AIS PennHIP

Training Manual

AIS PennHIP

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Chapter 1: Introduction and Overview

Welcome to AIS PennHIP. This AIS PennHIP training manual parallels and supplements the online training program and can serve as a reference for in-depth questions about canine hip dysplasia and the science to support the AIS PennHIP method. The manual provides detailed instruction on how to perform the method and describes the exercises you will do in your clinic to get official certification as a PennHIP member. The manual also covers how to take full advantage of your training to help pet owners manage this highly prevalent disease in their pet dogs. You will also learn how to use time-tested genetic principles to help breeders make informed breeding decisions using the AIS PennHIP method as a selection tool.

AIS PennHIP consists of three integral components: the stress-radiographic diagnostic method, the network of trained veterinarians and technicians, and the AIS PennHIP database. Our goal in this training program is to emphasize the value of this synergy and your importance in it. Again, welcome.

Brief History of PennHIP

In 1983 Dr. Gail Smith conceived and developed what was to become PennHIP in his laboratory at the University of Pennsylvania. After 10 years of testing, refinement, and clinical validation, the University of **Penn**sylvania **H**ip **I**mprovement **P**rogram (PennHIP) was established. Research proved the diagnostic method through the Distraction Index (DI) to be a superior way to measure hip laxity in dogs as young as 16 weeks of age. Importantly the DI was shown to be the primary risk factor for osteoarthritis of canine hip dysplasia, meaning that knowledge of the DI would permit a veterinarian to estimate the risk of a dog developing the OA of hip dysplasia later in life. The first training program was organized in 1993 as a cooperative scientific initiative to serve as a multicenter clinical trial of the new hip dysplasia diagnostic technology. In 1996 The United States Patent Office issued a patent for the PennHIP technology and a second patent was issued recently, in 2014. The program was successful and grew beyond the resources and purpose of a university research laboratory. In late 2013, all facets of PennHIP were purchased by Antech Imaging Services and are currently operating within the Antech Imaging Services framework. It is now called AIS PennHIP.

Current Status of CHD

In the United States alone, dogs afflicted with hip dysplasia number conservatively in the millions. Despite efforts on the part of dog breeders and veterinarians to reduce the frequency of canine hip dysplasia by selective breeding, published prevalence figures do not show clinically meaningful progress in reducing the frequency of CHD. The most popular hip-screening systems worldwide base hip status on the conventional ventrodorsal, hip-extended pelvic radiograph. With the hips in this position the underlying hip laxity is masked such that the number of dogs with susceptibility to show hip OA later in life is vastly underestimated. Of equal importance, these systems allow voluntary submission of hip films. As mentioned earlier, it is widely recognized that prevalence figures from such databases are biased and that actual prevalence of hip dysplasia is much higher than reported. One published study found the prevalence of CHD in 2-year-old Golden Retrievers randomly sampled from the PennHIP database to be 54% in contrast to OFA database figures of 24% and for Rottweilers it was 42% vs OFA figures of 23%. From another study, 47% of all hip radiographs ostensibly taken for hip evaluation were not submitted for evaluation while 53% were submitted. Of those submitted 4% were scored dysplastic, in stark contrast, 50% of those not submitted were scored dysplastic; more than a 10-fold difference.

The total monetary cost of CHD to society has not been accurately calculated, but from insurance company data, the estimate is easily in the 100's of millions of dollars per year (unpublished data in prep). The total cost of the disease, however, exceeds the monetary value. An accurate appraisal would require integrating the monetary, emotional and functional losses to pet owners, dog breeders, dog trainers, sportsmen, working dogs, and those disabled who depend on service dogs. Though not measurable, it is clear that the total loss to society attributable to CHD should be of great concern.

Many breeders and veterinarians have strictly adhered to OFA hip screening and in so doing they have demonstrated a sincere commitment to eliminating CHD from the dog world. It is estimated that 40,000 dogs undergo hip radiography each year for evaluation by the OFA, costing breeders and owners approximately 5 million dollars in professional fees to veterinarians and the OFA. While it is generally believed this cooperative effort in the U.S.A. has resulted in an overall decrease in the *severity* of CHD, as shown earlier the *incidence* of CHD has remained essentially unchanged. Hip dysplasia as a problem is further compounded by the absence of a clinically effective medical or surgical cure.

Requirements for Improved Hip Screening

Hip dysplasia remains the most common heritable orthopedic condition seen in veterinary practice and affects to variable degrees virtually every breed of dog seen by the practicing veterinarian. Also, we now recognize that hip dysplasia afflicts purebred cats at a rate much higher than previously thought. In tackling this disease there were several obvious requirements:

First, there was the need for an early and reliable diagnostic test to identify hip phenotypes that correlate with the ultimate development of CHD. It was generally recognized that the current diagnostic methods were associated with disappointing progress in reducing the frequency of CHD. Also, the age of testing was not ideal. Dogs must be one year of age (in UK and Europe) or two years of age (USA) before the radiographic test can be done. An earlier test would facilitate earlier decision-making on the part of prospective owners as well as dog breeders…and perhaps surgeons.

Second, the diagnostic procedure needed to be performed competently by veterinarians and technicians and made widely available to dog owners and dog breeders. This entailed training many veterinarians in private practice to perform the diagnostic procedure with precision and reliability.

Third, it was necessary to develop and maintain a comprehensive database to collect, manage and interpret the hip data from large populations of dogs of all breeds coming from the multiple regional and global centers. Ongoing statistical analysis and scientific scrutiny of the data would ensure that the technology continued to be effective toward its primary goal of reducing the incidence of CHD.

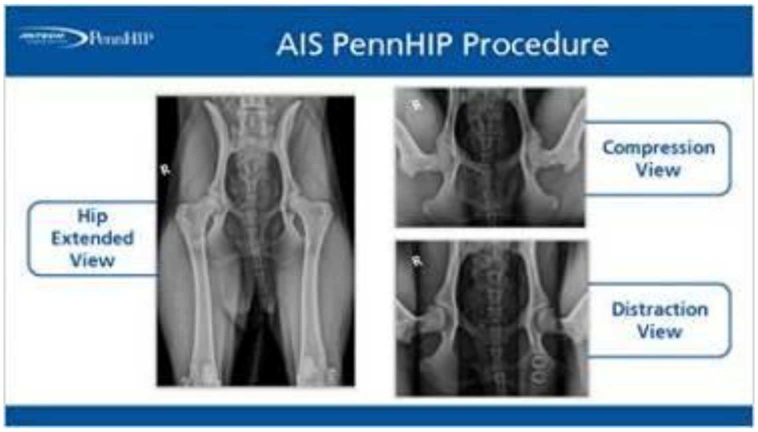
Fourth, to draw accurate conclusions from the database, it is imperative that sample data be truly representative of the hip status of the breeds of dogs under study. This objective could only be achieved by **mandatory submission of all hip films** from both dysplastic and non-dysplastic dogs. None of the widely used hip scoring systems globally has a mandatory radiograph submission policy. Such systems are biased toward normalcy because the best-looking hip radiographs have a greater chance of being submitted than the obviously dysplastic ones.

Finally, a DNA test for hip dysplasia is the ultimate goal and over the past decades much research has been focused on this objective. However, to date disappointing progress has been made. Reports have shown some association between the conventional hip dysplasia phenotype and genomic markers or gene loci but not sufficient to provide a clinically accurate screening test. When a DNA test is discovered it will almost certainly be the PennHIP phenotype against which genomic association will be made. This bold statement can be made based on the high heritability of the PennHIP phenotype, and the strong association of the phenotype with the ultimate development of hip OA. These topics will be covered in sections to follow.

PennHIP Strategies

Canine hip dysplasia (CHD) is a very common heritable orthopedic disorder. The disease causes pain and discomfort in dogs and results in markedly reduced performance and work longevity. No effective cure for the disease exists and the medical or surgical treatments currently practiced are at best palliative. For the pet owner, early PennHIP evaluation provides an estimate of the risk that a dog will develop the hip OA of canine hip dysplasia. Such information will help the veterinarian prescribe preventive measures to lower the risk for hip OA, and ameliorative measures to slow progression and control the associated pain. PennHIP testing is also important to dog breeders. The data compiled in the PennHIP database provides critical information that facilitates science-based selection of dogs to breed. The data also provides a logical stepwise quantitative genetic strategy that over generations will rapidly reduce the incidence and severity of CHD. To accomplish these objectives will require large populations of dogs to be tested using the PennHIP procedure. The data compiled in the PennHIP database can be investigated with respect to many parameters, including age, weight, gender, breed and the radiographic presence of hip OA. Utilization of appropriate statistical methodology yields relationships between passive hip laxity and the expression of osteoarthritis (OA) both within generations and across generations. The hip database also helps scientists and clinicians to address other important clinical questions, including, but not limited to, breed-specific biological and clinical expressions of hip disease and the efficacy of hip treatment as a function of preoperative PennHIP scores.

The AIS PennHIP Procedure



The AIS PennHIP procedure consists of three separate radiographs: the hip-extended view, the compression view and the distraction view. The hip-extended view is used to obtain supplementary information regarding the existence of osteoarthritis or OA of the hip joint. The subsequent compression and distraction views were developed to obtain accurate and precise measurements of joint laxity through the Distraction Index or DI.

Much greater detail about each of these views will be covered in upcoming chapters.

AIS PennHIP Certification

The process to become certified to perform the AIS PennHIP procedure begins with registering for the online training courses. This Manual supplements the courses. You will view all 5 courses and pass and complete the final online test for the program. **Once registered for the online program, you will have 14 days to complete it.** If, for some reason, you cannot complete it, you will simply re-register and start the online program over. After successfully completing the program you'll receive a certificate that shows your RACE credit and you will be eligible to go on to complete the AIS PennHIP Certification process.

To achieve consistent and reliable diagnostic results, the AIS PennHIP procedure requires that all members pass a certification process, which is the final step to determine clinical competency in performing the procedure.

To complete certification exercises you'll be submitting radiographs for 3 dogs. Specifically you will be submitting 5 radiographs for each dog: 1 - Hip Extended view, 1 - Compression view and 3 - Distraction views, therefore a total of 15 radiographs.

You'll have 45 days from the time you complete the on-line program to submit your certification radiographs. Images will be assessed for quality assurance, positioning technique and repeatability. Once your radiographs have met the established criteria, you'll receive your certification. Be sure to identify the 3 dogs you plan to use for certification before completing the online course. This facilitates completing the exercises within the 45 day interval. See Chapter 7 for complete details on the certification process.

Purchasing a Distractor

A distractor is needed to perform the distraction radiograph in the AIS PennHIP procedure. An AIS team member will be in contact with you via email or phone shortly after you register for the course to work with you to purchase a distractor. Your distractor will then be sent promptly so that you can begin the certification process. Email AIS at info@antechimagingservices.com to learn the current pricing for the distractor.

Antech Imaging Services

Once you become a certified member you will be submitting your radiographs to AIS PennHIP and the images will be interpreted by highly trained personnel. Learning the submission process is quick and easy. PennHIP is but one facet of Antech Imaging Services and you may find your practice can benefit from the other services provided by AIS. To help you better serve your clients and your patients, AIS offers you access to 39 board certified radiologist who are the experts in imaging and who will find answers to your imaging questions. AIS also works with Sound™ to find solutions to your digital imaging needs. AIS helps you improve the quality of medicine in your practice by providing easy, affordable access to board certified specialists for more thorough diagnostics in areas such as cytology, oncology, cardiology, and internal medicine, among others. By sending images to AIS and having your studies read by board certified specialists, it elevates your standard of care to set you apart from your competitors who don't use AIS. And by using AIS services, you will increase practice revenue because you have the ability to offer more services and diagnostics based on the results provided to you from AIS.

Summary

PennHIP was introduced clinically in 1993 as a science-based stress radiographic method for determining hip joint laxity and the development of OA. Funding for pivotal research came from The *University of Pennsylvania*, *The Morris Animal Foundation*, *The Seeing Eye, Inc.*, *Nestle Purina, Inc.* and several breed clubs, among others. Since 1983, a large pool of research had accumulated to definitively establish the efficacy of this diagnostic method prior to its being introduced clinically in 1993. From this body of work, hip laxity as measured by the PennHIP distraction index has been shown to be the primary phenotypic risk factor predicting the osteoarthritis of CHD. This discovery is a major step forward in the understanding of the origins of CHD.

However, how you measure hip laxity is critical. Hip laxity appearing on the conventional VD hip-extended radiograph has not been shown to accurately predict the OA of CHD. Moreover, no clinically meaningful progress in reducing the incidence of hip dysplasia has been made by using scoring of the hip-extended radiograph to select breeding dogs. The benefits of the PennHIP system for hip screening are substantial to veterinarians, dog breeders, dog trainers and the general dog-owning public. A major advantage of the PennHIP method is its proven efficacy to evaluate young dogs (16 weeks of age) and to predict with clinical accuracy the risk of developing OA later in life. Of equal importance, however, is its ability to identify those dogs with tight hips that are not at risk to develop OA. Using the PennHIP method of hip evaluation, veterinarians can test dogs early in life to determine the risk of developing hip dysplasia. With this information preventive measures to offset the risk or ameliorative measures to control the pain and disability of CHD can be prescribed. For future generations of dogs, time tested principles of quantitative genetics when combined with PennHIP laxity data represent a powerful tool for breeders to make real improvement in the hip quality of dogs. First and foremost, **AIS PennHIP is about dogs.**

References (included in the following chapters) Scientific Documents

For up-to-date information on the expanding pool of scientific documentation of the PennHIP method including comparisons to other methods, visit the PennHIP web site at:
www.antechimagingservices.com/pennhip

Chapter 2: CANINE HIP DYSPLASIA: Etiology, Pathogenesis, and Diagnosis

Introduction

Hip dysplasia is the most common orthopedic condition of the dog, causing joint inflammation and secondary osteoarthritis, which lead to variable degrees of clinical discomfort.[66] Genetically, it is a disease of complex inheritance, meaning that multiple genes, combined with environmental influences, ultimately cause expression of the condition. It was first described in 1935 by Gerry Schnelle,[161] and since that time, numerous investigators have reported on an array of potential causes.* To date, the underlying etiology and pathogenesis of the condition remain unclear. A central theme of most studies, however, is that hip joint laxity somehow plays a role in the development of osteoarthritis of canine hip dysplasia. See Figure 59-1 for degrees of hip dysplasia diagnosed from the hip-extended radiograph. Historically, the understanding that hip dysplasia has a genetic basis, coupled with the empirical observation that hip laxity plays a role in disease expression, led to diagnostic (screening) methods aimed at assessing hip laxity early in life with the hope that selecting the best candidates for breeding would lower the frequency of this common disease. Screening methods have ranged from palpation[7–9,132] to radiography[†] and, more recently, ultrasound, computed tomography (CT), and magnetic resonance imaging (MRI).[‡] Despite 75 years of observation and investigation, the diagnosis and treatment of hip dysplasia remain controversial. This chapter will attempt to compile available information on the role of hip laxity in the diagnosis of hip dysplasia and will cover genetic and other nonsurgical strategies used to lower the frequency of the disease, delay its expression, or ameliorate its severity. Special importance will be given to studies that were designed and conducted using the scientific method and contribute to evidence-based medicine.

