THE USE OF FORCE PLATE ANALYSIS TO ASSESS THE LONG TERM OUTCOME OF TRIPLE PELVIC OSTEOTOMY FOR THE TREATMENT OF DOGS WITH CANINE HIP DYSPLASIA

A Thesis

Presented to

The Faculty of Graduate Studies

of

The University of Guelph

by

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In partial fulfilment of requirements

for the degree of

Doctor of Veterinary Science

September, 1997

0-612-27469-1

ABSTRACT

THE USE OF FORCE PLATE ANALYSIS TO ASSESS THE LONG TERM OUTCOME OF TRIPLE PELVIC OSTEOTOMY FOR THE TREATMENT OF DOGS WITH CANINE HIP DYSPLASIA.

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A retrospective case study was done to determine the long term outcome of surgery in dogs treated for canine hip dysplasia with a triple pelvic osteotomy (TPO). Twenty four dogs with bilateral hip dysplasia that had had a unilateral TPO performed between January 1988 and June 1995 were assessed at the Ontario Veterinary College. Assessment included a physical, orthopedic and lameness examination, standard blood work, pelvic radiographs and force plate gait analysis. These dogs were compared to bilaterally dysplastic dogs with no surgical treatment and clinically normal dogs. Coxofemoral joints with a TPO showed significant improvement in Norberg angles and subluxation scores but still developed degenerative joint disease as early as 12 months after surgery. The degree of degenerative joint disease and instability increased significantly from the pre-operative to the follow-up time in the operated limbs. The degree of DJD was generally less, although not significantly so than that in the contralateral unoperated limbs. Despite development of DJD the TPO limbs bore more weight and transferred more force as shown by force plate assessment, peak vertical force (PVF) and mean vertical force over stance (MVF). Following TPO, dogs did not have significantly less lameness or joint pain in the operated hip compared to the unoperated hip or compared to the unoperated dysplastic or control dogs.

Acknowledgments

I would like to gratefully thank my committee members, Drs. Joanne Cockshutt, Craig Miller, Dave Holmberg, Jeff Thomason and John Brooke, for their guidance throughout the development and growth of this project and preparation of this thesis.

I would like to thank Amanda Hathway and Karen Dupont for their endurance and willingness to walk dogs across the force plate over and over again!

A special thanks to Connie Taves and Anne Valliant for their patience and enthusiasm in answering my many questions. Without their expertise in force plate assessment this project would not have been possible.

Last but not least my many thanks to the Ontario Veterinary College's Pet Trust Fund for financial support of this project.

DECLARATION OF WORK PERFORMED

The work completed on this thesis was done by me as the principal investigator and included: Contacting prospective cases, scheduling of all cases to return to the OVC for evaluation, creation of the client questionnaire, and scoring systems for data, development of a method to calculate velocity, performance of general orthopedic, and lameness examinations, collection of force plate data, reviewing all videos to determine velocity and foot strikes, scoring of the radiographic data, tabulations of data from all scoring criteria and data obtained in the medical record and client questionnaires, and generation and interpretation of statistical tests.

The following work was integral to the thesis and was done with the assistance of several other departments. Complete blood counts and serum biochemistry profiles were analyzed by the clinical pathology department. The client questionnaire was created with the assistance of Dr. Brenda Bonnett. Force plate data was collected with the assistance of Connie Taves, Amanda Hathway and Karen Dupont. Radiographs were taken with the assistance of the radiology department. Scoring criteria of the radiographs was generated with the guidance of Dr. Howard Dobson and he also served as the second reader of the radiographs. Several statistical tests were run by Anne Valliant with the assistance of Dr. M. Shoukri.

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Chapter 1

1.0 Introduction

Hip dysplasia, which is an abnormality in development was first described in dogs in 1935 by Schnelle (1935). The coxofemoral joints of affected puppies are normal at birth (Riser & Shirer 1966) but some dogs go on to develop joint laxity. The incidence of hip dysplasia varies between breeds (Keller & Corley 1989) and has been reported as high as 82% in St. Bernards (Henricson, Norberg & Olsson 1966). Hip dysplasia in dogs has a polygenic mode of inheritance, with environmental factors that influence the phenotypic expression of the disease (Brass 1989).

Many theories have been investigated to determine important environmental associations with hip dysplasia. However, no one major environmental factor has been identified as a primary influence on genotype, causing more severe phenotypic expression of the disease. Until all causative factors are identified and controlled, complete disease prevention is unlikely. Given that inheritance and environmental factors play an important role in expression of the disease, the approach to treatment and elimination must also be multifaceted. The standard for diagnosis of the disease is by radiographic evaluation of the pelvis (Whittington 1961). Newer techniques are being developed in an attempt to improve sensitivity of the radiographic diagnosis (Smith, Biery & Gregor 1990). Investigation of different modes of treatment and success of treatment is necessary. Currently available therapeutic options are non-surgical conservative management (Wallace 1987; Barr, Denny & Gibbs 1987; Banfield, Bartels, Hudson *et al.* 1996 a,b) or surgical intervention. Surgical approaches consist of preventive (Prieur

1987; Poss 1984; Jenssen 1989; Brinker 1971; Schrader 1981 & 1986; Slocum & Devine 1986), palliative (Rosenthal & Pogust, 1972) or salvage procedures (Elkins 1981; Piermattei 1965; Olmstead, Hohn & Turner 1981; Paul & Bargar 1986). Each surgical approach has distinct criteria for a dog to be considered a candidate for the procedure and each surgery has different goals.

1.1 Goals and hypotheses:

The goals of this project were to investigate the long term effects of triple pelvic osteotomy (TPO) as a corrective surgical procedure for hip dysplasia. To date only uncontrolled case series have been published evaluating the effects of TPO. Though this project is also a retrospective case series it does make blinded comparisons of operated to unoperated limbs and it uses a more objective measurement tool: the force platform.

The hypothesis is that dogs that received a TPO on only one of two dysplastic coxofemoral joints would have more normal weight bearing in the limb that had surgery as compared to the unoperated contralateral limb. The second hypothesis is that the TPO limb would transmit more force than the than limbs from bilaterally dysplastic dogs with no surgical treatment. The third hypothesis is that the TPO limbs would transmit forces similar to dogs with radiographically normal joints. The fourth hypothesis is that the TPO treated limb would have less degenerative joint disease and signs of instability compared to the unoperated limb. Lastly, that DJD would not progress to the same degree as in the unoperated limb. Lameness scores, joint pain scores, radiographic measurements of Norberg angles, degenerative joint disease and instability and force plate measurements of peak and mean vertical forces were used to test these hypotheses.

1.2 General Literature Review

1.21 Pathophysiology of Hip Dysplasia

Following a group of dogs from birth to approximately nine months of age, Riser (1973) correlated the radiographic signs with gross anatomic pathological changes. To summarize his findings, between birth and thirty days 84 of 87 dogs had grossly normal coxofemoral joints. Three of 87 had an edematous teres ligament with a few torn fibers within the ligament and capillary hemorrhage present on the surface. From 30 to 60 days, radiographs showed the first signs of disease which were subluxation of the femoral head and a lag in the development of the craniodorsal acetabular rim. The gross anatomic change of the joint capsule was stretching and the teres ligament was longer than normal although not necessarily stretched. From 60 to 90 days, radiographic evidence of subluxation of the femoral head increased and the lag of ossification at the craniodorsal acetabular rim was more noticeable. On examination the joint capsule was thickened from the 10 to 2 o'clock position, the teres ligament was swollen and pulled ventrally away from its attachment in the acetabular fossa, and the articular cartilage on the dorsal surface of the femoral heads was worn and roughened where it contacted the acetabular rim. Additionally, as congruency was lost between the femoral head and acetabulum, the contacting area that forms an arc on the femoral head was narrowed. This narrowed arc caused the compressive forces to be increased on the femoral head, acetabular rim, and traumatized the pliant cartilage of the acetabular rim. The change in stress on the acetabular rim led to new bone formation on the dorsal acetabular articular surface and stimulated the resorption of bone on the ventral surface of the acetabular cavity. From

12 to 20 weeks, radiographs showed continued subluxation of the femoral head, incongruity of the two joint surfaces, lag in development of the acetabular rim and change in shape of the joint components. The next anatomic finding was rounding of the acetabular rim from the 10 to 2 o'clock position. From 20 to 35 weeks, the subchondral bone became sclerotic and the acetabulum was shallow. At this point the first radiographic bony changes of hip dysplasia appeared in the acetabulum as filling in of the acetabular fossa with new fiber bone. Changes appeared on the femoral head: a rim of newly formed bone encircling the neck at the junction of the head and neck. Many gross anatomic changes were occurring during this time period. There was fibrillation and microfracturing of the dorsal acetabular rim and articulating surfaces were stripped of cartilage. There was eburnation of the exposed subchondral bone which became ivory-like in appearance, smooth and highly polished. A corresponding area of eburnation was present on the femoral head. The joint capsule was thickened to five to seven mm which restricted range of motion. The synovial fluid had lost viscosity and density and there was an increased leukocyte count. The teres ligament continued to deteriorate. It was now stretched and sometimes detached from the acetabular fossa. Individual fibers were ruptured and the ligament was so edematous that it prevented the return of the femoral head to its normal position in the acetabulum. After nine months of age changes in the dysplastic hip occurred quickly. There was roughening of the ilium and ischium from abnormal excessive weight bearing forces and pull from the gluteal muscles and internal obturator muscle attachments. The femoral head was eburnated except for the periphery and as the stresses changed, the femoral neck gradually shifted to a more valgus position.

Lipping of the femoral head remained at the margin of the femoral head and neck. The width of the articular cartilage varied because of inconsistent nourishment. This contributed to osteophyte formation. Osteophytes also formed on the dorsal surface of the neck and extended laterally to the trochanter and into the concave fossa between the trochanter and femoral neck.

Synovitis, microfractures of the subchondral bone, irritation of periosteal nerve endings by osteophytes, stretching of ligaments, joint effusion and/or secondary degenerative joint disease all contribute to the pain and lameness associated with hip dysplasia (Wallace 1987). Healing of the microfractures as the dog matures allows some of the pain to dissipate and dogs may become clinically normal until secondary osteoarthritis causes lameness in the older dog (Wallace 1987).

1.22 Proposed Factors in the development of hip dysplasia

Heritibility of hip dysplasia in dogs has been found to be 0.2 - 0.6 (Henricson 1966; Leighton, Linn, Wilham *et al.* 1977; Hedhammer 1979). It has a polygenic mode of inheritence (Hutt 1967).

Considering the degree of heritability it is likely that environmental factors are responsible for approximately 50% of the variation of the severity of the disease in dogs (Henricson *et al.* 1966).

An early study considered the outcome of breeding dysplastic sires to dysplastic dams and found that 93.3% of offspring of such a mating were affected with hip dysplasia while breeding two dogs with normal hips resulted in 43.4% dysplastic pups. When both parents were dysplastic there was a statistically significant increase in the number of dysplastic puppies (Riser, Cohen, Lindqvist *et al.* 1964).

Early rapid growth and weight gain (Riser *et al.* 1964; Kasstrom 1975; Kealy, Olsson, Monti *et al.* 1992; Kealy, Lawler, Ballam *et al.* 1997), restricted exercise (Lust, Geary & Sheffy 1973), abnormal development of the pectineus muscle (Lust, Craig, Ross *et al.* 1972a; Lust, Craig, Geary *et al.* 1972b; Cardinet, Guffy & Wallace, 1974a; Cardinent, Guffy & Wallace 1974b; Ihemeland, Cardinet & Guffy, 1983), pelvic muscle mass (Riser & Shirer 1967), volume of synovial fluid (Lust, Beilman & Rendano 1980), and estrogen levels (Thieme & Wynne-Davies, 1968; Pierce, Bridges & Banks, 1965; Gustafsson 1968; Gustafasson & Beling 1969; and Pierce & Bridges 1967) have been implicated in the development of canine hip dysplasia..

Rapid growth and weight gain

One study looking at early rapid growth and weight gain found that there was a marked relationship between body weight at 60 days of age and the occurrence of hip dysplasia in the German shepherd dog (Riser *et al.* 1964). In following 222 German shepherd puppies it was found that 63% of the dysplastic animals were over the average body weight of all pups at 60 days of age. There was a significant difference ($p \leq 0.04$) between the average weights of normal and dysplastic puppies. Males generally weighed more than females, and the dysplastic males and females weighed more than normal males and females.

Hedhammer (1974) showed that Great Danes fed *ad libitum* developed a variety of musculoskeletal lesions, one of which was hip dysplasia. Kasstrom (1975) followed up Hedhammer's work looking at five litters of pups with a high parental frequency of hip dysplasia. He confirmed that hip dysplasia was more frequent, occurred earlier, and became more severe in dogs with a rapid weight gain caused by increased caloric intake than in dogs which had a low weight gain because of restricted feeding.

Another study looked at high calorie versus low calorie diets, and exercised versus non-exercised dogs (Lust *et al.* 1973). Unlike many of the early studies that primarily dealt with German shepherd dogs this study looked at 68 Labrador retrievers, six golden retrievers, six German shepherd-golden retriever crossbreeds and six beagle-Labrador retriever crossbreeds. All of the above 92 dogs had at least one parent with hip dysplasia. All dogs in the high calorie (n=8) and low calorie (n=8) groups developed hip dysplasia. Also all dogs placed on either high exercise (n=13) or no exercise regimes (n=13) developed hip dysplasia. The only dogs that had a lower incidence of hip dysplasia were the very slow growing Cesarian-delivered, hand reared pups. This study also concluded that rapid weight gain could be detrimental to the development of normal coxofemoral joints.

Two additional studies comparing limit fed to *ad libitum* fed paired littermates were reported. Kealy *et al.*, assessed Labrador Retrievers up to two (Kealy *et al.* 1992) then five (Kealy *et al.* 1997) years of age. In a two year study, the dogs fed *ad libitum* had a higher degree of hip dysplasia i.e., more subluxation and degenerative joint disease of the coxofemoral joint. In a five year study it was determined that body weight was positively correlated with osteoarthritis scores.

Pectineus muscle

An abnormality of the pectineus muscle has been implicated as a cause of canine hip dysplasia. This muscle originates on the iliopectineal eminence of the pubis and attaches at the popliteal surface of the distal femur. It functions as an adductor of the hind limb (Evans & Christensen 1979). It was theorized that if the pectineus muscle was shortened or in spasm when a pup was very young, there would be an upward displacement of the femoral head against the acetabular rim, resulting in upward deflection of the acetabular rim and dysplasia (Barden & Hardwick 1968). To test this theory Barden severed the pectineus muscle at its insertion unilaterally in a group of eight week old pups. These pups were predicted by palpation to have Grade 3 - 4 hip dysplasia. At six months of age radiographs were made of the pelves. All eight pups had grade 3 or 4 dysplasia on the unoperated leg while all legs with a transected pectineus muscle had only grade 1 or 2 dysplasia. The authors concluded from this and other work that surgery could not completely correct a Grade 3 or 4 dysplasia. They also conceded that additional study of the pectineus and other adductors should be done.

Lust *et al.* (1972a) examined the possibility that pelvic muscle tissue abnormalities were associated with hip dysplasia. They agreed with Barden and Hardwick that palpation for hip joint laxity, in eight to nine week old puppies, was associated significantly with pelvic radiographic changes consistent with hip dysplasia. However, surgical excision of the pectineus muscles from potentially dysplastic pups (based on palpation) did not prevent hip dysplasia. In the same publication, Lust and colleagues also examined protein synthesis and structural changes of the pectineus muscles. Pelvic muscle protein synthesis was found to be normal in all pups up to three months of age. After that age the protein formation decreased in dysplastic dogs. Although a decreased rate of protein synthesis was found in dysplastic dogs there is no way of knowing whether this change was the cause, or an effect of hip dysplasia.

Lust *et al.* (1972b) also reported another study designed to search for histopathological changes in the pectineus and determine how those changes compared with predictions of the early diagnostic estimate of hip dysplasia. They concluded that histopathological changes were present in the pectineus muscle of dysplastic dogs but did not correlate well with future disease. Palpation of the pectineus muscle was an unreliable indicator of hip dysplasia in older dogs. Surgical excision of the pectineus did not significantly alter the development of hip dysplasia in this study.

Cardinet *et al.* (1974b) examined radiographic and pathoanatomic data from German shepherd dogs that had unilateral pectineal tenotomies at four, eight, or 12 weeks of age. At 12 months of age it was found that pectineal tenotomy caused no significant difference between operated and unoperated sides.

In related work, a comparison was made between greyhounds and German shepherd dogs that received unilateral pectineal myectomies at eight to nine weeks of age. Radiographic and pathoanatomic examination of the coxofemoral joints of all dogs was done at 12 - 47 months of age. It was concluded that there was no significant difference in the status of coxofemoral joints between operated and unoperated sides (Cardinet *et al.* 1974a).

Histopathology done on 23 pectineus muscles from two month old German shepherd dogs showed a significant difference between pectineus muscles from dogs that grew to have normal hips and dogs that had dysplastic hips (Ihemelandu *et al.* 1983). The principal changes were the size of myofibers and the amount of nonmyofiber components present (e.g., mysial connective tissue elements, blood vessels and nerve branches). This seemed to indicate a relationship between pectineal myofiber hypotrophy and hip dysplasia.

Tenotomy, myotomy or myectomy of the pectineus muscle has shown variable effectiveness in eliminating or decreasing the severity of canine hip dysplasia. There is also variable evidence regarding changes in the pectineus muscle that may contribute to hip dysplasia

Pelvic muscle mass

Riser calculated a pelvic muscle mass index in 95 dogs by dividing the total weight of pelvic muscle by live weight of the dog and the result was multiplied by 100. (Riser 1967) It was found that a pelvic muscle mass index greater than 12.0 was a significant indicator of normal hip configuration. Since there was no control group, it cannot be determined whether decreased muscle mass allowed laxity which led to hip dysplasia, or if the dogs had hip pain due to hip dysplasia that resulted in disuse atrophy.

Synovial fluid

The amount of synovial fluid and capital ligament volume and their influence on joint laxity have been investigated. Subluxated coxofemoral joints had greater volumes of both fluid and ligament than normal coxofemoral joints (Lust *et al.* 1980). However, the data provided no insight into the cause of canine hip dysplasia or into a temporal sequence of the changes that lead to joint laxity. It does not resolve the issue of increased synovial fluid and ligament volume being a cause or effect of joint laxity.

Estrogen

Andren and Borglin (1961) found higher urinary estrogen levels in newborn human infants with congenital dislocation of the hip joints compared to those with normal joints. These findings could not be repeated by others (Thieme *et al.* 1968). Several veterinary investigators reached the conclusion that hip dysplasia may be induced experimentally with postnatal administration of estradiol (Pierce *et al.* 1965; Gustafsson 1968; Gustafsson *et al.* 1969). Gustafsson *et al.* (1969) injected bitches with estradiol in the third trimester of pregnancy and compared the resulting puppies with others that received only postnatal estradiol, and with control puppies. The control animals had normal hip joints with no signs of laxity and did not develop hip dysplasia. The pups that received postnatal estradiol all had smaller than normal femoral heads and joint laxity, and developed hip dysplasia. The offspring of the estradiol-injected bitches also had changes in femoral head size and joint laxity but did not go on to develop hip dysplasia. The authors suggested that hip dysplasia and development of joint instability, in certain breeds of dogs, is caused by changes in the estrogen metabolism during pregnancy, either by an increased production in the placenta or by normal placental production with an abnormal capability of metabolism by the fetus.

Pierce and Bridges (1967) investigated the urinary excretion of estradiol-17B in normal dogs and dysplastic dogs. They found the excretion was lower in normal dogs indicating that dysplastic dogs had less capacity to metabolize estradiol. However, more recent work conducted by the Orthopedic Foundation for Animals concluded that there did not appear to be a sex predilection for hip dysplasia (Keller *et al.* 1989). If there was an obvious gender predilection for canine hip dysplasia with females predominating then perhaps a more convincing statement could be made to implicate estrogen as a main cause of hip dysplasia. It does appear that injections of high levels of estrogen consistently causes joint laxity but this has no bearing on the normal female dog or clinical manifestation of the disease.

Many theories on the causes of hip dysplasia have been examined. Genetics and rapid weight gain stand out as the most convincing influences on dogs that develop hip dysplasia. The most recent feeding studies (Kealy *et al.* 1992; Kealy *et al.* 1997) were well controlled and nicely demonstrated that, faster growing, heavier pups fed *ad libitum* developed more joint laxity, as evidenced by a greater degree of radiographic subluxation, and more degenerative joint disease at two years of age and significantly more DJD at five years of age. The other environmental factors, estrogen, pelvic muscle mass, and abnormalities in the pectineus muscle all may contribute in some degree to the phenotypic expression of disease but further investigation is warranted.

1.23 Assessment of Hip Dysplasia/Lameness

Physical exam

Early diagnosis of hip dysplasia would be helpful for breeders and veterinarians. This would save considerable costs associated with raising breeding stock only to find that they are dysplastic. Many techniques for early diagnosis have been described. In

1968 Barden *et al.* published a technique for palpating pups as young as 8 weeks old and claimed 85% accuracy in predicting hip dysplasia. They found that all dogs predicted to be dysplastic went on to develop hip dysplasia. A few dogs considered normal went on to develop hip dysplasia (false negatives). They felt that the depth of anesthesia and clinician bias could affect results of palpation.

Ortolani's sign is another palpation technique for diagnosing coxofemoral joint laxity (Ortolani 1976). With proper manipulation and palpation of the hind limbs it is possible to subluxate and then reduce the femoral heads if joint laxity is present. A "click" can often be heard as the femoral head is reduced into the acetabulum. A positive Ortolani sign (subluxation and reduction) helps confirm the presence of coxofemoral joint laxity most likely due to hip dysplasia.

Radiographic

Radiography has been and is still the method of choice for diagnosing hip dysplasia. A paper in 1962 described the technique for achieving the extended leg view in a consistent manner (Riser 1962). This positioning done under tranquilization was recommended by the panel on hip dysplasia (Riser 1962; Whittington 1961). It was suggested that accurate evaluation of radiographs is best achieved with correct positioning of the patient and high diagnostic quality radiographs.

The radiological features of hip dysplasia have been described in detail (author unknown JSAP 1974). The structures and changes to be looked at include: the cranial acetabular edge which may appear flattened, subluxation and loss of sperical contour of the femoral head, medial widening of the joint space, an irregular dorsal acetabular edge that is difficult to identify, and the cranial effective acetabular rim that may have exostosis present which could alter measurement of the Norberg angle (defined below).

