Interday and intraday stance analysis variability in dogs with hindlimb lameness and comparison of the effect of dog, surgeon, and TPLO surgical procedure variables on improvement of eight-week post-operative static weight-bearing.

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Abstract

Interday and Intraday stance analysis variability in dogs with hindlimb lameness

Objective: The purpose of this study was to assess the same day and next-day repeatability of data collected with a Pet Safe Stance Analyzer on animals with naturally-occurring lameness presented for veterinary orthopedic examination. Our hypothesis was that dogs would show consistent repeatability with regards to body weight distribution on the Pet Safe Stance analyzer.

Materials and Methods:

Interday Variability Trial: Thirty-one consecutive dogs presenting for hindlimb lameness were included. The PetSafe Stance Analyzer was used with the dog standing in their natural standing position with each foot placed in its respective quadrant on the Stance Analyzer. A minimum of 5 valid measurements were collected and averaged to find the mean distribution of weight on each limb. This process was repeated the following day with the same handler and recorder.

Intraday Variability Trial: Fifteen consecutive dogs were placed on the Pet Safe Stance analyzer and measurements were collected for each of 5 trials identical to the interday group. Four additional assessment trials followed with reintroduction of the animal to the room at each assessment.

Results:

Interday Variability Trial: There were no significant differences between Day 1 and Day 2 measured variables except for a significant increase in the Forelimb Symmetry index on Day 2

compared to Day 1. Lin's Correlation Coefficients % body weight measured on Day 1 compared to Day 2 were significantly correlated on the lame hindlimb (0.524) and contralateral hindlimb (0.733).

Intraday Variability Trial: There were no significant differences across trials for measured variables of % weight on the lame hindlimb, contralateral hindlimb, ipsilateral forelimb, or contralateral forelimb. Lin's Correlation coefficients showed strong correlation between trials for the lame hindlimb (0.682), contralateral hindlimb (0.817), body weight (0.863), and hindlimb symmetry index (0.726).

Clinical Significance: A commercial stance analyzer is a repeatable method of measurement of weight-bearing on lame hindlimbs of dogs between days and in repeated trials over one day. Day-to-day forelimb weight-bearing in dogs who are lame on a hindlimb is more variable, likely because of trial to trial changes in weight redistribution from lameness.

Comparison of the Effect of Dog, Surgeon, and TPLO Surgical Procedure Variables on Improvement of Eight-week Post-operative Static Weight-Bearing

Objective: To compare the effect of surgeon and tibial plateau leveling osteotomy (TPLO) procedure variations on the outcome of TPLO in naturally-occurring cranial cruciate-deficient stifles.

Materials and methods: Records from 142 dogs receiving a TPLO were reviewed for information regarding surgical procedure, status of meniscus at the time of surgery, surgeon identity, ACVS diplomate or resident, meniscal release, progression of healing at the progress evaluation based on radiographic interpretation, and complications encountered. The primary outcome measure was static force on the operated limb at recheck on a PetSafe Stance Analyzer[a].

Results: Recheck tibial plateau angle (TPA) was negatively and significantly correlated with improvement ($r=-0.2132$, $p=0.013$). Post-operative, and Recheck TPA's were all significantly correlated with one another. The amount of TPA change from initial to immediate post-operative values was significantly correlated with the Initial TPA ($r=0.628$, $p<0.001$). Surgeon, surgical experience, arthrotomy, meniscal damage, meniscal intervention, complications, post-operative TPA, and initial TPA had no significant effect on weight-bearing at recheck.

Clinical Significance: TPLO's show improvement of 4.58% BW on the operated limb at 6-12 week rechecks on a stance analyzer. Surgeon, surgical experience, arthrotomy, meniscal damage, meniscal intervention, complications, post-operative TPA, and initial TPA have no effect on surgical outcome.

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Chapter 1 - Review of Lameness Assessment in Dogs

Assessment of lameness and long-term post-operative function in clinical cases is challenging and often based on owner assessment through subjective evaluation, questionnaires, and kinetic gait analysis.[1]

It is believed that severity of lameness is associated with the amount of pain a dog is experiencing.[2] Unfortunately, detection of lamenesses that are not evident in a clinical setting are challenging, and methods of lameness evaluation are also variable between examiners.[2,3]

Subjective Analyses

Subjective analyses consist of numeric rating scores or visual analog scores that use a line to represent a continuum of lameness with one end representing normal and the other end non-weight bearing.[4] While these can be used to measure, communicate and report limb function, inherent weaknesses are present. In numerical rating scoring systems, there are a limited number of lameness groups (typically 4-5) and within a group, significant differences in lameness may be present. Inter- and intra-observer agreement is highly dependent on the severity of the lameness with greater agreement seen more commonly in severe lameness.[4,5] Several studies have compared visual analogue scales to objective measures of limb weight-bearing using force plates.[1,2,5,6] Those objective measures most commonly include peak vertical force and vertical impulse.[6] When using the objective measures as the gold standard, there is generally poor agreement between the methods. One study concluded that visual analogue scales cannot accurately discriminate normal from abnormal gaits in Labrador Retrievers, a breed commonly over-represented in studies involving cranial cruciate ligament disease. Agreement between force plate analysis and visual analogue scales was also found to be low in an experimentally induced hindlimb lameness.[5] In a population of dogs with unilateral forelimb lameness caused by a fragmented medial coronoid process, a visual analogue scale was compared to objective gait analysis to assess for improvement following arthroscopic retrieval of the fragmented medial coronoid process.[7] As time passed after surgery, owners and clinicians tended to underestimate asymmetry in the gait when using a visual analogue scale compared to force plate data.

Canine Brief Pain Inventory

In an attempt to improve subjective lameness detection, researchers have sought to develop validated owner-reported questionnaires to increase the ability to detect more subtle or intermittent lamenesses.[2,8] The Canine Brief Pain Inventory (CBPI) was developed as a method to allow for assessment of pain as well as lameness in dogs. (Appendix A) The CBPI was modified from established human pain scales to account for canine behavior.[8] The CBPI was designed as an owner-completed instrument to quantify the owners' perception of chronic pain in their dogs with osteoarthritis. Its aim was to assess both severity and the impact of chronic pain on the dog. Brown et al assessed construct validity and reported excellent reliability.[8-10]

Force Plate Gait Analysis

An objective measure, used alone or in combination with subjective questionnaires, is kinetic gait analysis, also known as force plate gait analysis or ground forces analysis. This is the study of forces generated between the limb and the ground.[1] Kinetic gait analysis allows clinicians to collect objective data on the forces between the limb and the ground during the stance phase in a non-invasive manner and allow for numeric comparisons between different populations.[1,11] Single force plates or multiple in-line force plates can be used, although multiple are recommended to allow for evaluation of consecutive strides. They can be free standing, floor mounted, ground level, embedded into the ground raised, or pit-installed.[1] Force plate analysis typically requires a dedicated gait analysis lab or large area to house the device and allow unrestricted movement of the animal over a reasonable walkway distance. Most force plate systems are designed for medium to large breed dogs, and thus stride length prevents the use of force plates in small or very large dogs. Ideally, the size of the force plate should allow for contact of one limb at a time, although a metod has been developed to accommodate animals with shorter strides.[12] Force plates embedded in treadmills have been used in an attempt to allow investigators with limited space to perform force plate analysis studies.[1] Because animals must be trained or habituated to the treadmill, the applicability of treadmills on spontaneous clinical patients is limited. Force plate data can be influenced by a variety of factors including: subject variation, interday variation, variation in trial repetitions, handler differences, morphometric differences between subjects, subject velocityand force plate sensitivity.[11,13,14] Mickelson et al also found mild alterations in weight bearing in patients particularly with hindlimb lameness as trial number increased.[15] Velocity has been found to vary cyclically within a gait cycle causing variability between individuals or runs.[11,16] To overcome this variation in velocity within a gait cycle, Bertram et al have used a series of 4 force platforms to independently collect data from fore limbs and hindlimbs in 3 consecutive steps allowing for regression analysis to determine which gait variables vary with velocity.[16]

Some studies have focused on attempts to overcome the variability associated with force plate analysis. For example, in an attempt to minimize the variability associated with velocity, relative velocity has been calculated using Froude's number ($(v/gh)^{1/2}$) where v equals velocity, g is the acceleration due to gravity, and h is limb length. To overcome differences between different breeds/sized dogs, another study recommended the use of wither-height relative velocities to allow for collection of valid trials and minimize velocity effects on vertical impulse or peak vertical force.[17] Acceleration influences ground reaction forces by increasing ground reaction forces during acceleration and decreasing during deceleration.[14] For this reason, it is yet another variable recommended to be controlled for in force plate analysis.

Force plate data can be used to determine normal body weight per limb distribution, forces present during limb-ground contact, effects of medications or surgical treatments on orthopedic conditions and to evaluate additional variables related to weight bearing.[1] Force plate analysis was found to be superior to visual observation in detection of lameness as previous discussed, however, the high cost of equipment, intensity of labor, and requirement for a large dedicated area limits availability.[18] Despite several advantages of force plate analysis over questionnaires such as the CBPI, numeric lameness scales, or visual analogue scales, the variability of force plate analysis results in an inability to interpret results between many studies and often within studies.[11,15,17] There are many limitations associated with force plate analysis including exacerbations of lameness associated with repeated trials, a steep learning curve for the operator, and patient size and weight prohibiting adequate data collection due to stride length.[19] Results may be influenced by subject velocity, acceleration/deceleration, positioning of the handler, proximity of the closest wall, location within an enclosed space and local environment.