Etiology and Pathogenesis

The study of the etiology and pathogenesis of canine hip dysplasia has been long and circuitous, and a comprehensive description of this history is not within the scope of this chapter. Multiple factors have been linked to the expression of canine hip dysplasia—some well-studied, and others empirically associated with the disease.[§]

The true cause of canine hip dysplasia remains unclear; however, it has been accepted that the disease reflects the interaction of multiple genes with environmental influences. The manifestation of the disease phenotype occurs in genetically predisposed animals exposed to environmental (nongenetic) factors that enhance expression of the genetic weakness. Probably the most descriptive definition of the disease was put forth by Olsson et al.[59] in 1966: "Hip dysplasia is a disease that stems from a 'varying degree of laxity of the hip joint, permitting subluxation during early life, giving rise to varying degrees of shallow acetabulum and flattening of the femoral head, finally inevitably leading to osteoarthritis.'" The early phenotype of canine hip dysplasia therefore has been defined empirically as hip joint laxity with or without radiographic evidence of osteoarthritic joint changes. In the sections to follow, we will show how this empirical definition of hip dysplasia continues to confound progress in unraveling the mysteries of hip dysplasia.

Hip Development

At birth, canine hip joints are normal,[112,153] and they are thought to continue normal development if complete congruity between the femoral head and the acetabulum is maintained.[150,182,183] During development of the hip, the earliest dysplastic joint changes are observed at 30 days of age: an edematous ligament of the head of the femur with torn fibers and capillary hemorrhage at the tearing sites.[131,151,156] Increased volume of the ligament of the head of the femur and increased synovial fluid volume have been considered the earliest findings of canine hip dysplasia.[17,100,167] In one study, the volume of the ligament of the head of the femur was significantly greater in puppies already displaying overt artorius itis but also in puppies at high risk for osteoarthritis based on parental phenotype.[100] Another study showed that Labrador Retrievers at high risk for osteoarthritis (as determined by a high distraction index) had an edematous ligament of the head of the femur and edematous cartilage in the respective lesion areas of the femoral head.[17] During the first month of life, the ligament of the head of the femur is thought to be primarily responsible for maintaining hip joint stability, such that in the first 2 weeks of life, the ligament is so short that the femoral head fractures at the fovea (attachment of the ligament) if forced to luxate.[151,156] After the initial 2 weeks, the ligament slowly begins to lengthen, and it has been posited that in dysplastic dogs it is this excessive lengthening that permits lateral subluxation of the adult hip joint.[151,156]

The first radiographic signs of canine hip dysplasia, seen as early as 7 weeks of age, are subluxation of the femoral head and underdevelopment of the craniodorsal acetabular rim.[151,156] At this time, the joint capsule is stretched but is not otherwise structurally altered, and the ligament of the head of the femur is lengthened. From 60 to 90 days of age, the degree of subluxation increases and significant radiographic changes are evident. Gross pathology reveals thickening and stretching of the joint capsule, permitting the femoral head to displace laterally and, in the most severely affected cases, dorsally. When subluxation occurs, the articular cartilage is worn and roughened on the dorsal surface of the femoral head at its point of contact with the acetabular rim (Figure 59-2). Evidence of palpable or radiographic laxity appears prior to degenerative structural changes. It has been reported that in a group of 48 Labrador Retrievers followed longitudinally to the end of life (i.e., the lifespan study), coxofemoral subluxation as seen on the hip-extended radiograph occurred by 2 years of age and not thereafter.[174]

Figure 59-1 Three hip-extended radiographs with degrees of dysplasia. **A,** Adult canine hips with no evidence of osteoarthritis. **B,** 7-month male Irish Setter showing subluxation on the left hip joint, poor femoral head coverage on the right hip, and femoral head metaphyseal sclerosis bilaterally with no signs of osteoarthritis. **C,** Adult canine hips with bilateral subluxation and severe osteoarthritis with bilateral femoral periarticular osteophyte formation, osteophytes on cranial and caudal acetabular margin, and advanced joint remodeling.

Figure 59-2 Gross necropsy specimen showing severe cartilage wear on the dorsomedial margin of femoral head, directly dorsal to the fovea capitis. The *red arrows* indicate the location of cartilage wear consistent with “catastrophic reduction” of the femoral head into the acetabulum upon foot strike. The *black arrows* show the extent of cartilage fibrillation and remodeling of the femoral head. **A,** Dorsoventral view. **B,** Craniocaudal view

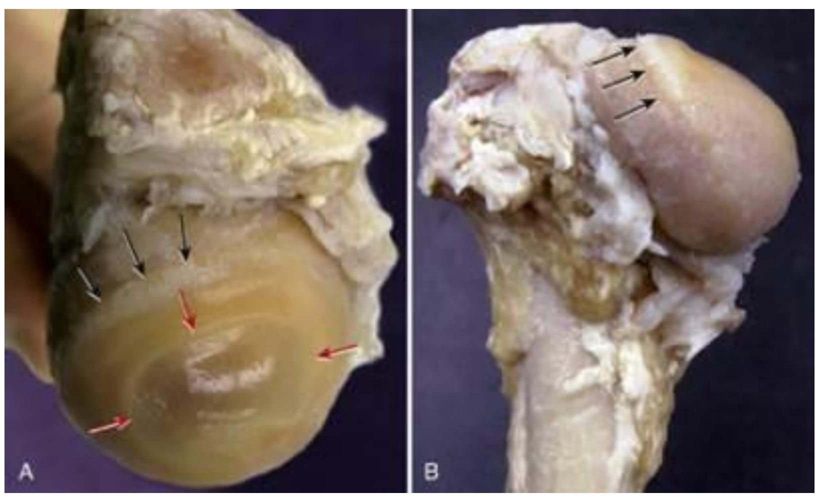
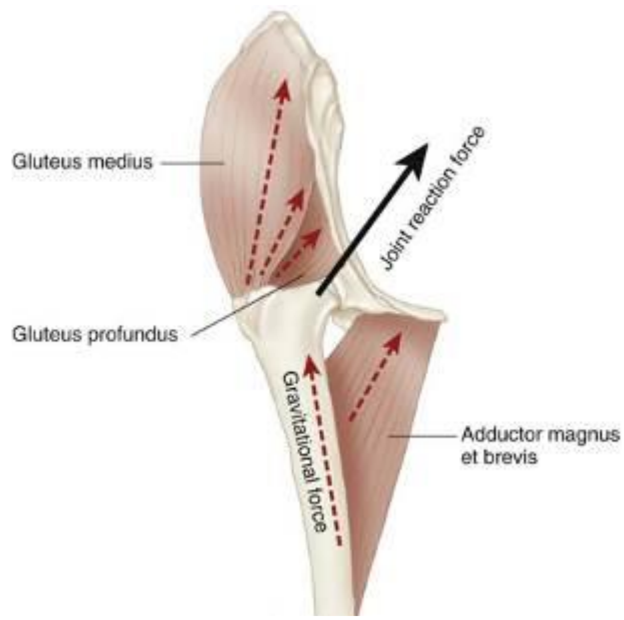


Figure 59-3 Cranial view of transarticular musculature during weight-bearing. The illustration shows the major muscles contracting during weight-bearing. The illustration is of a cranial view of the pelvis. The large gluteal muscle group acts to extend and abduct and internally rotate the hip whereas the adductor magnus et brevis muscles have compensatory adduction and external rotation (attributable to its insertion on linea aspera of femur). The illustration shows the lines of action of each muscle and the gravitational force *(red dashed lines),* which sum to make up the joint reaction force *(black line)*. The co-contraction of these muscles, along with the biceps femoris, semimembranosus, and semitendinosus *(not shown),* sum to form a large resolved force tending to reduce (and stabilize) the femoral head into the acetabulum during weight-

bearing. During the swing phase, however, the transarticular muscles acting to advance the hind limb in preparation for foot strike are the rectus femoris, artorius, and iliopsoas. These muscles have long muscle bellies with lines of action more parallel to the axis of the femur. Although they generate much lower loads than the muscles of weight-bearing, their orientation makes them prime candidates to cause subluxation in a lax hip joint. We propose that the femoral head subluxates during the swing phase of gate and upon foot strike the larger hip extensor muscles cause catastrophic reduction of the femoral head producing the characteristic cartilage erosion shown (see Figure 59-2).



(Modified from Evans HE: Miller's anatomy of the dog, ed 3, Philadelphia, 1993, Saunders/Elsevier.)
References 20, 38, 43, 60, 63, 95, 97, 107, 130, 137, 138, 151, 154, 167, 169, 176, 181, and 193.
† References 35, 40, 46, 65, 106, 126, 129, 147, 165, 169, 198, and 201.
‡ References 1, 25, 37, 44, 47, 49, 81, 111, 127, 144, 188, and 199.
§ References 21, 31, 42, 59, 84, 105, 109, 117, 119, 151, 164, 169, 179, and 191.

Biomechanics

In a healthy, congruent hip joint, forces during weight bearing are distributed across the entire cartilaginous surface of the acetabulum. The forces crossing the joint, the so-called *joint reaction force,* represent the vector addition of gravitational forces (the shared weight of the dog proximal to the hip joint) coupled with the muscle forces necessary to balance the moments of standing and locomotion (Figure 59-3). The muscle forces usually exceed the gravitational forces by a large margin, particularly during exertion. For example, in man, jogging may impose a peak hip joint reaction force of 4.3 to 5.0 times body weight (gravitational force) and stumbling 7.2 to 8.7 times body weight.[67] In the canine subluxated (lateralized) hip, the transarticular muscle forces must substantially increase to generate higher moments necessary to compensate for lateralization of the center of rotation of the joint. Additionally, cartilage stress (force divided by area of contact) is vastly increased in the subluxated (lateralized) hip because forces acting on the articular cartilage are spread over a markedly reduced surface area, namely the dorsal labrum of the acetabulum. Therefore, two destructive events accompany functional subluxation: (1) the forces crossing the joint increase, and (2) the area over which the forces are transmitted decreases. The associated increase in cartilage stress beyond its failure limits causes cartilage damage, joint inflammation, and ultimately osteoarthritis.

For dogs with functional subluxation, it is not known whether the hip is seated properly during the swing phase and then subluxates under the combined load of weight bearing and locomotion or, more likely, whether the hip is subluxated during the swing phase when the limb is not weight bearing, and the femoral head moves medially (and traumatically) toward a reduced position under the abrupt application of weight bearing and locomotor forces (see Figure 59-3). Although this was not described previously, mechanical justification exists for the latter mechanism for two important reasons. First, when the canine hip is weight bearing, the large and powerful muscles necessary for weight bearing and locomotion (propulsion) are acting. These muscles, particularly the gluteal and opposing adductor muscles, are oriented about the hip in such a way that each co-contraction creates a large resolved force, tending to reduce the femoral head into the acetabulum (see Figure 59-3). During the swing phase, on the other hand, the muscles necessary to advance the hind leg in preparation for the next foot strike generate relatively lower peak contractile forces, but, critically important, these muscles (e.g., the rectus femoris, iliopsoas and artorius) are oriented more parallel to the femur, making the orientation of the net load on the hip vertical and therefore more conducive to subluxation. If the hip happens to be in the subluxated position when foot strike occurs, traumatic hip reduction ensues. Second, the characteristic location of cartilage wear on the femoral head and acetabulum (see Figure 59-2) supports the latter theory that subluxation occurs during the swing phase. If subluxation, leading to cartilage wear, primarily occurred during weight bearing, one would expect the site of cartilage wear to be codirectional with the summation of those propulsive and weight-bearing forces crossing the coxofemoral joint (i.e., along the weight-bearing axis) and thereby more cranial and in line with the axis of the ilial shaft. The characteristic position of cartilage wear, directly dorsal to the fovea capitis and not in line with maximum propulsive forces, however, suggests that *catastrophic reduction* at foot strike is the cause, rather than *catastrophic subluxation* at the point of maximal contractile muscle forces during weight bearing. Admittedly, this is a theory based on observed anatomy and assumed mechanics and is in search of definitive proof.

