Ground reaction force analysis of unilateral coxofemoral denervation for the treatment of canine hip dysplasia

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Summary
Coxofemoral denervation has success rates of 90–96% reported retrospectively for palliative treatment of hip dysplasia. The aim of this study was to objectively evaluate ground reaction forces (GRF) in dysplastic dogs after unilateral denervation. Unilateral coxofemoral denervation was performed by means of a previously reported technique on 10 dogs with asymmetric gait. GRF were measured at zero, one and three months. Statistical analysis was performed using repeated measures analysis of variance and paired t-tests, with p≤0.05. There was a lack of significant difference in mean peak vertical force (PVF) or vertical impulse (VI) in the operated limb (TX) over time. For the unoperated limb (UnTX), mean PVF and VI significantly decreased over time. The dogs were significantly more lame in the TX limb initially and at one month, however, there was no significant difference between limbs by three months. In the UnTX limb, 40% of dogs decreased PVF by >5%, by three months. Over time, there was no significant difference in mean average rise or mean average fall for TX or UnTX limbs. Between limbs, mean rise in the TX limb was significantly less at zero months, but not at one or three months. Decreased compensatory load shifting to the UnTX limb due to procedural efficacy could explain decreases in the UnTX limb. Worsening disease could also explain decreases in the UnTX limb, and may indicate a protective effect denoted by a lack of change in the TX limb. Longer follow-up would be required in improved dogs in order to document continued efficacy.

Keywords
Denervation, hip dysplasia, force plate, canine

Introduction
Coxofemoral denervation in the canine has been reported in several publications as a palliative treatment for pain related to hip dysplasia(1–7). Denervation procedures have been previously reported in human medicine for treatment of pain localized to the hip (8, 9), ankle (10), wrist (11), and lumbar articular facets (12, 13). In the original technique, denervation involves a dorsolateral approach to the hip joint, and curettage of the peristeme along the acetabular rim, with transection of microscopic nerves supplying the joint capsule (1). The procedure is technically simple, and is purported in order to minimize pain sensation. After the procedure, 90–96% of patients are reported as ‘improved’, and 50.4–69.2% as ‘normal’ (1, 2, 4–6). There are relatively few potential complications, and most are related to short term effects, such as seroma formation, incisional site infections and complications of general anesthesia. The recovery period after surgery is brief, requiring only two weeks of limited activity (1, 4–6).

The innervation of the canine coxofemoral joint has been thoroughly investigated in several anatomic studies (14–16). With the current denervation procedure, only branches from the cranial gluteal nerve, cranially located articular branches of the sciatic nerve, and perioseal branches of the peritendinous muscles are disrupted, resulting in selective denervation of the cranial and caudal articular aspect of the joint capsule (4, 5) (Fig. 1).

Other palliative treatments for pain related to hip dysplasia include: femoral head and neck ostectomy, total hip replacement, and daily therapeutics, including non-steroidal anti-inflammatories. The simplicity of the denervation procedure, combined with minor potential complications, low cost, and quick recovery period are all factors that make it an attractive treatment choice. To date, the procedure has primarily been evaluated via subjective methods (clinical examination and client satisfaction surveys) (1, 2, 4–6), leading to debate about the efficacy of the procedure. Measurement of ground reaction forces is considered to be the gold standard for objective analysis of weight bearing, and allows direct comparison between pre- and post-operative evaluations.

Lincoln et al. reported on the use of force plate analysis in order to evaluate 13 dogs undergoing bilateral denervation via a modified, minimally invasive procedure (17). They did not find any significant changes in peak vertical force compared to pre-operative values over a six month period. This failure to document any significant changes is in direct contrast to previously reported results.

The aim of this project was to objectively evaluate unilateral coxofemoral denervation using force platform analysis over a three month period, using the original technique. By limiting the study to unilateral treatment, the opposite limb is a source of comparison data. The null hypothesis was that a significant difference in ground reaction forces would not be noted.

