goniometer at the center of the stifle joint with one arm over the long axis of the femur and the other over the tibial long axis as previously described.²⁶ Stifle circumference was measured at the level of the distal patella with the stifle in full extension by using a Gulick II tape measure (Performance Health, Warrenville, Illinois).²⁷

Kinetic analysis was performed before and 2 and 8 weeks after surgery by using a force platform embedded in a 40-m

runway (force plate model No. OR6-WP-1000; Advanced Medical Technology, Newtown, Massachusetts). Data logging (100 Hz; Acquire V7.3; Sharon Software, Dewitt, Michigan) was triggered by a force of 5 N on the force platform. Three successful trials at a velocity of 1.5 to 2.5 m/s and acceleration of ± 0.0 to 0.9 m/s² were recorded for each limb. Dogs were acclimated and trained to trot across the force platform during the presurgical gait trial, and trained handlers walked the dogs for all testing. Ground reaction forces were normalized to body weight measured at each time point. Peak vertical force (PVF; N/kg) and vertical impulse (VI; N-s/kg), the highest vertical force and total force during the stance phase, respectively, as well as the average velocity (m/s), average acceleration (m/s/s), time to peak vertical force (ms), peak braking force (N/kg), braking impulse (N-s/kg), time to peak braking force (ms), peak propelling force (PPF; N/kg), propelling impulse (N-s/kg), time to PPF (ms), maximum rising slope (N/ms), and maximum falling slope (N/ms) were quantitated. By using the mean value of the three trials of each hind limb, the symmetry index (SI) was calculated at each time point as $SI = ((X_l + X_r) - (|X_l - X_r|)) / (X_l + X_r)$, where X is the mean of a given gait variable for the left (l) and right (r) hind limb for a given time point.

2.3 | Surgical technique

A complete blood cell count and serum biochemistry profile was performed for all dogs prior to standard anesthesia protocols customized for individual dogs by the hospital anesthesia service. Perioperative cefazolin (22 mg/kg IV every 90 minutes) was administered to all dogs and was discontinued within 24 hours after surgery.

Surgeries were performed or directly supervised by small animal surgeons certified by the American College of Veterinary Surgeons and according to Synthes guidelines (DePuy Synthes Vet, West Chester, Pennsylvania).²⁸ Briefly, intra-articular structures were exposed via a minimedial parapatellar arthrotomy, and the CrCL and menisci were assessed. Partial meniscectomies were performed for meniscal tears. There were no meniscal releases or other treatments on intact menisci. A TPLO jig was used in two cases, both in the control cohort. Partial elevation of the popliteal muscle to expose the caudomedial tibial cortex was performed in all but one dog. In that surgery, the popliteal muscle was elevated from the caudal tibia, and a gauze sponge was packed between the muscle and the bone. An osteotomy of the proximal tibia was then performed with an oscillating saw. The tibial plateau was rotated according to presurgical measurements.²⁹ The osteotomy fragments were stabilized with a locking TPLO plate and screws (DePuy Synthes Vet). Orthogonal postoperative

radiographs were acquired prior to recovery from surgical anesthesia.

A pure μ -agonist (such as hydromorphone 0.05-0.1 mg/kg IV every 4-6 hours or fentanyl 2-5 mcg/kg/hour IV) was administered until extubation, at which time a single dose of an NSAID (carprofen 2.2 mg/kg subcutaneously or metacam 0.1 mg/kg subcutaneously) was administered. All dogs received tramadol (3-7 mg/kg orally every 8 hours) for 10 to 14 days and carprofen (2.2 mg/kg orally every 12 hours) or meloxicam (0.1 mg/kg orally every 24 hours) for 10 days. Owners were instructed to restrict dogs to kennel confinement with strictly controlled ambulation for 8 weeks. The length and frequency of leash walks was limited to 5 minutes three to four times per day for the first 2 weeks, followed by a gradual increase in duration by 5 minutes per week until the last recheck appointment.