The timing of functional subluxation within the gait cycle may be of no importance for hips having the most extreme forms of laxity, the so-called *luxoid* hips. For these hips, reduction cannot occur and the hip is permanently subluxated. At the origin of the cascade leading to hip osteoarthritis is functional hip joint laxity; accordingly, all diagnostic tests aim to assess hip joint laxity in a variety of positions. Heyman et al.,[60] from mechanical testing of cadaver hips, reported that passive hip-joint laxity is at its maximum when the joint is placed in a neutral weight-bearing position. This neutral stance position is defined as 15 degrees of extension, 10 degrees of abduction, and 0 degrees of internal/external rotation, relative to the plane and axis of the pelvis.[17] Pulling the hindlimbs into extension

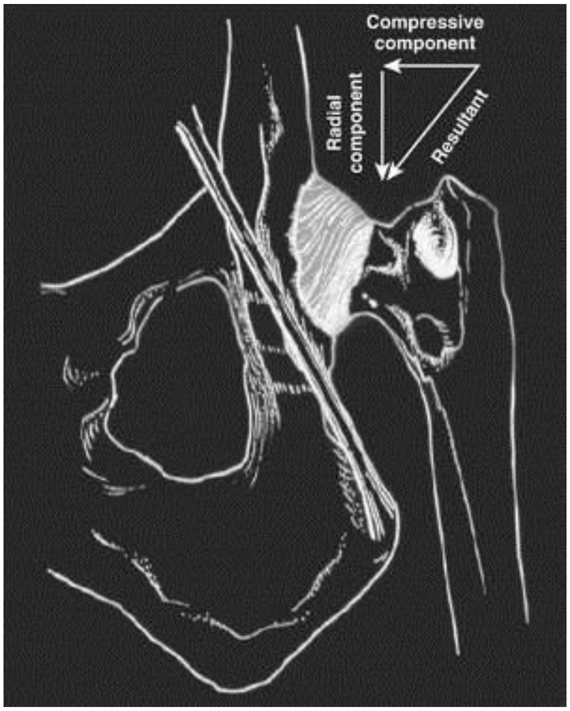


Figure 59-4 Coxofemoral joint capsule windup during extension. Figure shows the resultant force of capsular tightening with the hip in full extension resolved into two orthogonal components: the radial component prevents further rotation (extension) of the coxofemoral joint and the compressive component forces the femoral head into the acetabulum. The compressive component is absent in the neutral distraction radiographic position, which explains the 2.5 to 11 times more passive hip laxity that can be measured.[74]

(Modified from Smith GK, Biery DN, Gregor TP: New concepts of coxofemoral joint stability and the development of a clinical stress-radiographic method for quantitating hip joint laxity in the dog. J Am Vet Med Assoc 196:59, 1990.)

as typically performed for radiographic hip screening, was shown to produce a windup of the coxofemoral joint capsule, which severely limited the lateral movement of the femoral heads (Figure 59-4),[60] thereby limiting observable hip laxity. Furthermore, mechanical testing of cadaver canine hips in this neutral position indicated that the degree of lateral femoral head displacement is not directly proportional to the applied force, as some have proffered. In fact, the hip joint can be modeled as a ball on a rope (biphasic behavior) rather than a ball on a spring (so-called *hookean* behavior). The understanding that displacement of the femoral head from the acetabulum was maximized in the neutral position and was largely independent of the distraction force (Figure 59-5)[173] formed the research basis for a diagnostic method (the University of Pennsylvania Hip Improvement Program [PennHIP] method). The relative independence of lateral displacement from applied force also suggested that multiple examiners performing this method should expect high method repeatability both within and between examiners.[60,70,104,168,171]

Genetics

The holy grail for diagnosing hip dysplasia would be the identification of all gene mutations that collectively underlie the expression of canine hip dysplasia and osteoarthritis. Molecular genetic studies on canine hip dysplasia are ongoing, but to date progress has been slow and somewhat disappointing based on predictions. For example, it was predicted by a prominent human geneticist that the genes for canine hip dysplasia would be identified by 1997. Clearly, such a bold prediction has not come to fruition.

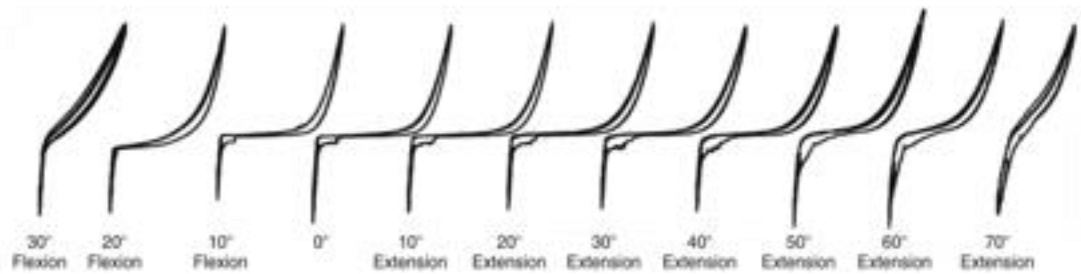
Similar slow progress has been observed in molecular genetic studies of quantitative traits in man. Such traits include cancer and Alzheimer’s disease, among others.[196] Some progress toward unraveling the genetic underpinnings of canine hip dysplasia has been made, however. Quantitative trait loci (QTL) for hip dysplasia or related phenotypes have been found in a few breeds. A QTL is a region on a chromosome that contains a gene or a group of genes that influences the phenotypic expression of a quantitative trait such as hip dysplasia. A QTL for acetabular osteophyte formation has been mapped to chromosome CFA03 (canine familiaris autosome 3) in Portuguese Water Dogs.[23] Susceptibility loci for canine hip dysplasia have been mapped to several chromosomes, including chromosomes 4, 9, 10, 11, 16, 20, 22, 25, 29, 30, 35, and 37.[22,113,192] QTL intervals associated with the distraction index on CFA11 and CFA29 have been refined using single nucleotide polymorphism genotyping. Linkage analysis showed that the QTL on CFA11 in the 16.2 to 21 cM region explained 15% to 18% of the total variance in distraction index. Evidence for an independent QTL on CFA29 was weaker than that on CFA11.[207] Most recently, a study identified four susceptibility single nucleotide polymorphisms associated with canine hip dysplasia and two single nucleotide polymorphisms associated with hip osteoarthritis. Three of the single nucleotide polymorphisms are adjacent to human genes previously associated with human osteoarthritis.

Clearly there is a long way to go to equal or surpass the clinical utility of a phenotype like the distraction index or even the Norberg angle or the subjective hip-extended score. Continued progress in identifying candidate genes depends on the accuracy of the phenotype to which genomic association is made. Next steps in molecular biology include fine mapping of regions of interest, followed by screening for recognized candidate genes within these regions. It is conjectured that identifying a mutation or a genetic marker such as a SNP or a haplotype of single nucleotide polymorphisms could be combined with the pedigree and other phenotypic information in a complex mathematical formula, suitably weighted, to arrive at more accurate estimates of breeding value related to hip conformation.[208] However, it is doubtful that all phenotypic variation will be explained by focusing on association or candidate gene identification because not all phenotypic variation originates from the genes. It is a sobering recognition that *epigenetics*, which is the study of inherited changes in phenotype or gene expression caused by mechanisms other than changes in the underlying DNA sequence, could be responsible for 50 to 100 times more phenotypic variation than that produced by the genes themselves.[24,116]

Joint Laxity

Joint laxity as measured by distraction index has been shown to be the primary risk factor for the development of coxofemoral osteoarthritis in all breeds studied (Figures 59-6 and 59-7).[159,169,175,177] Passive hip laxity, an estimation of functional hip laxity, permits subluxation of the femoral head during the gait cycle, resulting in abnormal force distribution across the joint, leading to premature wear of the articular cartilage and microfractures in the subchondral bone and ultimately progressing to osteophyte formation and osteoarthritis.[157] Dogs with higher degrees of joint laxity are at

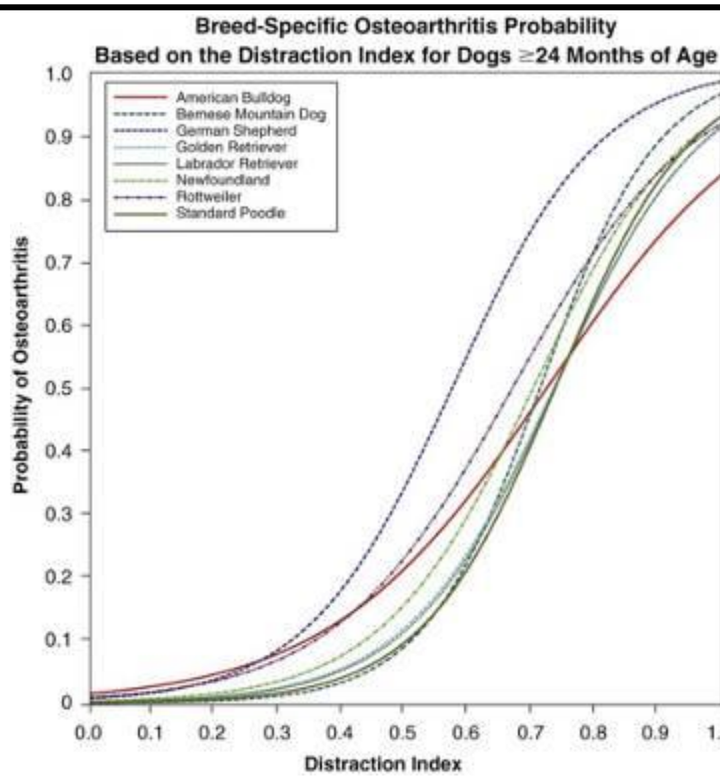
Figure 59-5 Load/displacement curves from the hip joint of a dog at 10 degree increments from flexion to extension. Each tracing represents five complete load/displacement cycles at each extension/flexion angle. Abduction and internal rotation was held constant at 10 degrees and 0 degrees, respectively. Displacement is plotted along the horizontal axis with load along the vertical axis. Applied load ranges from 40 N of compression to 80 N of distraction. The figure illustrates the linear nature of the curve at extremes of flexion and extension with sigmoidal shape at neutral positions. The obvious sigmoidal shape at neutral position means that at low distractive loads a large amount of lateral translation occurs (horizontal portion of the curve) but at high distractive loads very little additional displacement is observed (vertical portion of the curve). This load-displacement behavior explains the high repeatability of measurable lateral translation of the hip with the application of sufficient force (>30 newtons).



(Modified from Smith GK, LaFond E, Heyman SJ, et al: Biomechanical characterization of passive laxity of the hip joint in dogs. Am J Vet Res 58:1078, 1997.)

Figure 59-6 Metrics of hip laxity estimation. These laxity measurements are calculated from radiographs of a 25-month-old intact female Golden Retriever, with the Norberg angle and % femoral head coverage measurement made from the hip-extended radiograph and the distraction index measured on the distraction radiograph taken at the same radiographic session. Each of these metrics is consistent with hips of increased passive laxity. **A,** Norberg angle (NA) is a measurement of femoral head displacement from the acetabulum. NA is calculated by drawing a line connecting the centers of the femoral heads and one from the center of each femoral head to the craniolateral acetabular rim on the same side. NA ≥105 degrees is considered normal by one source.[201] This dog's Nas of 96 degrees and 93 degrees on left and right hips, respectively, are consistent with increased hip laxity. **B,** The distraction index is the measurement of maximal femoral head displacement from the acetabulum when the legs are placed in a neutral position and a distractive force is applied. The distraction index is calculated by dividing the distance between the geometric center of the femoral head and the geometric center of the acetabulum by the radius of the femoral head. Risk of osteoarthritis increases as the distraction idex exceeds 0.3. This dog's distraction index of 0.71 is consistent with increased laxity and increased risk of osteoarthritis. **C,** Percentage of femoral head coverage (% FHC) is a measurement of femoral head displacement from the acetabulum. Normal FHC (i.e., good hip joint congruity) is defined as ≥50% coverage; therefore the % FHC of 30.87% shows increased laxity and poor femoral head coverage.

Figure 59-7 Logistic regression curves showing probability of radiographic osteoarthritis as a function of the PennHIP distraction index for dogs of eight common breeds that were ≥24 months of age at time of evaluation based on the PennHIP database in November 2010. The numbers of dogs used to generate each breed-specific curve are 497 Bulldogs, 380 Bernese Mountain Dogs, 1600 German Shepherd Dogs, 2962 Golden Retrievers, 4136 Labrador Retrievers, 335 Newfoundlands, 695 Rottweilers, and 508 Standard Poodles. Note the spatial shift to the left for the German Shepherd Dog, indicating increased risk of expressing osteoarthritis at a given distraction index compared with other dog breeds.



(Similar curves, based on data in the PennHIP database at the time of each publication, were published in Smith GK, Mayhew PD, Kapatkin AS, et al: Evaluation of risk factors for degenerative joint disease associated with hip dysplasia in German Shepherd Dogs, Golden Retrievers, Labrador Retrievers, and Rottweilers. J Am Vet Med Assoc 219:1719, 2001; and Runge JJ, Kelly SP, Gregor TP, et al: Distraction index as a risk factor for osteoarthritis associated with hip dysplasia in four large dog breeds. J Small Anim Pract 51:264, 2010.)

increased risk for developing osteoarthritis compared with those with lower degrees of laxity.[159,169,175] Laxity measurements by distraction index are predictive of osteoarthritis susceptibility. The risk of osteoarthritis increases as the distraction index increases beyond 0.30, and dogs with distraction index below 0.30, such as most Greyhounds and Borzois, are not susceptible to acquiring osteoarthritis, even later in life (Figure 59-8).[70,169,175] Subluxation, a subjective assessment of hip laxity, derived from the hip-extended radiograph is another risk factor for osteoarthritis. Data from a lifespan study showed that dogs with coxofemoral subluxation developed osteoarthritis on average 9 years earlier than those without subluxation;[174] however, 98% of dogs in that study developed osteoarthritis by end of life, whether or not they showed subluxation. This was explained by the fact that all dogs in the study had hip laxity in the osteoarthritis-susceptible range as measured by distraction index (DI > 0.30).[174]

Although laxity appears to be a common and well-recognized factor in the development of osteoarthritis, it is unclear what actually causes joint laxity. Several causes have been proposed.

Joint Fluid

Significantly increased passive joint laxity and incidence of canine hip dysplasia have been reported in dogs with significantly higher volumes of synovial fluid and a thickened ligament of the head of the femur.[96,100] In a cadaver study, the experimental addition of fluid to the hip joint caused an increase in passive laxity; similarly, removal of excessive joint fluid reduced joint laxity.[173] It is still uncertain whether these changes are the primary cause of hip laxity, or if they occur as secondary changes caused by the disease of hip dysplasia. Homeostatic mechanisms to regulate hip synovial fluid volume have not been identified. Synovial production is primarily mediated by dialysis of blood from the intracapsular vessels whereby the endothelium, connective tissues, and synoviocytes modify the plasma for synovial fluid production. Equilibrium between new formation and removal of synovial fluid is maintained by drainage through the intracapsular veins and lymphatic vessels; however, the mechanism for volume control is not understood. This equilibrium becomes impaired when inflammatory processes occur in the form of capsular edema and leakage of proteins from the synovial vasculature.[3,100,146] Inflammatory, effusive, and degenerative changes may obscure the specific nature of the disease, making it impossible to distinguish between primary and secondary alterations.[109] However, the finding that joint laxity as measured by distraction index (itself a reflection of synovial fluid volume) is essentially constant during development ($r_i > 0.82$)[169] and for the periods measured (up to 3 years) provides evidence to suggest a genetic basis for the regulation of synovial fluid volume.[33]

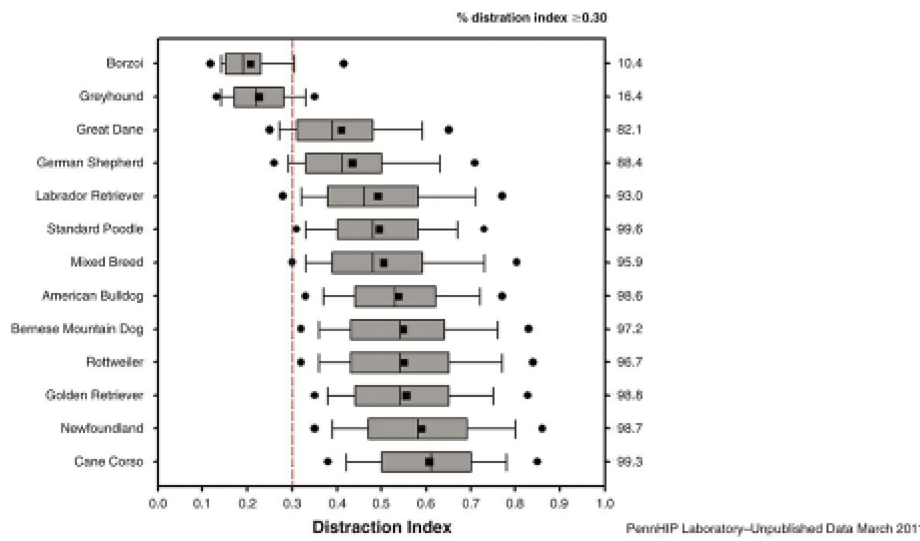
Pelvic Muscle Mass

A positive correlation between pelvic muscle mass and the prevalence of hip dysplasia has been reported.[152] Investigators stated that a disparity between strength of the pelvic muscles and rapid weight growth in the young dog led to joint instability (laxity) and ultimately to hip dysplasia. It was found that the muscle mass of dysplastic breeds of dog was less than that of nondysplastic breeds, with Greyhounds having large thigh muscles and a low incidence of hip dysplasia compared with the small thigh muscle mass of German Shepherd Dogs with a high incidence of hip dysplasia.