Materials and methods
The patients that were admitted with chronic hindlimb lameness were examined by a single surgeon. Full orthopaedic examination and gait evaluation were performed in order to confirm that one limb was visibly more affected with the pain localized to the hip, and to rule out other sources of lameness. Severity of lameness
ranged from ‘mild’ to ‘moderate’ weight-bearing lameness, with no patients being non-weight bearing or toe-touching lame. Pelvic radiographs were utilized in order to confirm the diagnosis of hip dysplasia. Osteoarthrits, subluxation, and muscle atrophy were evaluated radiographically. The degree of osteoarthrits and subluxation were subjectively categorized as ‘not present’ (0), ‘mild’ (1), ‘moderate’ (2) and ‘marked’ (3). Diameter of thigh musculature was measured for each hindlimb at an equidistant point from the stifle on the extended ventrodorsal pelvic radiograph. The patients were included for enrollment in the study if one hindlimb was clinically more affected on gait evaluation, history and radiographs, and if there was not any evidence of additional orthopaedic diseases. Pain medications and joint supplements were discontinued a minimum of seven days prior to surgery. Post-operative, the patients were treated with non-steroidal anti-inflammatories and opioids for a maximum of three to five days after discontinuing any further treatment for the duration of the study. The patients received either morphine (0.5 mg/kg SQ) (Baxter Healthcare Corp, Deerfield, IL, USA) or hydromorphone (0.05–0.1 mg/kg SQ) (Baxter Healthcare Corp, Deerfield, IL, USA) for the first 12–18 hours postoperative, before receiving a non-steroidal anti-inflammatory (either Deramox® 1–2 mg/kg q24h or carprofen® 2 mg/kg q12h) and tramadol (4–5 mg/kg PO q8h) (Amneal Pharmaceuticals, Paterson, NJ, USA) or acetaminophen with codeine (1–2 mg/kg PO q8h) (CorePharma LLC, Middlesex, NJ, USA).

As in the procedure described by Kinzel and Kupper (1), a limited craniolateral approach to the hip was performed via a 3–5 cm craniolateral incision centered at the level of the greater trochanter. Using blunt dissection, the gluteal muscles were elevated from the body of the ilium, and the tendon of insertion of the deep gluteal muscle was elevated from the underlying joint capsule. A large Hohmann retractor was placed dorsal to the ilial shaft in order to retract the gluteal muscles, and to expose the ilium and cranial and dorsal aspect of the acetabulum. Using a sharp bone curette, the periosteum was elevated in a wide strip parallel to the acetabular margin, beginning at the ventral-most aspect of the ilial body and extending as far caudally as possible. The periosteum was also removed circularly to surround the origin of the rectus femoris, cranioventral to the joint capsule. The degree of periosteal removal was considered sufficient when a visible defect could be seen on the surface of the bone. The surgical site was closed routinely in several layers. The same surgeon performed all of the surgeries.

Prior to surgery, and at one and three months post-operative, ground reaction forces were measured using a commercial force plate (model 9287, Kistler Instrument Corp., Amherst, NY, USA), built into a 25 foot walkway. The forceplate was operated using software (Acquire, version 7.5, Sharon Software, Detroit, MI, USA). Velocity and acceleration were measured using three photoelectric cells and a millisecond timer. Trials were considered valid when both the ipsilateral fore and hindlimbs struck the plate at a trot. Velocity and acceleration were controlled to within 1.6–2.3 m/s and ± 0.5 m/s². The first five valid trials were collected for both the right and left hindlimbs, and the results were averaged. Data evaluated included peak vertical force (PVF) and vertical impulse (VI), as well as average rise and fall for each hindlimb. Average rise and fall were obtained from the slope of the curve for the vertical force vector, which reflects the rate of loading and unloading of the limb. The patients were weighed prior to each analysis, and data were expressed as percent body weight. At each follow-up visit, full orthopaedic examination was repeated in order to ensure that no additional problems had developed in either the operated (TX) or the unoperated (UnTX) limbs.