Despite the many potential confounding variables with force plate analysis, it has been used in several studies evaluating the efficacy of different medications and treatments for a variety of diseases.[20--22] It is used alone or in combination with visual analogue scales, the CBPI, and numeric lameness scales.[2,5,23,24] The CBPI has been used in several research settings but it has primarily been used in osteoarthritis studies in combination with force plate gait analysis to assess efficacy of different treatments including intraarticular dextrose prolotherapy, monoclonal antibodies against nerve growth factor, carprofen, and pulsed signal therapy.[24-27] Sherwood et al evaluated the use of intraarticular dextrose prolotherapy using the CBPI and force plate gait analysis and found a small improvement in the prolotherapy group compared to their control group in force plate data, but the change was not statistically significant and no change was seen with the CBPI.[25] The CBPI was used in a population of dogs with osteoarthritis to assess the effect of a monoclonal antibody against nerve growth factor finding.[26] In this study, pain severity scores within the CBPI were significantly improved at 2 and 4 weeks post administration. However, at 6 weeks post administration, while values were improved, no significant difference was seen from baseline. Brown et al. used the CBPI and force plate analysis to compare carprofen treated dogs to a group receiving no medications for osteoarthritis.[24]They found an improvement in both the CBPI and vertical forces assessed via force plate analysis but the values did not correlate with each other suggesting they are quantifying different aspects of chronic pain in these animals and ultimately the choice of outcome assessment tool depends on the study question to be answered. The lack of correlation between the change in owner scores and vertical forces seen on the force plate suggested the improvement interpreted by owners on the CPBI was not associated with the lameness but rather behavioral changes that reflected efficacy of treatment The CBPI was also used to evaluate the effect of *S*-adenosyl L-Methionine (SAMe) for the treatment of presumptive osteoarthritis.[28] No significant effect was seen in reduction of pain scores in these patients. Force plate gait analysis was used as an objective measure in this study also finding no significant differences between the SAMe treatment group and control group. Sullivan et al used gait analysis in combination with the CBPI to evaluate the efficacy of pulsed signal therapy in patients with osteoarthritis.[27] This study reported a significant improvement in the CBPI, however changes in peak vertical force assessed via gait analysis were not statistically significant. Force plate analysis has been used to evaluate the efficacy of external beam radiation for osteosarcoma pain.[21] Roush et al evaluated the use of fish oil omega-3 fatty acids on weight bearing in dogs with osteoarthritis showing an improvement in weight bearing with short term supplementation.[20] Hielm-Björkman et al. fed a green lipped mussel preparation to a group of dogs with chronic pain associated with osteoarthritis.[22] Green lipped mussel, while not as effective in alleviating pain as a positive control group which received Carprofen, may be beneficial in dogs when non-steroidal ant-inflammatory drugs are contraindicated. Case et al reported the treatment of a dog with a gastrocnemius tendon strain treated with autologous mesenchymal stem cells.[29] Long-term follow-up was performed utilizing force plate gait analysis, finding that custom, progressive, dynamic orthosis with autologous mesenchyme stem cell transplantation may be a viable technique for calcaneal tendon injuries in dogs. Kieves et al compared a modified Robert-Jones bandage to cold compression therapy or a combination of the two following tibial plateau leveling osteotomies in dogs.[30] While no significant differences were seen in weight bearing post-operatively, patients that had cold compression therapy tended to have a greater increase in weight bearing after surgery.

Force plate gait analysis has also been used to assess outcomes following several surgical procedures including: total hip replacements, triple pelvic osteotomies, osteochondrosis dissecans treatment, dorsal decompression for lumbosacral stenosis, carpal arthrodesis, and supraspinatous tendon calcified lesions.[23,31-35] Force plate analysis has also been used in combination with the CBPI, visual analogue scales and other methods of assessment to evaluate surgical outcome for treatment of lameness.[23] Seibert et al. used force plate analysis to evaluate the hindlimb more significantly affected prior to a total hip replacement and then used force plate analysis to evaluate progress post-operatively. Statistically significant differences were identified when comparing the affected limb to the non-affected limb both pre- and post-operatively. Tano et al used force plate analysis to evaluate patients after receiving unilateral triple pelvic osteotomies and found operated limbs had significantly greater peak and mean ground reaction forces than unoperated limbs.[31] Van der Peijl et al used force plate analysis to assess tarsal osteochondrosis dissecans in Labrador Retrievers, finding that neither age nor size of osteophytes at the time of surgery correlated with lameness scores.[32] Van Klaveren et al. found a return of propulsive forces in the hindlimbs in dogs 6 months after dorsal decompression for lumbosacral stenosis.[33] Maarschalkerweerd et al, evaluated maximal vertical loading rates in dogs following carpal arthrodesis and compared them to clinically normal dogs finding similar values.[34] Muir et al reported the use of force plate analysis as an objective measure of improvement of lameness in two dogs receiving surgical excision of calcified lesions of the supraspinatus tendon without additional medical treatment.[35] Force plate analysis has also been used to objectively compare pre-operative and post-operative values using different stabilization methods for cranial cruciate deficient stifles as well as assess variables within standard procedures used for cranial cruciate ligament tears.[6,36-39]

Pressure Mat Gait Analysis

Pressure mat gait analysis allows for collection of data seen with force plate gait analysis but in addition to this it allows for evaluation of paw contact area and kinematic information on locomotion[40-43] Paw contact area, like vertical impulse and peak vertical force can be used to evaluate for lameness with improved sensitivity when compared with a visual gait assessment.[42]

Keebaugh et al evaluated the effect of leash side and handler on pressure mat gait analysis values and found handler and leash side may be changed without affecting hindlimb values.[41] However, when forelimbs are evaluated, an equal number of trials with the handler on the left and right are recommended. Pressure mat gait analysis has been used in the swine industry as an objective measure to assess for lameness in an attempt to improve diagnosis and ultimately assess treatment strategies.[43] It's also been used to assess the gait of healthy cats finding they have similar gait symmetry to healthy dogs and peak vertical force and vertical impulse are reliable gait parameters.[40]

Static Stance Analysis

As an alternative to the use of force plate analysis for data collection at a stance, a computerized device to simultaneously measure static quadruped load distribution has been investigated.[44] Static weight distribution has been measured in dairy cattle to assess for lameness. and recently the use of these devices has spread to companion animals.[45,46] Meadows et al evaluated bone-defect healing in operatively created defects in the tibial cortex with a pair of bathroom scales to assess weight bearing in hindlimbs as healing progressed in two groups of dogs, one of which was allowed to bear weight on the operated limb post-operatively, while one was not.[47] Bathroom scales under the hindlimbs were used by Hyytianinen et all in 2012 to assess asymmetry of hindlimb static weight bearing in dogs with varying degrees of radiographic evidence of osteoarthritis.[46] Forelimb weight bearing was not assessed in this study because in their experience a bathroom scale under each limb in practice was difficult and non-rewarding. Phelps et al used the Quadruped Biofeedback system (QBS) to measure static quadruped load distribution.[44] The system consists of four sensor pads and a computer workstation. This system is noted to be more practical than a force plate because of its reduced cost, size, and ease of use.

This study as well as a previous report, found when comparing static quadruped load distribution to dynamic peak vertical forces derived from force plate gait analysis, there was a greater difference detected in weight bearing between lame versus non-lame limbs with the static quadruped load distribution system, suggesting the QBS may be more sensitive than force plate gait analysis when it comes to detecting small weight bearing differences.[44,48]

The Pet Safe Stance Analyzer[a], a commercial device patterned after the QBS, has been reported to be a diagnostic tool for subtle lameness as well as a source to monitor changes during rehabilitation programs following a number of different orthopedic and neurologic injuries.[49] The stance analyzer measures the distribution of body weight on each limb at a stand and may allow for subtle differences to be seen between the outcomes of many different surgical procedures and allow assessment of progression of disease or recovery over time. Purported benefits of a stance analyzer compared to a standard force plate include the requirement for less space and time, lower cost, and ease of use and data acquisition. While stance analysis has been used for decades in bovine medicine, it is rarely referenced in small animal medicine.[45,49,50] A comprehensive review of canine gait analysis, performed in 2016, failed to even mention stance analysis when discussing gait analysis. Cole and Millis recommended the use of a stance analyzer to aid veterinary practitioners in evaluating the redistribution of weight-bearing after amputation.[50] In the following chapters, we first assess trial repetition on the assessment of lameness in dogs using a commercially available stance analyzer. We then assess outcome, surgeon, and procedural variables associated with tibial plateau leveling osteotomies (TPLO).