In young dogs, early radiographic evidence of hip dysplasia may be detected as bone spurring occurring on the caudal aspect of the femoral neck as viewed on the ventrodorsal view (Morgan 1987). Articular borders undergo remodeling in an effort to extend the articular surface area, and osteophytes (enthesophytes) may form within the insertion lines of the joint capsule, ligaments, or tendons. In a review of pelvic radiographs over a ten year period this bone spurring was present in 54% of dogs that had radiographic changes characteristic of hip dysplasia and in 15% of the dogs judged to be radiographically normal (Morgan 1987). This review did not follow the 15% of dogs with the spurring to determine if hip dysplasia was demonstrated at a later date. This report suggests the bony spur may be recognized as an early change of secondary joint disease and an indicator of joint instability.

Norberg angle is defined by a line drawn through the centers of the femoral heads and a line drawn from each femoral head center to its respective cranial acetabular rim (Figure 1.0). A measurement of 105° or greater is considered normal (Manley 1993). In a two year controlled study, Norberg angle measurements at 30 and 42 weeks of age were correlated to two year OFA scores which emphasized the predictive value of early subluxation to later hip dysplasia in dogs (Kealy *et al.* 1992).

A distracted view, as opposed to the extended leg view, of the pelvis has been proposed (Smith *et al.* 1990). A study by Heyman determined the range of flexion/extension, adduction/abduction and internal/external rotation associated with maximal passive laxity of the hip joint (Heyman, Smith, & Confone 1993). Radiographing joints at the point of maximum laxity would be the most sensitive indicator of laxity and could aid in eliminating dogs from the breeding population that are susceptible to disease. It was determined that extended leg positioning tightened the joint capsule thereby decreasing the degree of laxity apparent on radiographs. A new positioning for diagnostic pelvic radiographs was described in the veterinary literature in 1990. The Pennsylvania Hip Improvement Program (PennHIP) was developed in 1990 (Smith *et al.* 1990). Proponents of the program propose that the dogs be placed in a supine position with hips at a neutral (standing) angle. A compression view, with the femoral heads fully seated, and a distraction view, obtained by levering a custom designed device between the legs, are taken. The distraction device produces maximal lateral displacement of the femoral heads. An objective score is created and termed the distraction index (DI). The DI range is from 0 to 1, with 0.3 considered the threshold between normal hips and hips susceptible to degenerative joint disease. It is believed that this technique will allow more objective scoring of radiographs, and that it is a better evaluation for hip laxity and therefore susceptibility to DJD. Ultimately the goal is to eliminate dogs with hip laxity from the breeding stock and therefore decrease the number of dogs afflicted with hip dysplasia.

The degree of joint laxity as determined by distraction radiography was correlated during the same time and prospectively to subjective score, and to evidence of degenerative joint disease from conventional hip-extended radiography in dogs (Smith, Gregor & Rhodes 1993). Three radiographic views, extended leg, compression and distraction, were taken at four, six, 12, 24, and 36 months. The standard extended view was evaluated by three methods: subjective according to the standard seven point Orthopedic Foundation for Animal (OFA) scoring scheme, Norberg angle (NA), and a subjective scoring by a veterinary surgeon for radiographic evidence of DJD. The hips in the distraction view were evaluated for passive hip laxity, as measured by the distraction index. The study indicated that at any given age all methods of hip evaluation correlated with each other however the strength of that correlation improved as age increased. Longitudinally, the between-method correlations were usually significant but not at a sufficiently high level to permit reliable between-method prediction. Prospective within-method analysis of the hip-scoring methods indicated that DI was superior to NA and OFA in comparability of score over time. The distraction index had a much lower false negative rate compared to Norberg angle or OFA scoring system. A lower false negative rate will more accurately classify diseased dogs as having laxity. Therefore these dogs would be removed from the breeding population.

1.24 Treatment Options for Canine Hip Dysplasia

1.241 Non-surgical management

Veterinarians and owners rely on the mainstays of medical management, rest and analgesics, to manage many dogs with hip dysplasia. The objectives of non-surgical management are to control pain and maintain limb function (Wallace 1987). The pain associated with hip dysplasia does not come from the articular cartilage, which is aneural, but from the structures associated with the joint such as joint capsule, synovium and subchondral bone (Brandt & Slowman-Kovacs 1986).

Non-steroidal antiinflammatory drugs

Non-steroidal antiinflammatory drugs (NSAIDS) are commonly used analgesics (Brandt *et al.* 1986, Wallace 1987). Acetylsalicylic acid (ASA) is frequently prescribed for treatment of degenerative joint disease but other NSAIDS such as phenylbutazone, meclofenamic acid, and piroxicam are also used (Wallace 1987). Acetylsalicylic acid's ability to relieve pain is by blocking the effects of inflammatory mediators such as bradykinin (Davis 1980). The anti-inflammatory effect is the result of cyclooxygenase inhibition, thus reducing the formation of prostaglandins. Prostaglandins are important in maintaining the integrity of gastric mucosa by several mechanisms (Murtaugh, Matz, Labato *et al.* 1993). The common side-effects noted with NSAIDS are gastric irritation and ulceration, nephrotoxicity and decreased platelet aggregation.

The sulfated glycosaminoglycans (GAGs), chondroitin sulfate and keratan sulfate are constituents of proteoglycans (PGs) (Palmoski & Brandt 1979). Proteoglycans afford cartilage its elasticity and stiffness on compression. Therefore loss of proteoglycans results in softening of the tissue and impairment of load bearing. The salicylates and ibuprofen have been implicated in the inhibition of proteoglycan synthesis *in vitro* (Palmoski *et al.* 1979; Palmoski & Brandt 1980). Piroxicam was not found to have an appreciable negative effect on proteoglycan synthesis *in vitro* (Palmoski 1983). However, it has not gained much attention in veterinary medicine for the treatment of osteoarthritis mostly due to its gastrointestinal side effects.

Carprofen® (Rimadyl) is a veterinary product recently approved in the United States. Like other NSAIDs, it works by inhibiting cyclooxygenase and blocking the production of prostaglandins. Its inhibition of prostaglandin biosynthesis is milder than other NSAIDs resulting in fewer reported adverse effects such as gastrointestinal irritation or ulcers (Holtsinger, Parker, Beale *et al.* 1992). In a double-blinded clinical trial carprofen was administered to dogs documented to have radiographic evidence and clinical signs (pain, lameness, crepitus, disuse atrophy, and/or decreased range of motion) of degenerative joint disease in the affected leg(s). Dogs with the same clinical problems received a placebo and the two groups were compared. Dogs receiving carprofen were 24.8 times more likely than dogs in the placebo group to have fewer clinical signs of degenerative joint disease and receive a positive evaluation by the veterinarian (Holtsinger *et al.* 1992).

Polysulfated glycosaminoglycans

Polysulfated glycosaminoglycans (PSGAGs), Adequan® and Cartrophen®, are another class of drugs that are gaining popularity for the treatment of degenerative joint disease. PSGAGs are reported to induce articular cartilage matrix synthesis and to decrease matrix degradation (Todhunter & Lust 1994). Osteoarthritis is characterized by erosion and eventually loss of cartilage and the development of osteophytes. The amount of cartilage matrix degradation is greater than the amount of new matrix synthesized (Todhunter *et al.* 1994). There are differing reports in the literature concerning the effects of PSGAGs. Generally, it is believed that the PSGAGs exert their effect in the matrix of the cartilage. The changes in the matrix include an increase in production of hyaluronan by synovial fibroblasts, and prevention of cartilage degradation by enzyme inhibition (Todhunter *et al.* 1994).

PSGAGs are a semisynthetic heparin analogue. Therefore, use in animals with existing coagulopathies is not recommended (Todhunter *et al.* 1994). It was found that single intramuscular administration of 25mg/kg of Adequan® prolonged the activated partial thromboplastin time and prothrombin time in cats (deHaan, Beale, Clemmons *et al.* 1994). These changes were transient and dose-dependent.

Glycosaminoglycan polysulfate (Adequan®) was used in four litters of Labrador Retriever puppies in an attempt to mitigate the signs of incipient hip dysplasia (Lust, Williams, Burton-Wurster *et al.* 1992). Puppies from dysplastic parents that were administered Adequan®, twice a week from six weeks to eight months of age, had a decreased degree of subluxation compared to saline treated controls. The mechanism of this action was not known.

A clinical trial that evaluated the effects of three different doses of intramuscularly administered PSGAG on clinical signs of hip dysplasia in adult dogs, and identified the systemic and local adverse reactions to the drug was undertaken in 1994 (deHann, Goring & Beale 1994). It was found that dogs treated with the middle dose range showed the most improvement in orthopedic scores although there was no statistically significant difference between groups including a placebo group. There were no local or systemic reactions related to the drug based on complete blood counts, blood urea nitrogen, creatinine and physical examination findings. It was concluded that intramuscular treatment of PSGAG was safe, but there was no significant improvement in clinical signs.

Conservative treatment

Even though medical management is often recommended to owners of young dysplastic dogs, there is limited information on how well the dogs do long term. In one study that specifically assessed the long term results of conservative management (Barr, Denny & Gibbs 1987) it was found that 76% of dogs with moderate to severe osteoarthrosis of the coxofemoral joints had minimal gait abnormalities. However, of the 50 dogs with reported follow-up, 31 of those dogs were evaluated solely by the owner. Only 19 dogs were returned to the investigators for assessment. Of those 19, six (31.5%) were on intermittent use of anti-inflammatory drugs. Seventeen (89%) had no gait abnormalities detected. Radiographs of these same 19 dogs found that although the amount of subluxation was the same or decreased in 8 (42%) compared to initial exam, the degree of periarticular new bone was increased in 17 (89%) of cases. The authors of this paper also found that 12 (63%) animals demonstrated no discomfort even on forced extension of the hips.

In a retrospective report on military dogs with hip dysplasia it was found that 12.9% of the dogs were euthanized due to hip dysplasia (Banfield, Bartels, Hudson *et al.* 1996). The mean age of these dogs at the time of death was 110 months. These dogs had been working patrol (i.e., attack) or drug detection dogs throughout their career. The dogs were not treated with analgesics until they demonstrated lameness. Of the 7/15 (46.6%) that received medication, five (71%) responded and continued to work for 11 - 36 months. Two of seven (29%) did not respond and were euthanized after four months. These two long term studies suggest that dogs with hip dysplasia are very capable of leading an active lifestyle and that often intervention is not needed until later in life. Thus, conservative management is a reasonable option for dogs with hip dysplasia.

1.242 Surgical Management

The main reasons to perform surgery on a dysplastic dog are to relieve pain, return the animal to as near normal function as possible or to prevent or retard the progression of degenerative joint disease. Surgical treatment of canine hip dysplasia is generally separated into three categories: palliative, salvage and preventive.

Palliative

Pectineal tendonectomy has been reported to alleviate pain associated with canine hip dysplasia (Rosenthal *et al.* 1972). This procedure is not a cure and does not lead to better joint stability but it may provide temporary relief to the painful joint. The rationale for a pectineal myectomy is that it releases adduction and dorsal pull on the femur. Transection of either the tendon of origin or insertion has been described (Wallace 1971). Pectinectomy was performed on an unspecified number of dogs over a 3.5 year period with a 94% success rate (Rosenthal *et al.* 1972). Success was deemed relief in pain. The reason pain was reduced was not clear-cut but believed to be due to reduction of excessive tension on the coxofemoral joint structures. Long term follow-up was not assessed in these patients. It is generally felt that transection of the pectineus tendon or muscle belly itself offers only temporary relief until secondary degenerative joint disease progresses and the dog becomes painful again (Wallace 1987).

Salvage

Femoral head and neck excision arthroplasty and total hip replacement are the two main procedures employed to salvage a usable limb for the dog with severe degenerative joint disease. The objective of an excision arthroplasty is to create a pain-free, false joint which relies on muscular and fibrous connection with the pelvis (Elkins 1981). Following removal of the femoral head a pseudoarthrosis is formed (Lewis, Bellah, McGavin *et al.* 1988) over the greater trochanter as it pushes dorsally into the gluteal muscle mass and the proximal end of the femur becomes suspended in a muscular sling (Piermattei 1965). Excision arthroplasty appears to be both simple in execution and consistent in producing a useful gait for pets suffering from severe coxofemoral joint disease (Piermattei 1965).

There are several reports of femoral head and neck excision arthroplasty in the veterinary literature (Spreull 1961; Ormrod 1961; Rex 1963; Piermatti 1965; Duff & Campbell 1977). These all found early success of the procedure with most dogs returning to an acceptable lifestyle. One study showed that 37.1% of dogs had fair to poor results with excision arthroplasty. Dogs with poor results had an average body weight (16.7kg) twice that of dogs with excellent results (8.03kg) (Gendreau 1977). Dogs with clinical signs for an average of more than 6 months had poorer results than dogs that had been lame for only 1 month. It was believed this poorer outcome was due to the femur being pushed into the acetabular rim and the pelvis (Lippincott 1981). Techniques for transposing muscle between the osteotomy site and the pelvis, thereby preventing bone on bone contact have been described (Lippincott 1981; Lippincott 1984; Berzon, Howard, Covell *et al.* 1980). Based on owners' response Tarvin and Lippincott concluded that transposition of the biceps muscle sling improved use of the leg (Tarvin & Lippincott 1987). However, an objective study that compared standard femoral head and neck excision to excision arthroplasty with a biceps femoris muscle flap concluded that there was no advantage of the biceps muscle flap technique over the standard technique in clinically normal large breed (20 - 30 kg) dogs (Mann, Tangner, Wagner-Mann *et al.* 1987). A later study found that the partial thickness biceps muscle sling performed better than the deep gluteal muscle sling or no muscle sling (Prostredny, Toombs & VanSickle 1991). It is still debatable whether placement of a muscle sling improves either the function or the long term results of femoral head and neck excision arthroplasty (Lewis *et al.* 1988).

Descriptions of total hip replacement techniques prior to the early 1980's are mostly research oriented. Olmstead published an early clinical report describing the procedure for placement of a Richards Canine II Total Hip Prostheses with follow-up results on 120 cases (Olmstead *et al.* 1981). In this early report results were satisfactory in 92.5% of cases with three or more months of follow-up. The one complication that resulted in a 100% chance of implant removal was deep infection.

Modifications to placement of the Richards Canine II Total Hip Prostheses were subsequently described (Paul *et al.* 1986). The complication rate in this study was 10.8% which was considerably lower than other reported complication rates (Lewis & Jones 1980; Olmstead, Hohn & Turner 1983).

Preventive

In general, preventive techniques are performed in young dogs, with little or no osteoarthritis present in the joint. By selecting dogs with no preexisting hip disease, clinicians have the best opportunity to prevent disease and save a joint otherwise destined to become arthritic.

Intertrochanteric osteotomy was described in the human literature as a successful treatment for coxofemoral osteoarthritis in 1933 (Hey 1933). It was not reported in the veterinary literature until 1987 (Prieur 1987). The goal of an intertrochanteric osteotomy is to reestablish the congruity of the acetabular and femoral joint surfaces and therefore improve the biomechanical function of the joint (Poss 1984; Knodt 1971). Intertrochanteric osteotomy changes the congruency of the hip by changing the angle of the femoral neck from a valgus to a varus position (Prieur 1987; Walker 1987) There is limited follow-up on this procedure in the veterinary literature. Intertrochanteric osteotomy reportedly benefited 37 dysplastic hips for up to 48 months (Braden, Prieur & Kaneene 1990). Owners and clinicians felt the most benefit was gained in the first postoperative year. Few dogs were followed longer than three years post-operatively but it appeared that degenerative joint disease progressed and clinical signs of pain returned on average by 48 months post-operatively. Another study assessed 29 dysplastic hips in 18 dogs, to determine whether the progression of degenerative joint disease could be prevented by intertrochanteric osteotomy (Evers, Kramek, Wallace *et al.* 1997). Long term follow-up of 47.50 ± 15.71 months after surgery was limited to 14 hips. In these 14 hips there was a statistically significant worsening of degenerative joint disease scores when compared to pre-operative values. It was concluded that although the dog owner's evaluation indicated improvement there was no prevention of progression of degenerative disease of the dysplastic coxofemoral joint .

Shelf arthroplasty utilizing a biocompatible osteoconductive polymer (BOP) material was introduced in 1989 as a potential treatment for dogs with subluxation of the hip due to hip dysplasia (Jensen 1989). Two studies that examined the polymer concluded that the material, although somewhat biocompatible, was not osteoconductive (Trevor, Stevenson, Carrig *et al.* 1992; Lussier, Lanthier & Martineau-Doize, 1994). The recommendations given were that further studies utilizing BOP mixed with cancellous bone were warranted before use of BOP arthroplasty was incorporated into routine treatment protocols for hip dysplasia.

Acetabuloplasty was developed as a modification of the innominate osteotomy (Salter 1961) that was created for the treatment of congenital dislocation and subluxation of the hip in children. The idea is to provide outward rotation of the acetabulum to accommodate the femoral head. The deeper the femoral head is seated in the acetabulum the better the stability and potential for improving future growth.(Brinker 1971) There is limited information on acetabuloplasty in dogs and it has not captured widespread attention.

Pelvic osteotomy procedures were introduced in the 1960's by Salter (Salter 1961; Salter 1966). These techniques were directed at young children with congenital dislocation or subluxation of the hip. Hohn and Janes (1969) described the first pelvic osteotomy technique in the dog using Salter's technique as a model. Only the ilium and the ischium were cut, however the pubis broke on a few occasions which allowed better rotation of the acetabulum. They found that the best results were on six to 10 month old dogs and those with Grade I or II versus III or IV hip dysplasia.

Schrader introduced the first triple pelvic osteotomy (TPO) in the dog (Schrader 1981). His technique involved three osteotomies of the pelvis. The ischium was approached just caudal to the acetabulum. Care around the sciatic nerve was imperative with this approach. The ilium was exposed by a standard lateral approach and then a trochanteric osteotomy of the femur was completed. The pubis was exposed from this lateral approach. The pubic osteotomy was completed to allow easier acetabular rotation. The ilial osteotomy was then performed and fixation of the ilium was done with a bone screw and cerclage wire. The greater trochanter was transposed distally and caudally. Schrader felt that his technique of performing the osteotomies close to the acetabulum was important to minimize the muscle pull on the free segment. Short term follow-up of five dogs (nine hips)0 showed that the dorsal femoral head coverage was improved in all joints and bony union was achieved in all cases without implant failure. Also all owners were happy with their dogs' clinical performance.

Schrader subsequently reported follow-up on 77 hips that had received a triple pelvic osteotomy with transplantation of the greater trochanter (Schrader 1986). He routinely rotated the acetabular fragment 70 to 90 degrees. Long term follow-up was available on 55 (71%) of the hips one to five and one half years later. Functional ability was considered satisfactory in 51 (93%) of the limbs though few dogs had a normal gait. All hips were stable on palpation and all but one was non-painful. There was generally restricted range of motion when trying to abduct the limb. Forty five (82%) of the hips had little or no evidence of degenerative joint disease. Overall a satisfactory functional, physical and radiographic result was obtained in 40 (73%) of the hips.

A modified version of the triple pelvic osteotomy was described in 1986 (Slocum *et al.* 1986). The osteotomies were completed with a separate approach to each bone. The ischial osteotomy was done on the caudal aspect of the ischium. The pubis was approached ventrally and a segment of pubis was removed after pectinectomy. The ilial osteotomy was made perpendicular to the ilium, directly caudal to the attachment of the sacrum. Slocum utilized a four, five or six hole 3.5 mm ASIF (Association for the Study of Internal Fixation) dynamic compression plate. The plate was twisted to an angle needed to achieve axial rotation and femoral head coverage. This angle was determined by preoperative palpation of the joint and determination of the angles of reduction and subluxation (Ortolani sign). Slocum and Devine reported on the results of pelvic osteotomy in 119 dogs over a seven year period (Slocum *et al.* 1987). The main complication was screw loosening in 12 of 119 dogs. Three dogs required surgery to replace implants while nine were managed with exercise restriction to prevent further disruption. At one year 113 dogs were re-evaluated. All dogs were reported subjectively by owners to have normal function and activity. Complete bone healing and congruency of the hip joint was present radiographically in all dogs. Each year, for the following six years, a declining number of dogs returned for further assessment. There were consistent findings of normal activity and radiographically the hips maintained congruency and the osteoarthritic changes associated with hip dysplasia did not progress.

It was noted that the most common complication of plate fixation of the ilial osteotomy was screw pullout. In response to this Hunt and Litsky (1988) investigated the pull-out strength of three types of screws in the ilium. They theorized that the strength of the internal fixation was related to the holding power of the screw. A clinical study of 42 pelvic osteotomies stabilized with 2.7 mm ASIF dynamic compression plate was done. Also *in vitro* pull-out tests were completed on 2.7 mm cortical, 3.5 mm cortical and 3.5 mm cancellous bone screws. In the clinical study all osteotomies had healed by six weeks post-operatively. Screw loosening was found in 11 osteotomies (26%). In the *in vitro* study there was no significant difference in pull-out strength of the three types of screws. The screws did not break but the bone failed. It was suggested that the 2.7mm system might offer a clinical advantage over the 3.5 mm system because additional screws could be used due to their smaller diameter. Screws loosening cranially is most likely due to the soft corticocancellous bone in the wing of the ilium. The authors felt it was best to try to anchor two screws into the sacrum for additional stability. Other factors that may have contributed to complications were plate contour and wire placement around the ischium. The 2.7 mm plate is more easily contoured to the ilium but is weaker and more vulnerable to bending and weakening due to contouring. The wire loop around the ischial osteotomy increased the load on the plate by pulling it medially. Therefore, the authors advised not wiring the ischial osteotomy (Hunt *et al.* 1988).

Slocum developed a plate specifically for triple pelvic osteotomy and patented the design as The Canine Pelvic Osteotomy Plate. This plate is designed in three set angles of 20, 30 or 40 degrees. He reported on a large number of cases that had received triple pelvic osteotomy (Slocum *et al.* 1987) but it was unclear whether these 138 dogs were different from the above mentioned 119 (Slocum *et al.* 1986). In this report dogs were grouped by degree of hip dysplasia or other injuries (luxation or premature closure of the proximal femoral physis). Subjective assessment suggested that activity and radiographic assessment improved over the follow-up period. It was concluded with this report that TPO was an acceptable treatment for dogs with all grades of hip dysplasia.