Mean velocity and acceleration were calculated for each set of trials at time 0 (pre-operative), one and three months. Mean PVF, VI, and average rise and fall were calculated for each hindlimb at time zero, one and three months. Repeated measures analysis of variance and Newman-Keuls multiple comparisons post-hoc tests were run in order to evaluate for significant differences in PVF, VI, average rise and fall, trial velocity and acceleration over time for both the TX and UnTX limbs. Differences between the TX and UnTX limbs at each of the three time points were compared using paired t-tests. Differences were considered statistically significant for p<0.05.

**Results**

Ten canines were enrolled in the study and completed the full three month follow-up period. None of the animals were lost to follow-up. The patient population included six Labrador Retrievers, one Boxer, one Golden Retriever cross, one German Shepherd Dog cross, and one Saint Bernard. The patients ranged in age from eight months to 10 years, with a mean age of 3.7 years. The dogs ranged in weight from 25 to 57.27 kg, with a mean weight of 35.81 kg. The average duration of lameness prior to sur-
gery was 13 months (2–42 months). Nine of 10 dogs had a left coxofemoral denervation. None of the patients had any adverse complications during the study period.

All the 10 patients were clinically, radiographically and, by the measurement of the ground forces, more affected on one hind-limb than the other. However, nine patients had evidence of bilateral hip dysplasia as seen on their radiographs. One dog had unilateral coxofemoral osteoarthritis which had developed after a femoral fracture three years previously. One of the patients had undergone a triple pelvic osteotomy on the UnTX limb two years prior to enrollment in this study. From the pelvic radiographs, all of the dogs had measurably less muscle mass in the TX limb, as measured in the mid-thigh region (average 10.7 mm larger musculature in the UnTX limb, range 6–23 mm). The average osteoarthritis score was 2 in the TX limb (moderate), and 1.3 in UnTX limbs (1 being ‘mild’, 2 being ‘moderate’). The average subluxation score was 1.5 in the TX limb and 0.7 in the UnTX limb.

Pre-operatively, an average of 79 trials was required to obtain five valid trials for each hindlimb. An average of 55 and 56 trials were required in order to obtain sufficient valid trials at the one and three month rechecks. There was no significant difference in mean velocity or acceleration for the trials at any time, or between the trials for the TX and UnTX limbs at any time (Table 1).

Based on subjective assessment from physical examination, gait evaluation, and owners opinion, 50% of the dogs in this study were considered to be moderately to markedly improved, and 50% of the dogs were mildly improved or unchanged.

From objective evaluation, there was no significant difference in mean PVF in the TX limb over time. For the UnTX limb, mean PVF had significantly decreased at three months (63.94 ± 6.32) compared to pre-operative values (69.13 ± 5.37) (p=0.036). Mean PVF was significantly less for the TX limb compared to the UnTX limb both pre-operative (p=0.005) and at one month (p=0.043). There was no significant difference in mean PVF between the TX and UnTX limbs at three months (p=0.166).

Mean PVF in the TX limb had improved in five of 10 dogs by three months post-operative compared to pre-operative values. Six dogs improved by >3% by one month, while only three dogs were improved by >3% at three months. Only two dogs improved by more than 5%. Just two of 10 dogs had improved mean PVF in the UnTX limb compared to pre-operative. Seven of 10 dogs had decreased mean PVF by greater than 3% in the UnTX limbs, and four of 10 dogs had decreased by >5% by three months.

For mean VI, there was not any significant difference for the TX limb at any time. For the UnTX limb, mean VI had significantly decreased at three months (9.45 ± 1.72) compared to pre-operative values (10.89 ± 1.70) (p=0.010). Mean VI was significantly less in the TX limb compared to the UnTX limb both pre-operative (p = 0.004) and at one month (p=0.009). By three months, there was no significant difference in mean VI between the TX and UnTX limbs (p=0.175).