Abbreviations

CBPI – Canine Brief Pain Inventory

SamE – *S*-adenosyl L-methionine

QBS – Quadruped Biofeedback System

TPLO – Tibial Plateau Leveling Osteotomy

Footnotes

a. Stance Analyzer, LiteCure Companion Animal Health, Newark DE

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Chapter 2 - Interday and Intraday Stance Analysis Variability in Dogs with Hindlimb Lameness

Introduction

Kinetic gait analysis, as assessed on a force plate or pressure mat, has become the gold standard for objectively evaluating limb function in animals. The high cost of the equipment, large amount of space required, and the need for specially-trained operators for data acquisition make this form of analysis largely unavailable in most clinical settings.[1] Several numerical rating and visual analogue scales have been validated to subjectively evaluate limb function in patients as an alternative to kinetic gait analysis, but show little agreement between scoring systems and most accurately reflect force plate gait analysis only when the lameness is severe.[2,3] Gillette and Angle reviewed recent developments in locomotor analysis in 2008 and commented on the validity of both kinetic and kinematic analysis in veterinary medicine, noting again the limitations of cost, space needs, and specialized knowledge on locomotor analysis.[4] Rumph et al reported interday variation in clinically normal greyhounds at a trot on the force plate over 3 days and suggested that studies evaluating medical or surgical treatments should be interpreted with caution due to the variation in ground reaction forces within days and between days.[5]

In practice, many clinicians use a subjective assessment of body weight distribution in a standing dog when lameness is not visually evident by manually lifting individual feet and subjectively assessing the amount of weight-bearing.[6,7] Objectively, percent body weight (%BW) on each limb at a stance can be evaluated with force plate analysis. A study performed by Seibert et al. found that %BW is a valid measurement for differentiating which leg is most affected.[8] As an alternative to the use of force plate analysis, a computerized device to simultaneously measure static quadruped load distribution has been investigated.[9] Previously, bathroom scales under each limb have been used to measure static quadruped load distribution.[10] In this study, bathroom scales were placed only under the hindlimbs because placement under each limb, forelimbs included, was perceived in practice as difficult and unrewarding. A platform with four individual recording units for weight bearing has been used in lameness and hoof discomfort in dairy cattle since at least 2006.[11,12] Recently, similar devices have been used for lameness evaluation in dogs. In a recent study comparing static quadruped load distribution to dynamic peak vertical forces derived from force plate gait analysis, there was a greater difference detected in weight bearing between lame versus non-lame limbs with the static quadruped load distribution system, suggesting it may be more sensitive than force plate gait analysis for detecting small weight bearing differences.[9]

The Pet Safe Stance Analyzer[(i)] , a commercial stance analyzer patterned after the static quadruped load distribution system, has been reported to be a diagnostic tool for subtle lameness as well as a source to monitor changes during rehabilitation programs following orthopedic and neurologic injuries.[13] The stance analyzer measures the distribution of body weight on each limb during stance, and may detect subtle differences between the outcomes of different surgical procedures and provide a means for assessing progression of disease or recovery. Benefits of a stance analyzer compared to a standard force plate include the need for less space and time, lower cost, and ease of use and data acquisition. Deficiencies of the commercial analyzer as a research tool include an inability to save individual measurement data (rather than mean data from each trial) within the software, and a lack of ability to assess motion variables such as craniocaudal and mediolateral braking forces. Cole and Millis have recommended the use of a stance analyzer to aid veterinary practitioners in evaluating the limb with the largest expected increase in weight bearing following amputation for possible overuse.[1] While stance analysis has potential benefits, results may be influenced by positioning of the handler, proximity to the closest wall, position within the enclosed space and local testing environmental factors.[9] The purpose of this study was to assess the same day and next-day repeatability of the Pet Safe Stance Analyzer on animals with naturally-occurring lameness presented for veterinary orthopedic examination. Our hypothesis was that lame dogs would show consistent repeatability with regards to body weight distribution on the Pet Safe Stance analyzer.

Materials and Methods

Data Collection Protocol

Interday Variability Trial: Thirty-one consecutive dogs presenting to the Kansas State University Veterinary Health Center Orthopedic Service for lameness and potential orthopedic surgery were included. Medical records were reviewed. Data recorded from the medical records included signalment, limb affected, and diagnosis. The PetSafe Stance Analyzer was placed in the center of a dedicated gait analysis laboratory and dogs were walked onto the device with a leash from behind the analyzer and encouraged to stand in their relaxed standing position with each foot placed in its respective quadrant on the Stance Analyzer. A minimum of 5 valid measurements were collected over a 30 second time period and averaged to determine the mean distribution of weight on each limb. This process was repeated the following day prior to administration of any presurgical medications. The same handler and recorder were used for each trial. Stance analyzer measurement of dogs with clinical lameness occurred under a protocol for clinical research approved by the Institutional Animal Care and Use Committee.

Intraday Variability Trial: Fifteen consecutive dogs presenting to the Kansas State University Veterinary Health Center Orthopedic Service for lameness and potential orthopedic surgery were included. Medical records were reviewed. Data recorded from the medical records included signalment, limb affected, and diagnosis. Dogs were placed on the Pet Safe Stance analyzer and measurements were collected for in a manner identical to the interday study group. The dog was then walked out of the room and returned immediately for each of 4 additional trials.

Statistics

Interday Variation Trial: Measured or calculated variables of each repeated stance trial included lame hindlimb, contralateral hindlimb, ipsilateral forelimb, contralateral forelimb, body weight, forelimb symmetry index, and hindlimb symmetry index. Forelimb and hindlimb symmetry indices (SI) were calculated as SI=200[(%BW1-%BW2)/(%BW1+%BW2)] for each dog where %BW1 was the higher and %BW2 the lower value, as previously described.[14] A symmetry index of 0 indicates perfect symmetry with this calculation. Measured percent body weight on each limb, body weight (kg) and calculated symmetry indices were compared by paired T-test between Day 1 and Day 2 trials on a commercial statistical calculator[(ii)]. A $p \leq 0.05$ was considered significant for all comparisons. Data is reported as the mean ± SD for all dogs across trials on each day. Lin's Concordance Coefficient was calculated using an online calculator[(iii)] to assess repeatability of measurements. A mean coefficient of variation (COV) was calculated for each measured variable as the standard deviation of paired trial measurements/mean of paired trial measurements and then expressed as a percentage.

Intraday Variation Trial: Measured or calculated variables of each repeated stance trial included lame hindlimb, contralateral hindlimb, ipsilateral forelimb, contralateral forelimb, body weight, forelimb symmetry index, and hindlimb symmetry index. Symmetry indices were calculated as previously described. Measured percent body weight on each limb, body weight (kg) and calculated symmetry indices were compared by repeated analysis of variance between each of the five trials with posthoc Newman-Keuls Multiple Comparison on a commercial statistical calculator[(ii)]. A $p \leq 0.05$ was considered significant for all comparisons. Data was reported as the mean ± SD for all dogs across trials. Lin's Concordance Coefficient was calculated using an online calculator[iii] to assess repeatability of measurements. A mean coefficient of variation (COV) was calculated for each measured variable as the standard deviation of repeated trial measurements/mean of repeated trial measurements expressed as a percentage.

Results

Interday Variation Trial : The thirty one subjects consisted of 11 Labrador retrievers, 4 golden retrievers, 4 mixed-breed dogs, 2 German wire-haired pointers, 2 Australian shepherds, 2 pitbulls and one of each of the following: English bulldog, Bernese mountain dog, Chihuahua, bullmastiff, whippet, and akita. There were 18 spayed females, 10 castrated males, 2 intact females, and 1 intact male and age ranged from 1.71 years to 10.42 years (mean 6.02±2.59 years). Left hindlimb lameness represented 16/31 (51.61%) of dogs, and right hindlimb lameness15/31 (48.39%). 28/31 dogs (90.32%) were diagnosed with a unilateral cranial cruciate ligament tear. Two out of 31 (6.45%) were diagnosed with a combined medial patellar luxation and cranial cruciate ligament tear and one dog (3.23%) had a hip luxation.

There were no significant differences between Day 1 and Day 2 measured variables except for a significant increase in the Forelimb Symmetry index on Day 2 (SI=39.28) compared to Day 1 (SI=26.58) (p=0.0429) (Table 1). The mean change in weight-bearing on the lame hindlimb between days was +1.07%BW (range -8%-13%). Thirteen/31 dogs showed worsening of lameness on day 2, while 18 improved. Redistribution was primarily to the contralateral hindlimb, exhibiting a mean change of --1.23%BW on the second day. The ipsilateral forelimb (+0.19%BW), and contralateral forelimb (--0.07%BW) showed only minimal interday changes. The coefficient of variation (COV) for the % body weight on each limb ranged from 12.72% in the contralateral forelimb to 37.62% on the lame hindlimb. Lin's Correlation Coefficients % body weight measured on Day 1 compared to Day 2 were significantly correlated on the lame hindlimb (0.524) and contralateral hindlimb (0.733) (Table 1). Day to day measurement of total body weight on the Stance Analyzer demonstrated consistency (Lin's Correlation Coefficient = 0.9990) and a low COV (2.93%).