Hormonal Factors

Various hormones, including estrogen and relaxin with their synergistic effects, contribute to the relaxation of pelvic and coxofemoral ligaments during parturition.[6,200] Administration of high doses of exogenous estrogen to young pups and pregnant bitches resulted in increased coxofemoral joint laxity in the pups, along with other skeletal malformations.[54,137,200] Estrogen levels in the physiologic range, however, have not been shown to cause changes in hip laxity or dysplasia in the dog. Hassinger et al.[55] followed nine bitches through a single estrous cycle, measuring serum hormone concentrations and hip laxity (distraction index and Norberg angle) during each phase of the estrous cycle. No association was found between serum hormone levels and hip laxity. Laxity measurements by distraction index remained constant throughout the entire cycle with intraclass correlations of 0.93 and 0.92 for left and right hips, respectively. Variability of Norberg angle measurements was slightly greater than that of distraction index measurements throughout this study, but the measurements could be considered constant throughout the cycle having high intraclass correlations of 0.86 and 0.82 for the left and right hips, respectively. Relaxin, however, found in high concentrations during the last trimester of pregnancy and in the milk of lactating bitches, has been associated with increased peripheral joint laxity in human beings and dogs. Higher levels of relaxin were found in a group of Labrador Retrievers than in a group of Beagles. The authors concluded that this might contribute to the relatively higher incidence of canine hip dysplasia in Labrador Retrievers.[180]

Figure 59-8 Box and whisker plots of the PennHIP distraction index in 13 breeds of dogs, including the eight breeds in Figure 59-7. *Box* indicates 25th to 75th percentiles; *vertical line* indicates the median; *square* indicates the mean, with *circles* indicating the outliers. Figure indicates the vastly different breed laxity profiles, particularly comparing Greyhounds and Borzois versus breeds with increasing susceptibility to canine hip dysplasia. In breeds of dogs in which all members have a distraction index of ≥0.30, it is possible that canine hip dysplasia susceptibility is genetically fixed. The numbers of dogs used to generate each breed-specific box plot are 67 Borzois, 55 Greyhounds, 847 Great Danes, 9659 German Shepherd Dogs, 21,148 Labrador Retrievers, 1875 Standard Poodles, 5453 Mixed-breed dogs, 2503 American Bulldogs, 1692 Bernese Mountain Dogs, 2199 Rottweilers, 13,524 Golden Retrievers, 1636 Newfoundlands, and 1090 Cane Corsos.

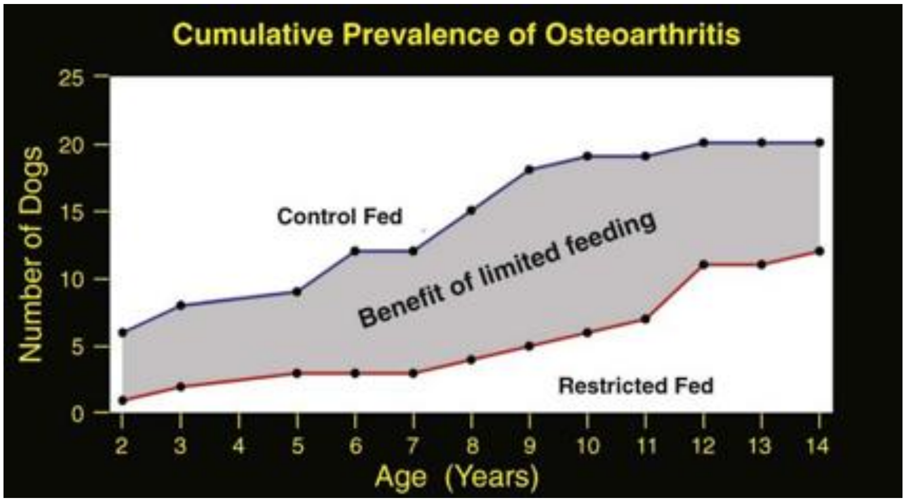


Weight and Growth

Hip dysplasia development has been linked to the age and weight of the animal. In 1964, it was reported that rapidly growing pups had a higher incidence of canine hip dysplasia at maturity than those with slower weight gain. In a group of German Shepherd Dogs, it was observed that the heaviest males and the heaviest females at 60 days of age had the highest incidence of canine hip dysplasia at maturity.[149] A contribution to the development of canine hip dysplasia was attributed to the rate of acetabular growth plate fusion, with earlier fusion seeming to lead to dysplastic joints.[99]

Body weight has proved to be an influential environmental factor through several studies.[79,176] Although increased body weight does not cause canine hip dysplasia, it plays an instrumental role in the manifestation of the disease phenotype in dogs having genetic susceptibility for the disease. In a life span study following 48 Labrador Retrievers, it was reported that heavier dogs developed radiographic osteoarthritis on average 6 years earlier than their thinner littermates. See Figure 59-9 for the benefits of restricted feeding to slow the onset of hip osteoarthritis.[176] Heavier dogs required long-term treatment for osteoarthritis 3 years earlier on average than slimmer dogs.[75] Weight reduction has been accepted as a highly effective preventive strategy for delaying or preventing the onset of osteoarthritis in susceptible dogs.[58,73,149] Puppies delivered by cesarean section and raised at drastically reduced rates of weight gain developed lower frequency of canine hip dysplasia at adulthood. Although radiographically negative for hip dysplasia, these dogs are known to be susceptible to canine hip dysplasia because their offspring tested positive for the disease.[98]

Figure 59-9 Cumulative prevalence of hip osteoarthritis in control-fed versus restricted-fed dogs. The figure is taken from the lifespan study in Labrador Retriever Dogs and illustrates the benefit of restricted feeding in the onset of hip osteoarthritis. At 2 years of age, one restricted-fed dog expressed hip osteoarthritis compared with six dogs in the control-fed group.



(From Smith GK, Paster ER, Powers MY, et al: Lifelong diet restriction and radiographic evidence of osteoarthritis of the hip joint in dogs. J Am Vet Med Assoc 229:690, 2006.)

Nutrition

No dietary deficiencies have been shown to “cause” hip dysplasia, but dietary excesses have been found to contribute to development of the disease.[78,121–123,148] Vitamin C has a role in collagen synthesis; which is diminished in states of extreme deficiency. The resulting disease is known as *scurvy*. An early theory was that megadoses of vitamin C given to pregnant bitches and puppies for 2 years after birth prevented canine hip dysplasia.[11] However, this hypothesis was never rigorously investigated. Furthermore, megadoses of vitamin C can be harmful, potentially leading to hypercalcemia in puppies and resulting in delayed bone remodeling and cartilage maturation.[148] High dietary calcium and excessive vitamin D increased calcium absorption in the intestinal tract, causing delayed endochondral ossification and skeletal remodeling and ultimately leading to canine hip dysplasia.[56,57,108] High dietary anion gap was associated with a corresponding increased osmolality in synovial fluid, higher synovial fluid volume, and increased joint laxity as measured by the Norberg angle on the ventrodorsal hip–extended radiographic projection.[78] Protein and carbohydrate quality and concentrations were investigated as causal for hip dysplasia; however, valid evidence to support these theories does not currently exist.

Environmental Factors

Hip dysplasia is known to be a complex trait (also known as a *quantitative* or *polygenic trait*); therefore by definition, it has both a genetic and an environmental basis to explain the observed variation in expressed phenotype. For example, in gender-matched cohorts of Labrador Retriever littermates, food restriction (an environmental influence) to maintain a lean body mass was shown to have a profound effect on delaying the onset and lowering the severity of hip dysplasia.* Because genetic variation in the two feeding cohorts was minimized by pairing littermates, the variation in observed hip phenotype could be attributed to diet restriction—an environmental (nongenetic) factor. This life span study followed earlier studies, leading to similar conclusions.[58,73,149]

One additional environmental factor shown to delay the expression, or lessen the severity, of canine hip dysplasia in puppies is injectable polysulfated glycosaminoglycan. Twice weekly intramuscular injections of polysulfated glycosaminoglycan administered from 6 weeks to 8 months of age to puppies derived from dysplastic parents reduced hip subluxation scores and reduced histopathologic evidence of arthritis at 8 months of age when compared with untreated controls.[103] Other potentially ameliorative candidate strategies await discovery, including the use of pharmaceuticals, nutraceuticals, omega-3 fatty acid diets, or specific exercise and rehabilitation regimens, to mention a few. Adequate longitudinal trials imposing these strategies in cohorts of puppies matched for osteoarthritis susceptibility have not been carried out; however, this is an exciting area for future investigation.

References 76, 77, 79, 139, 174, 176, and 186.

Other Causes

It has been hypothesized that the ratio of collagen type I to type III was related to the development of canine hip dysplasia. It was initially believed that lack of type I collagen (responsible for strength) was found in the joint capsule in dysplastic animals; however, when the ratios were compared between dysplastic and nondysplastic dogs, no significant difference was found. It was theorized that the amount of procollagen type III (PIIINP) in serum and synovial fluid would be indicative of dysplasia; however, these levels stay the same throughout adulthood, and no differences between dysplastic and nondysplastic dogs have been found.[109]

Pectineal muscle myopathy was associated with hip dysplasia. Tight pectineal muscles generated a pull on the femur that pushed the femoral head dorsally onto the acetabular rim. Histologic changes were found in the myofibers of the pectineus; however, neither myectomy nor tenotomy reduced the incidence of canine hip dysplasia.[18,19,63]

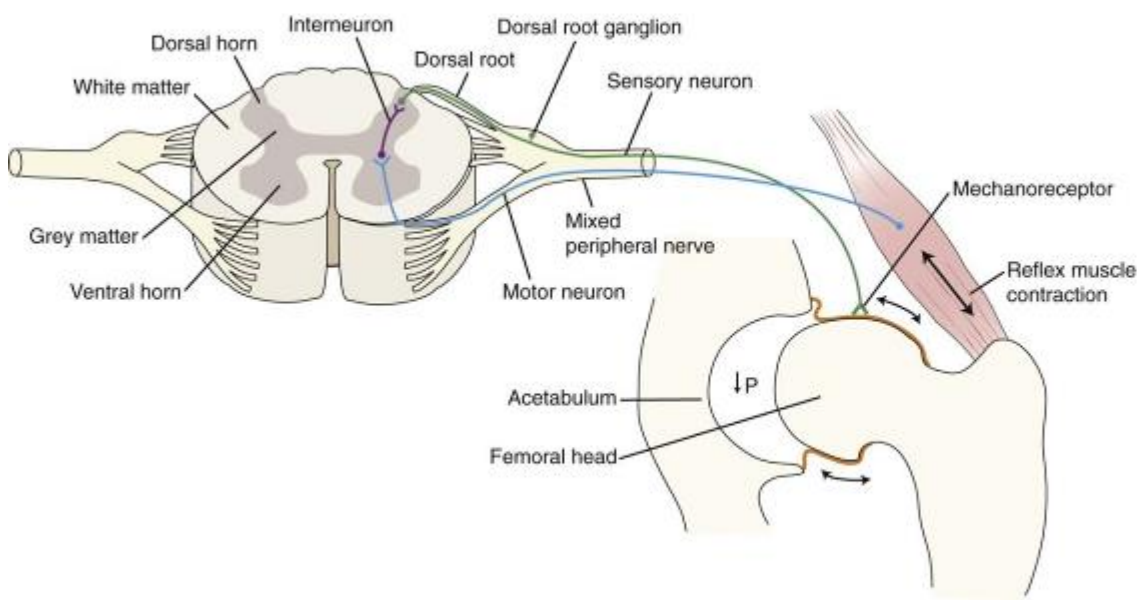
In toto, none of the proposed etiologies in this section fully explains the development of canine hip dysplasia, and none has led to a reliable diagnostic test that provides more predictive value than the measurement of hip joint laxity. The most compelling pathogenic factor is the synovial fluid volume theory[168] to explain observed early joint laxity in puppies. Of course it is possible that a combination of causes could be acting in concert.[35,96,168] Some have argued that synovial fluid volume could be simply joint effusion resulting from the trauma of instability of hip dysplasia—an effect rather than a causal factor.[197] However, if such were the case, the volume of synovial fluid would not be expected to be so tightly biologically regulated as demonstrated by the constancy of joint laxity in dogs from 16 weeks to 3 years of age.[169] This theory is central to the distraction diagnostic method that is gaining increasing acceptance for detection of susceptibility to canine hip dysplasia.