Over time, there was not any significant difference in mean average rise or fall slope for the TX or UnTX limb. However, between limbs, pre-operative mean average rise in the TX limb was significantly less then in the UnTX limb (p=0.006). By one and three months, there was no longer a significant difference in mean average rise slope between the two sides (p=0.092 and p=0.143, respectively). Between limbs, there was no significant difference in mean average fall slope at any time.

### Discussion

By three months, 50% of the dogs had documented improvement in PVF, however, only 30% of the patients had improved by greater than 3%, and 20% by greater than 5%. When looking at the overall group of dogs, we failed to document a significant difference in PVF compared to pre-operative data. Power calculations were performed, and 25 dogs would have been required in order to document a significant improvement for the overall group, based on the magnitude of observed improvement. After unilateral total hip replacement, by 6 months mean PVF is reported to improve by 8–10.6% in the treated limb (18, 29). In a report evaluating efficacy of carprofen via force plate analysis, improvements of >5% in individual dogs were considered to be signifi-

### Table 1

<table>
<thead>
<tr>
<th>Parameter</th>
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<th>3 months</th>
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<td>66.18 ± 5.10 ab **</td>
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cant, as variability of up to 5% in ground reaction forces is thought to occur (20). Based on subjective assessment from physical examination, gait evaluation, and owners opinion, 50% of the dogs in this study were considered to be ‘moderately’ to ‘markedly’ improved, and 50% of the dogs were ‘mildly’ improved or unchanged.

When looking at previous reports, 90–96% of dogs are reported to be ‘improved’ or ‘normal’ without evidence of pain or lameness after coxofemoral denervation (1, 2, 4–6). With only 30% of dogs improving by greater than 3%, our data is in direct contrast to these previous studies. Other studies that reported a greater degree of efficacy relied on subjective analysis of results, using physical examination and client questionnaires. Subjective grading scales, such as visual analogue scales and numerical grading scales, generally have low agreement between observers, with data only accurately reflecting force plate data when lameness is severe (21). These types of analysis leave the studies open to the placebo effect, as well as investigator bias in interpreting the results.

Coxofemoral denervation can, at most, only be considered to be a partial sensory denervation, as branches from the obturator and femoral nerves would not be affected. Individual variability in efficacy may be due to individual variation in the location of nerve branches. Some variability in the presence of obturator branches has been documented in anatomic studies, as well as the exact location of sciatic branches, and the number and location of perarticular muscular branches (14–16). Also, only some of the perarticular indirect muscular branches would be transected. Conceivably, in dogs with more caudally located sciatic branches, denervation may not be as effective compared to dogs with more cranially located branches.

At three months, 70% of the dogs had decreased values for the UnTX limb, with a significant decrease in PVF and VI for the overall group. Although significant changes in average rise slope for each side were not documented, a significant difference between sides was initially present, with the TX limb being loaded at a slower rate. This difference was no longer present at one and three months, as both sides were loaded at similar rates. An initial significant difference in PVF and VI was also present between limbs, with decreased values for the TX limbs. By three months this difference was no longer present, due to the combined effects of a significant decrease in values for the UnTX limb and a non-significant increase in values for the TX limb.

Several potential reasons for this combination of results are possible. The majority of dogs had bilateral disease. Worsening pain in the UnTX limb could account for decreasing values for PVF and VI. All of the dogs had discontinued medical management for the duration of the study period. If pain and inflammation were worsening either due to progression of time or lack of ancillary medical management, bilateral decreases in values would have been expected, particularly considering that the TX limb was significantly more affected preoperatively than the UnTX limb. The lack of deterioration on the TX limb (in fact, a non-significant increase in values seen) could actually imply some protective effect from the procedure.

The other more likely reason for decreasing values in the UnTX limb is more even weight distribution among hindlimbs due to efficacy of the procedure. Prior force plate analysis studies have demonstrated that compensatory load sharing occurs with lameness, with increased weight bearing to the unaffected limbs (22–24). With hindlimb lameness, load sharing is primarily to the opposite hindlimb, with no significant increases in values for the forelimbs (22, 25).