Intraday Variability Trial: The 15 clinical patients consisted of 4 Labrador retrievers, 2 Golden retrievers, 2 pitbulls, and one each of the following: Beagle, Bernese Mountain dog, Greater Swiss Mountain dog, Great Pyrenees, American bulldog, Goldendoodle, and Rottweiler. Age ranged from 1.30 years to 11.05 years (mean 5.65±2.66 years) with 9 castrated males and 6 spayed females. Nine of 15 (60%) dogs had a left hindlimb lameness with the remainder right sided (6/15 – 40%). Fourteen dogs had unilateral cranial cruciate ligament tears, and one dog had bilateral cranial cruciate ligament tears but was visibly lame only on the left hindlimb on orthopedic examination.

There were no significant differences across trials for measured variables of %weight on the lame hindlimb, contralateral hindlimb, ipsilateral forelimb, or contralateral forelimb (Table 2). There was no significant difference of body weight measured across trials. The forelimb symmetry index was not significantly different across trials. The hindlimb symmetry index varied significantly with the mean hindlimb symmetry of trial 2 (63.8 ± 69.0) and trial 4 (69.5 ±63.1) significantly lower than trial 3 (94.4±63.1), ($p=0.022$). The COV for the % body weight on each limb were similar (range 13.99-20.98%), while the COV of the body weight was low (0.93%). The COV of the hindlimb symmetry indices (28.48%) was lower than that of the forelimb symmetry index (67.43%). Lin's Correlation coefficients showed strong correlation between trials for the lame hindlimb(0.682), contralateral hindlimb (0.817), body weight (0.863), and hindlimb symmetry index (0.726).

Discussion

Stance analysis allows for elimination of the variable of velocity in kinetic force plate gait analysis, but there are no reports of the degree to which many other common variables associated with force plate gait analysis may influence stance analysis data. Factors reported to induce variability in force plate gait analysis include velocity, acceleration, trial, handler, habituation, and day. [5,14,15] Our study assessed repeatability within a day and between days. Habituation prior to measurement collection in this study was not performed. Given the ease of the task of standing, we felt that habituation would not be necessary nor substantially influence results of repeated trials and believed that a lack of habituation better represented routine use of the Stance Analyzer in clinical patients. The purpose of this study was to assess the effect of day and repeated analysis on the variability of stance analysis, with handler and observer kept the same for all dogs.

Stance analysis is a consistent method of measurement of % body weight on the lame hindlimb and contralateral hindlimb from one day to the next. Lin's Correlation Coefficients for these limbs of 0.524 and 0.733 respectively demonstrated the strong repeatability of the method for dogs with hindlimb lameness. Correlation coefficients of the forelimbs are lower likely because of day-to-day and moment-to-moment variations in redistribution of weight-bearing by individual dogs with lameness. The coefficient of variation for weight-bearing ranges from 12.72% on the contralateral hindlimb to 37.62% on the lame hindlimb. These results are similar to previous studies on force plate variability, which found that the percentage of variance attributable to dogs and to repetitions ranged from 14% to 59% and from 29-85% respectively.[16]. In this study, interday variation is most likely due to daily changes in pain due to orthopedic disease as perceived by individual dogs. Dogs in the interday trial improved slightly in weight-bearing on the lame hindlimb from the first day to the second (+1.07% BW), which is consistent with the magnitude of change of % weight bearing day to day in previous studies. This improvement is likely due to the overnight rest in a standard clinic cage they experienced while awaiting their surgical procedure. However, the magnitude of change of % weight bearing day to day is similar to previous studies.[17] Phelps et al. found a greater difference detected in weight bearing between lame versus non-lame limbs with the quadruped biofeedback system (QBS) suggesting it may be more sensitive than force plate gait analysis during ambulation for detecting small weight bearing differences. This suggests that the larger variation with stance analysis may represent increased sensitivity rather than decreased.[9]

Stance analysis is also a consistent method of measurement of % body weight measured on the lame hindlimb and contralateral hindlimb during repeated trials on the same day. Lin's Correlation Coefficients of 0.682 and 0.817 in 5 consecutive trials, respectively for the lame hindlimb and contralateral hindlimb, demonstrate the strong repeatability of the method. Lin's Correlation Coefficients of the forelimbs are again less consistent because of likely individual variation in redistribution of weight-bearing. This variation may be attributed to habituation of the dog to the room, handler, and stance analyzer. Additionally, insufficient trials may have been performed to allow for adequate habituation and normalization of measurements. Coefficients of variation range from 14-21% for %BW measurements, which is consistent with a previous report with coefficients of variation for force plate variability between trials.[16]

Force plate gait analysis can be influenced by body type or size.[14] Stance analysis on the commercial system used here is not limited as much by body size or conformation and is thus more versatile for assessing vastly different breeds than force plate analysis. Breed and size were not controlled for in our study, leading to a likely increase in variability. Molsa et al. found that after removing the relative velocity, functional limb length, and body weight by using analysis of covariance (ANCOVA), there were no significant differences between breeds when assessing for differences in ground reaction forces between healthy Rottweilers and Labrador Retrievers without orthopedic disease.[18] Standardization of methods of normalization, conformation and body weight have a significant influence in reducing variability. It is unknown if measurement of a more homogenous population of dogs would improve repeatability of stance analysis.

Many different statistical analyses have been used to assess continuous variables in an attempt to evaluate reproducibility of measurements from trial to trial including the Pearson correlation coefficient, the paired *t*-test, the least squares analysis of slope and intercept, the coefficient of variation, and the interclass correlation coefficient.[16,18-21] Unfortunately, there are drawbacks to all of these as none alone can fully assess the desired reproducibility characteristics. Lin's Concordance (condordance correlation coefficient) is a recently developed measurement for laboratory repeatability and was chosen as a statistical method in this study because it avoids the shortcomings associated with the statistical methods mentioned above.[22] In this study, Lin's Concordance Coefficient demonstrated strong repeatability of the assessment of individual limbs on the Stance Analyzer. The commercial stance analyzer also measures total body weight very consistently day to day (Lin's coefficient = 0.990), which is an indication of both repeatability and validity of the day to day data(COV=2.93%). This interday COV was higher, however, than that seen in the intraday weight measurements (COV=0.93%), likely due to changes in hydration overnight and holding off food in preparation for surgery on the 2nd day for the interday weight.

Trial repetition has been reported to lead to variations in ground reaction forces.[23] However, Fanchon et al. found that after a single training session on a treadmill, reliable data can be obtained. From day 1 to day 2 in our study, only forelimb symmetry index changed day to day, while the lame hindlimb and contralateral hindlimb were more repeatable. Given the lack of significant changes between day 1 and 2 for all but the forelimb symmetry index, it appears that a training period is not needed to acclimate the dogs to the stance analyzer for the assessment of hindlimb lameness. In addition, a lack of significant changes of intraday trial data suggests the same. Rumph et al reported interday variation in clinically normal greyhounds at a trot on the force plate over 3 days suggesting small variations in ground reaction forces within days and between days found in studies evaluating medical or surgical treatments should be interpreted with caution.[5] Our study did not evaluate efficacy of treatment and the magnitude of change in %BW or symmetry index needed to detect clinical changes in lameness remains unknown. We have not evaluated whether dogs with forelimb lameness demonstrate more consistent forelimb symmetry indices in interday trials.

Forelimb symmetry indices varied more than hindlimb symmetry indices likely because weight-bearing shifts from the lame limb in an inconsistent manner that varies by dog and by many other factors (health of the other limbs, environmental factors, or concurrent systemic disease potentially causing exercise intolerance. The hindlimb symmetry index has a high Lin's Correlation Coefficient demonstrating correlation between trials, although the mean hindlimb symmetry index varied significantly in individual dogs over trials. This variability could again be contributed to increased sensitivity of stance analysis compared to force plate analysis.

In a study by Keebaugh et al., pressure mat analysis of gait characteristics in small-breed dogs was used to assess the influence of handler and leash side. No significant differences were seen with different handlers, however, leash side significantly influenced symmetry indices of the dogs' forelimbs but not hindlimbs.[15] Coefficients of variation on each limb was also evaluating revealing similar values to our study ranging from 21%-36%. Forelimb symmetry indices were also found to differ in our study compared to the analysis by Keebaugh et al. In our study, the handler remained constant for all measurements. Leash side was not recorded in this study, although the handler was directly behind the dog, and the recorder in front of the dog, in most trials. It is unknown if the change in the forelimb symmetry index can be attributed to leash side. Phelps et al assessed the position of the QBS in a gait analysis lab and found positioning of the QBS in the center of the room resulted in the dog leaning towards the handler with the forelimbs and away from the handler in the hindlimbs.[9] When the analyzer is placed along a wall, dogs have a tendency of leaning towards the wall. To prevent this, the stance analyzer in our study was placed in the center of the room. The forelimb symmetry index increased significantly from day one to day two in our study. This could be due to habituation with the room, handler, and stance analyzer. This is consistent with Fanchon et al and measurement of ground reaction forces in dogs trotting on a treadmill.[23]

Conclusion

A commercial stance analyzer is a consistent and repeatable method of measurement of weight-bearing on individual limbs of dogs when compared to historical variability in measurement on force plates. %body weight measured on the lame hindlimb and contralateral hindlimb are consistent from day to day and in repeated trials over one day. Day to day forelimb weight-bearing in dogs who are lame on a hindlimb is more variable, likely because of changes in weight redistribution and other factors as previously discussed.