2.4 | Intervention

The ESWT was administered immediately after radiographs were completed postoperatively before anesthetic recovery and then 2 weeks later with the dogs in lateral recumbence on the unaffected leg and heavily sedated (butorphanol 0.2 mg/kg IV and dexmedetomidine 2.5-5 mcg/kg IV). The second treatment was administered after collection of kinetic gait analysis. The stifle was clipped, coupling gel was applied, and 1000 pulses at an energy flux density of 0.15 mJ/mm² were administered with a 5-mm trode (PulseVet Technologies, Alpharetta, Georgia) at four locations around the stifle joint, proximolateral, distolateral, proximomedial, and distomedial, as previously reported.²¹ Treatment was not applied over or directly adjacent to the bone plate.

2.5 | Statistical analysis

Measures included stifle range of motion and circumference, subjective pain score, kinematic variables, and SI for ground reaction force (GRF) metrics. Prognostic factors included age, breed, body weight, body condition score, OA grade, and presence of meniscal tear. The Shapiro-Wilks test was used to assess for normality. Outcomes and prognostic factors that were normally distributed were summarized as mean \pm SD. Nonnormally distributed data were presented as median (range). Contingency tables were generated for the categorical variables. A mixed effects repeated measures analysis of variance (ANOVA) was used to assess fixed effects of treatment and time with animal as a random effect. Significant differences were evaluated with Tukey's post hoc comparisons of least-squares mean. Age, breed, body weight, body condition score, OA grade, 8-week osteotomy healing score, complications, and presence of meniscal

TABLE 1 Descriptive statistics

Dog	Treatment group	Weight, kg	Age, y	BCS	Breed	Leg	Meniscal tear	Postop TPA	TPLO jig
1	A	39	10	3.5	Labrador	L	Yes	6	No
2	A	29	9	2.5	Mix	L	No	7	No
3	A	65	5	3	Great Dane	L	Yes	12	No
4	A	26	5	2.5	Labrador	L	Yes	5	No
5	A	43.5	3	3.9	Labrador	R	No	8	No
6	A	75.2	2	3.3	Great Dane	L	No	9	No
7	A	30	6	2.5	Mix	L	Yes	5	No
8	A	21	3	2.2	Mix	L	No	6	No
9	A	29.6	3	3.3	Labrador	R	No	7	No
10	B	31	3	3	Labrador	R	No	6	No
11	B	30.7	9	4	Mix	L	No	6	No
12	B	41	6	3.3	Mix	R	No	9	No
13	B	36.5	4	4.4	Mix	L	Yes	7	Yes
14	B	30.3	2	3.3	Staffordshire	L	No	6	Yes
15	B	20.6	7	3.3	Mix	L	Yes	7	No
16	B	35.4	3	3.9	Mix	L	No	6	No

Abbreviations: A, ESWT cohort; B, Control cohort; BCS, body condition score; ESWT, extracorporeal shockwave therapy; L, left; Postop, postoperative; R, right; TPA, tibial plateau angle; TPLO, tibial plateau leveling osteotomy.

TABLE 2 Outcome measures

Time point	Circumference, cm (SD)		Flexion, degrees (SD)		Extension, degrees (SD)		Pain scores (range)	
	ESWT	Control	ESWT	Control	ESWT	Control	ESWT	Control
Pre	29.6 (6.2)	29.0 (4.7)	46 (8)	45 (10)	145 (10)	149 (5)		
24 h Postop	32.8 (5.7)	32.4 (2.8)	65 (10)	53 (13)	146 (12)	143 (14)	3.5 (1-6)	3 (0-7)
2 wk Postop	30.7 (6.0)	29.6 (2.9)	51 (6)	52 (7)	145 (14)	147 (10)	1 (0-4)	1 (0-3)
8 wk Postop	30.8 (5.5)	28.8 (2.7)	50 (11)	48 (4)	150 (16)	158 (13)	1 (0-2)	1 (0-2)

Note: There were no differences between groups at any time point for any variable evaluated.

Abbreviations: ESWT, extracorporeal shockwave therapy; Postop, postoperatively; Pre, before surgery.

damage were compared between treatment cohorts via Fisher's exact test, Mann–Whitney U test, or Student's *t* test, depending upon the nature of the data. Significant factors were included as fixed effects or covariates in the ANOVA model described above. Model assumptions (normality and homoscedasticity of residuals) and influential data points were assessed by examining standardized residual and quantile plots. $P < .05$ was considered significant. All analyses were performed in SAS Version 9.4 (SAS Institute, Cary, North Carolina).