Because of compensatory load shifting, the use of the opposite limb as a control is not recommended in the experimental setting when performing studies on previously normal dogs (23, 24). In the clinical situation, dogs present with pre-existing lameness and compensatory increases are already occurring at the initial force plate evaluation. Although the exact amount of compensatory shift is variable between dogs, change in weight distribution after an interventional procedure, particularly when evaluating groups of dogs and summary statistics, is a valid parameter. After unilateral total hip replacement, compensatory unloading of the untreated limb has been shown to occur as the treated limb improves, and increased loading rates for the treated limb are of note in demonstrating increased willingness to weightbearing (18). In our study, a statistically significant decrease in the values for the UnTX limb were documented, which could be consistent with increased load sharing and loss of compensatory increases. Some corresponding increases to the TX limb were noted, however, a statistically significant increase was not noted. Statistically significant differences between loading rates was initially present at the preoperative evaluation, and this difference was no longer present by one and three months, which suggests improved willingness to weight bear on the treated limb. Some potential other concerns after coxofemoral denervation include long-term efficacy, as well as the effects of sensory denervation on the joint surface and progression of osteoarthritis. Longer term follow-up of several years would be required in dogs demonstrating improvement in PVF in order to document continued efficacy of the procedure. We chose a three month follow-up period, as our main concern was in documenting initial efficacy.

The sensory components of articular innervation are important both for perception of pain and proprioception. Sensation-mediated neuromuscular reflexes may have an important role in protecting or slowing the occurrence of further damage in a diseased joint. Studies have demonstrated that osteoarthritis is more rapidly progressive in dogs with loss of sensory function and an unstable joint. However, when sensory function alone is lost, no ill effects are noted (26, 27). With hip dysplasia, instability is present before the development of osteoarthritis, and increased progression of osteoarthritis is likely to occur after sensory denervation. The partial nature of the sensory denervation may ameliorate some of this effect, however, this should be considered before performing the procedure on patients with palpable Ortolani and existing laxity. In adult animals, once osteoarthritis and joint fibrosis has developed, instability is not a significant factor in the hip joint, and the effect of sensory denervation should not have an effect on osteoarthritis progression.
The main limitation of our study was patient recruitment. By only enrolling dogs with asymmetric symptoms, many dogs with hip dysplasia were excluded. This limited our ability to obtain large patient numbers. Also, many of the dogs that were initially evaluated for asymmetric symptoms and hip dysplasia, were actually diagnosed with other orthopaedic problems, and were thus excluded. Pelvic radiographs were taken of all of the dogs, but full limb radiographs were not taken. Reliance was placed on the orthopaedic examination to exclude dogs with other orthopaedic or neurologic signs. There is a possibility that some dogs with asymmetric signs had other mild diseases in the affected limb that could confound results. However, full orthopaedic and neurological exams were repeated at both one and three month rechecks, and additional problems were not diagnosed over the study period. A true control group was not used, with either use of an age-matched control group which did not undergo surgery, or use of a group of dogs undergoing sham surgery. Since the patients were selected from clinical, client-owned patients, the use of a sham surgery would have raised ethical concerns. The use of age-matched controls would have been difficult, due to the large amount of symptomatic variability that exists with hip dysplasia. As the primary goal was to compare force plate data for the treated limb from before and after an interventional procedure, as well as for load shifts between hindlimbs, the study design was considered valid.

In conclusion, 50% of dogs did demonstrate an improvement in peak vertical force. However, overall, no significant improvement in PVF was noted for the study population. When considering the statistically significant changes in the unoperated limb, there is evidence of the efficacy of the procedure. Given the low cost of the procedure, and the few potential complications, coxofemoral denervation should be considered to be a valid treatment option, given that clients understand that only 30–50% of dogs will be improved. If the procedure is unsuccessful, total hip replacement, femoral head and neck osteotomy, or further medical management are still viable options.

Acknowledgements

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References