Abbreviations

%BW – Percent Body Weight

IS – Symmetry index

COV – Coefficient of variation

QBS – Quadruped Biofeedback System

ANCOVA – Analysis of covariance

Footnotes

i. Stance Analyzer, LiteCure Companion Animal Health, Newark DE

ii. Winks, SDA 7.0.9., Texassoft, www.texasoft.com

iii. https://www.niwa.co.nz/node/104318/concordance

Tables

Table 2.1: Paired T-test, Lin's Concordance Coefficient, and Coefficient of Variation results for interday trials. Values of hindlimb force are expressed as %BW.

Variable	Day 1	Day 2	Paired T p-value	Lin's Concordance Coefficient	Coefficient of variation % (COV)
Lame hindlimb	7.77 ± 4.92	8.84 ± 6.42	0.2925	0.524	37.62
Contralateral hindlimb	25.0 ± 8.16	23.77 ± 7.75	0.2421	0.733	12.72
Ipsilateral Forelimb	35.16 ± 7.51	35.35 ± 9.15	0.9034	0.446	13.72
Contralateral forelimb	32.10 ± 6.07	32.03 ± 8.73	0.9683	0.288	15.51
Body Weight	31.13 ± 11.50 kg	30.85 ± 11.49 kg	0.3344	0.990	2.93
Forelimb Symmetry Index	26.58 ± 23.34	39.28 ± 30.45	0.0429	0.215	60.36
Hindlimb Symmetry Index	103.54 ± 59.21	103.97 ± 50.20	0.9666	0.467	29.71

Table 2.2: Repeated ANOVA, Lin's Concordance Coefficient, Coefficient of Variation results for 5 repeated intraday trials. Values of hindlimb force are expressed as %BW

Variable	Mean ± mean SD	Repeated ANOVA p-value	Lin's Concordance Coefficient	Coefficient of variation (COV) %
Lame hindlimb	10.73 ± 2.25	0.053	0.682	20.97
Contralateral hindlimb	20.68 ± 2.89	0.502	0.817	14.00
Ipsilateral Forelimb	33.85 ± 5.78	0.541	0.214	17.06

Contralateral forelimb	34.87 ± 5.64	0.715	0.176	16.18
Body Weight	39.75 ± 0.37 kg	0.101	0.863	0.93
Forelimb Symmetry Index	33.69 ±22.72	0.561	0.190	67.44
Hindlimb Symmetry Index	75.61 ±21.53	0.022	0.726	28.48

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Chapter 3 - Comparison of the Effect of Dog, Surgeon, and TPLO Surgical Procedure Variables on Improvement of Eight-week Postoperative Static Weight-Bearing

Introduction

Cranial cruciate ligament disease is a multi-billion dollar disease in veterinary medicine and a number of different surgical procedures are used to address the instability resulting from cranial cruciate ligament rupture (CCLR). No current surgical procedure for treatment of cranial cruciate ligament deficient stifles consistently halts progression of osteoarthritis.[1,2] Tibial plateau leveling osteotomy (TPLO) is one of the most commonly performed procedures for treatment of cranial cruciate ligament deficient stifles and has demonstrated advantages over some procedures.[3-6] A systematic review of surgical treatments for cranial cruciate ligament disease in dogs performed by Bergh, et al. found the best available evidence most strongly supports TPLOs for a normal return to clinical function, however, this study could not resolve clinical controversies because it was limited by confounding variables that decreased evidentiary value.[3]

Meniscal injury occurs concurrently with CCLR in 32.2% - 83% of dogs.[7-9] Physical examination findings of a "meniscal click" have been reported to have 45.8% sensitivity and 94.4% specificity for diagnosing a meniscal tear.[10] When combined with the finding of pain on flexion, the diagnostic accuracy was 76%.[11] Arthroscopy has been reported to be the gold standard for diagnosis of meniscal injury compared with physical examination, ultrasonography and magnetic resonance imaging.[12] Slocum recommended a medial meniscal release to decrease the risk of subsequent meniscal tears by allowing the caudal pole of the meniscus to retract caudally away from the femoral condyle.[13] Pozzi et al. suggested that a medial meniscal release may not be necessary in a TPLO stabilized stifle because a TPLO neutralizes tibial thrust and eliminates the wedge effect on the medial meniscus.[14] There is no commonly accepted standard for addressing or preventing meniscal damage associated with CCLR.

In practice, many clinicians use a subjective assessment of body weight distribution in a standing dog to evaluate limb pain and lameness when it is not evident in a walking or trotting dog.[15,16] Objectively, percent body weight (%BW) can be evaluated using force plate analysis.[15,16] A study performed by Seibert et al. found that %BW is a valid measurement for differentiating which leg is most affected by hip joint pain.[17] Bathroom scales under each limb have been used to measure static quadruped load distribution.[18] Another computerized device, the Quadruped Biofeedback System, has been investigated to simultaneously measure static quadruped load distribution.[19] A platform with four individual recording units for weight bearing has been used in lameness and hoof discomfort in dairy cattle for greater than 10 years.[20,21] Recently, similar devices have been used for lameness evaluation in dogs. In a recent study comparing static quadruped load distribution to dynamic peak vertical forces derived from force plate gait analysis, there was a greater difference detected in weight bearing between lame and non-lame limbs with the static quadruped load distribution system compared to force plate analysis, suggesting it may be more sensitive for detecting small weight bearing differences.[18,22]

The purpose of this study was to compare the effect of surgeon, dog TPA variation, and TPLO procedure variations on the outcome of TPLOs in naturally-occurring cranial cruciate deficient stifles. Analyzed variables included pre-operative and post-operative tibial plateau angle using a previously described measurement technique,[23] meniscal injury, and surgeon experience. A commercial stance analyzer[a] was used as an objective outcome measure of surgical outcome. Our hypotheses were that greater surgeon experience, decreased postoperative tibial plateau angle, lack of arthrotomy, performance of meniscal release, and treatment of meniscal injury would each result in improved weight bearing between 6 and 12 weeks post-operatively.

Materials and Methods

Data Collection Protocol

A retrospective study was performed of dogs that were diagnosed with a cranial cruciate ligament rupture and that had been placed on the PetSafe Stance Analyzer[a] pre-operatively as well as during routine progress re-evaluation 42-84 days post-operatively. Medical records were identified for client-owned dogs with a naturally-occurring cranial cruciate ligament rupture treated by TPLO and that were evaluated by stance analysis between March 2013 and June 2017 at both the initial examination and progress evaluation 42-84 days post-operatively. Dogs rechecked for stance analysis were determined by client choice to return for the exam. Data recorded from the medical records included signalment, limb affected, concurrent surgical procedures performed, concurrent lameness, evaluation of the joint via arthrotomy or no evaluation, status of the menisci at the time of surgery (if evaluated), surgeon identity, ACVS diplomate vs. resident as primary surgeon, use of meniscal release, progression of healing at the progress evaluation based on radiographic interpretation, and occurrence of surgical complications. The affected limb was determined from physical examination findings.Meniscal evaluation or lack thereof, was recorded and meniscal treatment, if performed was obtained from the surgery report. The degree of healing and presence of patellar tendon desmitis was determined from radiographic reports. Complications were determined from the medical record and radiographic reports. Pre-operative, immediately post-operative, and post-operative tibial plateau angles were measured using a previously reported technique[24] by a single observer (MLW).

Using the PetSafe Stance Analyzer in a dedicated gait analysis lab, dogs were walked onto the device and encouraged to stand in their relaxed standing position with each foot placed in its respective quadrant on the mat. A minimum of 5 valid measurements were collected over a 30 second time period and averaged to find the distribution of weight on each limb. Data was collected prior to administration of any medications that day. Stance analyzer measurement of dogs with clinical lameness occurred under a protocol for clinical research approved by the Institutional Animal Care and Use Committee.

Statistics

Preoperative and recheck body weight were compared with a paired T-test. Initial percent body weight (%BW) on each limb was compared with recheck %BW on the same limb by paired T- test. Symmetry indices were calculated for forelimbs and hindlimbs at each time period as SI=200[(PVF1-PVF2)/(PVF1+PVF2)] for each dog where PVF1 was the higher and PVF2 the lower value, as previously described.[25] A symmetry index of 0 indicates perfect symmetry with this calculation. Symmetry indices on the forelimbs and hindlimbs were compared between the initial and recheck periods by paired T-test.

Continuous variables of initial weight, weight at recheck, sex, age, number of days to recheck, improvement at recheck (calculated for the operated limb by the initial %BW subtracted from the %BW at recheck), initial TPA, immediate post-operative TPA, recheck TPA, initial % of body weight (%BW) on each limb, and recheck %BW borne on each limb were grouped by individual surgeon and compared by ANOVA with post-hoc Newman-Keuls Multiple Comparisons and by independent T-test grouped for the dichotomous variables of surgeon experience (diplomate or resident), arthrotomy (y/n), damaged meniscus (y/n), meniscal resection (y/n), meniscal release (y/n), opposite cruciate rupture (y/n), patella desmitis at 8 week recheck (y/n), osteotomy healed at 8 week recheck (y/n), and whether known complications occurred (y/n). Pearson correlations were performed to compare outcomes with continuous variables as noted in Table 1. A positive $p \leq 0.05$ was considered significant for all tests. Analysis of covariance was performed to evaluate between subjects and within subjects assessed for the effects of sex, surgeon experience, lame limb, initial TPA, post-operative TPA, arthrotomy, meniscal removal, and healing on initial weight-bearing, post-operative weight-bearing, or improvement.