Proposed Pathogenesis of Hip Dysplasia

With the discovery in the 1980s that mechanoreceptors exist within the joint capsule and other fibrous constraints of the joint, a new awareness of the complexity of joint function followed. The joint was an organ—not just a system of ropes, pulleys, gliding surfaces, and lubrication. The joint was constantly sending out signals to the brain and surrounding tissue as to its position, location in space, and state of loading. By this reasoning, a cruciate ligament under conditions of high strain or load might send a signal (by pathways as yet not fully understood) to the semitendinosus muscle, recruiting contraction to assist the anterior cruciate ligament in its function and protecting it from dangerously high loads.[92]

Although the knee has been the subject of much more investigation than the hip in this regard, we can for this exercise assume the two joints to be more similar than different in terms of their neurobiology and feedback mechanisms. A theoretical pathogenic mechanism to explain how increased synovial fluid volume might lead to destructive joint forces in the hip is illustrated (Figure 59-10). Under ideal conditions, the synovial fluid volume of the hip is fixed and minimal, such that when the joint tends to subluxate during the swing phase (also theoretical, see Figure 59-3), the low intracapsular pressure generated severely limits possible translation. With low synovial fluid volume, critical pressure differentials would cause the capsule to invaginate, thereby stretching the capsule.[167] This stretching early in the translation of the femoral head would trigger capsular mechanorecepters to recruit appropriate periarticular muscles into protective roles. The protective muscle action would serve to position the femoral head close to the acetabulum, such that when the much larger loads of foot strike and weight bearing are initiated, little or no abrupt reduction of the hip occurs. In contrast, with increasing synovial fluid volume, these protective mechanisms are triggered progressively later during hip subluxation of the swing phase (i.e., it takes greater subluxation of the femoral head to cause the same stretching of the capsular mechanoreceptors), and it is conceivable that in the extremely lax joint, no muscle recruitment whatsoever occurs. With the hip subluxated at the point of foot strike, increasingly catastrophic reduction of the femoral head into the acetabulum would ensue. The degree of functional subluxation would correspondingly increase with the increasing volume of synovial fluid, resulting in greater and greater impact of the femoral head on the acetabular labrum upon foot strike, producing cartilage damage and erosion at the characteristic sites and ultimately leading to osteoarthritis. Although this description is admittedly theoretical, it does begin to piece together our evolving understanding of the anatomy, mechanics, and neurobiology of the hip joint. Other joints in a dog diagnosed with hip dysplasia may have similar increased synovial fluid volume, but by reason of anatomic design, these joints (such as the knee or elbow) may be more geometrically constrained and less dependent on synovial fluid volume for stability. However, high synovial fluid volume may still be detrimental. Evidence of this possibility can be derived from a study showing that 8-year-old Labrador Retrievers having radiographic hip osteoarthritis had a greater likelihood of showing radiographic osteoarthritis of the shoulder and elbow than dogs without hip osteoarthritis at 8 years of age.[76]

Figure 59-10 Theorized hip-joint capsule mechanoreceptor feedback loop. Under ideal conditions, the synovial fluid volume of the hip is fixed and minimal, such that when the joint tends to subluxate during the swing phase (also theorized), the low intracapsular pressure *(P)* created is one factor tending to limit possible translation. A second factor is an active factor, a feedback loop triggered by this capsular stretching. With lower synovial fluid volume, critical pressure differentials would occur earlier in the subluxation process, causing the capsule to invaginate and thereby stretching it. This stretching early in the translation of the femoral head may activate capsular mechanorecepters to recruit appropriate periarticular muscles into protective roles. The protective muscle action would serve to position the femoral head closer to the acetabulum such that when the much larger loads of foot strike and weight bearing are initiated, little or no abrupt reduction of the hip occurs. With increasing synovial fluid volume, these protective mechanisms are triggered later and later during the subluxation of swing phase (i.e., it takes greater subluxation of the femoral head to trigger stretching of the capsular mechanoreceptors). In dogs having the most severe hip laxity, it is possible that recruitment of protective mechanisms fails to be successfully initiated prior to foot strike. As proposed earlier (see Figure 59-2), this would lead to catastrophic hip reduction at foot strike.



Signalment and History

Canine hip dysplasia can affect any breed of dog, but it is most commonly reported in large and giant breeds, such as German Shepherd Dogs, Rottweilers, Labrador Retrievers, Golden Retrievers, Saint Bernards, and many more.[26,28,29,45,202] In contrast, sight hounds, such as Greyhounds and Borzois, have a very low risk of canine hip dysplasia, and it is almost nonexistent in these breeds. See Figure 59-8 for how Greyhound and Borzoi distraction index distribution compares with breeds with higher canine hip dysplasia prevalence.[70,154,169]

The clinical signs of canine hip dysplasia can vary extensively from slight discomfort to severe acute or chronic pain. Although disease onset has a linear progression over time,[176] the clinical signs can be divided into two forms. In the juvenile or severe form, dogs typically present between 5 and 12 months of age.[151] Young dogs often present with sudden onset of unilateral or bilateral hindlimb lameness, bunny-hopping, difficulty rising after rest, reluctance to walk, run, jump, or climb stairs, exercise intolerance, or pain/soreness of the hindlimbs. These early acute clinical signs are thought to be the result of extreme joint laxity. Histologic examination of such juvenile dogs with canine hip dysplasia has shown that stretching and tearing of the joint capsule (synovitis), ligaments, and muscles, along with microfracture of the dorsal acetabular rim from overloading, are the most likely causes of pain in young patients.[151] As dogs become older, the capsular strain and inflammation induced by joint laxity cause periarticular fibrosis. This phase of the disease is often associated with reduction or even elimination of clinical signs. It had been thought that fibrosis helps to stabilize the joint.[10,28] However, another study[51] showed that hips develop increased laxity as chronic osteoarthritis progresses.

The more common chronic form of canine hip dysplasia has highly variable onset of clinical signs in the mature dog, with some never showing overt signs, and with diagnosis detected incidentally upon radiography that includes the pelvis. In the older dog, as the disease progresses, patients suffer pain most often related to degenerative joint disease. The mature canine hip dysplasia patient can present with sudden onset of clinical signs, but most affected dogs have a more chronic presentation because of the slow progression of degenerative changes. Patients often present with a history of bilateral or unilateral pelvic limb lameness, have difficulty rising, have stiff pelvic limbs especially after rest or the day following strenuous activity, prefer to sit, and may be reluctant to walk, run, or jump.

Physical Examination

A complete general physical examination should be performed both to rule out other disease processes and to determine the health of the patient for sedation and/or general anesthesia. Orthopedic and neurologic examinations are necessary to localize clinical signs to the coxofemoral joint and to eliminate other orthopedic or neurologic conditions that may have a similar presentation to canine hip dysplasia. Because many breeds at high risk for canine hip dysplasia have a high incidence of other causes of hindlimb lameness, such as panosteitis, osteochondrosis, or rarely, hypertrophic osteodystrophy in the juvenile dog, and cranial cruciate disease, lumbosacral disease, or neoplasia in the mature dog, it is imperative to accurately localize the clinical signs to avoid inappropriate diagnosis and treatment of canine hip dysplasia. For instance, one study[141] found that 32% of dogs referred to a teaching hospital for management of canine hip dysplasia actually had clinical signs attributed to cranial cruciate ligament rupture. Within some breeds of dogs, hip dysplasia may affect more than 90% of the breed in later life, so it is important to rule out coincident orthopedic diagnoses before arriving at canine hip dysplasia as the source of clinical signs.[141,174]

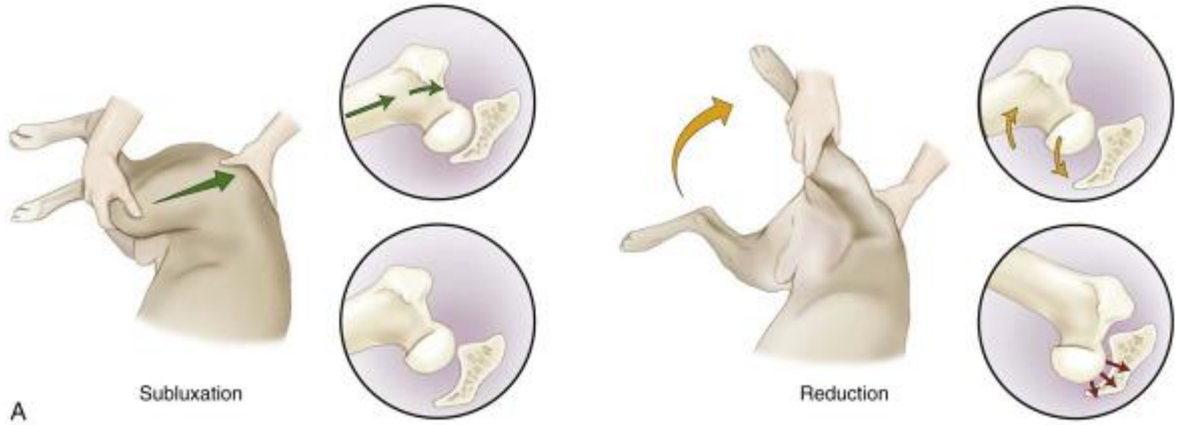
On visual inspection of dogs with the severe form of canine hip dysplasia, extreme permanent subluxation of the femoral heads resulting in protrusion of the greater trochanters dorsally and laterally may be observed. Subluxation may also make the dog appear low and wide in the hind end, which may become exaggerated as muscles atrophy. Dogs with hip dysplasia can have a wide- or narrow-based stance, depending on the stage of disease. Initially, dogs are thought to have a wide-based stance in an attempt to keep their hip reduced; when this compensation fails, they develop a narrow-based stance to decrease the discomfort caused by reduction of the femoral head after subluxation.

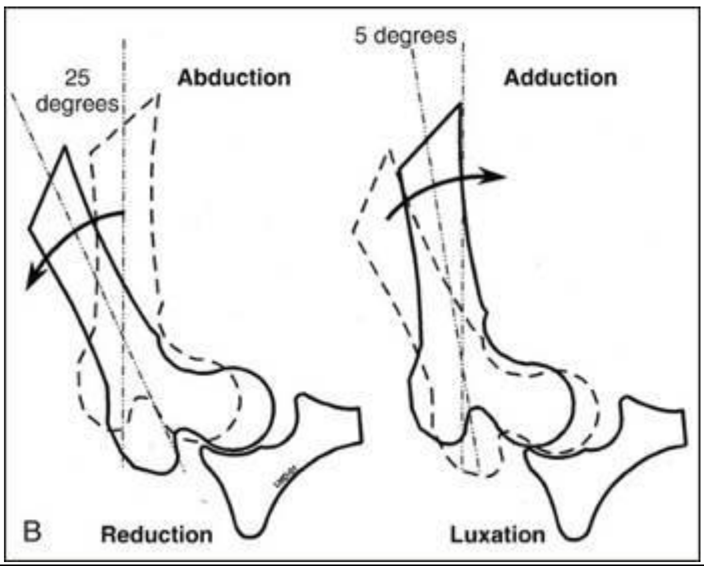
When the gait of a dysplastic dog is observed, a hip or spinal sway may be noticed, which is hypothesized to be an attempt to decrease pain by decreasing hip excursion. Patients with canine hip dysplasia have a stiff, short-strided gait, along with a shift of their weight to the thoracic limbs by extending both their stifle and tarsal joints. Therefore, these patients tend to have increased muscle mass of the thoracic limbs and atrophied pelvic limb musculature, as well as an arched-back stance. A bunny-hopping gait, in which the dog uses both pelvic limbs together, particularly when running or going up stairs, is sometimes seen in puppies with severe hip laxity. Similar to spinal sway, it is thought that the bunny-hopping gait is an attempt to decrease pain by decreasing range of motion of the hip joint and allowing the spine to take on more of a role in forward propulsion. Also, the forces on each hip during weight bearing and propulsion are divided in half by using both hind legs together.

On palpation, pain sometimes can be elicited when pressure is applied over the hip or during range of motion, most notably during extension, particularly in dogs having the severe juvenile form of the disease. Coxofemoral range of motion may be decreased and typically is most limited during extension. As the disease advances, crepitus can be palpated during range of motion. In the young dog, semiquantitative palpation maneuvers may be used to assess joint laxity, including the Bardens, Barlow, and Ortolani tests.[7–9,132] The most widely adapted maneuver is the Ortolani test (Figure 59-11). When the Ortolani test is performed, the patient can be placed in dorsal or lateral recumbency according to practitioner preference. In the lateral position with the hip in neutral orientation, one hand is placed on the distal aspect of the stifle, and the other is placed on the dorsal pelvis and spine to provide stabilization. The first part of the Ortolani is the Barlow test, in which the limb is in an adducted position and a force is directed through the femur toward the dorsum of the dog via the hand grasping the dog's stifle. This force causes dorsal subluxation of the femoral head in dogs with hip laxity. The Barlow test is considered to be a provocative test in that it creates subluxation of the lax hip. In the second part of the Ortolani test, the limb is abducted, maintaining force up the axis of the femur, and a click or clunk can be heard and/or palpated as abrupt reduction of the hip occurs. This clunk is interpreted as a positive Ortolani sign and suggests laxity of the coxofemoral joint. The Ortolani test is considered a reduction maneuver.

The Bardens method for hip joint palpation is performed with the dog in lateral recumbency with the femur perpendicular to the plane of the pelvis; a direct lateral force is manually applied with one hand lifting the femur, without abduction, and the other hand resting on the greater trochanter. Finger pressure on the medial thigh to elicit Bardens method can cause discomfort in the awake dog. This discomfort is not related to hip pain. Any movement of the greater trochanter by more than 1/4 inch suggests laxity of the joint. In the mature dog, a positive Ortolani sign or Bardens test is rarely palpated, even in dysplastic dogs, most likely because of the presence of periarticular fibrosis, remodeling of the dorsal acetabular rim, or the presence of a shallow acetabulum. The older dog's physical examination findings likely will be consistent with the chronic pain of degenerative joint disease, and, for the typical pet-quality dog, it is often difficult to find any clinical signs associated with mild osteoarthritic changes. Although the presence of a positive Ortolani sign is consistent with joint laxity, this has not been shown definitively to be a predictor of later development of clinical signs or osteoarthritis; conversely, Ortolani-negative dogs have not been shown to be normal throughout life. For example, the authors of one study reported that although distraction index was significantly associated with positive Ortolani, such that for every 0.1 increase in distraction index the risk of a positive Ortolani increased by 3.1 times, 50% of Ortolani-negative dogs, and therefore assumed to be normal, had hip laxity indicating osteoarthritis susceptibility by distraction index.[143] Subjective tests, like the Ortolani sign, need to be combined with complete assessment of the patient before an accurate diagnosis and a potential treatment plan can be implemented. These palpation techniques are further reviewed later in the chapter.