In 1991 the first objective assessment of TPO was published (McLaughlin *et al.* 1991a). In this prospective study, dogs treated for canine hip dysplasia with a unilateral (n=5) or bilateral (n=10) TPO were followed for 28 weeks. Ten dogs with normal hips were used as controls. Force plate analysis of gait using Fourier coefficients as well as lameness scores and "hip scores" were used to assess lameness and radiographic progression of degenerative joint disease. Radiographic evidence of degenerative joint disease was graded and each hip was given a "hip score" based on the combined acetabular and femoral changes. Assessments were made at five, 10, 15 and 28 weeks post-operatively. Three donated dogs were euthanized at week 28 for gross and histopathological examination of the coxofemoral joints. Force plate data showed that young dysplastic dogs transmitted significantly less vertical force through the hip joints than normal dogs. The force transmitted through treated hips reached or approached control levels by week 28 and was significantly greater than the force transmitted through untreated hips. The forces transmitted through the untreated limbs remained significantly less than controls at week 28. Lameness was improved in 23 of 25 treated hips (92%). In unilaterally treated dogs the lameness in the untreated limbs increased over the study period in 4 of 5 dogs. Radiographic changes were mild with minimal increases in degenerative joint disease in 7 of 25 hips. Three of five untreated hips had increased DJD at week 28 although there were no significant differences in hip scores from before surgery to week 28. It appears that dysplastic dogs transmit much less force through the hip joints than control dogs. This force was increased after treatment with a triple pelvic osteotomy.

In a separate publication, McLaughlin evaluated hip joint congruence and range of motion before and after bilateral triple pelvic osteotomy on the same 15 dogs (McLaughlin & Miller 1991b). The Ortolani sign was used as a determination of laxity. Goniometry was used to measure the degree of hip flexion, extension, adduction, abduction, internal rotation and external rotation. Radiographs were taken and Wiberg angle and percentage of femoral head coverage was determined. Ortolani signs were eliminated in all 30 hips by 15 weeks post-operatively. Wiberg angles and percentage of femoral head coverage improved significantly from preoperative values. Internal and external rotation of the second hip was significantly decreased at week 28. Otherwise changes in range of motion were variable and no significant loss of range of motion was detected. The trend was that joint congruence gradually improved for five to ten weeks after triple pelvic osteotomy. This may indicate remodeling changes within the joint.

A radiographic evaluation of TPO with comparison of the Canine Pelvic Osteotomy Plate (CPOP) and a twisted dynamic compression plate (DCP) was done (Koch, Hazewinkle, Nap *et al.* 1993). Several measurements were made on radiographs taken preoperatively, immediately post-operatively and at six and 12 weeks post-operatively. Overlay of the acetabulum on the femoral head and Norberg angles improved significantly throughout the study. Hip congruence was not improved immediately post-operatively but was significantly improved by 6 weeks. Osteophyte formation progressed and by the three month evaluation, 57% of cases had developed osteophytes. In comparing the CPOP and DCP groups it was found that congruence and Norberg angles were more improved in the CPOP group. There were no differences between groups in overlay, pelvic width, or osteophyte formation. There was no correlation between angle of torsion of plates and any post-operative measurement. It was concluded that TPO was an effective treatment for early hip dysplasia and the CPOP plate offered advantages over the DCP because the Norberg angle and congruence reached higher values.

Another paper investigated the effects of TPO on pelvic canal narrowing (Sukhiani *et al.* 1993). This experiment performed TPO's on 10 cadaver pelves. Fifteen, 35 and 50 % reductions in pelvic width occurred respectively with 0, 25 and 50% pubic remnant length. The angle of acetabular rotation did not affect the pelvic canal's width. However, both pubic remnant length and acetabular rotation significantly affected the pelvic canal cross sectional area. Conclusions drawn were that the pubic osteotomy should be done as lateral as possible and over-rotation of the acetabular segment should be avoided to help minimize the amount of pubic remnant rotated into the canal.

Lommasini described the use of an extra-articular suture between the ilial shaft and the greater trochanter in conjunction with a TPO in order to improve stability of the coxofemoral joint (Lommasini *et al.* 1994). In 10 dogs there was immediate postoperative improvement in congruency between the femoral head and acetabulum. The radiographic appearance of the coxofemoral joint did not change over time with the last radiographic assessment at 90 days.

The most recent follow-up study of triple pelvic osteotomy compared TPO to excision arthroplasty and conservative treatment (Planté, Dupuis, Beauregard *et al.*). A retrospective case series was done. The dogs included in this study had bilateral hip dysplasia with clinical signs of lameness or pain, and they were immature at the beginning of treatment. Treatment consisted of either bilateral TPO, bilateral excision arthroplasty or bilateral conservative management. Seven conservative management cases, eight TPO's and five excision arthroplasty cases were returned for evaluation. The shortest follow-up period was for the TPO group at 38.5 months, while the excision group had the longest at 47 months. Owner evaluation based on pain and activity scores was that TPO was far superior to excision arthroplasty or conservative management. Lameness and pain scores were assigned to each hind limb by the investigators and the conservatively treated dogs had significantly higher scores than the excision or TPO dogs. The TPO limbs also had significantly better goniometric scores than limbs in the other two groups. Degenerative joint disease was significantly less in the TPO hips than the conservatively treated hips. However, DJD was higher in the TPO hips than in control hips. Compared to pre-operative values, the DJD score increased significantly over time in the hips treated conservatively, but not in the TPO hips. Physical examinations done by the investigators found that the TPO performed better than either of the other treatments. Owners of dogs also scored the TPO superior to the other two treatments.

Part 2 of Plante *et al.'s* work investigated ground reaction forces in dogs treated with a bilateral TPO, bilateral excision arthroplasty, bilateral conservative management and bilaterally normal dogs (Plante, Dupois, Beauregard *et al.* 1997b). They found by force plate analysis that the hind limbs belonging to the triple pelvic osteotomy group had, at a trot, ground reaction forces not significantly different than the bilaterally normal dogs. Also the bilaterally conservative managed dogs were not significantly different than the TPO or the normal dogs. The forelimbs of each group except the normal dogs had higher peak propulsive forces on the forelimbs. It was speculated that this may be compensatory action to make up for deficient hind limb function. They also found that the TPO and conservatively managed dogs had significantly longer stance times compared to the excision arthroplasty or control dogs. This was not completely understood but consider to be either within normal variation or due to those groups slightly larger stature. Despite, not being significantly different than the TPO or normal dogs with regards to ground reaction forces they concluded that the conservatively managed group had the poorest results during locomotor and physical examination.

1.3 Objective Measurement of Gait

1.31 Force Plate Analysis

Kinetics deals with the forces that produce, stop, or modify motion. Kinematics deals with the characteristics of motion without regard to forces (Dalin & Jeffcott 1985). Kinetics combined with kinematics is kinesiology which is the science of motion. Force plate analysis is used to evaluate the kinetics of motion. Four force plate designs have been developed and all of these systems either measure force based on acceleration of the object or resistance offered by the object to some external force (Anderson & Mann, 1994). Generally the magnitude of the force is measured by deflection of a sensing element and in most systems the deflection is proportional to the force applied. With use of the force plate three orthogonal forces can be measured: mediolateral (Fx), craniocaudal (Fy) and vertical forces (Fz) which are known as ground reaction forces. In early force plate work all three orthogonals were assessed. It was quickly determined that mediolateral forces were very inconsistent (Budsberg, Verstraete & Soutas-Little 1987) and evaluation of this orthogonal is generally no longer done.

Force plate analysis has been used to assess different orthopedic treatments or effects of induced lameness. In 1977 Dueland and his colleagues used the force plate to compare excision arthroplasty and total hip replacement (Dueland, Bartel & Antonson 1977). Their purposes were: to evaluate the feasibility of canine gait analysis using the force plate, to evaluate vertical and horizontal forces in the gait of unoperated dogs and in dogs following total hip and excision arthroplasty, and correlate to clinical impressions with gait analysis in comparing total hip and excision arthroplasties. Vertical and horizontal forces were measured at walking and running gaits with varied velocities. Normal dogs showed normal gait and comparable vertical forces (Fz) for right and left hips however the horizontal force (Fy) showed more scatter. It was also shown that peak vertical force (PVF, maximum force applied during stance phase) increased in a linear relationship with velocity. It was concluded that force plate analysis was a good objective measurement of gait and it may enhance, explain and strengthen clinical impressions. Also, vertical forces were more reliable and consistent than horizontal forces.

Force plate analysis has also been used to assess surgical correction of cranial cruciate ligament injury (Budsberg, Verstraete, Soutas-Little *et al.* 1988). Twelve clinical cases were tested before, and seven to 10 months after, surgical correction of a cruciate-deficient stifle. Vertical, craniocaudal and associated impulses (total force applied over stance time) were evaluated. After surgery the operated stifle had significantly increased peak vertical force, impulse and weight distribution. The weight bearing by the repaired limb was consistent with values reported for clinically normal dogs. The extracapsular surgery was considered a success and the study demonstrated the applicability of force plate analysis in assessing changes in canine gait before and after surgical procedures.

Force plate analysis has been also used to assess the effect of treatment on induced lameness. Rumph *et al.* created an acute stifle synovitis and the dogs were then treated with saline, phenylbutazone or one of two proprietary non-steroidal anti-inflammatory drugs (Rumph, Kincaid, Baird *et al.* 1993). The objective was to evaluate, by force platform analysis of gait, the pattern of peak vertical force redistribution in untreated limbs of dogs during acute synovitis. It was clear that during acute synovitis episodes there was a redistribution of peak vertical ground reaction forces among limbs. The contralateral hind limb showed greater peak vertical force during synovitis episodes. These authors cautioned against using an untreated limb in the same animal as a control during acute lameness studies.

Griffon and colleagues completed a similar study but induced a forelimb lameness to assess redistribution of vertical ground reaction forces (Griffon, McLaughlin & Roush 1994). Force plate analysis was done pre-operatively and at day three and seven post-operatively. On day three there was a significant decrease in peak vertical force on the operated limb and the ipsilateral hind limb while the force applied by the contralateral forelimb and hind limb significantly increased. By the seventh post-operative day all weight distribution had returned to pre-surgical levels.

A study to investigate redistribution of vertical ground reaction force in dogs with chronic hind limb lameness was done on dogs (Rumph, Kincaid, Visco *et al.* 1995). The cranial cruciate ligament was surgically transected in one stifle of each dog. Gait analysis by force plate assessment was performed at 2, 6 and 12 weeks after surgery. At all sessions the peak vertical force and vertical impulse in the cruciate deficient stifle were significantly less than the corresponding pre-surgical values. The contralateral hind limb had significantly higher values than the corresponding pre-surgical mean and the cruciate deficient stifle. They concluded that the relationship between lameness and compensatory loading of other limbs seemed certain. This finding was similar to Rumph's 1993 study.

Another cruciate repair study was conducted to compare an extracapsular technique to an intracapsular one (Jevens, DeCamp, Hauptman *et al.* 1996). Eighteen dogs had the left cranial cruciate ligament transected. The dogs were equally divided into three groups, one of which received an extracapusular repair, the second an intracapsular repair and the third was left untreated. Peak vertical force and vertical, braking and propulsion impulses were recorded at four, eight, 12, 16 and 20 weeks after surgery. The peak vertical forces and vertical impulses were significantly decreased at all times in the control and intracapsular groups compared to the preoperative values. However, the extracapsular repair group had forces that were not significantly different from the group's preoperative values at the 20 week evaluation period. The study concluded that there was a significant relationship between peak vertical force and clinical grade of lameness in dogs with chronic hind limb lameness.

A number of studies have assessed different variables associated with force plate measurements in heallthy dogs. Budsberg *et al.* correlated ground reaction forces and associated impulse (total force applied over time) distributions in healthy dogs at a walking gait (Budsberg *et al.* 1987) to morphometric variables (i.e., femur length, humeral length and paw length). Peak vertical forces were used to calculate the percentage of distribution of the dog's weight among the four limbs. It was found that there were negative correlations between peak vertical forces and body weight, humeral length, femoral length and paw lengths. Weight was evenly distributed between left and right limbs while approximately 60% of body weight was carried on the forelimbs and 40% on the hind limbs. Braking forces were greater in the forelimbs and propulsion greater in the hind limbs. Mediolateral forces were examined but were too inconsistent to draw conclusions. It was determined that ground reaction forces and impulses were linearly correlated with all morphometric measurements. Peak vertical forces correlated inversely with physical size (i.e., the larger the dog, the lower the maximum vertical force exerted by each limb). Body weight was the most accurate and reproducible value compared to other morphometric measurements and probably should be the standard measurement for future investigations involving ground reaction forces.

Another study investigated the overall coefficients of variation and evaluated the contribution of dogs, handlers and trial repetition to variance for peak vertical force and for vertical and cranial/caudal impulses recorded for healthy dogs at a trot. (Jevens, Hauptman, DeCamp *et al.* 1993). Five healthy adult greyhounds and 5 different handlers were used. Velocity was measured with photoelectric cells with a start-interrupt timer system and velocity was maintained between 2 and 2.5m/s. It was found that the percentage of variance attributable to handlers varied between 0 and 7%, and that variance attributable to dogs and to repetitions ranged from 14 to 69% and from 29 to 85%, respectively, depending on which force or impulse was evaluated. It was felt that the variation of handler was trivial and multiple handlers in a study would not affect results. It would be best if the size of dog remained the same and the number of repetitions were of an adequate number.

Budsberg previously demonstrated that body weight was linearly associated with vertical force (Budsberg *et al.* 1987). A follow-up to this work was completed in 1993 (Riggs *et al.* 1993). Riggs and his associates used seven healthy greyhounds and three velocities within a gait (trot) to evaluate the effects of velocity on vertical, craniocaudal and mediolateral peak forces and impulses. Velocity was measured with photoelectric switches and a millisecond timer. Peak vertical forces in the forelimb increased significantly (19.9%) from the slower velocity range (1.5 to 1.8 m/s) to the fastest velocity (2.7 to 3.0 m/s). In the hind limb this increase was significant at 9.8%. There were no significant differences over the three velocities in the craniocaudal (braking or propulsion) or mediolateral forces. Impulses for vertical forces decreased significantly for forelimbs and hind limbs from the slower velocity to the fastest velocity. It was concluded that variations in forward velocity resulted in variation in force variables. Other important conclusions were that subjective evaluations of velocity by the handler and trial observer were not consistently reliable when compared with the timer. Also, a variation in velocity of greater than 0.6m/s yielded significant changes in vertical peak forces and impulses. Large velocity ranges may introduce unnecessary variation within an experiment.

McLaughlin and Roush published two papers evaluating the effects of subject stance time and velocity on ground reaction forces in clinically normal greyhounds at a walk (Roush & McLaughlin 1994) or trot (McLaughlin & Roush 1994). They assessed five greyhounds at two distinct velocities within the assigned gait (walk or trot) and correlated the velocity with stance time (duration the foot is in contact with the force plate). Stance time had a strong negative linear correlation with velocity: as velocity increased stance time decreased at both the walk and trot. Stance time was a good indicator of subject velocity and correlated more closely with changes in some ground reaction forces than did velocity. Subject velocity and stance time would be expected to change with lameness, abnormal gait or in dogs with significantly different morphometric characteristics.

McLaughlin and Roush further investigated velocity change and its relation to ground reaction forces by assessing the affects of increasing velocity on braking and propulsion times in normal greyhounds (McLaughlin & Roush 1995). In this work they used five velocities and determined the contact time spent in braking and propulsion in the forelimbs and hind limbs. The total limb contact time decreased significantly as velocity increased within each velocity range. There was no significant difference in the percentage of contact time that the forelimbs and hind limbs spent in braking and propulsion between the walk velocities. At a trot, braking percentage increased and propulsive percentage decreased significantly in the hind limbs as the trot speed increased. The authors suggested that braking and propulsion are of interest in gait analysis because changes in these forces could be indicators of gait change.

Chapter 1

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Chapter 2

Chapter 2 of this thesis has been prepared in accordance with guidelines for submission to the journal Veterinary and Comparative Orthopaedics and Traumatology.

2.0 Introduction

Canine hip dysplasia was first described by Schnell in 1935. (1) Many theories have been proposed concerning the etiopathogenesis of the disease. (2,3,4,5,6,7,8,9) No single cause for canine hip dysplasia has been identified, however genetics and nutrition play major roles in the development of the disease.

A variety of treatments for canine hip dysplasia, both medical and surgical, have been reported. Innominate osteotomy was introduced by Salter for treatment of hip dysplasia in children. (10,11) The principle of innominate osteotomy is to redirect the entire acetabulum to reduce subluxation, produce a stable joint and promote early weight bearing. A more congruent joint allows early weight bearing which stimulates a more normal osseous development of the hip. A pelvic osteotomy technique employing two osteotomies for canine hip dysplasia was described in 1969. (12) Triple pelvic osteotomy (TPO) in the canine was derived from Salter's innominate osteotomy technique. TPO was first described as a treatment for canine hip dysplasia in 1981 (12) and it has since been modified. (13,14) The purpose of a TPO is to improve acetabular coverage of the femoral head by utilizing the dog's own pelvic structures. (14) It is reported that the best results of TPO are achieved if the surgery is done in the immature dog that has minimal to no degenerative joint disease. (12,14)

There are several case series reporting the long term outcomes for dogs after TPO. These reports rely on owner assessment of function, palpation, clinician assessment of lameness, and various radiographic criteria to determine results. (14,15,16) To date these case series lack direct comparisons to unoperated hips and they are often subject to observer bias. The current study is also a case series but direct comparisons to unoperated dysplastic and normal hips are made. Also, attempts to reduce observer bias were made by using two observers for several radiographic assessments and by including blinded kinetic gait assessment using the force platform.

Force plate analysis is currently a commonly used evaluator of gait. Peak vertical force (PVF) is considered the most consistent ground reaction force in comparison to craniocaudal or mediolateal directions. (17) Computer assisted force plate analysis has been utilized to assess gait in human (18,19) and canine patients. (17,20,21,22,23,24,25,26,27,28) Various studies have looked at normal dogs at a walk, (21,27) a trot, (24,26) with various lamenesses, (22,25,28,29) and as an evaluator of different treatment protocols. (17,20,30)

There are only two reports utilizing force plate analysis as an objective assessment of limb function following a TPO. (20,31) To date there is one long term follow-up of TPO using force plate analysis as an objective means of gait analysis. In that study the dogs were bilaterally treated with a TPO. The purpose of this study is to further report the long term outcome of surgery in dogs. However, the dogs in this study had bilateral hip dysplasia and were treated with a unilateral TPO.

2.1 Materials and Methods

A retrospective non-randomized case series was conducted. Medical records of dogs admitted to the Ontario Veterinary College, Veterinary Teaching Hospital (OVCVTH) were searched for patients diagnosed with bilateral hip dysplasia that had received a unilateral triple pelvic osteotomy (TPO) between January 1988 and June 1995. A total of 53 dogs was found that met the above criteria and attempts were made to contact all owners. Twenty four of these dogs were returned to the OVCVTH for follow-up examination and force plate analysis and were assigned to Group #1. Of the remaining 29 dogs 14 were either lost to follow-up and five had had another orthopedic surgery (unrelated to TPO) or medical disease. A further 10 owners were unwilling to return to the OVC for a variety of reasons: five lived too far away, four were unwilling to have their dog radiographed again, and one owner was not satisfied with the results of the TPO.

Dogs with bilateral hip dysplasia with minimal or no clinical signs were assigned to Group #2 and large breed clinically normal dogs without evidence of hip dysplasia were assigned to Group #3. These cases were identified in the OVCVTH population owned by students, staff and faculty and used as controls. Data taken from each record included breed, age, sex, body weight, degree of hip dysplasia present in each hip prior to surgery, and where applicable, age at surgery, which hip received the TPO, and type of fixation used. (Appendix 1, 2 and 3 and Table 2.0)

2.11 Procedures

A complete physical examination and thorough orthopedic examination were completed by one investigator (CT). A complete blood count and serum biochemical profile were done to assess general health of all dogs. Lameness and joint pain were scored for each individual hind limb as shown in Tables 2.1 and 2.2. Lameness scores were adopted from a previously reported study. (20) All clients completed a questionnaire designed to elicit owner's impressions of their dog's lifestyle and performance.(Appendix 4)

2.12 Radiographs

Standard extended leg ventrodorsal pelvic radiographs, under acepromazine[1] (0.02mg/kg) and butorphanol[2] (0.2mg/kg) sedation, were done on all dogs. A Norberg angle (Figure 1.0), subluxation score (Table 2.3), periarticular osteophyte score (DJD) and enthesophyte score (instability) (Table 2.4) were calculated from radiographs taken before surgery, immediately post-operatively and at the follow-up visit for each Group #1 dog. Enthesophytes (osteophytes present at the insertions of tendons or ligaments) located on the dorsal acetabular margin and femoral neck and a Morgan line were considered to be evidence of joint laxity or instability. (32) (Figure 2.0) Periarticular osteophytes on the femoral head, within the acetabulum and at the cranial acetabular margin were considered to be signs of degenerative joint disease (DJD). The presence of subchondral sclerosis was included in the category of signs of DJD (Figure 2.1). Radiographs from dogs in Groups #2 and #3 were taken at the time of force plate

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[1] Ayerst Veterinary Laboratories, Guelph, Ont., CA N1K 1E4
[2] Ayerst Veterinary Laboratories, Guelph, Ont., CA N1K 1E4

analysis, and calculations of Norberg angles, subluxation scores, DJD and instability scores were done as for Group #1. Radiographs were read by two of the authors (CT & HD[3]) and a measure of agreement was done between examiners. The mean score of the two radiographic observers was used for reporting data on individual dogs and these mean scores were used when generating a mean score for the groups.

2.13 Force plate

All dogs were evaluated by force plate analysis to objectively assess weight bearing by the hind legs. Force plate analysis was done on a 25 meter walkway using a Kistler quartz force plate[4]. Peak and mean vertical force determinations were done on all dogs at a walking gait. Velocities were determined by videotaping all trials using vertical poles set 1.5 meters apart and marking the dogs with washable paint or tape at the caudal aspect of each scapula. Time to cross the measured area was determined with a video recorder[5] at 30 frames per second. The dog's speed in meters/second was calculated from this recorded time and distance. A pass was deemed valid when both the forelimb and ipsilateral hind limb (verified by video) landed on the force plate in one trip and velocity was subjectively considered consistent and was verified at a later date. Five valid passes were considered one trial and each dog completed one trial each for the right and left limbs. Peak vertical force (PVF), and mean value of force during the stance phase (MVF) were determined. All forces were measured in Newtons and normalized to the dog's body weight which resulted in a unitless number for analysis. The percentage of body weight

[3] Howard Dobson, Diplomate, American College of Veterinary Radiology
[4] Kistler force plate - model #6521. Kistler Instrument Corporation. Amherst, NY.
[5] Sony video recorder model EVO9800A

borne by each limb was calculated from the peak vertical force data. The dogs that received surgery had the TPO limb compared to the unoperated limb and these dogs were compared to the Group #2 and #3 dogs. To determine if the degree of pre-operative subluxation or DJD or instability affected the outcome, radiographic data were correlated to the force plate data.