3 | RESULTS

In total, 16 dogs, eight neutered males and eight spayed females, were included in the study with nine in the ESWT

cohort and seven in the control cohort (Table 1). Complete data sets are available for a total of 15 dogs because one control cohort dog did not return for the 8-week evaluation. Breeds included Labrador retriever (5), mixed (8), Great Dane (2), and Staffordshire terrier (1). The median age, weight, and mean body condition score of the study population were 4.5 years (range, 2-10), 30.9 kg (range, 20.6-75), and 3.5 ± 0.5 of 5, respectively. The body condition was different between cohorts (3.0 ± 0.5 ESWT, 3.5 ± 0.5 control, $P = .04$). The median OA score was 2 (range 1-2) for the ESWT cohort, which was higher than the score of 1 (range 0-2) for the control cohort ($P = .01$).

Cranial cruciate ligament disruption was confirmed in all dogs during surgery. Meniscal tears were present in four of nine dogs in the ESWT cohort and in two of seven dogs in the

control cohort. All meniscal tears were treated with partial meniscectomy. Complete CrCL tears were noted in three of nine dogs in the ESWT group and four of seven dogs in the

control group. All but two of the dogs were treated with fentanyl after surgery. Among the remaining dogs, one in the ESWT group was treated with hydromorphone and one in the control group was treated with methadone. There were no major complications requiring surgical intervention over the course of the study. Minor postoperative complications included gastrointestinal upset in close association with tramadol administration (1/16 [6%], $P = > .99$), licking or chewing at the incision site (3/16 [18%], $P = .55$), and increased subjective lameness observed by the attending clinician at the 8-week recheck (1/16 [6%], $P > .99$). Radiographically determined bone healing scores 8 weeks after surgery were 7.9 ± 2.2 for the ESWT cohort and 7.5 ± 2.4 for the control cohort ($P = .86$). The number of complications ($P > .99$), meniscal tears ($P = .63$), and partial vs complete CrCL disruptions ($P = .61$) were not different between cohorts. The 2-week recheck was performed at 13 ± 2.3 days in the ESWT cohort and at 13.3 ± 0.8 days in the control cohort. The 8-week recheck was at 60.4 ± 7.7 days in the ESWT cohort and at 57.8 ± 5.8 days in the control cohort.

Stifle circumference, goniometry, and subjective pain score were not different between cohorts at any time (Table 2). There was a decrease in stifle flexion (increased flexion angle) in both the ESWT ($65^\circ \pm 9^\circ$) and the control ($53^\circ \pm 13^\circ$) cohorts 24 hours after surgery compared with baseline ($46^\circ \pm 8^\circ$, $P < .0001$ and $45^\circ \pm 100$ 176° , $P < .0001$, respectively). Flexion was not different between cohorts at any time ($P = .06$).

The PVF (5.5 ± 1.0 N/kg) and the VI (0.67 ± 0.15 N-s/kg) were greater 8 weeks after surgery vs before surgery (3.8 ± 1.1 N/kg, $P < .0001$ and 0.48 ± 0.21 N-s/kg, $P = .0012$, respectively) in the ESWT cohort (Figure 1, Table 3). The PVF (2.9 ± 1.3 N/kg) and the VI (0.34 ± 0.22 N-s/kg) were lower 2 weeks after surgery vs before surgery (4.6 ± 2.3 N/kg, $P = .0001$ and 0.59 ± 0.35 N-s/kg, $P = .0003$, respectively) in the control cohort. Similarly, VI was lower 8 weeks after surgery (0.42 ± 0.20 N-s/kg) vs before surgery (0.59 ± 0.35 N-s/kg, $P = .0012$) in the control cohort. The PPF SI was