Results

From March 2015 to June 2017, 477 TPLOs were performed. Of these, 142 dogs met the inclusion criteria. Of the 142 dogs, 62 (43.66%) were castrated males, 74 (52.11%) were spayed females, 5 (3.52%) were intact females, and 2 (1.41%) were intact males. Breeds included 52 Labrador retrievers, 9 Australian shepherds, 7 bulldogs, 7 golden retrievers, 7 pitbulls, 5 boxers, 5 Border collies, 5 rottweilers, 5 German shepherd dogs, 4 mastiffs, 3 German short-haired pointers, 2 greyhounds, 2 catahoula dogs, 2 akitas, 2 cocker spaniels, and 1 of the following: Cairn terrier, German wire-haired pointer, presa Canario, chow-chow, English setter, Brittany spaniel, pembroke Welsh corgi, coonhound, whippet, and beagle. The remaining 15 dogs were mixed breeds. The mean age was 5.88 +/- 2.89 years (range: 0.00 to 14.00 years). The mean weight at the first visit was 33.51 +/- 10.26 kg (range: 6.92 – 67.82 kg) and at the second visit was 33.77 +/- 10.19kg (range: 7.35 – 74.50 kg). The average %BW on each limb initially and post-operatively and TPA is shown in table 2. Nine of the dogs (6.33%) had bilateral cranial cruciate ligament tears.

Initial body weight and recheck body weight of the dogs was not significantly different ($p=0.4155$) between groups. Mean number of days to recheck was 61 days (range: 42-84 days). There was no significant correlation of age, sex or neuter status with the initial TPA. Initial dog weight was significantly and negatively correlated with the initial TPA ($r=-0.19$, $p=0.025$), indicating that lighter dogs were more likely to have a greater TPA (Figure 1).

There was no significant difference between the initial and recheck %BW measured for either the ipsilateral or contralateral forelimbs (Table 3). The %BW of the affected hindlimb significantly improved by a mean 4.58% at recheck ($p<0.001$). The %BW of the contralateral hindlimb significantly decreased by 3.59% at recheck ($p<0.001$). The symmetry index of the hindlimbs significantly improved at recheck ($p<0.001$), while the symmetry index of the forelimbs did not change ($p=0.7697$). The improvement in symmetry index was not significantly affected by any dichotomous variable.

Seven different ACVS Diplomates or residents performed the TPLO's on these dogs. Surgeries per surgeon ranged from 7 to 49 with a median of 15 surgeries per surgeon. There was no significant difference in improvement at recheck between surgeons. There was no difference between surgeons on post-operative TPA ($p=0.2029$). There was no difference between surgeons on the recheck TPA after Newman-Keuls post-hoc ($p=0.0279$). There was no difference in post-operative TPA ($p=0.216$) or recheck TPA when the surgery was performed by a Diplomate compared to a Resident ($p=0.804$). To address whether extreme TPA's might affect this comparison, cases with an initial TPA of 26 or above were analyzed as a subset. In those 45 dogs, the Diplomate post-operative TPA was 6.10 ± 3.13, and the resident post-operative TPA 6.62 ± 4.29, statistically insignificant at $p=0.644$. Even in excessive TPA, there is no difference in level of training relative to TPA correction.

A meniscal release was performed in 11.97% of patients. Meniscal damage (0.447), meniscal removal ($p=0.120$), or the choice of a meniscal release ($p=0.498$) was not significantly affected by the initial TPA.

Improvement of %BW on the operated limb between initial values and recheck did not significantly differ for any of the dichotamous variables of diplomate/resident, arthrotomy, meniscal damage, meniscus removal, meniscal release, opposite cruciate rupture, previous opposite cruciate repair, or development of patellar tendon desmitis (Table 4). Analysis of covariance between subjects and within subjects assessed identified no statistically significant covariables.

Recheck TPA was negatively and significantly correlated with improvement (r=-0.2132, p=0.013), indicating that lower recheck TPA's showed more improvement in weight-bearing (Figure 2 and Table 5). Initial, post-operative, and recheck TPA's were all significantly correlated with one another, meaning the larger the initial TPA, the larger the change in TPA.(Table 5 and Figures 3 and 4).The increase in weight bearing (or improvement at 8 weeks) on the affected limb was negatively correlated to preoperative weight-bearing at p<0.001, with a Pearson's r Correlation Coefficient of -0.5374, meaning that the higher the preoperative weight-bearing, the lower the improvement seen.

There were no significant correlations, within the 42-84 day recheck period, between the number of days until recheck and %BW on the operated limb (p=0.265), improvement in %BW of the operated limb (p=0.851), hindlimb symmetry index at recheck (p=0.815), change in hindlimb symmetry index (p=0.595), or TPA change at recheck (p=0.140).

Discussion

This study compared the effect of surgeon and TPLO procedure variations on the outcome of TPLOs in naturally-occurring cranial cruciate deficient stifles using change in %BW on the operated limb as an objective measurement for improvement. The breeds represented, mean age, and mean body weight are consistent with many studies evaluating TPLOs.[1,26-28] Also consistent with these studies, breed, age, and body weight were found to have no significant impact on static force outcome.

On a force platform system, Chalayon et al. found healthy dogs had a ratio of approximately 63:37 fore:hindlimb weight distribution with a right to left distribution being 50:50 with less than a 3.2% difference between sides in clinically normal dogs.[29] When evaluating extracapsular stabilization for CCLR, %BW for the operated limb was less than the other limbs initially and improved to the point of returning to the previously stated normal ratios 7-10 months post-operatively.[29,30] In our study, evaluations were only 42-84 days post-operatively. It is unknown whether or not a return to normal weight bearing would be seen at a follow-up time similar to above in dogs receiving TPLOs.

Initial body weight and recheck body weight of the dogs were not significantly different. In contrast to our findings, Au et al. reported an increase in body weight at recheck examinations just 3 weeks post-operatively.[28] At the time of surgery, surgeons at our institution frequently discuss weight management strategies with owners.These recommendations may contribute to a lack of weight gain during the prescribed post-operative activity restriction phase. Initial dog weight was significantly and negatively correlated with the initial TPA ($r=-0.19$, $p=0.025$), indicating that lighter dogs were more likely to have a greater TPA. To the authors' knowledge, this finding has not been reported previously. While initial body weight was significantly and negatively correlated with the initial TPA, body condition scores or dimensional measurements such as height or limb length were not noted so such negative correlation should be interpreted cautiously.

A non-inclusion bias may be present due to the use of the stance analyzer as patients that were not placed on the stance analyzer were excluded from the study. No significant difference was found between the initial and recheck %BW measured of either the ipsilateral or contralateral forelimbs however the higher the initial %BW, the lower the improvement seen. Budsberg et al, evaluated %BW distribution on the operated limb pre-operatively and post-operatively and found an increase in %BW distribution on the operated limb. However, in that study, redistribution of weight on the remaining limbs was not reported.[30] Rumph et al reported percent increases in BW on unaffected limbs following induction of acute synovitis in one stifle.[31] Griffon et al. found PVF was increased in the contralateral forelimb and both hindlimbs initially and 7 days post-operatively in 5 greyhounds with a forelimb lameness induced by a craniolateral approach to the shoulder.[32] Three days post-operatively PVF on the operated limb and ipsilateral hindlimb had decreased while the contralateral side increased for both the forelimb and hindlimb.[32] While that study was an induced forelimb lameness, a similar change may be expected for a hindlimb lameness. Redistribution of weight-bearing from the hindlimbs to the forelimbs was not seen in our study and was not expected because a lesser percentage of overall body weight is placed normally on the hindlimbs compared to the forelimbs resulting in correspondingly less weight to offload. In our study, as weight-bearing improved on the operated limb, %BW decreased on the contralateral limb and therefore, a significant improvement in the symmetry index of the hindlimbs was seen as reported.[30] In our study, improvement in the symmetry index was not significantly affected by any dichotomous variable.

In a previous study, the authors suggested that lame dogs should be defined as the mean of the symmetry index±(2xstandard deviation).[33] In a study of 50 normal dogs presenting without obvious orthopedic disease, the high symmetry index cutoff for hindlimbs measured on a commercial Stance Analyzer was 79.17.(J K Roush, Kansas State University, Manhattan, KS, USA, 2017). In the current study, 90/142 dogs would have been diagnosed on the Stance Analyzer as lame on initial examination, and 52/142 lame at 6-12 week recheck, in contrast to the lameness noted on all 142 dogs by the attending clinician, possibly suggesting a decreased sensitivity for the stance analyzer compared to subjective lameness evaluation. A standard of twice the standard deviation of normal dogs as a determination of lameness may cause inaccurate determination of lameness when assessed by stance analysis. Stance analysis should be viewed as an additional tool to assess lameness and to assess changes in weight-bearing.