2.2 Statistical analysis

Chi-square analysis was used to investigate significant differences in lameness scores and joint pain scores between individual hind limbs of dogs and between individual hind limbs of the three groups. A paired Student's *t*-test was used to compare the TPO limb to the contralateral unoperated limb for each dog for force plate data and all radiographic scores. In addition a paired t-test was used to compare the mean percentage of body weight borne by each limb between left and right limbs and front and back limbs in each dog within the groups and an alpha-adjusted Bonferoni correction was used to compare the same data between groups. An unpaired *t*-test was used to compare the differences of pre-operative radiographic scores to peak vertical force (PVF) and mean vertical force (MVF) data. A one-way analysis of variance (ANOVA) of the mean difference of force plate data and radiographic scores of hind limbs was used to compare differences between groups. A one-way ANOVA with a general linear model was used to determine if there were significant changes in radiographic scores over time for Group #1 dogs. A one-way ANOVA was also used to compare the operated limb to the "better" dysplastic limb and the right leg while the unoperated limb was compared to the "worse" dysplastic limb and the left limb. Where significant differences were found, a Duncan's multiple range test was used to compare between groups. Spearman's correlation coefficients were generated for relations between force plate data and radiographic scores lameness scores and joint pain scores. Radiographic scores of the two scorers were averaged and this mean score was used for statistical analysis except when comparing pre-operative subluxation, DJD and instability scores to force plate data. Then only the scores of the principal investigator (CT) were used. A one way ANOVA to measure reliability was done on the data of the two radiographic observers. All data is reported as a mean $\pm$ standard error. A p-value of ≤ 0.05 was considered significant.

2.3 Results

2.31 Animals

Dogs were separated into three groups based on hip classification and treatment. Group #1 consisted of 24 dogs with bilateral hip dysplasia that had had a unilateral triple pelvic osteotomy (TPO) between January 1988 and June 1995. Dogs comprising Group #1 were 12 golden retrievers, 4 German Shepherd Dogs, 1 Rottweiler, 1 Bearded Collie, 1 Alaskan Malamute and 1 mixed breed dog. There were 10 females and 14 males. Body weight ranged from 29 to 53 kg with a mean of 38 and a standard error of 6.1 kg. Age at the time of surgery ranged from 6 to 11 months (mean 8.6 $\pm$1.46 mos) while age at follow-up ranged from 21 to103 months (mean 49.8 $\pm$19.7 mos). Follow-up time (time from surgery to time of evaluation) ranged from12 to 95 months (mean 42.3 $\pm$ 19.7mos). (Appendix 1 & Table 2.0) Ten of the TPOs were accomplished with a Slocum Canine Pelvic Osteotomy Plate while 14 used a Synthes dynamic compression plate twisted to the desired angle of rotation.

Group #2 consisted of 10 dogs that were pets of employees or students of the OVCVTH. The group comprised six mixed breed dogs, and one of each of the following: Newfoundland, Samoyed, Bernese Mountain Dog, and Giant Schnauzer. These dogs ranged in age from 18 to 105 months (mean 63.4 $\pm$ 32.5 mos) and body weight from 20 to 44 kg (mean 31 $\pm$ 8.6 kg). All had radiographic evidence of bilateral canine hip dysplasia with varying degrees of degenerative joint disease and five showed mild gait abnormalities (Appendix 2 & Table 2.0).

Group #3 consisted of 4 clinically normal dogs with no evidence of hip dysplasia.

This group was made up of dogs owned by employees or students of the OVCVTH. Breeds included Golden Retriever (1), Labrador Retriever (1), Rottweiler (1), and German Shepherd (1). These dogs ranged in age from 20 to 111 months (mean 46.8 $\pm$ 43.3mos) with a weight range of 31 to 40kg (mean 35.3 $\pm$ 3.9kg). All had radiographically acceptable coxofemoral joints and no evidence of lameness (Appendix 3 & Table 2.0).

There were no significantly abnormal findings in any of the dogs on general physical exam, complete blood count or serum biochemical profile. Twenty three of 24 of the Group #1 dog owners returned complete questionnaires. Most dogs, had little problem with daily activities such as rising from a sit, running, climbing into the car, climbing stairs or sitting (Table 2.5, Appendix 5) and 20/23 (87%) of owners found their dog's quality of life to be good to excellent compared to other dogs. Four owners (17%) considered their dog's quality of life average. Twenty one owners (91%) would have a TPO performed again if they acquired another young dysplastic dog. One owner (4%) felt that the procedure was too expensive and the other felt that subjecting the dog to surgery depended on the dog's personality. Amongst Group #1 dogs 9/23 (39%) used non-steroidal anti-inflammatory drugs occasionally after heavy exercise, one dog (4%) received an aspirin every 48 hours, one dog (4%) received aspirin daily and the remaining dogs (52%) were not given any medication (Appendix 5). The two dogs on regular aspirin therapy received the drugs as scheduled and treatment was not withheld on the day of force plate data collection. The other nine dogs on intermittent NSAID use had not received any medications for a minimum of several weeks prior to data collection for the study.

Nine of the 10 Group #2 owners returned a completed questionnaire. The Group #2 dogs had slightly higher mean scores for four of the five daily activities but still had only mild impairment (Table 2.5). Five of nine owners (55%) felt their dog's quality of life was good to excellent. Two owners (22%) rated their dog's quality of life fair and one owner (11%) felt their dog's quality of life was poor except if treated with Cartrophen®. Three of the Group #2 dogs (33%) received an occasional aspirin after heavy exercise and one dogs (10)% was on a regular regimen of Cartrophen® (Appendix 6).

Within Group #3 three of four dogs (75%) were rated as having no impairment with any daily activities however, one owner scored her dog as having occasional mild difficulty with four of the five daily activities. This dog had very good hips with mild subluxation noted on the left hip by one observer of the radiographs. This dog was also the oldest dog in the group at 111 months with no radiographic signs of instability or DJD present. This same owner (25%) felt her dog's quality of life was good and treated her dog in the fall with intermittent aspirin therapy while the other three owners (75%) felt their dog's quality of life was excellent and did not give any anti-inflammatory drugs to their dogs (Appendix 6).

2.32 Lameness Scores

Seven of the 24 Group #1 dogs were not visibly lame on either hind limb and one dog's score was not recorded at the time of assessment. The remaining 16 Group #1 dogs had a mean lameness score of 0.54 ± 0.16 for the TPO limb and a mean score of $0.68 \pm$

0.15 for the non-TPO limb. This difference in lameness scores was not statistically significant ($p \leq 0.63$) (Table 2.6, Appendix 7).

Bilaterally dysplastic Group #2 dogs had their hind limbs assigned as "worse" or "better" based on the radiographic scores on each hip. Five of the ten dogs in this group showed no visible lameness on either limb. Lameness scores for the remaining five were similar to Group #1 dogs with the "worse" hip having a mean of 0.44 ± 0.18 and the "better" hip scoring 0.33 ± 0.16. This difference in lameness scores between "better" and "worse" hips was not statistically significant ($p \leq 0.65$) (Table 2.6, Appendix 8).

No lameness was found in any of the four Group #3 dogs with radiographically normal coxofemoral joints. There was no statistically significant difference in lameness scores between the three groups (Table 2.6, Appendix 9).

2.33 **Joint Pain Scores**

Eleven of the Group #1 dogs showed no pain on manipulation of either coxofemoral joint. The remaining 13 dogs had a mean score of 0.39 ± 0.10 on the TPO limb and a mean of 0.57 ± 0.12 on the non-TPO limb. There was a trend towards a higher joint pain score on the limb without the TPO however, there was no statistically significant difference in joint pain scores between limbs ($p \leq 0.59$) (Table 2.6, Appendix 7).

In Group #2, nine of 10 dogs had pain upon manipulation of the coxofemoral joints. The joint pain scores were the same for each leg with a mean of 1.0 ± 0.17. (Table 2.6, Appendix 8)

One of the Group #3 dogs had mild joint pain of the left coxofemoral joint. The mean joint pain score of the left hip was 0.33 ± 0.33 on the left and zero on the right. There were no statistically significant differences in joint pain scores between the three groups (Table 2.6, Appendix 9).

2.34 Radiographs

Of the 24 dogs that had force plate data collected, five cases lacked complete sets of radiographs. Subluxation scores were determined for the pre-operative period on three of the four missing pre-operative radiographs by searching though the case's medical record. This could not be done for Norberg angles, instability and DJD scores since those were specific to this study.

Of the operated limbs 4% (1/23) had Grade 1 subluxation, 13% (3/23) had Grade 2, 52% (12/23) had Grade 3 and 30% (7/23) had grade 4 subluxation based on pre-operative radiographs (read by CT) and information in the dog's record (Appendix 1). Before surgery, in Group #1 dogs, Norberg angles were less than or equal to 90° in the coxofemoral joints that were about to receive the TPO. The Norberg angles of the unoperated contralateral limbs were all less than or equal to 95° except one dog at 102°. Norberg angles increased significantly from the pre-operative to immediately post-operative assessments and again to the follow-up time in all limbs that received a TPO ($p \leq 0.0001$). The mean Norberg angle increased from 72° to 90.1° to 114° in the operated limb over time. The mean Norberg angle of the unoperated limbs did not change significantly over time. The change was from $78.8 \pm 2.54°$ pre-operatively to $83.2 \pm 2.29°$ at the follow-up time. Over the two time periods of the study there was a significant increase in the mean Norberg angle of the operated limbs compared to the unoperated limbs in the Group #1 dogs ($p \leq 0.0002$) (Figure 2.2, Appendix 10).

For Group #2 dogs, the Norberg angles were lower than the expected normal angle of 105° reported in the literature.(33) The "better" limbs had a mean angle of 87.9 $\pm 2.3°$ while the "worse" limbs had a mean angle of $82.4 \pm 2.8°$(Figure 2.3, Appendix 13). There was no significant difference between the means of the angles of the "better" and "worse" limbs. All Group #3 dogs had Norberg angles equal to or greater than 105° with a mean of $111.4 \pm 1.8°$for the left and $112.9 \pm 1.5°$ for the right hip (Figure 2.4, Appendix 13).

The subluxation scores of Group #1 dogs followed an opposite trend to Norberg angles with the TPO leg showing less subluxation over time (Table 2.7, Appendix 12). Subluxation scores showed a significant decrease over time from the pre-operative to post-operative and again to the follow-up time ($p \leq 0.0001$). Over time there was also a statistically significant decline in subluxation scores in the operated limb compared to the unoperated limb ($p \leq 0.0003$).

The mean subluxation score for Group #2 dogs was 2.2 ± 0.21 for the "worse" hip and 1.63 ± 0.14 for the "better" hip. Group #3 dogs had no radiographically visible coxofemoral subluxation (Table 2.8, Appendix 13).

Pre-operative radiographs showed that 45% (9/20) of dogs had radiographic evidence of degenerative joint disease in the hip that was about to receive the TPO and 30% (6/20) had degenerative joint disease present in the hip that was not operated. By the follow-up time these percentages increased to 70% (14/20) on the TPO side and 85%

(17/20) on the up-operated hip. Amongst Group #1 dogs, 75% (15/20) had evidence of instability prior to surgery on the hip that was about to receive the TPO and 60% had radiographic signs of instability on the hip that was not operated. These progressed to 95% on each hip at the time of follow-up.

Both instability and DJD scores increased in severity from the pre-operative time to the follow-up time in the hind limbs of the Group #1 dogs. The DJD scores tended to be higher than the instability scores and both of these scores were higher for the unoperated limb than the operated limb at follow-up (Figure 2.4, Appendix 14 & 15). There was a statistically significant increase in instability ($p \leq 0.001$) and DJD scores ($p \leq 0.001$) over time on all hips. However, there was no significant difference in instability or DJD scores between operated and unoperated hind limbs in Group #1 dogs ($p \leq 0.53$ & $p \leq 0.30$, respectively).

Group #2 dogs had consistent scores for both criteria (Figure 2.5). There were no statistically significant differences between "better" and "worse" limbs. Group #3 dogs had little or no evidence of joint instability or DJD (Figure 2.5, Appendix 16 & 17).

When comparing the operated limbs of Group #1 to the "worse" limbs of Group #2 and the left limbs of Group #3 it was found that there was a significant difference in Norberg angles. The operated and left limbs were not significantly different (114° & 111.4° respectively) while the "worse" limb had a significantly lower Norberg angle (82.4°) ($p \leq 0.003$) (Figure 2.8). The "worse" limb also had a significantly higher subluxation score (2.2) compared to the operated (0.54) and left limbs (0.14) ($p < 0.0003$) (Figure 2.9). The instability scores were significantly different between all three groups

($p \leq 0.001$) with the "worse" hip having the highest score (2.8), the operated hip had the mid range score (2.05), and the left limb had the lowest score (0.14) (Figure 2.10). When assessing DJD the operated limbs were not different than the "worse" limbs but they both had a significantly higher score (2.05 & 2.42, respectively than the left legs (0.14) of the Group #3 dogs ($p \leq 0.0001$) (Figure 2.11).

When comparing the unoperated hips of Group #1 to the "better" hips of group #2 and the right hips of Group #3 it was found that there were significant differences in Norberg angle. The right hips of the Group #3 dogs had significantly higher Norberg angles (112.9°) than the "better" (87.9°) or unoperated hip (83.2°) ($p \leq 0.0005$). The "better" and unoperated hips were not significantly different. (Figure 2.8) The subluxation, instability, DJD and scores were not different between the unoperated (2.12, 2.3, 2.33, respectively) and "better" limbs (1.63, 2.3,1.95, respectively) however they were significantly higher than the right limbs (0,.29,.14, respectively) of Group #3 ($p \leq 0.0001$) (Figures 2.9,2.10 & 2.11).

The measure of reliability between the two radiographic scorers was best for the radiographic score of subluxation where reliability was 0.87. Norberg angle calculation had a good measure of reliability at 0.84. The more subjective scores of instability and degenerative joint disease had less reliability at 0.66 and 0.65 respectively.

2.35 **Force Plate Analysis**

The mean of the peak vertical forces (PVF) and mean vertical force (MVF) were significantly higher in the operated limb than in the unoperated limb of Group #1 dogs ($p \leq 0.001$) as shown in Figure 2.6 and 2.7. Mean PVF of the TPO limbs was 41.46% of body weight $\pm$ 0.79 while the unoperated limbs had a mean PVF of 38.95 $\pm$ 0.60 (Appendix 18). Mean MVF for the TPO limbs was 26.48 $\pm$ 0.25 and that of the unoperated limbs was 25.55 $\pm$ 0.26 (Appendix 19).

In the Group #2 dogs there was no statistically significant difference in mean PVF between the "better" and "worse" limbs (37.72 $\pm$1.10 and 38.17 $\pm$1.18 respectively) (Figure 2.6, Appendix 20). There was, however, a statistically significant difference in MVF between "better" and "worse" hips ($p \leq 0.006$). These values were 25.80 $\pm$ 0.60 for the "better" and 26.09 $\pm$ 0.61 for the "worse" hips (Figure 2.7, Appendix 21). There were no significant differences between left and right hind limbs in the Group #3 dogs for PVF (37.37 $\pm$ 1.70 & 39.28 $\pm$ 1.20, respectively) or MVF (26.86 $\pm$ 0.61 & 26.58 $\pm$ .32, respectively) (Figure 2.8 and 2.9, Appendix 22 & 23). Finally there were no statistically significant differences in mean PVF or mean MVF between the three groups.

From the peak vertical ground reaction force it is possible to determine the percentage of body weight borne by each leg. In Group #1 the dogs placed 60.90 $\pm$ 2.14% of body weight on the forelimbs and 39.10 $\pm$ 2.13 % on the hind limbs. There was no difference in weight-bearing in the front legs whether ipsilateral or contralateral to the TPO. The dogs supported 30.54 $\pm$ 1.13% of body weight on the ipsilateral forelimb and 30.36 $\pm$ 1.22% on the forelimb contralateral to the TPO (Appendix 24). There was a significant difference between the TPO limb and the non-TPO limb with 20.17 $\pm$ 1.62% of body weight being supported by the former but only 18.95$\pm$ 0.98% by the latter ($p \leq 0.001$).

The Group #2 dogs bore 62.00 $\pm$ 2.89% of body weight on the front limbs and 38.00 $\pm$ 2.88% on the hind limbs. There was no difference between left and right forelimbs or "better" and "worse" hind limbs with the limbs bearing 30.99 $\pm$1.63% and 31.01 $\pm$ 1.29% ("better" and "worse" side respectively) in the front and 18.91 $\pm$ 1.57% and 19.09 $\pm$ 1.52% ("better" and "worse" respectively) in the hind limbs in Group #2 dogs (Table 2.12, Appendix 25).

Group #3 dogs supported 60.4 $\pm$ 2.02% of their body weight on the front legs and 39.6 $\pm$ 2.02% on the hind legs. The left/right distribution was 30.24 $\pm$ 1.15% and 30.19 $\pm$ 0.98% respectively for the forelimbs and 19.81 $\pm$ 1.29% and 19.78 $\pm$ 0.73% respectively for the hind limbs.(Table 2.11, Appendix 26)

All dogs carried significantly more body weight on the front limbs than the hind limbs which is considered the normal distribution of body weight in the dog. When comparing weight bearing data between groups it was found that there was no statistically significant difference in the percentage of body weight being supported by the front or hind limbs between the three groups.

Neither pre nor post-operative Norberg angle, degree of subluxation, instability or degenerative joint disease scores correlated with PVF or MVF data collected at the follow-up period. However, there were several significant correlations between radiographic results at the time of follow-up and force plate data. The Norberg angle at the time of follow-up showed a positive correlation with PVF ($r = 0.27$, $p \leq 0.02$) and MVF ($r = 0.36$, $p \leq 0.002$). As Norberg angle increased PVF and MVF also increased. The subluxation and instability scores both showed a negative correlation with PVF ($r =$

-0.25, $p \leq 0.05$ & $r = -0.37$, $p \leq 0.002$) and MVF, ($r = -0.32$, $p \leq .009$ & $r = -0.39$, $p \leq 0.0009$). As subluxation and instability scores increased PVF and MVF decreased. Lastly, the DJD score was negatively correlated with PVF only ($r = -0.29$, $p \leq 0.01$). As the DJD score increased PVF decreased. There was no significant correlation between DJD and MVF scores.

All dogs traveled across the force plate at a walking gait. For each dog there was no variation of greater than 0.6m/sec between trials. The group #1 dogs had a mean velocity range of 0.91 - 1.83 m/sec. Therefore within the group there was a differece of more than 0.6 m/sec difference. However, only one dog traveled at an average speed of 1.63 m/sec otherwise the range was 0.91 - 1.31 m/sec for a difference of 0.4 m/sec within the group (Appendix 27, 28, 29).

Group #2 dogs had a mean velocity range of 0.96 - 1.2 m/sec therefore there was only a 0.24m/sec difference in velocity between any two dogs. The Group #3 dogs had an average velocity range of 0.96 - 1.14 for even less variation within that group.

2.4 General Discussion

This investigation assessed dogs with bilateral hip dysplasia that were treated with a unilateral triple pelvic osteotomy (TPO). We ascertained that the operated limbs supported more body weight and transmitted more load than unoperated limbs as determined by peak and mean vertical forces. The force transmitted by the operated limbs was not significantly different from that transmitted by the limbs of dysplastic dogs or normal dogs. Lameness and joint pain were somewhat, although not significantly, improved after TPO compared to untreated dysplastic dogs. Further we have documented that despite improvement in Norberg angles and degree of subluxation, degenerative joint disease (DJD) continued to progress in both the operated and unoperated hips. The amount of DJD was not statistically different from the contralateral limb or the limbs of the bilaterally dysplastic dogs. There was a significantly higher DJD score in the Group #1 & #2 dogs compared to Group #3. Also we have determined that in bilaterally dysplastic dogs with no treatment, the hind limb with the greater degree of DJD transmitted more forces than the contralateral less affected limb. Our group of dogs with radiographically normal hips were symmetrical from left to right and body weight distribution to the four limbs was similar to that reported in the literature. (21)

Distraction radiography for quantifying hip joint laxity is gaining popularity. It is reported that calculation of a distraction index is more repeatable over time than a Norberg angle. (33, 34) Distraction radiography was not chosen as a means of assessment here because of the study's retrospective nature. Distraction radiographs were not available for the pre-operative and immediately post-operative periods therefore, a comparison of distraction indices could not be done.

We found that performing a TPO on a dysplastic hip improves the Norberg angle and subluxation scores. Since the objective of the surgery is to improve femoral head coverage, improvement in these criteria is not surprising. The Norberg angle and subluxation scores of the unoperated limb did not improve significantly over time; they remained comparable to their pre-operative values which were very similar to the Group #2 dysplastic dogs' Norberg angle and subluxation score. The TPO had a significant positive effect on seating of the femoral head within the acetabulum and enhanced congruency of the joint. This improvement may contribute to the increased loading of the operated limbs when compared to the unoperated limbs.

Degenerative joint disease did progress substantially over time in the hips that received a TPO although to a lesser degree than in the unoperated hip. This is similar to Koch's finding that osteophytes increased considerably in dysplastic hips treated with a TPO by either a canine pelvic osteotomy plate or a twisted dynamic compression plate.(35) However, this is in contrast to other reports. (14, 16) The TPO limb had only slightly better DJD scores than the contralateral unoperated limb and the "worse" limb of the Group #2 dogs. Since the studied dogs were client owned, body weight was not controlled. It has been reported in a controlled study that an increased body weight contributed to higher degrees of degenerative joint disease. (36, 37) We can only speculate that DJD might have been less if all dogs were an ideal body weight. Histopathology done on dysplastic hips that received a TPO showed that articular degeneration was present as well as mild thickening of the joint capsule, eroded cartilage and exposed subchondral bone. (20) These changes were more severe in untreated hips in that study but active change was present in the treated hips indicating that the degenerative process had not been stopped. (20) So, despite improved congruency, it is likely that the degenerative process continues, causing the increase in DJD scores seen over time in this study.

It is of interest that pre-operatively the mean instability and DJD scores were higher in the hips that subsequently became the operated limb. By the time of follow-up the unoperated hips had the higher mean instability and DJD score. Therefore, the unoperated hips had both absolute higher instability and DJD scores at follow-up and a relatively greater progression of instability and DJD compared to the operated hips.

The hip joint is unique in that muscle pull by abductors combines with supported body weight and torque to exert force on the hip. (38) Changing the weight bearing forces by rotating the acetabular segment may affect the progression of degenerative joint disease by concentrating the forces to one point. Mechanical factors (subluxation) may cause the initial cartilage degeneration based on the consistent location of cartilage trauma on the femoral head, although it is not completely clear if mechanical stresses alone cause degenerative joint disease or if multiple factors such as alterations in synovial fluid volume or degree of subluxation are required. (39) The improved congruency of the coxofemoral joint due to the TPO may have accounted for the lesser degree of degenerative joint disease, however, if the TPO did not completely restore congruency then the progression of DJD might only be slowed, rather than prevented.