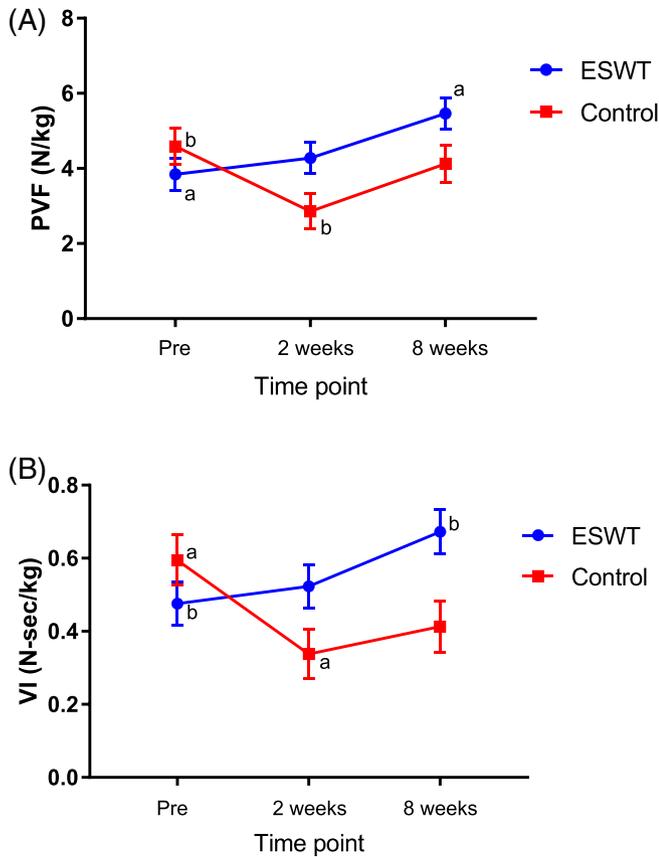


FIGURE 1 Peak vertical force (A) and vertical impulse (B) for treated (ESWT) and untreated (control) dogs before surgery (Pre) and 2 and 8 weeks after surgery. A, Peak vertical force was higher compared with baseline for treated dogs at the 8-week recheck (a; $P < .0001$) and lower compared with baseline for untreated dogs at the 2-week recheck (b; $P = .0001$). B, Vertical impulse was higher compared with baseline for the ESWT at the 8-week recheck (b; $P = .0012$) and lower compared with baseline for the control cohort at the 2-week recheck (a; $P = .0003$). ESWT, extracorporeal shock wave therapy; Pre, before surgery; PVF, peak vertical force; VI, vertical impulse

TABLE 3 Ground reaction forces

Group	Time point	Velocity, m/s	PVF (SD)	SI, PVF	VI (SD)	SI, VI	SI, PPF	SI, PI
ESWT	Pre	2.41 (0.52)	3.8 (1.1)*	0.85	0.48 (0.21)*	0.81	0.84	0.78
Control	Pre	2.07 (0.33)	4.6 (2.3) [#]	0.86	0.59 (0.35) ^{#†}	0.83	0.82	0.76
ESWT	2wk	2.31 (0.41)	4.3 (2.1)	0.86	0.52 (0.33)	0.82	0.86*	0.83
Control	2wk	2.17 (0.56)	2.9 (1.3) [#]	0.74	0.34 (0.22) [#]	0.71	0.63*	0.64
ESWT	8wk	2.26 (0.52)	5.5 (1.0)*	0.93	0.67 (0.15)*	0.9	0.88	0.87
Control	8wk	2.23 (0.35)	4.3 (1.9)	0.89	0.42 (0.2) [†]	0.85	0.85	0.83

Note: When values within a column are flagged with the same superscript symbol (*, #, †), that is to indicate that they are significantly different from each other. Abbreviations: 2wk, 2 weeks postoperatively; 8wk, 8 weeks postoperatively; ESWT, extracorporeal shockwave therapy; Pre, before surgery; PI, propelling impulse; PPF, peak propelling impulse; PVF, peak vertical force; SI, symmetry index; VI, vertical impulse.