Figure 59-11 Ortolani maneuver. **A,** Ortolani maneuver. Step 1: Subluxation. The dog is positioned in lateral or dorsal recumbency. In lateral recumbency, the examiner is caudal to the dog with one hand on the distal stifle (flexed to 90 degrees) and the other is dorsal to the pelvis, with the thumb resting over the greater trochanter. The limb is in an adducted position, and force is applied toward the dorsum of the dog up through the femur *(green arrow),* causing dorsal subluxation in a hip with joint laxity. Step 2: Reduction. The limb is slowly abducted *(yellow arrow)* while force along the axis of the femur is maintained. A positive Ortolani sign is felt when a click or clunk is heard or palpated as the subluxated femoral head reduces into the acetabulum *(red arrow)*. **B,** Line drawing illustrating the Ortolani angles of subluxation *(left)* and reduction *(right)*. Some surgeons use the angles palpated during the Ortolani maneuver as indications for triple pelvic osteotomy surgery. The angles of reduction and subluxation are thought to represent, respectively, the maximum and minimum angles needed for acetabular rotation to provide stability.





Imaging Examination

Radiography

Radiography is the principal diagnostic modality to detect canine hip dysplasia. Other diagnostic modalities, including clinical signs, palpation, ultrasound, CT, and MRI, have received attention in the literature; however, none has been shown to have improved diagnostic or prognostic utility.

Hip-Extended Radiography

The ventrodorsal hip-extended radiograph has been used to evaluate the canine hip since the first case of canine hip dysplasia was reported by Schnelle in 1935[162] with the first hip-extended radiograph of the pelvis published in 1937. The animal is positioned in dorsal recumbency, and the hindlimbs are pulled into extension with femora parallel and slightly pronated (internally rotated), such that the patella appears superimposed centrally over the trochlear groove (see Figure 59-1, *A*).[155] By convention, this hip-extended positioning has been accepted and used worldwide for nearly 50 years to screen for canine hip dysplasia.[4,12,155,168,198] Recently, it has come under closer scrutiny and has been reported to be an insensitive diagnostic tool having poor precision and predictive accuracy for diagnosis of canine hip dysplasia,[72,195,204] such that even among highly skilled examiners, radiographic interpretation of the hip-extended view varies greatly.[72,135,155,195]

In a biomechanical study of the hip joint, a windup of the coxofemoral joint capsule was observed when the hind legs were pulled into extension (see Figure 59-4), as they are for the hip-extended radiograph, forcing the femoral head to become more tightly seated in the acetabulum and thereby masking observable joint laxity (Figure 59-5). This phenomenon is thought to be one factor contributing to the high rate of false-negative diagnoses of canine hip dysplasia: dogs having joint laxity may appear normal via this radiographic technique.[60,168] Nonetheless, hip laxity, subjectively or objectively interpreted as subluxation on the hip-extended radiograph, has been empirically accepted as the earliest visible radiographic change associated with canine hip dysplasia.[59,157] In addition to subluxation, radiologists assess the radiographic presence of osteoarthritis to arrive at a confirmed diagnosis of canine hip dysplasia when evaluating the hip-extended projection (Box 59-1).

Box 59-1 Radiographic Evidence of Osteoarthritis

- Femoral periarticular osteophyte formation
- Subchondral sclerosis of the craniodorsal acetabulum
- Osteophytes on the cranial or caudal acetabular margin
- Joint remodeling from chronic wear

From Owens JM, Biery DN: Radiographic interpretation for the small animal clinician, Baltimore, 1999, Williams & Wilkins.

It is established that the development of radiographic signs of osteoarthritis lags behind the early structural changes associated with osteoarthritis. Early changes typical of osteoarthritis can, however, be found on arthroscopy or gross pathology and histopathology.[61,155] Because the characteristic radiographic signs of osteoarthritis take time to develop, radiologists have empirically accepted the presence of apparent joint laxity (subluxation) on the hip-extended radiograph to be diagnostic of canine hip dysplasia.

As mentioned previously, radiographic signs of osteoarthritis and therewith definitive diagnosis of canine hip dysplasia are strongly influenced by the age of the animal at the time of evaluation.[65,176,203] Jessen and Spurrell reported that at 6 months of age, 16% to 32% of the dogs examined were correctly diagnosed as dysplastic; at 1 year of age, correct diagnoses increased to 63% to 69%, and at 2 years of age, 92% to 95% of dogs were correctly diagnosed as dysplastic based on characteristic radiographic signs of canine hip dysplasia on the hip-extended radiographic evaluation performed at 5 years of age.[65] Their plot of cumulative canine hip dysplasia prevalence versus age of the dog suggested that no new cases of canine hip dysplasia develop after 5 years of age, although the dogs were not followed beyond 5 years of age. The Orthopedic Foundation for Animals (OFA) decided to limit the earliest age of hip screening in the United States to dogs 2 years of age or older on the basis of this Jessen and Spurrell study. A similar association between age and canine hip dysplasia diagnosis was reported by Smith et al., but in this study it was determined that osteoarthritis prevalence increased linearly with age (r^2 = 0.987) in a fixed cohort of Labrador Retrievers followed longitudinally for life.[174,176] Other hip-extended screening methods around the world such as the British, European, and Australian systems specify dogs 1 year of age or older to be screened for canine hip dysplasia, with the rare exception of a few specific large and giant breeds of dogs.[16,40,46,201] Based on available evidence, this practice is associated with a minimum error in diagnosis of 30%.

Radiographic changes associated with osteoarthritis have recently been under investigation. Over the past decade, three radiographic features on hip-extended radiography that were hitherto ignored have been considered to have clinical significance.[114,139,158,186] These are the *caudolateral curvilinear osteophyte (CCO),* the *circumferential femoral head osteophyte (CFHO),* and, for lack of a better term, what has been described as a "puppy line" in the area of the femoral neck. Evidence is fairly conclusive that the caudolateral curvilinear osteophyte and the circumferential femoral head osteophyte represent early radiographic osteophytic signs that predict later development of the characteristic (and well-accepted) radiographic signs discussed earlier in this chapter (Figure 59-12).[114,118,139,158,186] Adoption and application of these radiographic features are not yet standardized among veterinarians and veterinary radiologists.

The puppy line,[114,139,158] an indistinct subtle opacification on the femoral neck in the area of the caudolateral curvilinear osteophyte in young dogs, has been considered an incidental self-limiting radiographic finding (gone by 18 months of age). Both the puppy line and the caudolateral curvilinear osteophyte appear on the hip-extended radiograph in the same area of the femoral neck, making it important to differentiate between the two. Risler et al.[158] confirmed earlier published findings that there was no correlation between puppy line at 15 to 17 weeks of age and later osteoarthritis of the hip in high- or low-risk breeds, but an additive correlation was noted between caudolateral curvilinear osteophyte and circumferential femoral head osteophyte at 24 to 27 weeks, with prevalence of osteoarthritis by 42 to 52 weeks of age. These findings support the inclusion of these radiographic signs in current hip dysplasia screening systems. The major hip screening systems worldwide have not yet decided to include these radiographic features as osteophytes reflecting underlying hip dysplasia.

Orthopedic Foundation for Animals

In 1961, a panel of 10 veterinarians, recognized as experts on canine hip dysplasia, convened to consider standards for diagnosing and classifying canine hip dysplasia.[198] The panel formulated guidelines on radiographic equipment and positioning of dogs, as well as descriptions of the normal hip joint, hip dysplasia, and radiographic and clinical signs of the disease.[155,198] Although the American Veterinary Medical Association (AVMA) convened this panel of experts, the respective report and the described method of hip evaluation were not officially approved by the AVMA as the preferred method of hip screening in the United States.[5] The following statement, dated July 12, 2010, is the official position of the AVMA:

> "The AVMA has no policy addressing the positioning of dogs for the screening of hip dysplasia. In 1961 the AVMA convened a panel on Canine Hip Dysplasia that drafted a report for informational purposes. The report did not result in an AVMA guideline or standard. An adaptation of that report

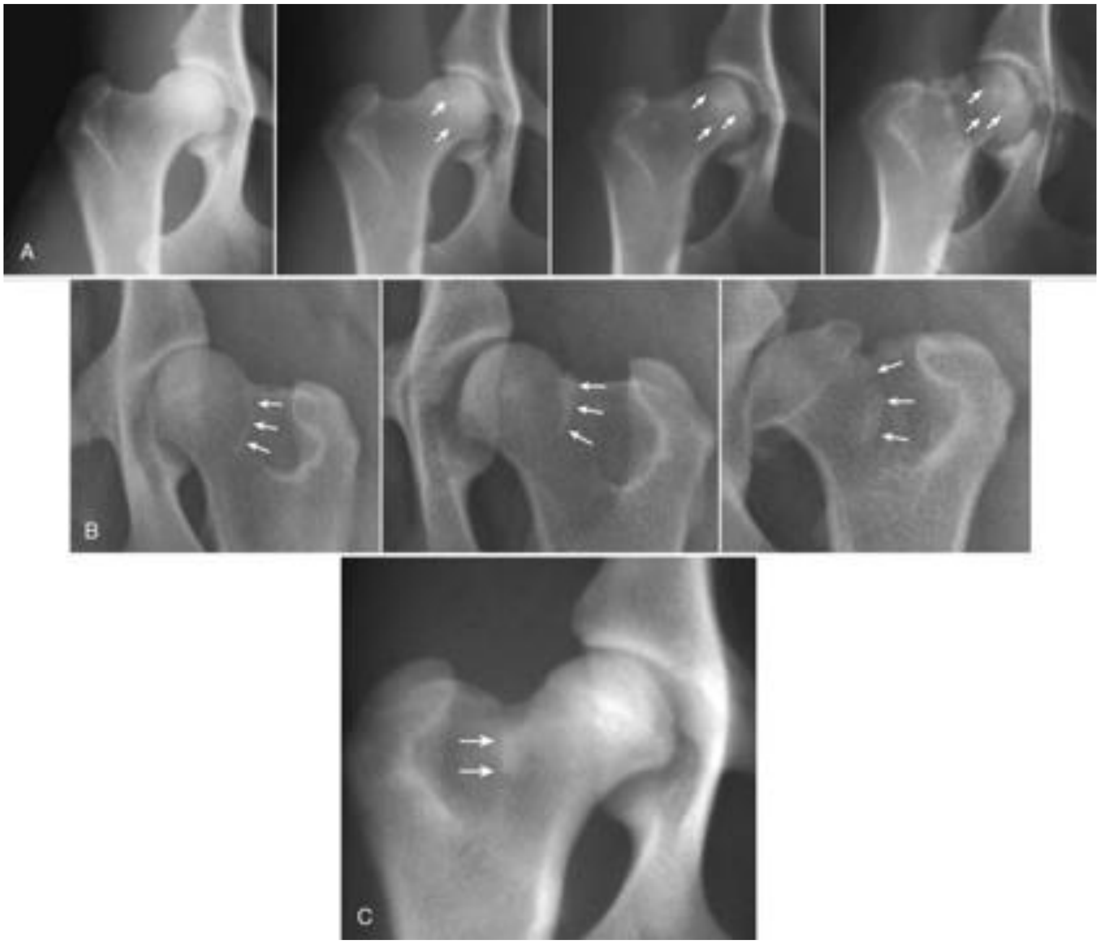
was published in the *Journal of the AVMA* in 1961."[5]

Based on the 1961 panel recommendations, Dr. Wayne Riser and others founded the Orthopedic Foundation for Animals (OFA) in 1966. This organization has become the primary hip screening body in the United States.

The OFA scores hips based on the consensus of three radiologists using a subjective seven-point ordinal grading system (excellent, good, fair, borderline, mild dysplasia, moderate dysplasia, severe dysplasia). Dogs must be at least 24 months of age at the time of evaluation[65] to receive official certification for breeding. Dog owners submit the hip-extended films to the OFA on a voluntary basis. Voluntary film submission, a common practice worldwide, subjects the respective database to a large "prescreening" (selection) bias.[68,69,135] It has been reported that radiographs of "normal-appearing" hips are 8.2 times more likely to be submitted for OFA evaluation than films showing joint abnormalities.[135] Although it has long been assumed that selection bias was not a factor for dogs having "normal appearing" hip films, one study[135] found that 50% of hip films withheld from submission to the OFA were considered "normal" by a board-certified radiologist. These data indicate that the practice of voluntary film submission produces indeterminate selection bias in dogs being screened by the OFA, whether normal or abnormal, making it untenable to arrive at accurate disease prevalence figures or to assess the rate of improvement in hip scores using a database with voluntary submission practices.

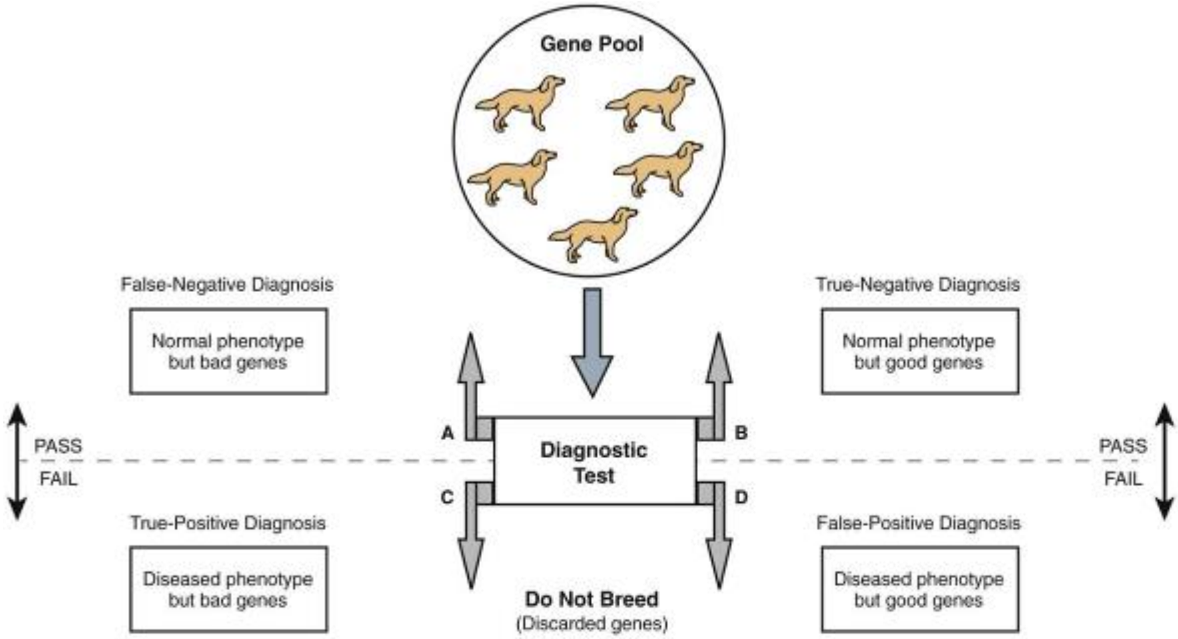
The precision and predictive accuracy of official OFA scores evaluated against ultimate osteoarthritis development have not been reported. In a direct comparison of OFA scores and distraction index, it was reported that 52% of hips scored OFA *excellent*, 84% of hips scored OFA *good*, and 94% of hips scored OFA *fair* had joint laxity in the osteoarthritis-susceptible range defined by DI $\geq$ 0.30.[140] Dogs carrying the genes (susceptibility) for canine hip dysplasia, falsely diagnosed as "normal," are unwittingly returned to the gene pool for breeding purposes based on OFA scores (Figure 59-13). Dogs, even breeding dogs, are not required to be evaluated later in life to determine whether the 2-year scoring is accurate.