Measures of agreement done on radiographic scoring by the two readers found the best agreement was in Norberg angle measurement and subluxation scoring. Norberg angle measurements are derived by a specified procedure but are still based on subjective assessment of landmarks. The subluxation scores had the best agreement between clinicians. Determining the percentage of subluxation is somewhat subjective, but the subluxation score has broad limits (i.e., 75% - 100% subluxation). Subluxation scores likely had better agreement than Norberg angles because of this wide range within categories. A small amount of remodeling of the femoral head or cranial acetabular margin could cause a difference in the exact measurement of Norberg angle between observers thus decreasing agreement.

The instability and degenerative joint disease scores had lower measures of agreement than the previous two categories. The scores of mild, moderate or severe are subject to variability amongst scorers. The difficulty in achieving agreement on radiographic assessment of coxofemoral joints has been shown in previous reports. (40) Agreement could have been improved by dichotomizing the data regarding the presence or absence of enthesophytes or DJD. In this study, few cases would have been difficult to classify as positive or negative of enthesophytes or DJD. However, it would have been more difficult to document progression of disease in the follow-up period.

Peak vertical force has been considered the most consistent ground reaction force for assessment of gait while mediolateral forces are inconsistent and contribute little to the analysis of gait. (17) It has been reported that horses show an increase in peak vertical force after nerve blocks are placed to eliminate pain from a joint. Therefore, one can presume that a higher peak vertical force translates into more weight bearing and better performance. (17)

It has been shown that performing a TPO caused dogs to redistribute load to the unoperated hind limb in the immediate post-operative period. (20) These investigators also showed that by six months the TPO limb bore more weight than the unoperated leg. We examined dogs as early as 12 months post-operatively and found on average the dogs bore more weight on the TPO limb than the non-TPO limb. This increase in weight bearing may reflect improved joint function caused by the TPO. It is also possible that the TPO caused increased loading of the contralateral limb, in the early post-operative period, accelerating its deterioration, thereby causing a shift of the load to the TPO limb. This is unlikely since the unoperated limbs of the Group #1 dogs were not significantly different in Norberg angle, subluxation, instabiltiy or DJD scores from the Group #2 "better" limbs had undergone the normal progression of the disease process. While operated limbs had values that were significantly different from Group #2 "worse" limbs in Norberg angle, subluxation and instability score.

The Group #2 dogs had a significant difference in MVF between the "better" and "worse" hip, and the hip with the higher mean DJD and instability scores was the limb with the higher MVF. This was not the case with the TPO dogs which had a lower DJD and instability score but higher MVF on the TPO limb. The joint pain scores of Group #2 dogs were the same for both hind limbs and therefore, joint pain could not be used to identify clinical differences between hips in this study. This supports the widely held clinical impression that radiographic assessment of DJD does not correlate well with clinical performance. It is possible that the "better" radiographic hip was clinically more painful for the dog which was not detected with the joint pain assessment done in this study. If the "better" limb is more painful the DJD may progress more rapidly in the contralateral hip due to increased use.

We found increased mean PVF and MVF in the TPO limbs compared to the unoperated limbs. These values were not statistically different from values for the Group #2 or #3 dogs, although they were approaching significance ($p \leq 0.07$) when compared to Group #2. Additional dogs in Group #2 may have allowed a significant difference to be found between the TPO dogs and the dysplastic dogs. In a previous report, PVF and MVF, following TPO remained significantly lower than for normal dogs in the 28 week follow-up period. (20) With the longer follow-up period of this study, dogs with a TPO did achieve ground reaction forces similar to those of normal dogs. McLaughlin's work also showed that young dysplastic dogs transmitted less load through their hips compared to control dogs. The dogs in that study were all under one year of age at initiation of data collection. The dysplastic dogs in our study did not bear loads significantly different from the control dogs. The younger dogs may experience more pain due to microfractures of the dorsal acetabular rim (41) and, as these heal, weight bearing forces are improved. Stabilization of the joint by thickening of the joint capsule may also contribute to the higher loads borne by the older dysplastic dogs.

Earlier force plate work has shown that dogs normally carry 60% of their body weight on the forelimbs and 40% on the hind limbs. (21) There is reportedly no difference in weight bearing between left and right limbs. (17,21) We confirmed these findings with our small group of normal dogs.

All radiographic data was examined for correlation to force plate data. There was no correlation between radiographic scores pre and post-operatively and force plate analysis done at the follow-up period. However, the radiographic scores for the TPO dogs at follow-up did correlate in several ways with force plate data. The more DJD and subluxation present the lower the peak or mean forces became in the Group #1 dogs. Also, as the Norberg angle increased, peak and mean forces increased. This would support the theory that improved joint congruency, as evidenced by less subluxation, allows more normal function and therefore loading of the limb.

We also compared the pre-operative degree of subluxation and DJD and instability scores to the follow-up force plate data. We used only the pre-operative radiographic scores of the principal investigator in this comparison because using a mean score would have made it impossible to compare a Grade 2 subluxation to a Grade 4. When comparing hips with a pre-operative Grade 2 score to a pre-operative Grade 4 subluxation score it was found that the degree of pre-operative subluxation approached statistical significance ($p \leq 0.06$) for PVF. This may be an indication that the dogs with a lower subluxation score prior to surgery may perform better in the long term. It is possible that with less subluxation prior to surgery there are fewer factors to correct. It has been shown that when subluxation is present the mean volume of synovial fluid and ligamentum teres increases significantly. (39) Also, articular cartilage damage is greater and there is more inflammation in the synovial membrane.

When comparing pre-operative DJD and instability scores to follow-up force plate data there was no evidence of a correlation between pre-operative scores and kinetic evaluation at follow-up. Comparing DJD scores of 0 to 1 to force plate data, a p-value of 0.09 was calculated. If additional cases had been available this correlation may have been significant. It would be of interest to know whether outcome can be improved if dogs are treated prior to the development of any degenerative joint disease.

It is generally believed that radiographic assessment of hip disease does not correlate well with the clinical performance of a dysplastic dog. The correlation here between radiographic scores and force plate variables suggest that the force plate is a more sensitive detector of gait changes than clinical lameness scoring systems. Based on owner and clinician evaluations, most of the dogs were doing well clinically despite the presence of DJD and subluxation. Since the TPO limbs had the lowest subluxation, instability and DJD scores and the bore higher forces, it is likely that the TPO limbs were contributing to the good clinical performance.

Mean PVF and MVF were both significantly greater in the TPO limbs than in the unoperated limbs. Rumph *et al* have cautioned against using a limb within the same dog as a control. Their work used normal dogs that had a surgical procedure performed unilaterally on a stifle and it was found that a redistribution of forces away from the operated limb occurred. (22,28) Our work also assessed dogs with unilateral hind limb surgery and these limbs were assessed for changes of forces between them. Joint loading was found to be improved in the limbs that underwent a TPO. Therefore, if we agree with Rumph's conclusions that a redistribution away from the painful limb occurs then we can presume the TPO limb is the least painful of the two hind limbs. The unoperated limbs in Group #1 dogs are not ideal controls but they provided an opportunity to evaluate the progression of hip dysplasia in operated and unoperated hips.

The importance of this study is the addition of a relatively unbiased, blinded case series to the veterinary literature describing the outcome of dogs with a TPO. It is not possible to be completely unbiased due to the presence of an orthopedic implant. Therefore, we were always aware of which hip received the TPO when reading the radiographs. Force plate analysis provided objective gait analysis. This retrospective study evaluated cases from 12 months to seven years and 11 months post-operatively. This information combined with the work of McLaughlin *et al* (20) essentially provides a continuum in the literature of objective follow-up on TPO cases. Although a decisive statement that a TPO is better than no treatment cannot be made with this study design, it appears that TPO results in improvement in the operated limbs based on radiographic scores and force plate data.

In conclusion, coxofemoral joints with a TPO showed improvement in Norberg angles and subluxation scores but still developed degenerative joint disease as early as 12 months after surgery. The degree of degenerative joint disease and instability increased significantly from the pre-operative to the follow-up period in the operated limbs. The degree of DJD was generally less, although not significantly so than that in the contralateral unoperated limbs. Despite development of DJD, the TPO limbs bore more weight and transferred more force as shown by force plate assessment (PVF and MVF) than the non-operated limbs. Following TPO, dogs did not have significantly less lameness or joint pain in the operated hip compared to the unoperated hip or compared to the unoperated dysplastic or control dogs. Radiographic data at the time of follow-up correlated with force plate data.

Untreated dysplastic dogs had an increased mean value of force (MVF) on the limb with the worse radiographic scores. This lends support to the clinical impression that radiographic signs do not predict clinical performance.

Chapter 2

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Table 2.0

Body weight, age at evaluation and time to follow-up. (time from surgery to evaluation, (Mean $\pm$ standard of deviation) Groups #1 dysplastic dogs with a unilateral TPO, Group #2 bilaterally dysplastic dogs with no treatment and Group #3 normal dogs.

	Body weight (kg)	Current age (mos)	Follow-up time
Group #1	38.0 $\pm$ 6.1	49.8 $\pm$ 19.7	42.3 $\pm$ 19.7
Group #2	31.0 $\pm$ 8.6	63.4 $\pm$ 32.5	N/A
Group #3	35.3 $\pm$ 3.9	46.8 $\pm$ 43.3	N/A

Table 2.1

Criteria and scoring system for lameness.

Score	Criteria
0	normal/ no lameness
1	mild, intermittent lameness with no loss of function
2	mild, persistent lameness with fair limb function
3	severe lameness or intermittent use of the limb with some weight bearing during standing and walking
4	non-weight bearing lameness

Table 2.2

Criteria and scoring system for coxofemoral joint pain

Score	Criteria
0	no pain elicited
1	mild pain on full extension
2	mild to moderate pain on any degree of extension and/or full flexion or abduction
3	moderate to severe pain on any degree of extension and/or flexion or abduction

Table 2.3

Criteria and scoring system for subluxation scores

Score	Criteria
0	greater than 75% of the femoral head is covered by the acetabular rim
1	50 - 74% of the femoral head is covered by the acetabular rim
2	25 - 49% of the femoral head is covered by the acetabular rim
3	1 - 24% of the femoral head is covered by the acetabular rim
4	100% or more of the femoral head is outside the acetabular rim

Table 2.4

Scoring and criteria of periarticular osteophytes (DJD) and enthesophytes (Instability)

Score	Criteria
0	absent
1	mild
2	moderate
3	severe

Table 2.5

Client scored data for daily activities and quality of life compared to other dogs (Mean ± standard error) for Group #1 dysplastic dogs with a unilateral TPO, Group #2 dysplastic dogs with no treatment and Group #3 normal dogs

	Rising from a sit	Running	Getting into car	Climbing stairs	Sitting	Quality of life
Group #1	0.95 ± 0.15	0.43 ± 0.12	0.93 ± 0.23	0.88 ± 0.19	0.48 ± 0.19	0.84 ± 0.14
Group #2	1.4 ± 0.40	1.30 ± 0.29	1.14 ± 0.55	0.33 ± 0.33	0.57 ± 0.37	1.70 ± 0.42
Group #3	0.33 ± 0.33	0 ± 0	0.33 ± 0.33	0.33 ± 0.33	0.33 ±0.33	0.33 ± 0.33

Table 2.6

Lameness and joint pain scores (Mean ± standard error) Group #1 dysplastic dogs with a unilateral TPO, Group #2 dysplastic dogs with no treatment & Group #3 normal dogs.

	Group #1		Group #2		Group #3	
	TPO	no- TPO	better	worse	left	right
Lameness score	0.54± 0.16	0.68 ± 0.15	0.33± 0.16	0.44 ± 0.18	0	0
Joint pain score	0.39±0.10	0.57 ±0.12	1.0 ±0.17	1.0 ±0.17	0.33 ± 0.33	0

Table 2.7

Subluxation scores (Mean ± standard error) of Group #1 dysplastic dogs with a unilateral TPO.

	Group #1 dogs	
Subluxation score	**TPO**	**non-TPO**
pre-op	**3.00 ± 0.11**	**2.40 ± 0.18**
post-op	**1.30* ± 0.21**	**2.30 ± 0.18**
follow-up	**0.50** ± 0.16**	**2.10 ± 0.18**

***denotes statistically significant decrease from the pre-operative value**
**** denotes statistically significant decline from post-operative period and a significantly lower value compared to the contralateral limb.**

Table 2.8

Subluxation, instability and DJD scores (Mean ±standard error) of Group #2 dysplastic dogs with no treatment and Group #3 normal dogs.

	Group 2		Group 3	
	"better"	"worse"	left	right
Subluxation	1.63 ± 0.14	2.2 ± 0..21	0.14 ± 0.14	0
Instability	2.3 ± 0.19	2.84± 0..9	0.4 ± 0.3	0.30 ± 0.18
DJD	1.95 ± 0.17	2.42 ± 0..16	0.14 ± 0.14	0.14 ± 0.14

Figure 1.0

Ventrodorsal radiograph showing a normal Norberg angle of a Group #3 normal dog.

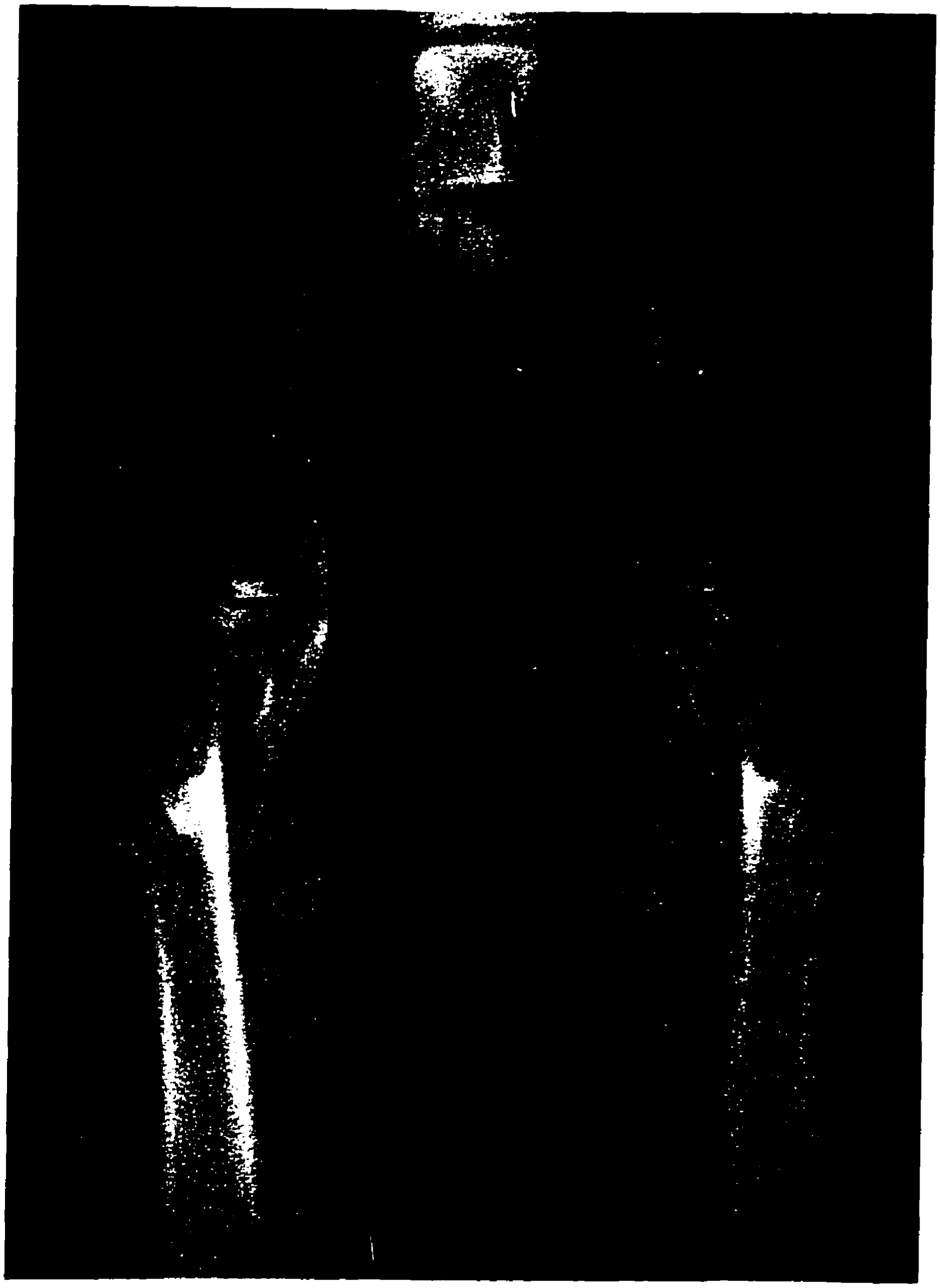


Figure 2.0

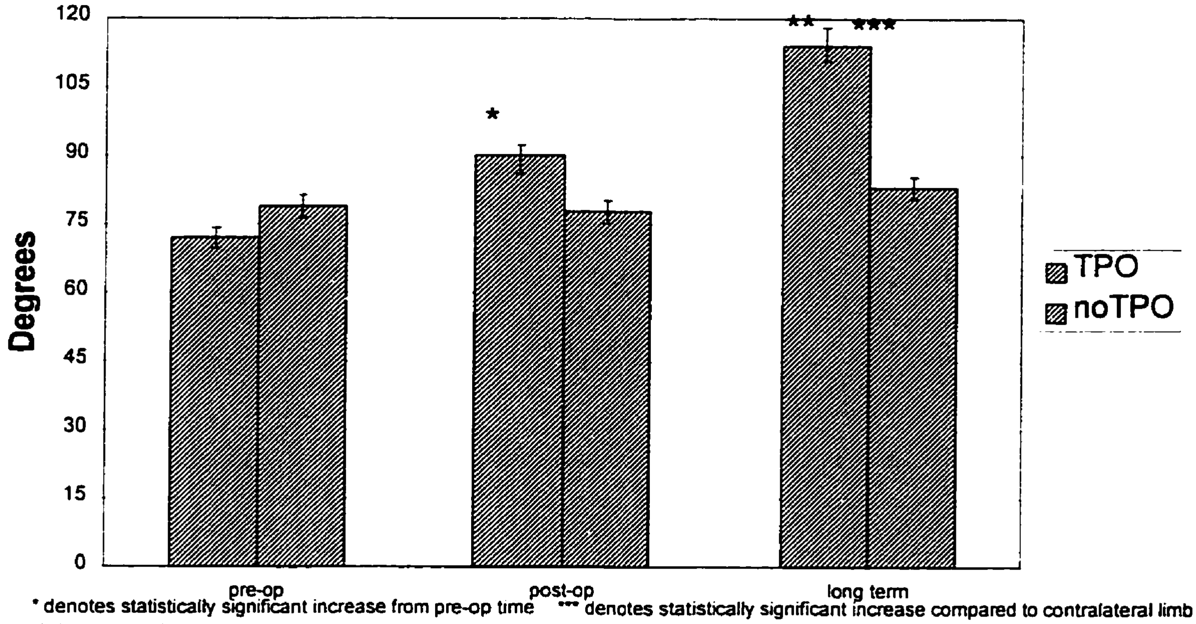
Ventrodorsal radiograph of a young dog showing thickening of the femoral neck (arrow), and a Morgan line (arrow head). Changes are consistent with early joint instability.

Figure 2.1

Ventrodorsal radiograph of a Group #1 dog, 20 months after a unilateral TPO. Note the severe osteophytes within the acetabulum (arrow), and subchondral sclerosis (arrow head).

Figure 2.2

Norberg angles (Mean ± standard error) for pre-operative, post-operative and follow-up time period for Group #1 dysplastic dogs that received a unilateral TPO.



* denotes statistically significant increase from pre-op time *** denotes statistically significant increase compared to contralateral limb
** denotes statistically significant increase from pre and post-op time

Figure 2.3

Norberg angles (Mean ± standard error) for Group #2 dysplastic dogs with no treatment and Group #3 normal dogs.

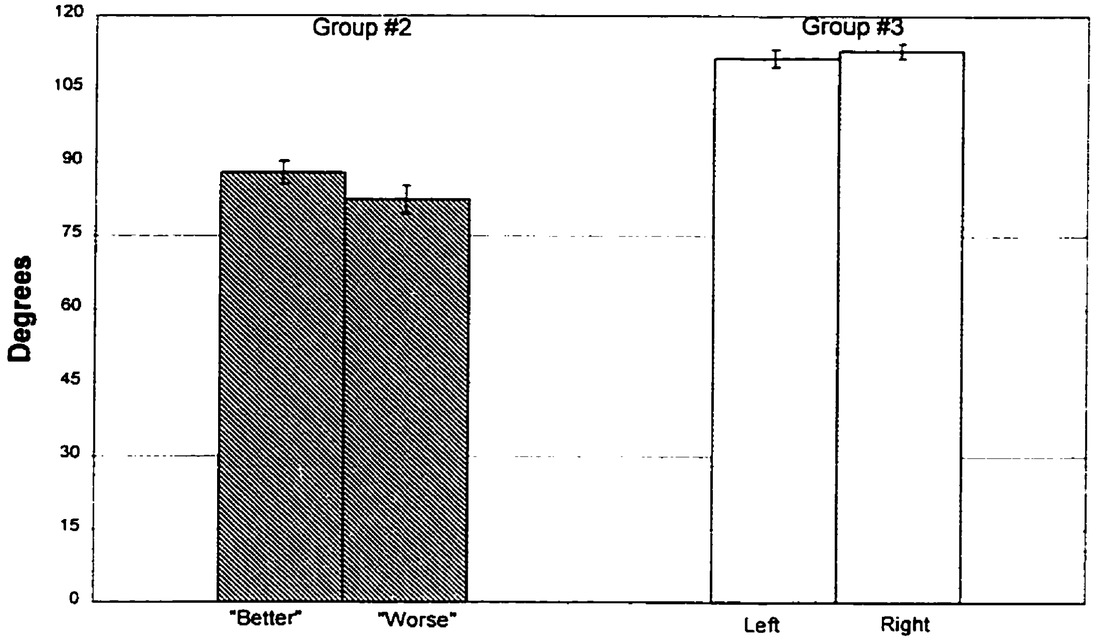
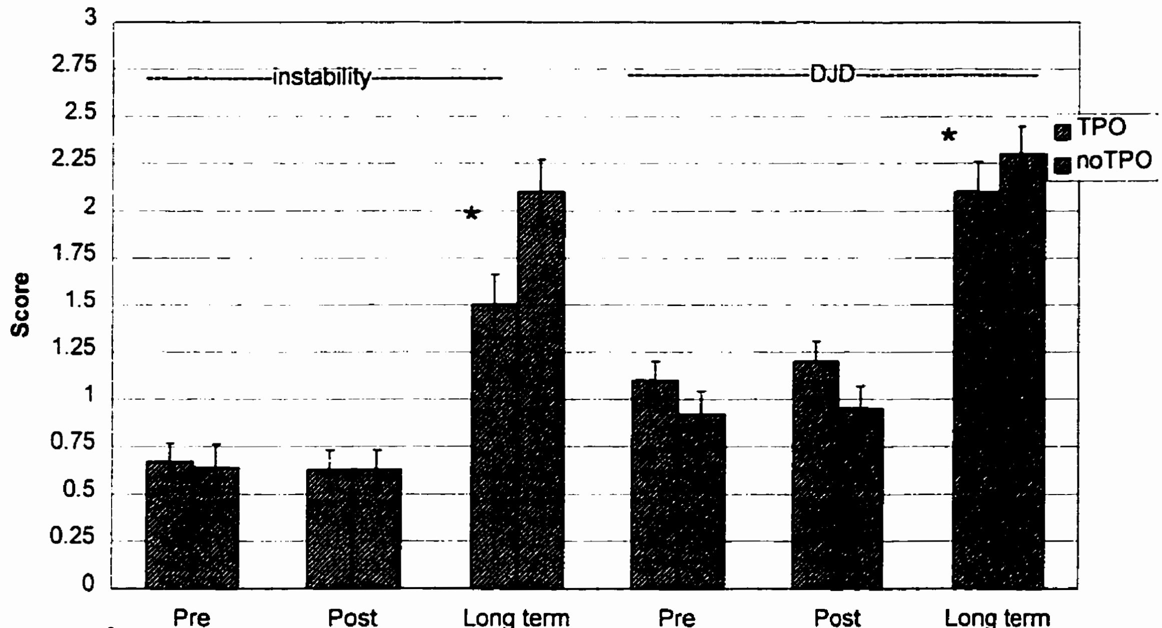


Figure 2.4

Instability and DJD scores (Mean ± standard error) for pre-operative, post-operative and follow-up time period for Group #1 dysplastic dogs with a unilateral TPO.