While 7 different surgeons with variable years of experience performed the TPLO's on these dogs, there was no significant difference in improvement at recheck between surgeons. Previous studies have found surgeon experience does not influence post-operative complications although outcome and post-operative TPA were not directly assessed.[34,35] Non-locking TPLO plates are most commonly used at our institution. Significant changes in the recheck TPA compared to immediate post-operative TPAs have been reported using both conventional TPLO plates and locking TPLO plates.[36] While not found to be significant, there was a 1.9° increase in the recheck TPA compared to the post-operative value in their study.[36] Measurements of both post-operative and recheck TPAs could have been influenced by positioning, plate placement, and progression of arthritis.[37] However, as long as the TPA is between 0° - 14° ground reaction forces are not significantly affected at >4 months post-operatively.[37] Unfortunately the majority of cases in the present study were not radiographically healed at the 8 week recheck making conclusions about a final change in TPA post-operatively impossible.

While the rate of meniscal injury was consistent with other studies, meniscal damage was only assessed in those patients that received an arthrotomy, therefore, meniscal damage may have been under-represented given the lack of joint exploration in several cases.[38-40] Performance of an arthrotomy or meniscal release was chosen by the individual surgeon. Partial medial meniscectomy was performed on those dogs that had a meniscal tear identified at the time of surgery via an arthrotomy. If no evidence of a tear was found, the decision to perform a meniscal release was surgeon dependent.[41]

The initial TPA of 25.05° +/- 3.75° in our study was slightly higher than that found in Morris and Lipowitz' study at 23.76° +/- 3.88°.[41]All TPA measurements in this study were made by a single observer, second year surgery resident, to avoid inter-observer variability.

Dichotomous variables of resident/diplomate, arthrotomy, meniscal damage, meniscal removal or release, opposite cruciate rupture, opposite cruciate repair, or development of patellar desmitis were not found to affect %BW initially or at recheck. Pacchiana et al. did not assess post-operative TPA but they did find the development of a complication was not associated with surgeon experience.[35] Christopher et al. however did find an increased complication rate with less experienced surgeons.[1] Pacchiana also found patients that had a standard parapatellar arthrotomy had a significantly greater number of complications.[35] Our study did not directly evaluate complications but rather %BW at recheck to evaluate progress. It is possible that the %BW as a single variable is not sensitive enough to detect changes between these dichotomous variables.

Limitations of this study include stance analysis of patients with bilateral disease, a lack of long-term follow-up, and a lack of meniscal evaluation in several patients. Additionally, while some of the comparisons in this study were statistically significant at p0.05, low Pearson's Correlation Coefficients (for example, Recheck TPA:Improvement with $p=0.013$ but $r=-0.2132$), indicate that these relationships are still only minor influences on the outcome variable. Statistical significance in those instances is more reflective of high study numbers, not high correlation.

Conclusions

The improvement in weight bearing with lower rechecked TPAs was in contrast to a previous study that found no statistically significant between post-operative TPAs and ground reaction forces when the TPA was between 0° and 14°.[37] In our study, lower rechecked TPA's at recheck showed more improvement in weight bearing which may indicate that the static quadruped load distribution system is more sensitive than force plate gait analysis when it comes to detecting small weight bearing differences.[18] Surgeon, surgical experience, arthrotomy, meniscal damage, meniscal intervention, complications, post-operative TPA, initial TPA have no effect on surgical outcome as determined by improvement in weight-bearing 6-12 weeks after surgery.

Abbreviations

CCLR – Cranial Cruciate Ligament Rupture

TPLO – Tibial Plateau Leveling Osteotomy

% BW – Percent Body Weight

TPA – Tibial Plateau Angle

SI – Symmetry Index

PVF – Peak Vertical Force

ANOVA – Analysis of Variance

ACVS – American College of Veterinary Medicine

Footnotes

b. Stance Analyzer, LiteCure Companion Animal Health, Newark DE

Figures

Figure 3.1: Bodyweight vs. initial TPA. Initial dog weight was significantly and negatively correlated with the initial TPA (r=-0.19, p=0.025), indicating that lighter dogs were more likely to have a greater TPA.

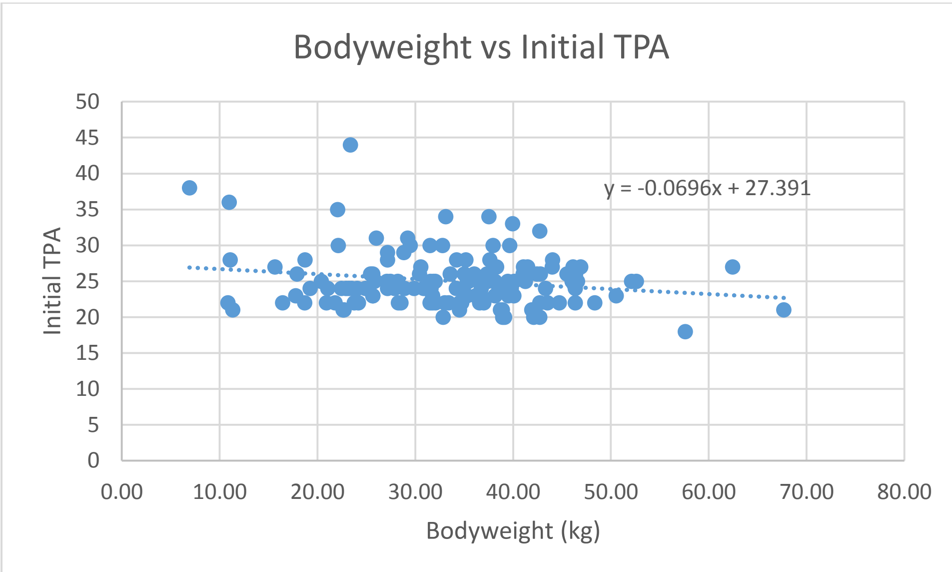


Figure 3.2: Recheck TPA vs. Change in weight bearing. Recheck TPA was negatively and significantly correlated with improvement (r=-0.2132, p=0.013)

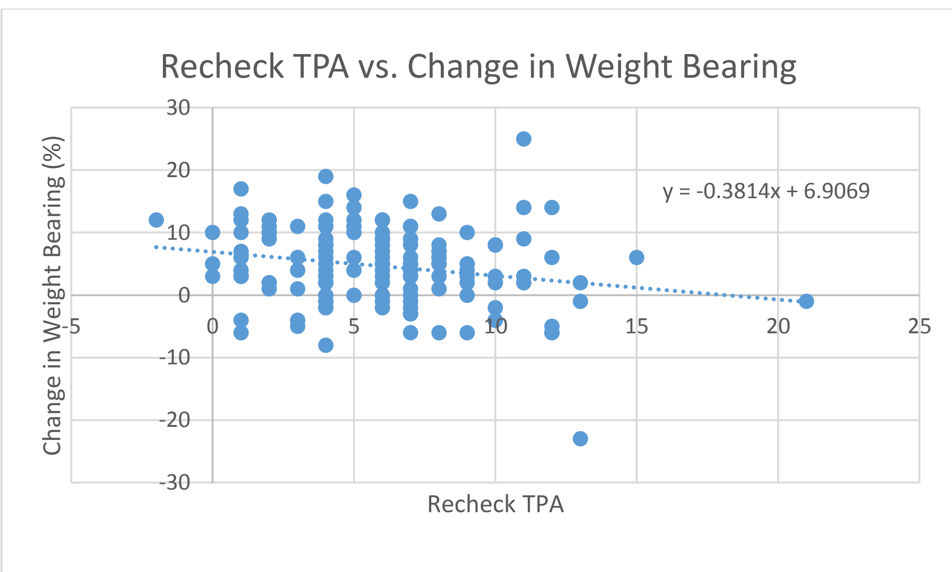


Figure 3.3: Initial TPA vs. Recheck TPA. Initial and Recheck TPA were significantly correlated with each other (r=0.4487, p<0.001)