Figure 59-12 Early radiographic osteophytosis. **A,** Circumferential femoral head osteophyte (CFHO). CFHO is seen as a *white line* at the articular margin of the femoral head that may or may not extend completely around the femoral head. Figure shows ventrodorsal hip-extended radiographic views of the right hip joint of a Labrador Retriever, indicating onset and progression of CFHO. From left to right, there is no CFHO (4 years of age), grade 1 CFHO (6 years of age), grade 2 CFHO (8 years), and grade 3 CFHO (11 years). **B,** Caudolateral curvilinear osteophyte (CCO). CCO, also called *Morgan's line,* is a well-defined linear density on the femoral neck between the greater trochanter and the capital physis in dogs 18 months or older. Figure shows ventrodorsal hip-extended radiographic views of the left hip joint of three different adult dogs showing *(from left to right)* grade 1 CCO, grade 2 CCO, and grade 3 CCO. **C,** Puppy line. A puppy line is an indistinct radiodense line on the femoral neck in dogs younger than 18 months of age in a similar location to the CCO, but it is more subtle, more diffuse, and shorter than the CCO. Figure shows ventrodorsal hip-extended radiographic view of the right hip joint of a juvenile dog with a puppy line. This radiographic feature is self-limiting and is not clinically significant.



(**A** from Szabo SD, Biery DN, Lawler DF, et al: Evaluation of a circumferential femoral head osteophyte as an early indicator of osteoarthritis characteristic of canine hip dysplasia in dogs. J Am Vet Med Assoc 231:889, 2007.)

Figure 59-13 Role of the diagnostic test in selective breeding. The objective of any diagnostic test for genetic disease is to lower the frequency of "bad genes" in the gene pool. This entails using the results of the genetic test, the phenotype, to estimate the genotype. Dogs are permitted to enter the gene pool based on normal results of the test (*arrow A* or *B*). A perfect test (*arrows B* and *C* only) would be capable of accurately separating "good" from "bad" genes on the basis of phenotype alone. Unfortunately, no diagnostic test of a complex genetic trait is 100% accurate. The greatest potential damage to the gene pool is a test result indicating that a dog has a normal phenotype (negative) but in fact harbors bad genes *(arrow A),* thereby recycling bad genes through the gene pool.



(From Kapatkin AS, Mayhew PD, Smith GK: Genetic control of canine hip dysplasia. Compend Contin Educ Pract Vet 24:681, 2002.)

Fédération Cynologique Internationale

The Fédération Cynologique Internationale (FCI) hip-grading system is used throughout continental Europe, Asia, and Russia, and parts of South America.[106] Hips are evaluated based on the hip-extended radiograph, with the optional addition of a frog-leg position radiograph. The FCI scheme, varying slightly by country, is based on letter grades A through E, with letters A and B having subgroups 1 and 2, and A1 representing the best grade. Hip-extended radiographs of dogs at least 12 months of age are evaluated, although for some large- and giant-breed dogs, the minimum age requirement is 18 months. Norberg angles (Nas) are measured to quantify laxity with angles greater than 100 degrees corresponding to scores A and B (see Figure 59-6, *A*).[15,106] Individual breed clubs select an examiner to grade hips of dogs within the club. These scores are then reported to the FCI central database. Due to FCI policy of accepting scores assigned by anyone, even laypersons who consider themselves expert in the evaluation of canine hip radiographs, the level of experience and the quality of the hip score vary greatly among examiners.[39,195] Interobserver agreement on FCI scores has been reported to be low, even among highly experienced evaluators, and the credibility of the FCI screening method as it is currently applied in most of Europe has been questioned.[27,194,195]

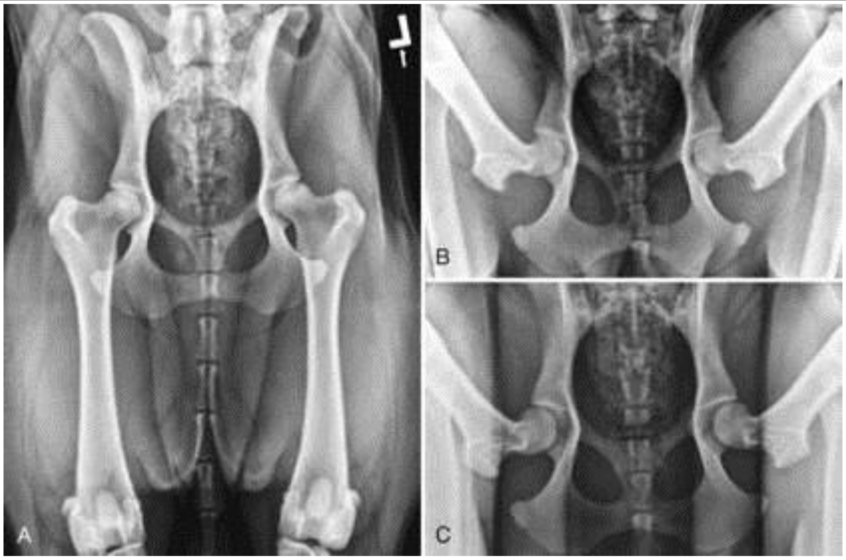
British Veterinary Association/Kennel Club

In 1978, the current British Veterinary Association/Kennel Club (BVA/KC) program for controlling hip dysplasia was established for the German Shepherd Dog and it applied to all breeds in 1983.[201] The BVA system is currently used in the United Kingdom, Australia (Australia Veterinary Association [AVA]), and New Zealand (New Zealand Veterinary Association [NZVA]) and is based on evaluation of hip-extended radiographs of dogs at least 12 months of age. Each hip joint is evaluated individually, with eight of nine radiographic features (both subjective and objective) scored on a scale from 0 to 6, and one feature scored from 0 to 5 (0 being ideal).[46,201] Scores are added for a maximum (worst) subtotal score of 53 per hip and a maximum total score for both hips of 106. Two of the nine features provide estimations of laxity, degree of subluxation and Norberg angle, whereas the remaining seven features evaluate the presence and severity of osteoarthritis. For breeding purposes, the BVA and each country (AVA, NZVA) individually keep records of mean and median scores for each breed. Only dogs with scores below the breed mean score are considered breedable; however, similar to the OFA and FCI schemes, film submission is voluntary, and breeding thresholds are not enforced.[204] Also, there is no requirement for later film evaluation to confirm the predictive accuracy of the 1-year assessment. Predictive accuracy for both the AVA and BVA systems were reported to be low.[72] Comparison of NZVA total hip scores versus laxity scores by distraction index showed that dogs classified as "low risk" by the NZVA scores (<2) did not have distraction index below the 0.30 threshold, and dogs scored as "low risk" by distraction index (<0.30) did not have total scores below 2.[204] Although the BVA system attempts to objectify a subjective measure, it still results in a high rate of false-negative diagnoses, thereby hindering further genetic progress toward eliminating canine hip dysplasia from the canine population (see genetic section).

Neutral-Position Radiography: AIS PennHIP

The University of Pennsylvania Hip Improvement (PennHIP) program was introduced in 1993. It is the most evidence-based hip screening method available to date.* Initial PennHIP research focused on the relationship of various measures of hip laxity to the

Figure 59-14 PennHIP radiographic views. **A,** Ventrodorsal hip-extended radiograph is evaluated by PennHIP for the presence of conventional osteoarthritis), caudolateral curvilinear osteophyte (CCO), and circumferential femoral head osteophyte (CFHO). This hip-extended radiograph of an adult dog shows adequate coverage of the femoral head, bilateral CCO, and no conventional osteoarthritis. At the writing of this chapter, neither the CCO nor the CFHO is interpreted by PennHIP to be osteoarthritis. This convention will likely change as corroborative research findings are published. **B,** Compression radiograph is evaluated by PennHIP for congruity of the coxofemoral joint, to determine bone landmarks for calculation of the distraction index, and to ensure that there is a difference in laxity between submitted compression and distraction radiographs. This compression radiograph shows good congruity of the coxofemoral joint due to complete compression of the femoral head into the acetabulum. **C,** Distraction radiograph is evaluated by PennHIP for calculation of the DI, which is the distance between the center of the femoral head and the center of curvature of the acetabulum divided by the radius of the femoral head. This distraction radiograph shows bilateral moderate laxity with a distraction index of 0.42, indicating mild to moderate risk of osteoarthritis as the dog ages.



ultimate development of osteoarthritis. This foundation research will be covered in a later section comparing the advantages and disadvantages of available hip screening methods. The PennHIP method requires that dogs be heavily sedated or anesthetized and positioned in dorsal recumbency.[168] Three radiographic exposures are made: a ventrodorsal hip-extended radiograph, a compression radiograph, and a distraction radiograph with the legs in the neutral position and the hips distracted (Figure 59-14). The distraction device is placed between the legs and acts as a fulcrum at the level of the proximal femur, serving to lateralize the femoral heads when the practitioner exerts a small adduction force. The neutral, stance-phase position was identified through mechanical testing of cadaver hips to be the position of maximal measurable passive hip laxity.[60] Positioning tolerances of ±5% were determined about the maximal position to permit high repeatability among examiners.

The distraction radiograph permits quantification of the relative degree of femoral head displacement from the acetabulum by means of a distraction index (see Figure 59-6). The distraction index ranges from 0 to >1, with 0 representing full congruency of the hip joint and 1 representing complete luxation. The compression radiograph shows the congruency and true depth of the hip joint and allows identification of critical bony landmarks, permitting highly repeatable laxity measurements from the corresponding distraction radiograph. A nonzero compression index, indicating lack of complete congruity, may be the earliest indicator of osteoarthritis of the hip, even before signs of osteoarthritis are identified on the hip-extended radiograph.[51] The hip-extended radiograph is included as part of a routine PennHIP evaluation to allow identification of conventionally defined osteoarthritis and to permit comparisons of the distraction index to the contemporaneous or future development of radiographic osteoarthritis. Multiple studies document the significant relationship between the distraction index and the development of hip osteoarthritis[114,159,169,175] within various breeds of dogs (see Figure 59-7).

Unlike other methods of hip dysplasia screening, the PennHIP method requires that the veterinarian performing the procedure be trained and successfully complete quality assurance exercises. To avoid selection bias in the database, it is mandatory for all PennHIP evaluations to be submitted, irrespective of hip status. Noncompliance with this policy is grounds for dismissal from the program. The

PennHIP procedure can be performed with documented accuracy as early as 16 weeks of age[2,169,170] compared with the 1 or 2 years minimum recommended age with other canine hip dysplasia screening systems previously discussed. The PennHIP report includes a distraction index for each hip, a subjective assessment of the presence and severity of osteoarthritis, and a laxity ranking of the individual dog (based on the looser of two hips) relative to other members of the breed. Because PennHIP is a continuous scale, it is not a pass/fail system; however, dogs showing definitive radiographic signs of osteoarthritis are given a designation of "confirmed hip dysplasia."

A major advantage of the PennHIP method for practicing veterinarians is its ability to assess the "risk" of a young dog developing the osteoarthritis of canine hip dysplasia later in life (see Figure 59-7).[114,138,159,169,175] Dogs with high distraction index (looser hips) will show radiographic (and clinical) signs earlier than those with lower distraction index (tight hips).[174] Dogs having the tightest hips (DI <0.30) have a very low likelihood of developing osteoarthritis of canine hip dysplasia. This information is critical for three strategic purposes. First, dogs with very tight hips (DI <0.30) are highly sought by service dog agencies. Such predictive information is vital for the selection of service dogs prior to the financial investment associated with training. Maximum working longevity is one of the primary goals for service dogs, and dogs having the tightest hips will have longer and more active service lives. Second, dog breeders, knowing the ranking of the individual dog within the respective breed, can use the information to select appropriate breeding candidates to make genetic changes toward better hip phenotype (discussed later). Third, for dogs in the current generation, the veterinarian can assess the risk of osteoarthritis in young dogs and begin a conversation with pet owners on the prospect of osteoarthritis later in life and how to prevent it. A logical opportunity to perform the PennHIP procedure would be at the time of anesthesia to neuter the dog (approximately 6 months of age or later). Based on osteoarthritis susceptibility, the veterinarian could recommend regular follow-up radiographic assessment of the dog's hips to determine the onset and progression of disease.

Clinically, one of the most exciting new strategies in medicine today, both human and veterinary, is *predictive medicine*. This is the principle of risk assessment followed by prescribed strategies for risk reduction. For the veterinarian managing a dog found to be at "risk" for the osteoarthritis of canine hip dysplasia, as determined by distraction index, it is now possible to implement evidence-based preventive measures, such as caloric restriction, early in life.[77,176] Data from a lifespan study in Labrador Retrievers showed the profound benefit of keeping osteoarthritis-susceptible dogs lean for life. The osteoarthritis of hip dysplasia was delayed in onset and reduced in severity in lean dogs (see Figure 59-9). Lean dogs on average lived 1.8 years longer and required pain management 3 years later compared with overweight dogs, emphasizing the longer length and improved quality of life in lean dogs.[75] Finally, for the dog with extreme joint laxity (DI >0.70) and for which preventive measures may be ineffective, the veterinarian has the opportunity to begin discussions with the owner when the dog is young about the possibility[10] that surgery (femoral head and neck resection or total hip replacement) may be indicated in the future, should the pain of end-stage hip osteoarthritis develop and persist despite symptomatic therapy.

References 1, 30, 48, 50, 51, 55, 60, 70, 82, 83, 93, 94, 104, 114, 128, 138, 140, 143, 159, 168, 173, 175, and 177.