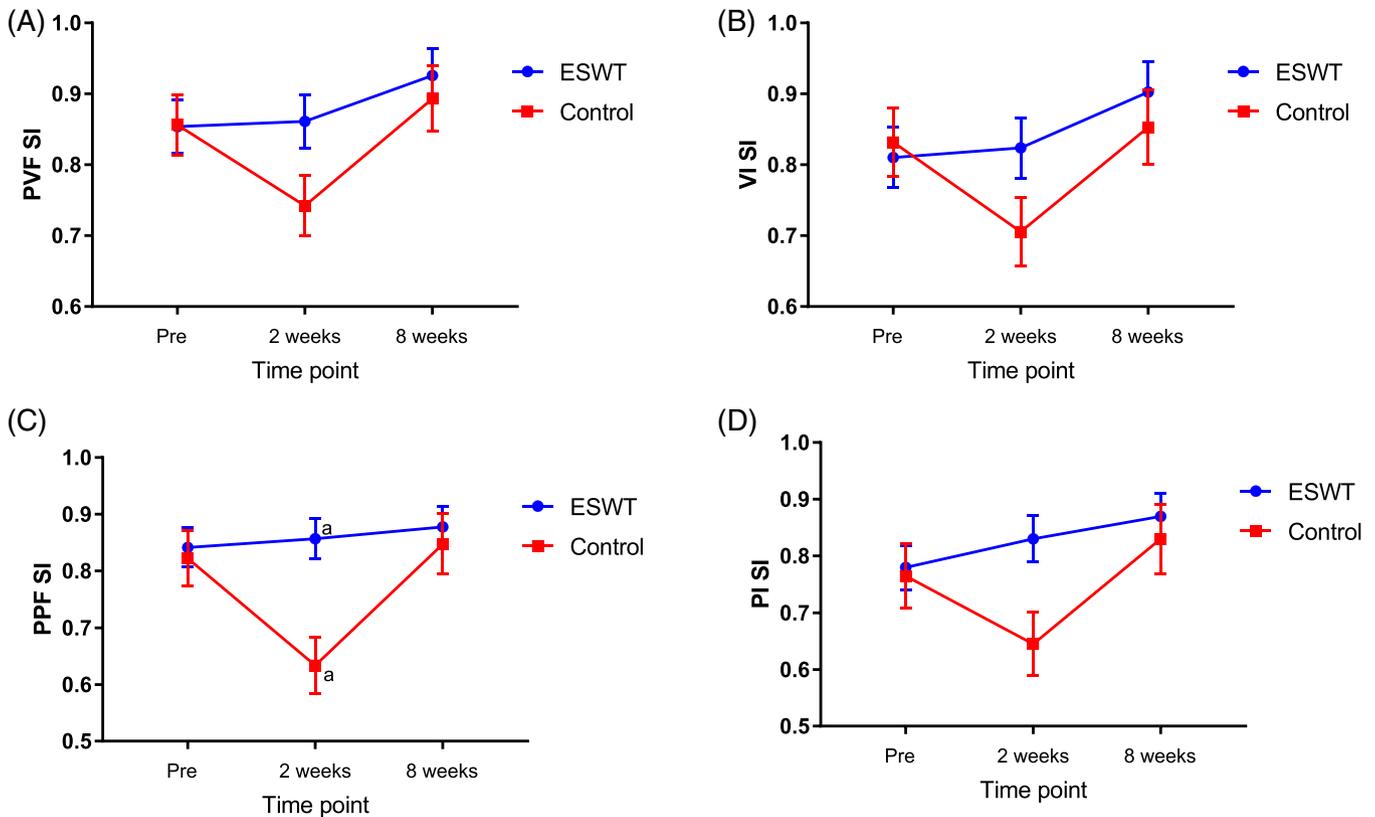


FIGURE 2 Symmetry index for PVF (A), VI (B), PPF (C), and PI (D) before surgery (Pre) and 2 and 8 weeks after surgery. Untreated dogs (control) were less symmetric for PVF, VI, and PI at the 2-week recheck compared with the ESWT group, but this was not significant. The SI for PPF (C) was lower for the control group at 2 weeks compared with the ESWT group (a; $P = .0074$). ESWT, extracorporeal shock wave therapy; PI, propelling impulse; Pre, before surgery; PPF, peak propelling force; PVF, peak vertical force; SI, symmetry index; VI, vertical impulse

higher in the ESWT (0.86 ± 0.04) vs the control (0.63 ± 0.05 , $P = .0074$) cohort 2 weeks after surgery (Figure 2). While the GRF SI appeared to increase in the ESWT cohort and decrease in the control cohort 2 and 8 weeks after surgery (Figure 2), these observations were not different.