*denotes statistically significant increase in Instability and DJD score at long term follow-up time compared to pre or post-operative time

Figure 2.5

Instability and DJD scores (Mean ± standard error) for Group #2 dysplastic dogs with no treatment and Group #3 normal dogs.

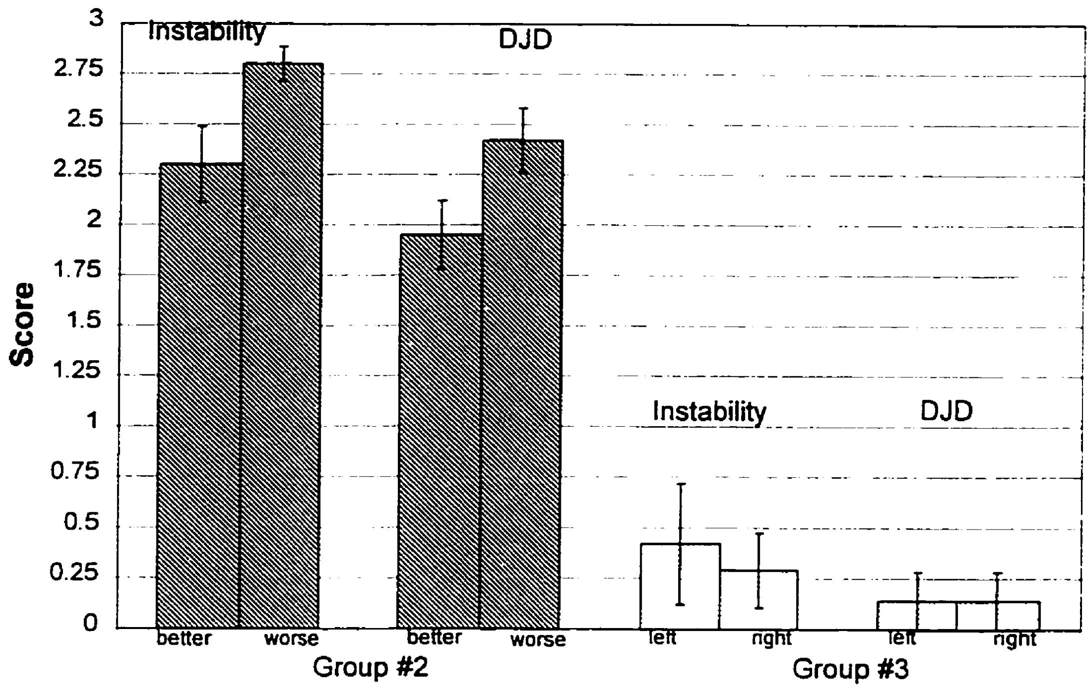


Figure 2.6

Peak vertical force (mean ± standard error) Group #1 dysplastic dogs with a unilateral TPO, Group #2 dysplastic dogs with no treatment and Group #3 normal dogs.

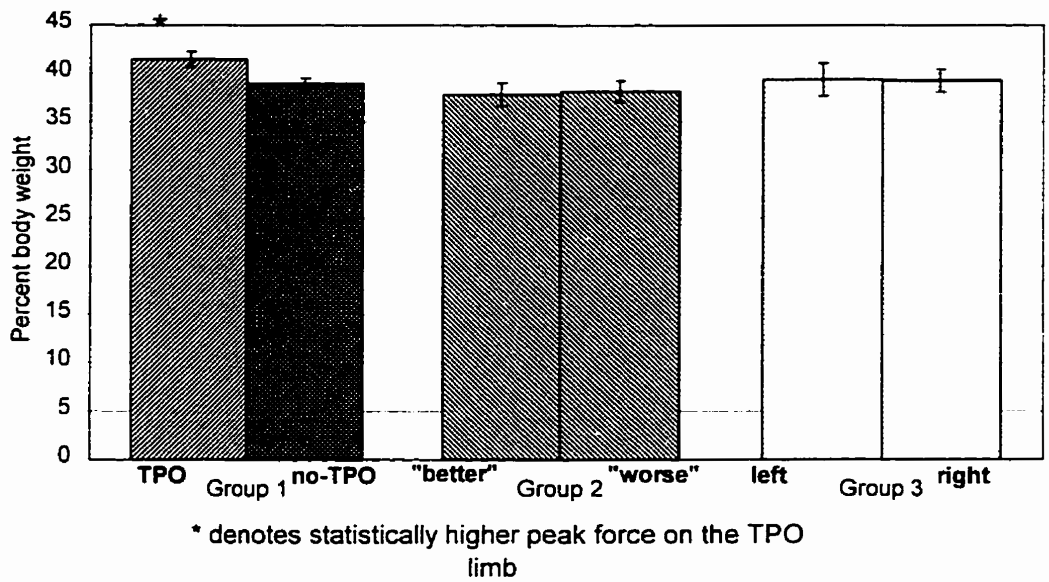
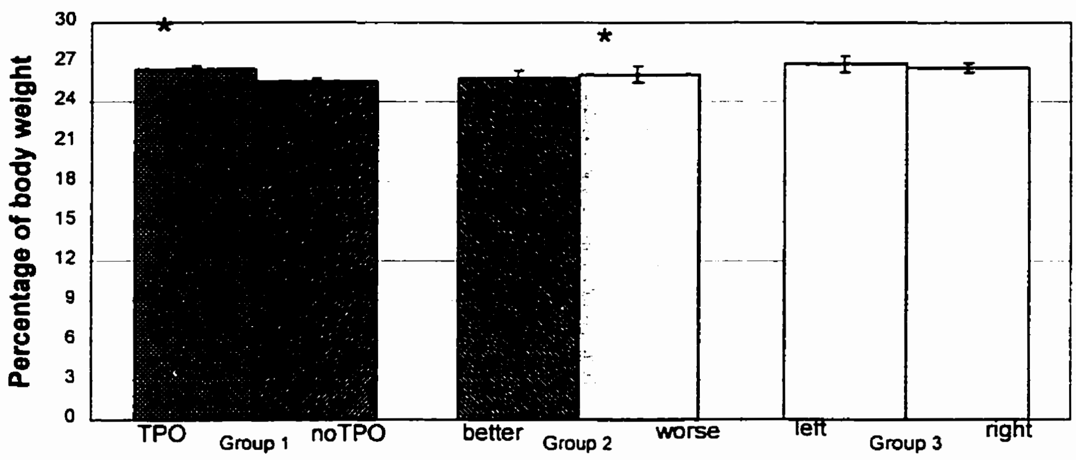


Figure 2.7

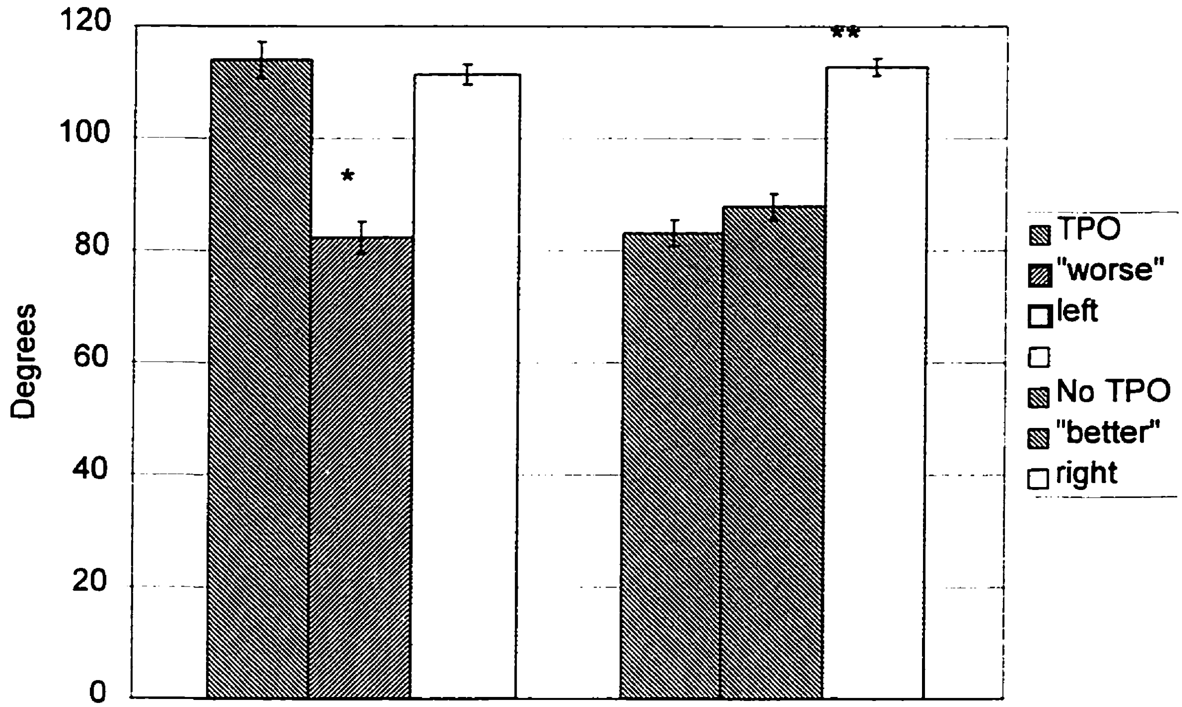
Mean vertical force (MVF) (Mean ± standard error) Group 1 dysplastic dogs with a unilateral TPO, Group 2 dysplastic dogs with no treatment and Group 3 normal dogs.



* denotes a significantly higher MVF in the TPO limb compared to the unoperated limb and the "worse" limb compared to the "better" limb.

Figure 2.8

Comparison of Norberg angles (mean ± standard error) of the operated TPO limbs (Group #1) to the "worse" dysplastic limbs (Group #2) and the left limbs (Group #3), and the unoperated limbs (Group #1) to the "better" limbs (Group #2) and the right limbs (Group #3).

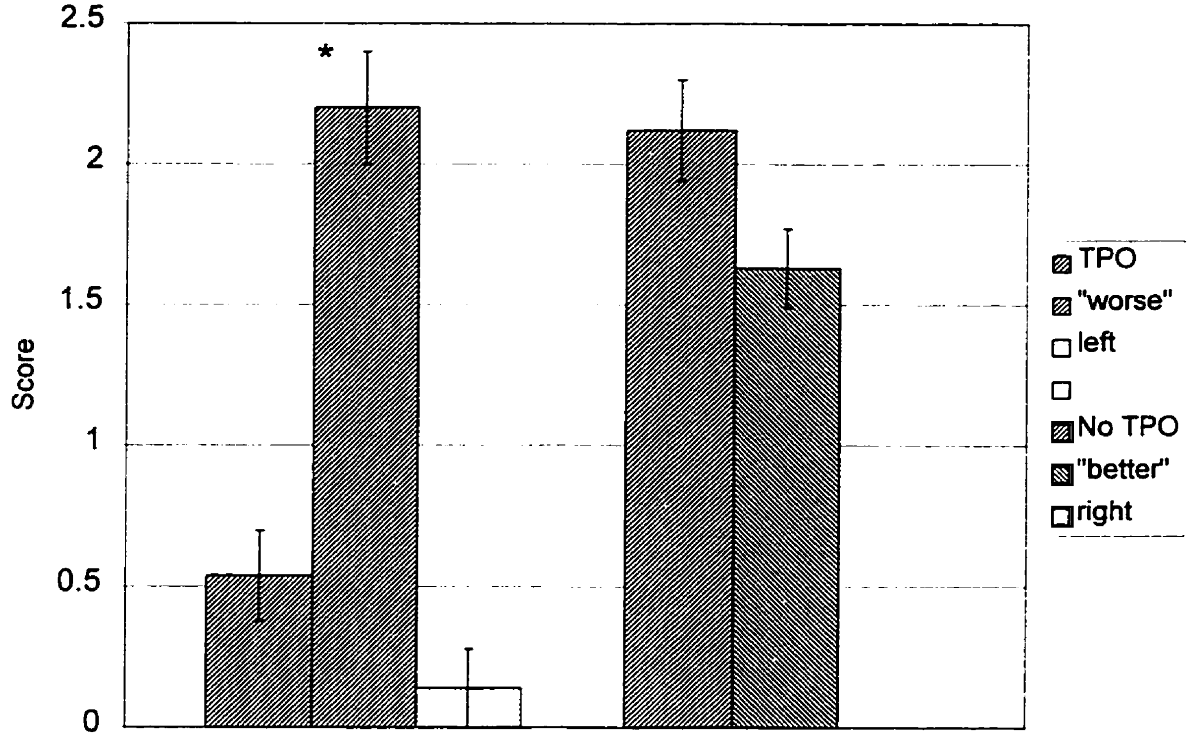


* denotes significantly lower Norberg angle in the "worse" limb compared to the TPO or left limb

** denotes significantly higher Norberg angle in the right limb compared to the unoperated or "better" limbs

Figure 2.9

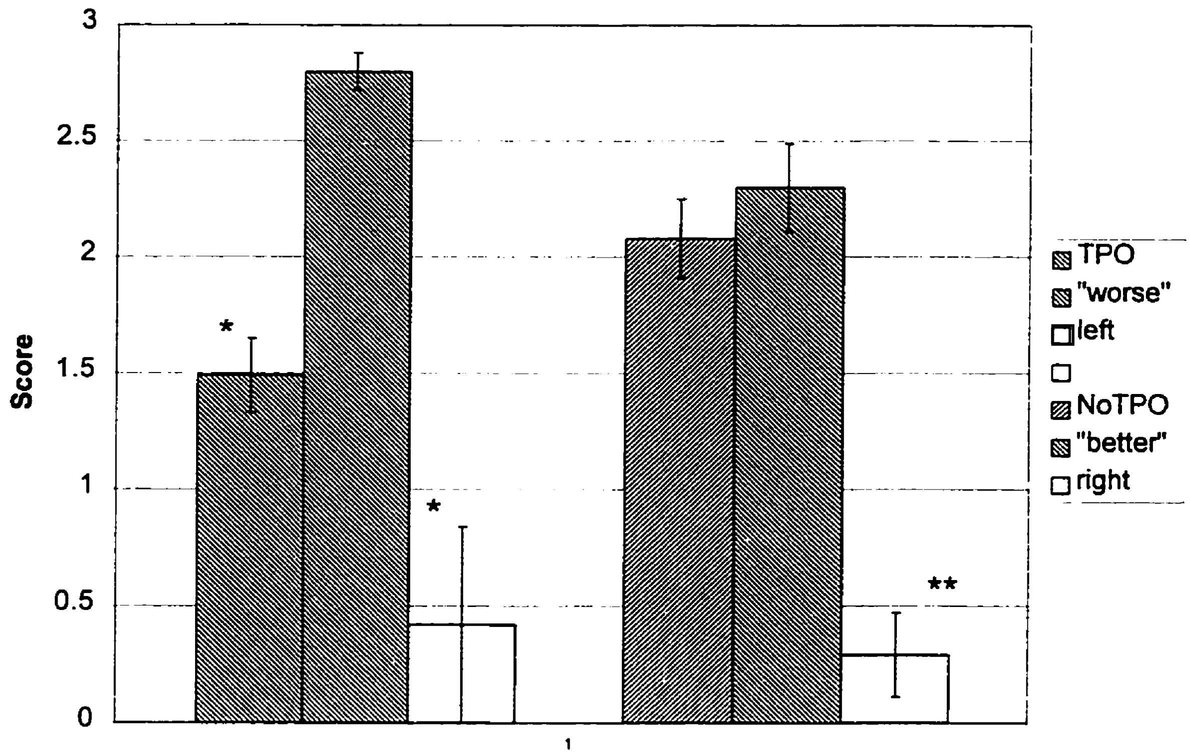
Comparison of subluxation score (mean ± standard error) of the TPO operated limbs (Group #1) to the "worse" dysplastic limbs (Group #2) and the left limbs (Group #3), and the unoperated limbs (Group #1) to the "better" limbs (Group #2) and the right limbs (Group #3).



* denotes significantly higher subluxation score in the "worse" dysplastic limbs than the TPO operated limbs or the left limbs

Figure 2.10

Comparison of instability score (mean ± standard error) of the TPO operated limbs (Group #1) to the "worse" dysplastic limbs (Group #2) and the left limbs (Group #3), and the unoperated limbs (Group #1) to the "better" limbs (Group #2) or right limbs (Group #3).

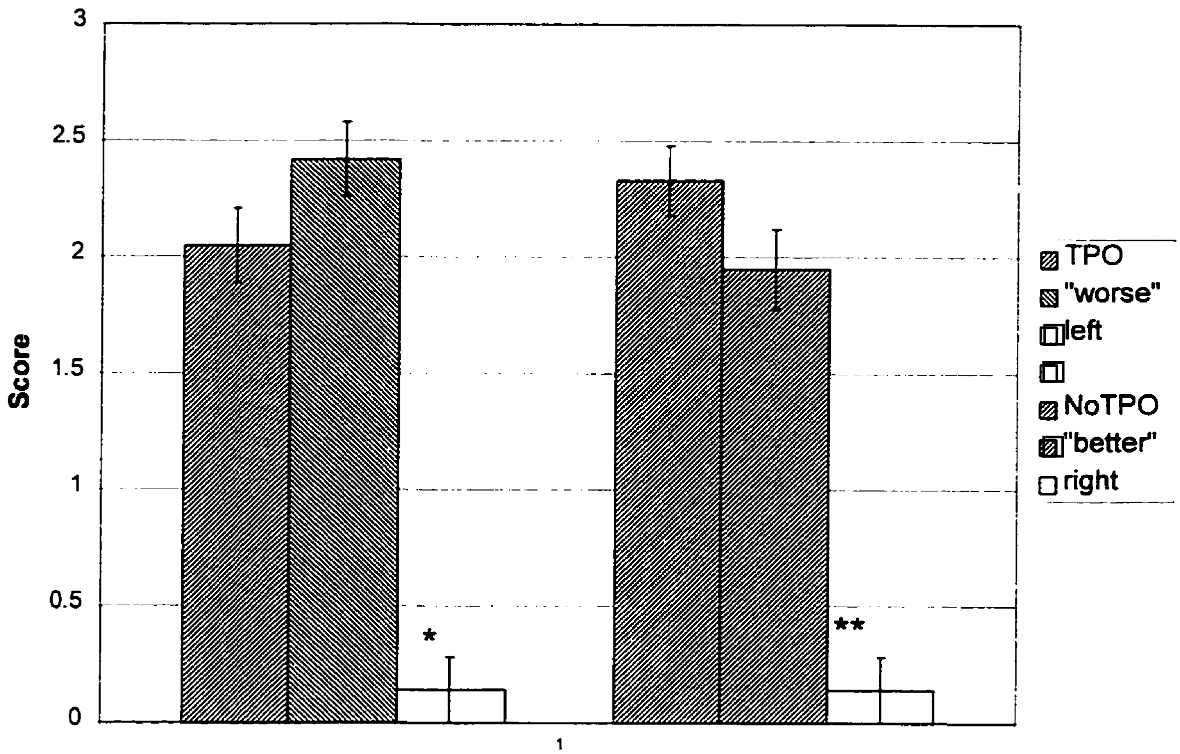


*** denotes a significantly lower instability score in the left limbs compared to the TPO limbs and a significantly lower instability score in the TPO limbs compared to the "worse" limbs.**

**** denotes a significantly lower instability score in the right limbs compared to the "better" dysplastic limbs or the unoperated limbs.**

Figure 2.11

Comparison of DJD score (mean + standard error) for the TPO limbs (Group#1) to the "worse"limbs (Group #2) and left limbs (Group #3),and the unoperated limbs (Group #1) to the "better" limbs (Group #2) and right limbs (Group #3).



*** denotes a significantly lower DJD score in the left limbs compared to the TPO or the "worse" limbs.**

**** denotes a significantly lower DJD score in the right limbs compared to the unoperated limbs or the "better" limbs.**

Chapter 3

3.0 Proposed future areas of research

A short term objective prospective evaluation of TPO has been completed. (1) A prospective long term follow-up project using objective gait analysis, clinical assessments and radiographic scoring may be more successful in documenting the course of events from the time of surgery to our cross sectional point in time. This current project was unable to document when improved weight bearing began to occur or, more importantly, what occurred in the other three limbs with regards to redistribution of load that may have affected the outcome of this study.

Two previous retrospective studies have reported that DJD progressed only minimally with mean follow-up periods of 2.7 and 3.2 years. (2,3) The mean follow-up of this study was 3.5 years and there was a significant increase in the degree of DJD over that time in the operated and unoperated hips. A prospective comparison of dogs with no radiographic evidence of DJD and dogs with DJD at initiation of the study would be helpful in determining if case selection could alter the outcome with regards to DJD.

We neared statistical significance comparing grade 2 to grade 4 subluxation scores. A prospective study that divided dogs into groups based on subluxation prior to surgery may determine if the degree of subluxation has significant impact on the outcome of the surgery.