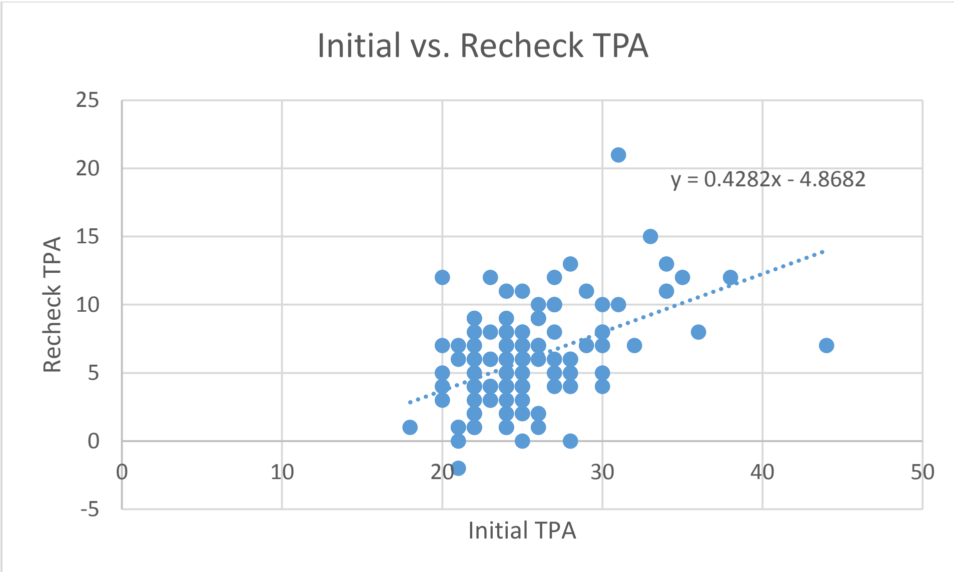
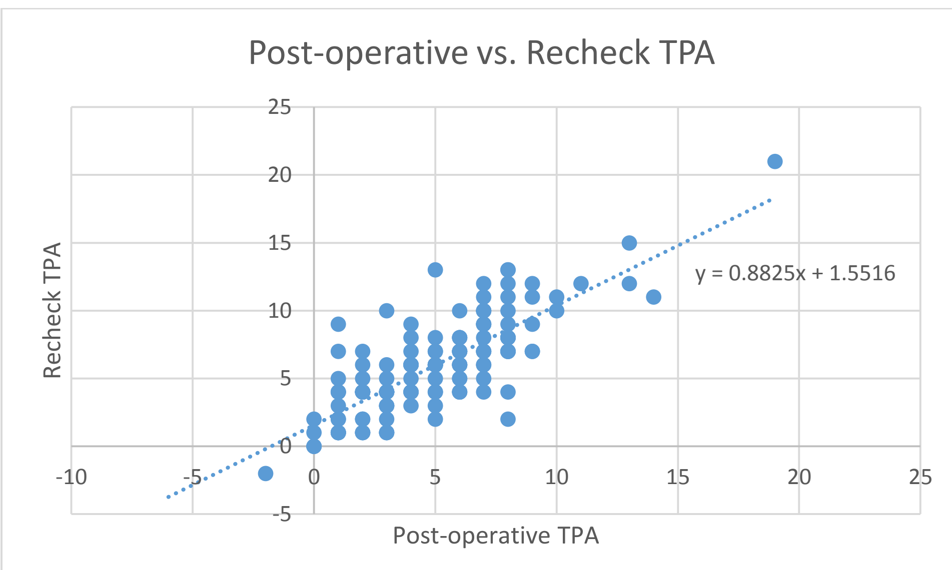


Figure 3.4: Post-operative vs. Recheck TPA. Post-operative and Recheck TPA were significantly correlated (r=0.788, <0.001).



Tables

Table 3.1: Pearson Correlation Comparison of outcomes with continuous variables.

Variable	Pearson correlation comparisons
Initial %BW on each limb	Recheck %BW on each corresponding limb
Improvement at recheck	Age, initial weight, number of days to recheck, initial TPA, immediate post-operative TPA, recheck TPA, initial %BW on operated limb, %BW on operated limb at recheck.
TPA 8 week recheck	Initial TPA and post-operative TPA

Table 3.2: Stance Parameters with average, standard deviation, and range.

Parameter	Average	StDev	Range
Age (years)	5.91	2.88	(0.00 - 14.00)
Weight (kgs) – initial visit	33.55	10.20	(6.90 – 67.68)
Weight (kgs) – recheck	33.27	11.01	(7.34 – 74.34)
Initial TPA (degrees)	25.05	3.75	(18.00-44.00)
Post-operative TPA (degrees)	4.92	3.50	(-9.00 – 19.00)
Recheck TPA (degrees)	6.03	3.59	(-2.00 – 21.00)

Table 3.3: Paired t-test comparison of initial stance parameter with the corresponding recheck stance parameter. A p<0.05 was considered significant for all comparisons.

Parameter	Initial	Recheck	P value
Ipsilateral Forelimb	33.63 ± 8.09 %BW	33.15 ± 7.76 %BW	0.532
Contralateral Forelimb	31.89 ± 7.92 %BW	31.54 ± 7.61 %BW	0.636
Operated hindlimb	8.46 ± 5.82 %BW	13.04 ± 5.94 %BW	<0.001
Contralateral hindlimb	25.89 ± 7.44 %BW	22.20 ± 7.22 %BW	<0.001
Symmetry index forelimbs	34.69 ± 28.85	35.64 ± 28.00	0.7697
Symmetry index hindlimbs	105.52 ± 54.37	71.14 ± 49.79	p<0.001
Body weight	33.55 ± 10.20 kg	33.27 ± 11.01 kg	0.4155

Table 3.4: Effect of dichotamous variables on improvement of operated limb at recheck. Values expressed as initial %BW of operated limb subtracted from recheck %BW operated limb, ±standard deviation. P≤0.05 considered significant for all comparisons.

Parameter	Yes/Diplomate	n=	No/Resident	n=	P value
Diplomate/Resident	3.98 ± 6.44	65	5.06 ± 6.52	77	0.324
Arthrotomy	5.01 ± 6.30	68	4.16 ± 6.66	74	0.436
Meniscus damaged	6.45 ± 6.96	33	3.66 ± 5.35	35	0.067
Meniscus removed	6.45 ± 6.96	33	4.00 ± 6.28	108	0.058
Meniscus released	6.88 ± 6.53	17	4.26 ± 6.44	125	0.117
Opposite cruciate rupture	4.40 ±6.11	45	4.76 ± 6.71	94	0.764
Opposite cruciate repaired	5.60 ± 6.77	20	3.77 ± 5.64	26	0.323

Patella desmitis at recheck	4.49 ±6.70	91	4.77 ± 5.83	44	0.814

Table 3.5: Pearson's Correlation Coefficient for comparison of continuous variables. p≤0.05 was considered significant for all correlations.

Comparison	Pearson's r	P value (2 tail)
Initial TPA: Post-op TPA	0.3917	<0.001
Initial TPA: Recheck TPA	0.4487	<0.001
Initial TPA: Improvement	-0.0363	0.668
Initial TPA: TPA recheck change (TPA Recheck-TPA Post-op)	-0.1061	0.219
Initial TPA: TPA operative change (TPA Initial-TPA Post-op)	0.6278	<0.001
Post-op TPA: Improvement	-0.1257	0.136
Post-op TPA: Postop %BW Oper limb	-0.0967	0.253
Post-op TPA: Initial %BW Oper limb	0.0413	0.626
Post-op TPA: Recheck TPA	0.788	<0.001
Recheck TPA: Improvement	-0.2132	0.013
Improvement: TPA operative change (TPA Initial-TPA PO)	0.0715	0.398
Improvement: Initial weight-bearing on the operated limb	-0.5374	<0.001
Improvement: Post-op weight bearing on the operated limb	0.5643	<0.001

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Appendix A - Canine Brief Pain Inventory

Today's Date: ☐☐ / ☐☐ / ☐☐
Month Day Year

Patient/Study ID#____________________

Canine Brief Pain Inventory (CBPI)

Description of Pain:

Rate your dog's pain.

1. Fill in the oval next to the <u>one number</u> that best describes the pain at its worst in the last 7 days.
   O 0 O 1 O 2 O 3 O 4 O 5 O 6 O 7 O 8 O 9 O 10
   No Pain Extreme Pain

2. Fill in the oval next to the <u>one number</u> that best describes the pain at its least in the last 7 days.
   O 0 O 1 O 2 O 3 O 4 O 5 O 6 O 7 O 8 O 9 O 10
   No Pain Extreme Pain

3. Fill in the oval next to the <u>one number</u> that best describes the pain at its **average** in the last 7 days.
   O 0 O 1 O 2 O 3 O 4 O 5 O 6 O 7 O 8 O 9 O 10
   No Pain Extreme Pain

4. Fill in the oval next to the <u>one number</u> that best describes the pain as it is **right now.**
   O 0 O 1 O 2 O 3 O 4 O 5 O 6 O 7 O 8 O 9 O 10
   No Pain Extreme Pain

Description of Function:

Fill in the oval next to the <u>one number</u> that describes how during the past 7 days **pain has interfered** with your dog's:

5. **General Activity**
   O 0 O 1 O 2 O 3 O 4 O 5 O 6 O 7 O 8 O 9 O 10
   Does not Interfere Completely Interferes

6. **Enjoyment of Life**
   O 0 O 1 O 2 O 3 O 4 O 5 O 6 O 7 O 8 O 9 O 10
   Does not Interfere Completely Interferes

Today's Date: ☐☐ / ☐☐ / ☐☐
Month Day Year

Patient/Study ID#____________________

Description of Function (continued):

Fill in the oval next to the one number that describes how during the past 7 days **pain has interfered** with your dog's:

7. **Ability to Rise to Standing From Lying Down**

   ○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

   Does not Interfere — Completely Interferes

8. **Ability to Walk**

   ○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

   Does not Interfere — Completely Interferes

9. **Ability to Run**

   ○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

   Does not Interfere — Completely Interferes

10. **Ability to Climb Up (for example Stairs or Curbs)**

    ○ 0 ○ 1 ○ 2 ○ 3 ○ 4 ○ 5 ○ 6 ○ 7 ○ 8 ○ 9 ○ 10

    Does not Interfere — Completely Interferes

Overall Impression:

11. Fill in the oval next to the one response that best describes your dog's overall quality of life over **the last 7 days?**

    ○ **Poor** ○ **Fair** ○ **Good** ○ **Very Good** ○ **Excellent**