4 | DISCUSSION

The results of this study provide objective quantitation of canine limb use with and without ESWT after TPLO. We accept the hypothesis that dogs treated with ESWT after TPLO have a faster increase in weight bearing compared with untreated dogs. This conclusion is supported by a steady improvement in GRF after TPLO in dogs treated with ESWT compared with decreased GRF dogs that did not receive ESWT. Extracorporeal shockwave therapy may provide multiple benefits after stifle surgery by increasing comfort and use of the limb while also stimulating bone healing.^{16,30,31} Overall, the study results support growing evidence that percutaneous ESWT may benefit TPLO recovery in dogs.

Promotion of bone healing is a previously documented effect of ESWT.^{30,32,33} Although there was not a difference

in bone healing between the two groups in this study, this finding is not entirely surprising. Instead of focusing the shock waves on the osteotomy site, treatment in this study was applied around the stifle joint. This area included the proximal tibia but did not focus on it. Radiographic assessment more easily detects radiopaque tissues and may have missed other more subtle aspects of bone healing. If enhanced bone healing after TPLO is the primary goal, a previously published protocol for treatment could be used.²⁵ Future studies combining this protocol with the one outlined in the current study may be useful for the promotion of bone healing and improvement in lameness after TPLO.

The energy flux density and number of pulses used in this study were based on manufacturer recommendations for treatment at the level of the stifle. Pulses were applied over the surgical site, specifically around the stifle joint. This protocol is similar to an application protocol used previously for canine stifle OA.²¹ The focus of the ESWT in this study was the joint vs the osteotomy site because the goal of this study was stifle pain vs bone healing. Application of treatment at distinct locations may augment the potential benefits highlighted in this study.

Although previous studies have provided evidence of improved limb use in dogs after ESWT for musculoskeletal pain of various etiologies, a definitive mechanism of action has not been identified.²¹⁻²³ Published reports of *in vitro* and *in vivo* studies in other species provide some proposed actions of the technology. Reduction of inflammatory cytokines characteristic of the CrCL deficient stifle by ESWT may be responsible for improved limb use.^{29,34} An *in vitro* study of injured human tenocytes that were harvested and then treated with ESWT confirmed reduced levels of interleukin 6 and metalloproteinases 1, 2, and 13 after ESWT of tendon cells in culture.³⁵ Alteration of these inflammatory mediators may have contributed to the improvement in lameness. Another proposed mechanism of action is an alteration of substance P or interference with nerve conduction velocity. Maier et al³⁶ found that substance P was elevated 6 and 24 hours after treatment of the distal femur in the rabbit. Extracorporeal shock wave therapy decreases sensory nerve conduction velocity 3 and 7 days after treatment according to recent equine studies, potentially by disruption of the myelin sheath without damage to cell bodies or axons.²⁰ This change is thought to result in a reversible local analgesic effect. Conjecture on the mechanism of action is beyond the scope of this study. However, contemporary work supports the study findings, and future investigations that include evaluations of joint fluid and periarticular tissues may provide additional insight.

There are several methods for the generation of extracorporeal shock waves that include electrohydraulic (used in the current study), electromagnetic, and piezoelectric mechanisms.¹⁵ Radial shockwave therapy has also been used to treat pain associated with hip OA, although it does not use true shock waves.^{37,38} Radial waves are mechanical pressure waves generated by accelerating an object with compressed air and typically have a more shallow depth of treatment. An electrohydraulic machine was used in the current study; it is unknown whether different mechanisms of ESWT generation lead to different effects on bone healing or pain relief.

Reported complications associated with ESWT include mild bruising, redness, transient superficial pain at the treatment site, and the requirement for sedation or general anesthesia for treatment.^{15,39,40} Subjective pain evaluation 24 hours after surgery in this study may not have been of sufficient resolution to detect differences between treatments, although the rubric used is well established for comparison of postoperative comfort levels.^{4,41,42} More objective forms of pain evaluation, such as kinetic gait, mechanical threshold testing with an algometer, or stance analysis, could have been performed.^{43,44}