It is reported that total hip replacement in dogs is required bilaterally 20 - 50% of the time. (4,5) A study to compare bilateral TPOs to unilateral TPO could be beneficial. If a dog treated with a unilateral TPO had clinical performance comparable to that of a dog with a bilateral TPO, the cost and morbidity associated with a second surgery might be avoided.

Also a prospective long term follow-up comparing dogs with hip dysplasia managed conservatively, with a TPO, with a femoral head and neck excision or a total hip replacement could be of benefit in determining which procedure may provide the best quality of life for the patient.

Chapter 3

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Section 4.0

Appendix 1

Breed, sex, age, body weight, degree of hip dysplasia and TPO hip, Group #1 dysplastic dogs with a unilateral TPO.

Case #	Breed	Sex	Current age (mos)	body weight (kg)	Age at sx (mos)	degree of hip dysplasia pre-op TPO/noTPO	TPO
197903	rottweiler	FS	21	43.6	9	1/2	L
194948	L Ret	FS	28	31.4	8	3/3	R
194675	GSD	M	27	30.0	8	3/3	R
195449	GSD	M	29	53.0	10	3/1	L
194474	GSD	F	30	40.0	9	?/2	R
192095	G Ret	FS	33	35.0	7	2/2	L
191724	G Ret	MC	35	38.0	8	3/0	L
189656	L Ret	F	42	32.0	10	3/3	R
189025	MAL	FS	46	32.0	10	4/3	R
187040	G Ret	M	46	45.0	9	4/2	R
187180	L Ret	M	44	34.0	6	3/2	L
186961	G Ret	M	46	36.0	7	3/3	L
185540	G Ret	FS	52	38.0	9	3/3	L
184810	GSD	MC	54	31.0	10	3/2	R
184759	G Ret	MC	54	38.0	8	4/4	R
184034	BECO	MC	55	27.0	7	3/?	R
182877	G Ret	M	60	33.0	11	4/3	R
181546	MIX	M	60	41.0	8	3/2	R
181805	L Ret	FS	61	32.0	7	2/2	L
180003	G Ret	MC	67	42.0	11	3/1	R
179970	G Ret	FS	70	29.0	13	2/3	R
175072	G Ret	M	80	41.0	8	4/4	L
174893	G Ret	M	79	31.0	7	4/4	R
168573	G Ret	FS	103	31.0	8	4/2	L

G Ret = Golden retriever
GSD = German Shepherd Dog
L Ret = Labrador retriever
BECO = Bearded collie

M = male
MC = castrated male
F = female
FS = spayed female
MAL = Malamute

Appendix 2

Breed, sex, age, body weight and degree of hip dysplasia Group #2 dysplastic dogs with no treatment.

Case #	Breed	Sex	AGE (mos)	Body weight (kg)	Degree of HD better/worse
203868	mix (shep)	MC	18	31	2 / 4
200099	Bernese	FS	19	34	2 / 2
192433	mix (shep)	FS	31	34	1 / 2
202428	mix (shep)	FS	56	38	2 / 2
203882	Samoyed	FS	57	20	2 / 2
177177	Pointer	FS	74	23	1 / 2
172527	G. Schan	FS	87	44	2 / 1
188284	Newf	FS	87	41	1 / 2
197287	mix (B. col)	FS	100	21	2 / 3
168886	mix (G. Ret)	FS	105	24	2 / 3

Shep = predominantly German Shepherd   FS = spayed female
B Col = predominantly Bearded Collie   MC = castrated male
G. Ret = predominantly Golden Retriever
Schan. = Schnauzer

Appendix 3

Breed, sex, age body weight and degree of subluxation Group 3 normal dogs.

Case #	Breed	Sex	AGE (mos)	Body weight (kg)	Subluxation L/R
202210	G Ret	MC	20	40	0/0
203055	L Ret	F	22	32	0/0
204070	Rott	FS	34	32	0/0
197140	mix (shep)	FS	111	37	0/0

G Ret = golden retriever   FS = spayed female
L Ret = Labrador retriever   F = female
Rott = Rottweiler   MC = castrated male

Appendix 4

Client Questionnaire for Canine Triple Pelvic Osteotomy Study.

Investigators: Dr. Cheryl A. Tano, Dr. Joanne Cockshutt

SECTION A = GENERAL INFORMATION

1. On which hip did your dog have surgery?

(A) right
(B) left
(C) not sure

2. Do you think your dog is less lame on his **operated** hip compared to before surgery?

(A) yes
(B) no
(C) can't recall

3. Do you think your dog is less lame on his **unoperated** hip compared to before s surgery?

(A) yes
(B) no
(C) can't recall

4. Do you feel your dog's "Quality of Life" was improved after surgery?

(A) yes
(B) no
(C) not sure, please add additional comments to explain your answer____

____

5. If you had another puppy with canine hip dysplasia would you have a triple pelvic osteotomy done again?

(A) yes
(B) no
(C) not sure, please add additional comments to explain your answer__________

____

SECTION A (continued)

6. Do you recall why only one hip was done?

(A) yes, please explain why. ______________________________________
____
____

(B) no

7. Since surgery have you ever had to use medication(s) for your dog specifically for lameness?

(A) yes
(B) no --- go to question 8

If you answered **yes** to question 7 please fill out the following table to the best of your knowledge. This table should include prescription drugs, e.g., phenylbutazone, non- prescription drugs e.g., aspirin or homeopathic remedies, e.g., shark cartilage

MEDICATION	DOSE	FREQUENCY (daily, weekly, as needed etc.)
example: ASPIRIN	1 tablet (325mg)	daily in the winter, as needed in the summer.

8. Has your pet ever been on medication for any other problems?
e.g., skin disease, ear problems, allergies, hormonal therapy?

(A) yes
(B) no ---- go to question 9

If you answered **yes** to question 8 please fill out the following table to the best of your knowledge. This should include any oral, injectable or topical medications.

example: PREDNISONE	5mg tablets	twice daily in the fall when he has fleas other wise none

9. Has your dog had any other surgery beside routine spaying or neutering?
(A) yes
(B) no

If you answered yes to question 9 please fill out the following information.

Reason for surgery ____

____

Type of surgery:____

____

Date or time of surgery: ____

____

SECTION A (continued)

10. Do you maintain health records for your pet

(A) yes
(B) no

11. Did you review these records prior to this visit?

(A) yes
(B) no

12. Who in the household is the primary caretaker of your pet?

(A) myself
(B) my spouse/housemate
(C) children
(D) all family members
(E) other

SECTION B = EXERCISE

13. Does your pet still exercise?

(A) yes
(B) no
(C) not any more

- If your answered **yes** to question 13 please complete **13a** below.

⇒ If you answered **no** to question 13 please **answer 13b** on the next page.

* If you answered **not any more** to question 13 please complete **13a** below and answer **13c** on the next page.

13a. Please complete the table below to describe the frequency, duration and intensity of your pet's activity.

Frequency should be noted as how often does the activity occur such as daily, weekly and/or seasonal. **Length of time** means how long does the activity last ie leash walks for 10 minutes or hunting for 3 hours. **Intensity** should be graded on a scale of 1 - 5 with 1 being low intensity, such as walks only, needs encouragement to 5 runs most of the time, needs to be leashed to slow him down.

- **Table 13a**

EXERCISE	FREQUENCY/TIME	INTENSITY
example: LEASH WALKS	20 mins twice a day, 1 hour twice a day on weekends.	4
(a) leash walks		
(b) walks off leash		
(c) fetching toys/balls		
(d) hunting		
(e) obedience class		
(g) agility class		
(h) free play with children or other pets		
(i) swimming		
(j) other (please describe)		

⇒ **13b.** Our pet does not exercise because....... *(circle all that apply)*

(A) he is to painful to exercise
(B) he is okay when exercising but is consistently painful afterwards
(C) no one in the house is available or can walk him
(D) he is an indoor dog and only goes out to use the washroom
(E) he is outdoors all the time and does not need additional exercise
(F) other, please explain ____
____

* **13c.** Our pet used to exercise but no longer does because.......... *(circle all that apply)*

(A) he was to painful to exercise
(B) he was okay to exercise but was painful when done
(C) no one is available anymore to exercise him
(D) he is now an indoor dog
(E) he has other medical problems that prevent exercise. please explain. _____
____
(F) other, please explain ____
____

SECTION C = DAILY ACTIVITIES

This section should be scored on a 0 - 5 scale with

0 = no difficulties with this activity
1 = occasionally has very mild difficulty or impairment
2 = frequent mild impairment or difficulty
3 = consistently has obvious difficulty or impairment
4 = can not perform this activity
5 = activity not observed therefore cannot be assessed.

Please circle the appropriate number

14. When your dog is rising to stand would you say he.......

0 --------------- 1 --------------- 2 --------------- 3 --------------- 4 --------------- 5

15. When your dog is running would you say.....

0 --------------- 1 --------------- 2 --------------- 3 --------------- 4 --------------- 5

16. When your dog is getting into the car would you say that......

0 --------------- 1 --------------- 2 --------------- 3 --------------- 4 --------------- 5

17. When your dog is climbing stairs would you say that......

0 ----------------1 --------------- 2 --------------- 3 --------------- 4 --------------- 5

18. When your dog is sitting down does he have.....

0 --------------- 1 --------------- 2 --------------- 3 --------------- 4 --------------- 5

For the next question please use the following scoring system.

0 = has an excellent quality of life ie no pain
1 = has a good quality of life
2 = has an average quality
3 = has a fair quality of life
4 = has a poor quality of life ie consistently painful

19. Compared to other dogs my dog .....

1 --------------- 2 --------------- 3 --------------- 4 --------------- 5

Appendix 5

Client scored data for daily activities, quality of life and use of non-sterioidal anti-inflammatory drugs for Group #1 dysplastic dogs with a unilateral TPO

case #	rising	running	into car	stairs	sitting	QOL	nsaids
197903	0	0		0	0	0	2
194948	2	0	1		2	2	1 (1 time)
195449	0	0	0	0	0	0	2
194474	1	1	1	1	0	1	*1
192095	1	0	0	1	0	0	2
191724	0	1	0	0	0	0	2
189025	1	0	2	1	0	1	1 EOD
187040	1	1	4	1	1	2	*1
187180	1	1	1	1	0	1	2
186961	0	0	0	0	0	0.5	2
185540	1	2	2	3	0	1	*1
184810	1	1	2	2	1	1	1 daily
184759	2	1	1	1	1	1	*1
184034	0.5	0	0	0	0	0.5	2
182877	0	0	0	0	0	1	2
181546	1	0	1	1	0	0	2
181805	2.5	0.5	0.5	0.5	3.5	1.5	*1
180003	1	0	0	0	0	0	2
179970	1	0	0	1	0	1	*1
175072	2	1	3	3	1	1	*1
174893	1	0	1	1	1	2	2
168573	1	0	1	1	0	1	*1
194675	0	0	0	0	0	0	2

0 = no difficulty	1=yes	
1 = occasionally has very mild difficulty or impairment	*1 as needed	
2 = frequent mild difficulty or impairment	2 = no	
3 = consistently has obvious difficulty or impairment	EOD =	every other day
4 = cannot perform this activity		
5 = activity not observed therefore cannot be assessed		

Appendix 6

Client scored data for daily activities, quality of life and use of non-steroidal anti-inflammatory drugs, Group #2 bilateral dysplastic dogs with no surgical treatment and Group #3 normal dogs.

Group #2

case #	rising	running	into car	stairs	sitting	QOL	nsaids
200099	0	0	0	0	0	0	2
192433	0	1	0	0	0	1	*1
203882	2	2	4		2	4	2,PSGAG
202428	2.5	1	0	0	0	2	2
177177	1	2	1	0	0	1	*1
172527	2	2	2	2	2	1	*1
188284	2	1	1	0	0	2	2
197287	0	0	0	0	0	1	2

case #	rising	running	into car	stairs	sitting	QOL	nsaids
202210	0	0	0	0	0	0	0
204070	0	0	0	0	0	0	0
203055	0	0	0	0	0	0	0
197140	1	0	1	1	1	1	*1

0 = no difficulty	1=yes	
1 = occasionally has very mild difficulty or impairment	*1 as needed	
2 = frequent mild difficulty or impairment	2 = no	
3 = consistently has obvious difficulty or impairment	EOD =	every other day
4 = cannot perform this activity		
5 = activity not observed therefore cannot be assessed		

Appendix 7

Lameness and Joint pain scores for Group #1 dysplastic dogs with a unilateral TPO

Case #	time since sx (mos)	lameness score L/R	joint pain score L/R	TPO side
197903 FS ROTT	12	1/1	0/0	LEFT
194948 FS LR	16	0/0	2/0	RIGHT
194675 M GSD	19	0/0	0/1	RIGHT
195449 M GSD	19	NR/NR	1/1	LEFT
194474 F GSD	21	0/0	0/0	RIGHT
192095 FS GR	26	0/0	0/0	LEFT
191724 MC GR	27	2/1	0/0	LEFT
189656 F LR	32	0/0	1/1	RIGHT
189025 FS MAL	36	1/1	1/1	RIGHT
187040 M GR	37	2/0	1/1	RIGHT
187180 M LR	38	0/0	0/0	LEFT
186961 M GR	39	0/0	0/0	LEFT
185540 FS GR	43	0/2	0/0	LEFT
184810 MC GSD	44	1/1	1/1	RIGHT
184759 MC GR	46	1/0	1/1	RIGHT
184034 MC BCO	48	1/1	1/0	RIGHT
182877 M GR	49	0/0	0/0	RIGHT
181546 M MIX	52	1/0	1/0	RIGHT
181805 FS LR	54	1/0	0/0	LEFT
180003 MC GR	56	1/1	0/0	RIGHT
179970 FS GR	57	2/2	1/1	RIGHT
175072 M GR	72	2/1	1/1	LEFT
174893 M GR	72	0/0	0/1	RIGHT
168573 FS GR	95	1/1	0/0	LEFT

GR = Golden Retriever
LR = Labrador Retriever
GSD = German Shepherd
Rott = Rottweiler
BOC = Bearded Collie
MAL = Malamute

Appendix 8

Lameness and Joint Pain Scores for Group #2 dysplastic dogs with surgical treatment

Case #	Lameness score L/R	Joint pain score L/R	hip with greatest DJD
203868	1/1	2/2	Left
200099	0/0	1/1	Left
192433	0/1	1/1	Right
202428	1/1	1/1	Left
203882	1/1	1/1	Left
177177	0/0	1/1	Left
172527	1/1	1/1	Left
188284	0/0	1/1	Right
197287	0/0	2/2	Left
168886	0/0	0/0	Left

Appendix 9

Lameness and Join Pain Scores for Group #3 normal dogs

Case #	Lameness Score L/R	Joint Pain Score L/R
202210	0/0	0/0
203055	0/0	0/0
204070	0/0	0/0
197140	0/0	1/0

Appendix 10 Norberg angle measurements for Group #1 dysplastic dogs with a unilateral TPO

Tano NA	pre TPO	prenoTPO	post TPO	post no T	f-up TPO	f-up no T
197903	75	80	120	90	110	80
194948	65	80	130	80	140	55
194675	60	65	90	70	135	85
195449	65	70	85	65	125	110
194474			115	80	140	85
192095	85	90	105	95	100	100
191724	105	70	130	70	135	90
189656	75	75	90	65	105	70
189025	45	50	60	55	135	80
187040	65	75	105	70	115	70
187180	75	90	100	95	120	90
186961	45	65	65	60	110	80
184810	60	80	60	95	90	110
182877	85	60	85	90	90	95
181805	90	85	125	90		
181546	80	75	70	80	110	80
180003	85	100	120	80	115	95
179970	90	90	70	90	105	85
175072	55	55	40	55	80	65
174893	55	50	50	40	90	65
168573	65	100	115	90	120	85
Dobson						
197903	85	85	120	90	125	80
194948	75	85	70	80	140	55
194675	55	65	90	55	125	65
195449	70	110	80	110	120	110
194474			65	85	135	85
192095	80	90	110	95	110	100
191724	75	105	130	75	125	90
189656	80	75	80	75	95	75
189025	60	60	55	60	135	80
187040	70	80	110	75	140	75
187180	80	100	95	105	130	95
186961	70	70	95	65	65	70
184810	70	80	70	70	90	100
182877	62	85	90	85	95	90
181805	90	85	130	85		
181546	80	80	75	85	114	80
180003	85	105	120	85	130	95
179970	90	90	80	90	110	85
175072	60	55	50	55	85	65
174893	55	55	55	55	85	65
168573	65	90	115	90	135	90

Appendix 11

Norberg angle scores for Group #2 dysplastic dogs with no surgical treatment and Group #3 normal dogs

Group #2

TANO			
Norberg	Case #	better	worse
angle	203882	90	90
	203868	75	50
	202428	100	90
	200099	75	85
	197287	85	75
	192433	90	75
	188284	100	80
	177177	90	90
	172527	85	90
	168886	70	70
Dobson	203882	95	90
	203868	70	65
	202428	100	105
	200099	85	80
	197287	85	80
	192433	90	80
	188284	105	90
	177177	90	95
	172527	95	95
	168886	85	80

Group #3

Tano		left	right
Norberg	Case #		
angle	202210	105	110
	203055	115	115
	204070	105	110
	197140	110	110
Dobson	202210	110	110
	203055	110	115
	204070	120	120
	197140	110	110

Appendix 12 Subluxation scores: for Group #1 dysplastic dogs with a unilateral TPO

Tano	Case #	preTPO	pre noTP	postTPO	post noTP	f-up TPO	f-up noTP
sublux	197903	2	1	0	1	0	2
	194948	3	3	0	2	0	3
	194675	3	3	1	3	0	2
	195449	3	1	2	0	0	1
	194474			0	1	0	1
	192095	2	2	0	2	0	1
	191724	3	0	0	3	0	2
	189656	3	3	1	3	0	2
	189025	4	3	4	3	0	2
	187040	4	2	0	3	0	4
	187180	3	2	0	1	0	2
	186961	3	3	1	3		3
	184810	2	3	3	2	3	
	182877	4	3	1	3	1	2
	181805	2	2	0	2		
	181546	3	2	3	2	0	3
	180003	3	1	0	3	0	2
	179970	2	3	2	2	0	2
	175072	4	4	2	4	2	4
	174893	4	4	4	4	1	4
	168573	4	2	1	3	0	2
Dobson							
	197903	2	1	0	1	0	2
	194948	3	3	0	2	0	3
	194675	3	3	1	3	0	2
	195449	3	0	2	0	0	0
	194474			1	0	1	0
	192095	2	2	0	2	0	2
	191724	3	0	0	3	0	1
	189656	3	3	1	3	0	3
	189025	4	4	4	4		
	187040	3	3	0	3	0	3
	187180	2	2	2	1	0	2
	186961	3	3	1	3	1	3
	184810	2	3	3	0	3	0
	182877	4	3	1	3	1	3
	181805	2	2				
	181546	2	2	2	2	3	0
	180003	3	1	0	2	0	1
	179970	3	3	2	2	0	2
	175072	4	4	3	4	1	4
	174893	4	4	4	4	3	3
	168573	4	1			0	2

Appendix 13

Subluxation scores for Group #2 dysplastic dogs with no surgical treatment and Group #3 normal dogs

Group #2 Group #3

Tano	Case #	better	worse	Tano	Case #	left	right
Sublux	203882	2	2	Sublux	202210	0	0
	203868	2	4		203055	0	0
	202428	2	2		204070	0	0
	200099	2	2		197140	0	0
	197287	2	3				
	192433	1	2	Dobson	202210	0	0
	188284	1	2		203055	0	0
	177177	1	2		204070	0	0
	172527	2	1		197140	1	0
	168886	2	3				
Dobson	203882	2	2				
	203868	2	4				
	202428	1	2				
	200099	2	2				
	197287	2	3				
	192433	1	1				
	188284	1	2				
	177177	1	1				
	172527	1	1				
	168886	3	3				

Appendix 14 Instability scores for Group #1 dysplastic dogs with a unilateral TPO

TANO	Case #	preTPO	prenoTPO	post TPO	postnoTP	f-up TPO	f-upnoTPo
instability	197903	1	0	1	0	2	2
	194948	2	0	2	0	2	3
	194675	1	1	1	2	2	3
	195449	0	0	0	0	3	0
	194474			0	1	0	2
	192095	0	0	0	0	2	1
	191724	0	0	0	0	1	0
	189656	0	0	0	0	2	3
	189025	1	0	0	0	0	2
	187040	0	0	0	0	0	3
	187180	1	0	2	0	1	3
	186961	1	2	2	2	3	3
	184810	0	0	0	0	3	
	182877	1	2	1	2	2	2
	181805	0	0	0	0		
	181546	0	0	0	0	0	3
	180003	0	0	0	0	3	3
	179970	0	0	0	0	2	1
	175072	2	2	2	2	3	3
	174893	1	2	1	2	2	3
	168573	0	1	0	1	0	3
Dobson							
	197903	1	0	1	1	1	2
	194948	1	0	1	0	1	3
	194675	1	1	0	1	1	3
	195449	1	0	1	0	1	0
	194474			0	0	2	0
	192095	1	1	1	1	2	2
	191724	0	0	0	0	0	1
	189656	1	1	1	1	1	3
	189025	0	0	0	0	0	2
	187040	1	1	1	1	1	1
	187180	1	1	1	1	1	3
	186961	1	2	1	2	1	3
	184810	1	1	1	1	3	1
	182877	1	1	1	1	1	2
	181805	1	1	1	1		
	181546	0	0	0	0	1	3
	180003	0	0	0	0	2	1
	179970	2	2	1	2	1	2
	175072	1	2	1	2	3	3
	174893	0	0	1	0	3	2
	168573	1	1	1	1	1	1

Appendix 15 Degenerative Joint Disease scores for Group #1 dysplastic dogs with a unilateral TPO

TANO	Case #	preTPO	prenoTPO	post TPO	postnoTP	f-up TPO	f-upnoTPo
DJD	197903	0	1	0	0	2	2
	194948	0	0	0	0	1	3
	194675	1	1	1	2	3	2
	195449	1	0	0	0	3	0
	194474			1	1	0	1
	192095	1	0	1	1	3	2
	191724	0	0	0	0	2	2
	189656	2	2	2	2	3	3
	189025	0	0	0	0	1	2
	187040	1	1	1	1	2	3
	187180	1	1	1	1	1	3
	186961	1	0	1	0	3	3
	184810	1	1	1	1	3	3
	182877	1	2	1	2	3	3
	181805	1	1	1	0		
	181546	1	1	1	1	2	3
	180003	1	0	1	0	3	3
	179970	1	1	1	1	3	2
	175072	2	1	2	1	3	3
	174893	1	3	2	3	3	3
	168573	0	0	2	0	2	2
Dobson	197903	0	0	0	0	0	2
DJD	194948	1	1	1	1	1	3
	194675	1	1	1	1	1	1
	195449	1	0	1	0	2	0
	194474			1	1	2	0
	192095	2	1	2	1	3	2
	191724	2	1	2	1	2	3
	189656	2	2	2	2	3	3
	189025	1	1	1	1	0	2
	187040	1	1	1	1	1	2
	187180	2	1	2	1	1	3
	186961	1	1	2	1	3	3
	184810	1	1	1	1	2	1
	182877	1	2	2	2	3	3
	181805	1	1	1	1		
	181546	2	2	2	2	2	3
	180003	1	0	1	0	1	3
	179970	2	1	2	1	2	3
	175072	2	2	2	2	3	3
	174893	1	2	2	2	3	3
	168573	0	0	0	0	1	2

Appendix 16

Instability scores for Group #2 dysplastic dogs with no surgical treatment and Group #3 normal dogs

Group #2 / Group #3

TANO	Case #	better	worse	Tano	Case #	left	right
Instability	203882	2	2	Instability	202210	0	0
	203868	3	3		203055	0	0
	202428	2	2		204070	0	0
	200099	1	2		197140	0	0
	197287	3	3				
	192433	1	3	Dobson	202210	2	1
	188284	2	3		203055	0	0
	177177	1	2		204070	1	1
	172527	1	3		197140	0	0
	168886	3	3				
Dobson	203882	3	3				
	203868	3	3				
	202428	3	3				
	200099	2	3				
	197287	3	3				
	192433	2	3				
	188284	3	3				
	177177	2	3				
	172527	3	3				
	168886	3	3				

Appendix 17

Degenerative joint disease scores for Group #2 dysplastic dogs with no surgical treatment and Group #3 normal dogs.