Additional stifle measures including circumference to quantitate joint effusion²⁷ and periarticular swelling and joint angles to quantitate range of motion also did not show

much difference among treatments. Slightly lower stifle flexion 24 hours after surgery in treated (65°) vs untreated (53°) dogs in this study was not significantly different. This is despite the fact that ESWT is reported to potentially cause bruising and enhanced neovascularization to treated tissues.¹⁹ Decreased stifle flexion and extension have previously been associated with higher lameness scores in dogs after TPLO,⁸ so the range of motion is directly related to function. It is possible that there was a transient increase in pain from ESWT in the joint that led to the decreased willingness or ability to flex the stifle immediately after surgery. However, the findings of this study do not support any negative effects of ESWT, and use of the technology did not increase the complication rate compared with previous studies.^{25,45}

Despite the improvement in weight bearing after surgery, there was no difference in pain scores between groups at any postoperative recheck. Pain was assessed via the short form of the Glasgow Composite Pain Scale, which includes six behaviors: vocalization, attention to wound, mobility, response to touch, demeanor, and posture/activity.⁴⁶ Although it is used to measure pain in dogs, the scale is subjective and may be influenced by how the dog interacts with observers, differences in interpretation of scoring criteria among observers, and varying thresholds of pain tolerance among dogs.⁴

Kinetic gait analysis was performed in the current study to provide an objective method for postoperative assessment. Alternative methods for the assessment of clinical outcome include owner questionnaires and subjective gait scoring by a veterinarian. Although they are easier to perform, subjective scales may not correlate with lameness identified with force plate gait analysis.⁴⁷ Previous studies in which lameness after treatment with ESWT has been evaluated have used both objective and subjective methods.²¹⁻²³ Because the force platform quantitates kinetic forces without observer bias, it was used to assess outcome in this study. Symmetry indices were determined for gait variables, and the PPF SI was higher in the treatment cohort. Dogs with cruciate disease exhibited decreased propelling force in affected limbs.⁴⁸ The higher SI for PPF in dogs treated with ESWT may provide additional evidence of improvement in weight bearing after TPLO. Larger case numbers in future studies may assist to further identify differences in gait after surgery.

Limitations of this study include the small population, different body condition scores between groups, relatively short follow-up time, and potential for variability in postoperative compliance with client-owned animals. Future studies with larger populations of dogs are required to validate the findings of this pilot clinical trial. The influence of body condition score on outcome variables is unclear, but it could affect postoperative ambulation and, therefore, the could

have affected the results of this study. Inclusion criteria with a more narrow range of body condition score in future studies may help eliminate differences between cohorts. The effects of ESWT have been shown to last beyond 8 weeks, so it is possible that a longer follow-up period would allow for identification of additional significant differences in outcome.^{16,19,30} An 8-week study period was chosen in this study so that there would be no additional rechecks beyond what would normally be expected after surgery. Although dogs were discharged with the same medication schedule and instructions, owner compliance with medication administration and exercise restriction could not be controlled. The authors assumed that owner compliance was similar between the two cohorts without evidence to suggest otherwise.

An additional limitation of this study is the small variations in surgical procedure, such as jig use and muscle elevation, which could impact clinical outcome. Use of different postoperative IV opioids and NSAID could also impact data, particularly 24 hours postoperatively. Although most dogs received postoperative fentanyl, two dogs received alternative, less potent, pure μ -agonist. Differences in pain medication may have impacted postoperative pain scores. Differences among NSAID drugs were generally a result of prescription by a primary care veterinary prior to referral to the surgical facility. The preoperative NSAID was continued in the postoperative period for continuity. Future studies without variation in postoperative opioids and NSAID will help avoid these study limitations.

In conclusion, the results of this study provide evidence that treatment with ESWT leads to improvement in weight bearing and a faster return to function after TPLO surgery. Extracorporeal shock wave therapy is a relatively simple method to help control postoperative pain and is not associated with an increase in complication rate. The benefits noted after treatment with ESWT in this study likely outweigh any potential complications (such as transient decreased stifle flexion and the requirement for sedation). Future studies with larger populations of dogs treated with various surgical procedures are required to expand the potential use of postoperative ESWT. Additional work to quantitate the biological effects of ESWT on healing tissue and arthritic joints will further elucidate the mechanisms of action of this therapy.

CONFLICT OF INTEREST

The authors have no financial or other conflicts of interest to disclose.

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