Group #2 Group #3

Tano	Case #	better	worse	Tano	Case #	left	right
DJD	203882	2	2	DJD	202210	0	0
	203868	2	3		203055	0	0
	202428	2	2		204070	0	0
	200099	2	2		197140	0	0
	197287	2	3				
	192433	1	1	Dobson	202210	1	1
	188284	1	2		203055	0	0
	177177	1	2		204070	0	0
	172527	1	1		197140	0	0
	168886	2	3				
Dobson	203882	3	3				
	203868	3	3				
	202428	1	2				
	200099	3	3				
	197287	2	2				
	192433	1	3				
	188284	3	3				
	177177	2	3				
	172527	3	3				
	168886	2	2				

Appendix 18

Peak vertical force (PVF) for each hind limb individually and all four limbs for Group #1 dysplastic dogs with a unilateral TPO

TPO dogs	PVF FT	PVF FnoT	PVF HT	PVF HnoT	PVF all 4
168573	60.56	59.38	41.82	40.15	198.67
175072	70.73	68.94	40.49	44.14	210.78
181805	65.16	61.71	46.59	39.19	199.09
184810	67.55	66.65	33.15	31.32	198.54
185540	59.55	60.78	48.99	41.46	207.35
186961	60.35	59.1	38.93	40.71	206.79
187180	62.11	63.73	37.69	35.01	212.66
191724	60.95	62.41	43.4	40.59	197.45
192095	60.23	61.32	43.64	41.6	207.56
195449	62.56	64.02	44.67	41.41	213.69
197903	61.7	61.97	35.27	38.51	204.3
174893	63.6	61.01	43.88	39.07	209.61
179970	63.79	65.56	43.5	40.84	213.04
180003	61.3	62.3	42.67	38.03	199.58
181546	62.7	59.53	47.68	39.7	212.44
182877	64.5	65.14	40.97	42.43	212.38
184034	60.51	57.87	44.28	36.92	209.28
184759	67.97	68.09	37.13	39.25	190.39
187040	63.9	66.13	42.04	40.31	199.84
189025	65.52	60.54	43.1	40.12	189.93
189656	58.46	59.79	38.79	33.35	198.15
194474	59.87	62.13	39.51	38.33	199.84
194675	59.11	58.28	36.45	36.09	205.4325
194948	61.65	60.07	40.4	36.03	198.15

PVF FT = PVF of the forelimb ipsilateral to the TPO
PVF FnoT = PVF of the forelimb contralateral to the TPO
PVF HT = PVF of the operated limb
PVF HnoT = PVF of the unoperated limb
PVF all 4 = total PVF of all limbs

Appendix 19

Mean vertical force (MVF) for each limb of the Group #1 dysplastic dogs with a unilateral TPO

TPO dogs	MVFFTPO	MVFFno	MVFHTPO	MVFH no
168573	41.43	39.52	27.39	26.2
175072	45.25	44.5	25.97	27.75
181805	43.95	41.95	26.92	25.3
184810	45.04	44.47	23.4	22.67
185540	42.92	41.68	27.61	26.26
186961	41.58	40.8	26	27.26
187180	42.9	45.02	26.69	23.93
191724	42.65	42.79	27.29	25.93
192095	41.95	42.69	28.91	27.04
195449	42.85	43.87	27.77	26.97
197903	42.71	43.89	24.58	26.31
174893	43.17	41.78	27.13	25.65
179970	42.26	42.8	26.13	26.07
180003	42.94	45.14	26.05	24.76
181546	44.1	39.41	28.16	25.66
182877	43.41	44.41	26.39	26.2
184034	40.3	40.19	26.54	24.81
184759	43.57	44.26	24.56	24.6
187040	43.65	44.36	27.58	25.46
189025	43.97	41.56	26.54	26.1
189656	40.15	39.61	25.24	22.91
194474	40.94	41.83	26.7	25.43
194675	40.47	41.6	25.65	25.6
194948	43.41	40.63	26.23	24.41

MVF F TPO = MVF of the forelimb on the ipsilateral side to the TPO
MVF F no TPO = MVF of the forelimb on the contralateral side to the TPO
MVF H TPO = MVF on the TPO limb
MVF H no TPO = MVF on the unoperated limb

Appendix 20

Peak vertical force (PVF) for each individual limb and all four limbs of Group #2 dysplastic dogs with no surgical treatment

DJD dogs	PVF Fbet	PVF Fwor	PVF Hbet	PVF Hwor	PVF all 4
168886	59.86	59.20	37.88	36.74	201.68
172527	60.77	60.01	38.11	41.35	201.44
177177	65.63	65.51	39.67	37.00	197.84
188284	64.27	63.89	37.76	35.75	209.80
192433	61.71	61.80	39.25	38.68	197.90
197287	61.52	62.57	35.90	37.86	198.27
200099	59.27	61.64	43.99	44.90	189.98
202428	57.98	59.17	41.12	39.64	197.90
203868	68.22	67.30	30.60	32.16	198.27
203882	59.86	58.54	33.96	37.62	189.98

PVF F bett = PVF of the forelimb ipsilateral to the better hip
PVF F wor = PVF of the forelimb ipsilateral to the worse hip
PVF H bet = PVF of the better hind limb
PVF H wor = PVF of the worse hind limb
PVF all 4 = total PVF of all limbs

Appendix 21

Mean Vertical Force (MVF) for each limb of the Group #2 dysplastic dogs with no surgical treatment

DJD dogs	MVF f bet	MVF f wor	MVF h bet	MVF h wor
168886	59.86	40.29	24.59	25.34
172527	42.27	42.16	26.93	28.2
177177	44.83	44.86	26.4	26.11
188284	44.8	45.13	25.99	24.33
192433	42.36	40.7	26.58	25.8
197287	40.47	43.04	25.09	26.68
200099	40.52	41.86	27.95	28.27
202428	40.23	41.77	28.43	28.52
203868	46.71	45.04	22.32	22.47
203882	42.18	43.68	23.74	25.17

MVF f bet = MVF of the forelimb ipsilateral to the better hip
MVF f wor = MVF of the forelimb ipsilateral to the worse hip
MVF h bet = MVF of the better hip
MVF h wor = MVF of the worse hip

Appendix 22

Peak vertical force (PVF) for each individual limb and all four limbs of the Group #3 normal dogs

Normals	PVF Fleft	PVF Frt	PVF Hleft	PVF Hrt	PVF all 4
197140	61.25	63.37	41.713	41.39	207.72
202210	58.48	58.02	42.01	40.94	199.45
203055	61.36	60.47	34.69	36.17	192.69
204070	58.74	57.83	39.07	38.64	194.28

PVF Fleft = PVF left forelimb
PVF Frt = PVF right forelimb
PVF Hleft = PVF left hind limb
PVF Hrt = PVF right hind limb
Pvf all 4 = total PVF of all limbs

Appendix 23

Mean vertical force (MVF) for each limb of the Group #3 normal dogs

Normals	MVF Fleft	MVF Frt	MVF Hleft	MVF Hrt
197140	42.68	42.72	27.75	27.3
202210	41.16	40	27.64	25.89
203055	42.34	42.03	25.12	26.21
204070	41.21	40.8	26.94	26.92
	MVF Frt	MVF Hleft	MVF Hrt	
MVF Fleft				

MVF Fleft = MVF of the left forelimb
MVF Frt = MVF of the right forelimb
MVF Hleft = MVF of the left hind limb
MVF Hrt = MVF of the right hind limb

Appendix 24

Percentage of body weight (%BW) borne, by each individual limb and forelimbs and hind limbs as a pair for Group #1 dysplastic dogs with a unilateral TPO

TPO dogs	%BWFT	%BWFnoT	%Bwfore	%BWHT	%BWHno	%BW hind
168573	29.99	29.41	59.4	20.71	19.86	40.57
175072	31.53	30.74	62.27	18.05	19.68	37.73
181805	30.64	29.02	59.66	21.91	18.43	40.34
184810	34.01	33.55	67.56	16.69	15.76	32.45
185540	28.25	28.84	57.09	23.24	19.67	42.91
186961	30.31	29.67	59.98	19.55	20.45	40
187180	31.28	32.1	63.38	18.98	17.93	36.91
191724	29.39	30.1	59.49	20.93	19.56	40.49
192095	29.13	29.65	58.78	21.1	20.12	41.22
195449	29.41	30.1	59.51	21.01	19.47	40.48
197903	31.25	31.39	62.64	17.86	19.5	37.36
174893	30.64	29.39	60.03	21.14	18.82	39.96
179970	29.85	30.68	60.53	20.36	19.11	39.47
180003	30	30.49	60.49	20.89	18.6	39.49
181546	29.91	28.4	58.31	22.75	18.94	41.69
182877	30.28	30.58	60.86	19.23	19.91	39.14
184034	30.82	29	59.82	22.19	18.5	40.69
184759	31.99	32.05	64.04	17.48	18.48	35.96
187040	30.09	31.14	61.23	19.79	18.98	38.77
189025	31.31	28.93	60.24	20.59	19.17	39.76
189656	30.71	31.4	62.11	20.37	17.52	37.89
194474	29.96	31.09	61.05	19.77	19.18	38.95
194675	31.12	30.68	61.8	19.19	19	38.19
194948	31.11	30.32	61.43	20.39	18.18	38.57

%BWFT = percentage of body weight borne by the forelimb ipsilateral to the TPO
%BWFnoT = percentage of body weight borne by the forelimb contralateral to the TPO
% Bwfore = percentage of body weight borne on the front limbs
%BWHT = percentage of body weight borne by the operated limb
%BWHno = percentage of body weight borne by the unoperated limb
%BW hind = percentage of body weight borne by the back legs

Appendix 25

Percentage of body weight (%BW) borne by each individual limb and forelimbs and hind limbs as a pair for Group #2 dysplastic dogs with no surgical treatment

DJD dogs	%BWFbet	%BWFwo	%Bwfore	%BWHbet	%BWHwo	%Bwhind
168886	30.91	30.57	61.48	19.56	18.97	38.53
172527	30.35	29.97	60.32	19.03	20.65	39.68
177177	31.58	31.52	63.1	19.09	17.8	36.89
188284	31.87	31.68	63.55	18.73	17.73	36.46
192433	30.63	30.68	61.31	19.48	19.2	38.68
197287	31.1	31.63	62.73	18.15	19.14	37.29
200099	28.25	29.38	57.63	20.97	21.4	42.37
202428	29.29	29.9	59.19	20.78	20.03	40.81
203868	34.41	33.94	68.35	15.43	16.22	31.65
203882	31.51	30.81	62.32	17.89	19.8	37.69

%BWFbet = Percentage of BW borne by the forelimb ipsilateral to the better hip
%BWFwor = Percentage of BW borne by the forelimb ipsilateral to the worse hip
%Bwfore = Percentage of BW borne by the front legs
%BWHbet = Percentage of BW borne by the better hind limb
%BWHwor = Percentage of BW borne by the worse hind limb
%Bwhind = Percentage of BW borne by the back legs

Appendix 26

Percentage of body weight (%BW) borne by each individual limb and the forelimbs and hind limbs as a pair for Group #3 normal dogs

Normals	%BW LF	%BW RF	%BW fore	%BW LH	%BW RH
197140	29.49	30.51	59.99	20.08	19.93
202210	29.32	29.09	58.41	21.06	20.53
203055	31.85	31.38	63.23	18.00	18.77
204070	30.24	29.77	60.00	20.11	19.89

%BW LF = percentage of body weight borne by the left front
%BW RF = percentage of body weight borne by the right front
%BW fore = percentage of body weight borne by the front legs
%BW LH = percentage of body weight borne by the left hind
%BW RH = percentage of body weight borne by the right hind
% BW hind = percentage of body weight borne by the back legs

Appendix 27

Velocities (each pass and mean for the passes) for Group #1 dysplastic dogs with a unilateral TPO.

Case #	TPO	nonTPO			Case #	TPO	noTPO
168573	1	1.22			191724	1.01	0.93
	0.9	1.07				0.83	0.97
	1	1				0.95	0.95
	1	1.09				0.88	1.01
	0.92	1.13				0.88	0.83
mean	0.964	1.102			mean	0.91	0.938
175072	1.14	1.08			192095	1.09	1.11
	1.29	1.08				1.03	1.09
	1.19	1.1				1.01	0.98
	1.06	1.1				0.89	0.88
	1.06	1.06				1.03	1.01
mean	1.148	1.084			mean	1.01	1.014
181805	1.08	1.06			195449	1.23	1.19
	1.03	1.03				1.08	1.26
	1.03	1.03				1.26	1.08
	1.06	1.03				0.98	1.1
	1.16	1.06				0.98	1.1
mean	1.072	1.042			mean	1.106	1.146
184810	1.06	1.14			197903	0.98	1.1
	1.08	1.14				1.07	1.07
	1.14	1.08				1.15	1.02
	1.19	0.89				1.05	0.88
	1.03	1.06				0.94	0.98
mean	1.1	1.062			mean	1.038	1.01
185540	1.1	0.94			174893	1.06	1.06
	1.13	1.07				1.1	1.06
	0.98	1.07				1.1	1.19
	1.07	0.87				1.16	1.1
	1.02	0.98				1.1	0.99
mean	1.06	0.986			mean	1.104	1.08
186961	0.88	0.98			179970	1.16	1.26
	0.88	0.92				1.16	1.26
	0.94	0.96				1.26	1.16
	0.92	0.96				1.23	1.19
	0.94	0.9				1.19	1.03
mean	0.912	0.944			mean	1.2	1.18

Appendix 27 (continued)

Case #				Case #		
181546	TPO	noTPO		194474	TPO	noTPO
	1.05	1.05			1.11	1.19
	1.05	1.1			1.06	1.11
	1.05	1.13			1.11	1.11
	1.05	1			1.11	1.06
	1.05	0.98			1.11	0.99
mean	1.05	1.052			1.1	1.092
182877	0.96	1.21		194675	1.18	1.02
		1.1			1.05	1
	1.01	1.16			1.02	1.07
	1.12	1.16			0.96	1.1
	1.03	1.08			1.28	1.07
mean	1.03	1.142			1.098	1.052
184034	0.99	0.9		194948	1.14	1.03
	1.06	0.96			1.06	1.11
	1.08	0.94			1.08	1.08
	0.9	1.08			1.06	1.03
	0.94	0.9			1.11	1.14
mean	0.994	0.956			1.09	1.078
184759	1.23	1.27		187180	0.85	1.03
	1.27	1.17			1.06	0.93
	1.33	1.33			0.84	1.08
	1.27	1.17			0.99	0.99
	1.47	1.27			0.94	1.06
mean	1.314	1.242			0.936	1.018
187040	1.22	1.22		180003	1.1	1.1
	1.18	1.22			1.02	1.22
	1.18	1.28			1	1.22
		1.15			1.15	1.1
	1.15	1.22			1.1	1.13
mean	1.1825	1.218		mean	1.074	1.154
189025	1.01	0.96				
	1.16	1.01				
	1.06	0.96				
	1.08	0.94				
	1.08	0.99				
mean	1.078	0.972				
189656	1.1	1.63				
	1.77	1.6				
	1.83	1.7				
	1.63	1.77				
	1.83	1.87				
mean	1.632	1.714				

Appendix 28

Velocities (passes and mean of passes) Group # 2 dysplastic dogs with no treatment

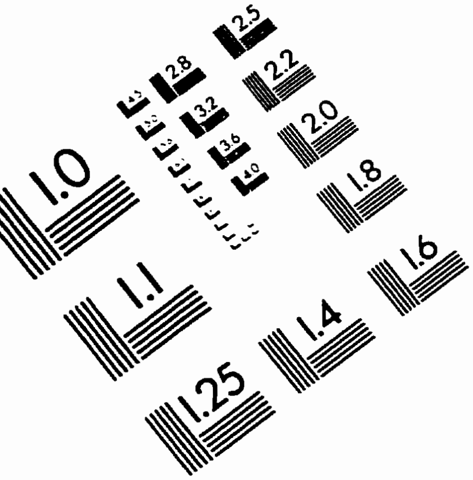
Case #	better	worse			Case #	better	worse
168886	1.15	1.05			197287	1.08	1.19
	1.02	1.05				0.94	1.03
	1.02	1.13				1.1	1.08
	0.98	1				0.99	0.99
	0.98	0.98				1.03	1.08
		1.02				0.99	
		1.07				1.021667	1.074
	1.03	1.042857			200099	1.1	1.05
172527	1.02	0.98				0.98	1.1
	0.9	0.85				1.08	1.08
	1.05	0.9				1.13	1.22
	1.02	0.94				1.13	1
	1	1.13				1.084	1.09
	0.98	1.02			202428	1.26	1.19
		0.96				1.19	1.26
	0.995	0.968571				1.08	1.14
177177	1.03	0.93				1.14	1.26
	1.01	1.03				1.19	1.23
	1.11	0.97					1.17
	1.03	1.06				1.172	1.208333
	1.03	1.08			203868	1.07	1.09
	1.042	1.014				1.05	0.98
	1.042	1.014				0.94	1.13
188284	1.28	0.94				1	0.96
	1.18	1				1	1.07
	1	0.85					1.07
	0.94	0.88					1
	1	1.07					0.72
	1.07	1					0.85
	1.02	0.98					1.02
		0.98					1
	1.07	0.9625				1.012	0.99
192433	1.16	1.16			203882	1.07	1.02
	1.19	1.11				0.98	0.94
	1.23	1.14				1	1
	1.19	1.16				0.9	1.02
	1.06	1.16				0.9	1.25
		1.16					1.02
		1.26					1.02
		1.06					0.98
	1.166	1.15125				0.97	1.03125

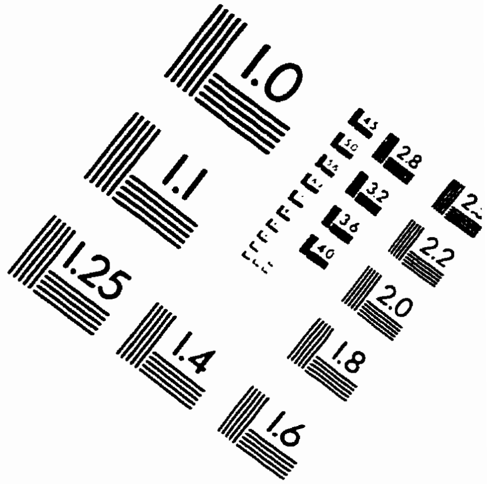
Appendix 29

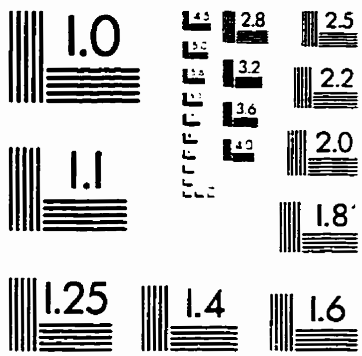
Velocities (each pass and mean of the passes) Group #3 normal dogs

Case #	left	right				
197140	1.08	0.98		202210	1.22	1.18
	1.19	1.26			1.07	1.02
	1.16	1.16			0.96	1.09
	0.98	1.13			1.15	1.18
	0.96	1.19			1.02	1.25
	1.22				1.09	1.07
mean	1.098333	1.144				1.25
				mean	1.085	1.148571
203055	1.07	1.02		204070	1.14	1.01
	1.02	0.96			0.96	1.06
	0.92	0.92			1.01	1.01
	0.96	0.94			0.94	1.01
	1	1			0.88	1.01
	1.02				1.03	1.03
	0.98				1.14	1.01
mean	0.995714	0.968		mean	1.014286	1.02

IMAGE EVALUATION TEST TARGET (QA-3)







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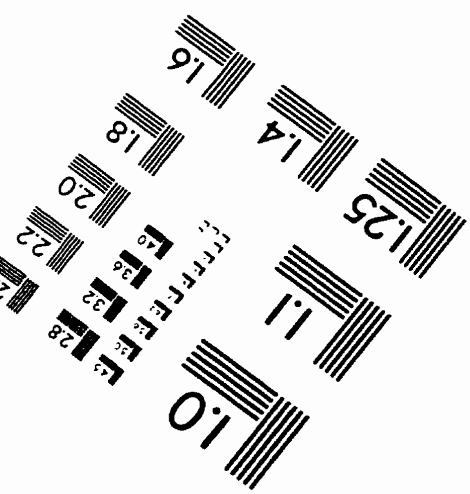

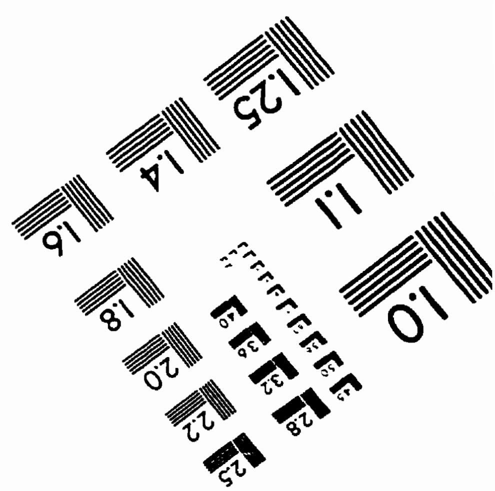

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