Dorsolateral Subluxation

In 1998, Farese et al.[36] introduced a radiographic positioning technique, similar in principle to other methods (Flückiger and PennHIP), to quantify the degree of hip joint laxity via measurement of dorsolateral subluxation (DLS) of the hip joint. Positioning for the dorsolateral subluxation method was initially claimed to simulate the functional hip joint laxity experienced during weight bearing. The anesthetized animal is placed in a kneeling, sternal recumbency, with femora adducted and stifles flexed (Figure 59-15).[36] The femoral heads are forced to subluxate in a dorsolateral direction, and the degree of subluxation is quantified by assessment of the percent femoral head coverage. The strong correlation between distraction index and dorsolateral subluxation score (r^2 = 0.76) led the authors initially to extrapolate a dorsolateral subluxation threshold of 56% femoral head coverage to have similar clinical applicability as a distraction index threshold >0.3.[36,169,177] No similar longitudinal studies in fixed cohorts directly linking dorsolateral subluxation score to the development of radiographic osteoarthritis have been performed. Shorter-term studies of gross and histopathologic cartilage damage in hip joints of 8 month old dogs as an outcome measure were suggestive of some predictive accuracy of the dorsolateral subluxation method.[101,102] Originators of the dorsolateral subluxation radiographic method theorized that this position allowed measurement of both joint laxity and components of joint structure and congruity, such as chondro-osseous joint conformation.[35,102,189,190] It was speculated that this chondro-osseous conformation contributes to functional stability of the hip joint, and its absence on the dorsolateral subluxation radiograph would therefore indicate no functional hip laxity. This claim, however, was not supported by the results of a study comparing the distraction index method to the dorsolateral subluxation method in a sample of dogs. In this study, 23% of dogs predicted to be unsusceptible to osteoarthritis by the dorsolateral subluxation method (% femoral head coverage ≥56) nevertheless showed radiographic evidence of osteoarthritis.[41] Such dogs would represent false-negative diagnoses. In a separate study, Lust et al.[101] claimed superior sensitivity of the dorsolateral subluxation method compared with the distraction index; however, this study applied an unprecedented distraction index threshold of 0.7 to arrive at this conclusion. Also, the outcome measure used was cartilage degeneration at necropsy in 8-month-old dogs. This outcome measure, or the absence of it, has not been shown to represent the ultimate phenotype of the hip joint with aging; therefore its meaning is uncertain at best. We now know from a life span study in Labrador Retrievers[174] that osteoarthritis of canine hip dysplasia can manifest

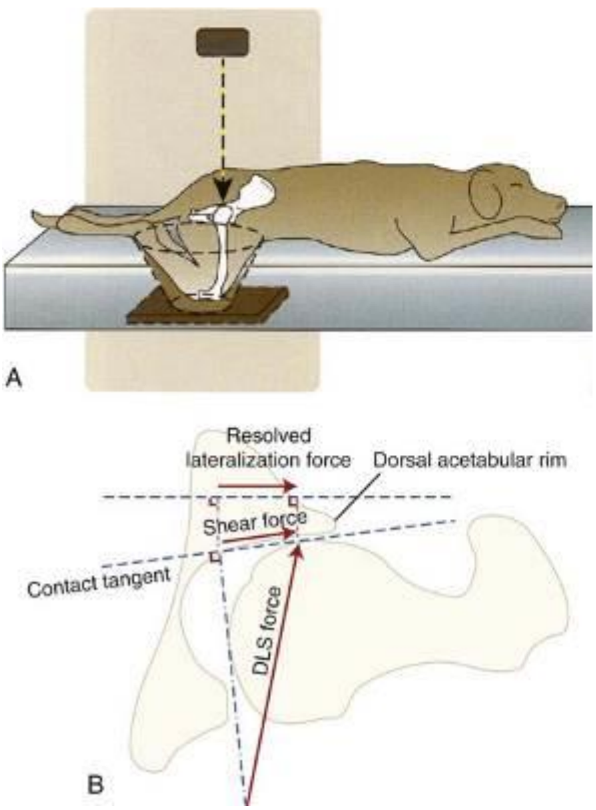


Figure 59-15 Dorsolateral subluxation (DLS) position. **A,** Illustration of a dog in sternal recumbency on a foam rubber mold for the DLS test. The stifles are adducted and bound with tape. The distal tibiae are also bound with tape. The distal lateral femoral epicondyle is palpated and positioned to be slightly caudal to the greater trochanter. Positioning is verified for symmetry. Pad height is approximately 5 inches.[167] **B,** Outline of CT cross-section of hip joint showing resolved lateralization force in the DLS test. The cartilage contact tangent becomes more vertical with progressive lateralization of the femoral head. This results in a decrease in the resolved lateralization force, meaning that femoral head displacement in the DLS test is strongly influenced by remodeling of the craniodorsal rim of the acetabulum, compromising measurement of maximum passive hip laxity.

at any time in a dog's life (if the dog is susceptible based on distraction index),[176] so an 8-month outcome gives an inaccurate estimate on which to base sensitivity and specificity determinations. Further evidence for this impression can be gleaned from the finding that 96% of Labrador Retrievers in the life span study had histopathologic evidence of osteoarthritis at the natural end of life[174] compared with only 28%[102] of Labrador Retrievers in the study by Lust and Todhunter et al.,[102] who used 8-month cartilage damage as an outcome reflecting the putative true hip phenotype of dogs. This discrepancy suggests that more than 60% of Labrador retrievers considered osteoarthritis-free in the Lust and Todhunter study would perhaps go on to show osteoarthritis later in life, representing false-negative diagnoses. Such data seriously question the claimed sensitivity and specificity determinations of the dorsolateral subluxation method.

Other criticisms of the dorsolateral subluxation method are that the hips are not truly in a weight-bearing position as suggested but rather are adducted and slightly extended. From the positional biomechanics of hip laxity,[60] this orientation of the coxofemoral joint shows an estimated reduction in the measureable passive laxity of at least 30% compared with neutral positioning, indicating that maximum passive laxity cannot be reproduced in this position. Although the correlation of the two measures may be high, the absolute amount of hip laxity is markedly reduced in the dorsolateral subluxation position. Also, the degree of subluxation as measured by the percentage of femoral head coverage is sensitive to errors in positioning, and its magnitude is affected by chronic arthritic changes, namely remodeling of the dorsal acetabular rim.

Reports have compared the dorsolateral subluxation method with the PennHIP method. Study conclusions have varied, ranging from the dorsolateral subluxation method being equivalent, to uniquely different, to superior to PennHIP (under artificial assumptions). However, the dorsolateral subluxation method has not been tested against a similar outcome measure as used in investigations of the distraction index, specifically, later development of accepted radiographic signs of osteoarthritis in sizeable populations of dogs.[159,175] The dorsolateral subluxation method places the legs of the dog in a position similar to the PennHIP method and applies a dorsally directed force, a resolved component of which lateralizes the femoral head (see Figure 59-15). Therefore, it is not surprising that more laxity can be detected than appears on the hip-extended radiograph. However, less laxity is revealed than appears in the PennHIP position.[41] Although the dorsolateral subluxation (DLS) percentage of femoral head coverage may be similar in concept to the PennHIP distraction index, in the opinion of this author, the dorsolateral subluxation screening test has not been shown to be an equivalent metric, and it offers no clinical or diagnostic advantages.

Flückiger Subluxation Index

Similar to the dorsolateral subluxation method, the subluxation index as described by Flückiger et al.[40] quantifies hip laxity radiographically by a dorsally directed force, causing dorsolateral displacement of the femoral heads (Figure 59-16). The dog, however, is in dorsal recumbency rather than the ventral recumbency used for the dorsolateral subluxation position. Hip position is approximately the same as in the dorsolateral subluxation method, except for a lesser degree of adduction. The *subluxation index* is measured similarly to the distraction index by using circle gauges laid over the structures of the femoral head and acetabulum. No follow-up studies have been published regarding the method's sensitivity, specificity, or predictive accuracy for diagnosing canine hip dysplasia or for predicting the development of osteoarthritis, particularly late in life.

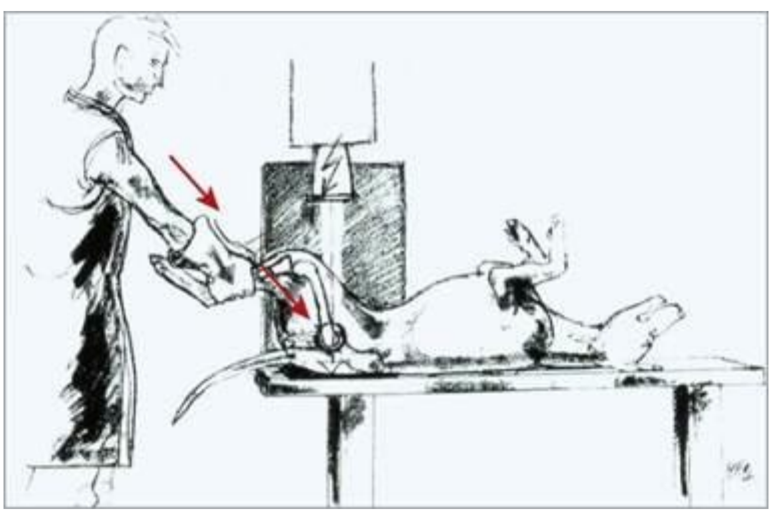


Figure 59-16 Flückiger stress technique. Radiographic stress technique for subluxation of the femoral head. Femora are angled at 60 degrees to the table top, and dorsally directed force is applied, causing dorsolateral displacement of the femoral heads. Hip laxity is quantified via this technique with the subluxation index through the use of circle gauges over the femoral head and acetabulum, similar to the distraction index. The mechanism producing lateralization of the femoral head is similar to that of the DLS method.

Palpation

Methods to palpate hip joint laxity, as previously described, have been used empirically for decades in both human and veterinary medicine. However, prospective analyses of the diagnostic sensitivity and specificity of these methods as a function of long-term outcome measures are sparse at best, and in veterinary medicine, such studies are nonexistent. Because many surgeons attach diagnostic significance to palpation of hip joint laxity, going so far as to use such measures as indication for surgery,[166] these methods are briefly reviewed here.

Ortolani in 1937 and Barlow in 1962 described methods for hip joint palpation to assess hip joint laxity in children; these methods have been adapted for use in the dog.[9,132,133] The Bardens method, described earlier, was thought to be subjective and to yield too many false-positive diagnoses. It was harshly criticized, particularly by proponents of hip-extended radiography;[163] however, had the basic principles of the method been further investigated, it is likely that our knowledge of hip laxity and its relationship to hip osteoarthritis would be vastly advanced.

The Ortolani method (or variations on it) is the most commonly used means of palpating hip laxity in the dog (see Figure 59-11). Several published reports have evaluated the accuracy of hip joint palpation, particularly as it relates to radiographic measures of hip joint laxity.[141,160,205] Such objective information is critical, because many surgeons use the angles of subluxation and reduction of the hip joint derived from Ortolani palpation as indications for surgery. The relationship of Ortolani hip palpation to radiographic measures of hip laxity, namely, distraction index, Norberg angle, or hip-extended score, has been described.[143] Of 95 dogs having normal hips by hip-extended score, 59% had a positive Ortolani sign, meaning that the absence of subluxation on the hip-extended radiograph did not accurately represent the underlying palpable laxity. The Norberg angle measured in dogs not showing signs of osteoarthritis was marginally correlated with Ortolani, but the presence of osteoarthritis made Norberg angle noninformative as to palpable joint laxity. The distraction index was strongly correlated with palpable laxity by Ortolani for dogs without radiographic signs of osteoarthritis; however, for dogs showing osteoarthritis, poor correlation was noted. Despite the much better correlation between distraction index and the Ortolani sign these two measures cannot be used as surrogates because more than 50% of dogs without an Ortolani sign, and therefore presumably having tight hips, had hip joint laxity indicating susceptibility to osteoarthritis (DI $\geq$0.30). A negative Ortolani sign may indicate that the dorsal rim of the acetabulum has already undergone remodeling. Therefore palpation using the Ortolani method is not a diagnostic alternative for distraction radiography, nor, in the opinion of the authors, should it be used as an indication for surgery without prospective, randomized controlled clinical trials to determine whether preventive procedures, such as juvenile pubic symphysiodesis or triple pelvic osteotomy, have definitive efficacy in delaying or preventing osteoarthritis.

Ultrasound

Ultrasound imaging of the human neonatal hip was first proposed in 1980 for detection of developmental dysplasia of the hip.[52] Ultrasound was shown to have better accuracy over palpation and greater safety than ionizing radiation. Today, ultrasound is used as a screening tool after physical examination in high-risk neonates.[110] However, ultrasonographic diagnosis of hip dysplasia in neonates has been found to have a high rate of false-positive diagnoses, resulting in overtreatment, which, in children, raises the risk of avascular necrosis of the femoral head.[64,120] Ultrasound has also been studied as an early indicator of joint laxity in puppies,[1,37,53,127] but the method has some disadvantages. Femoral head ossification, occurring at approximately 8 weeks of age, precludes ultrasonographic assessment of acetabular morphology or cartilage integrity later in life.

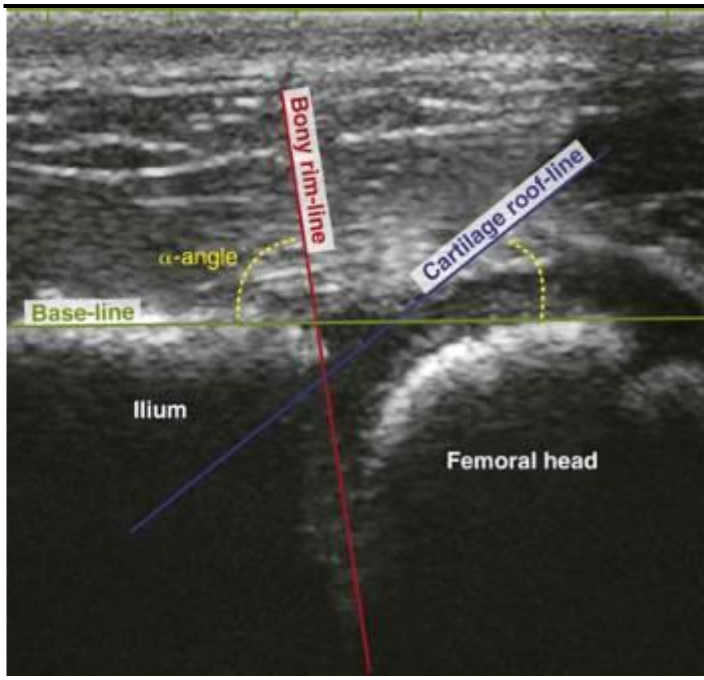
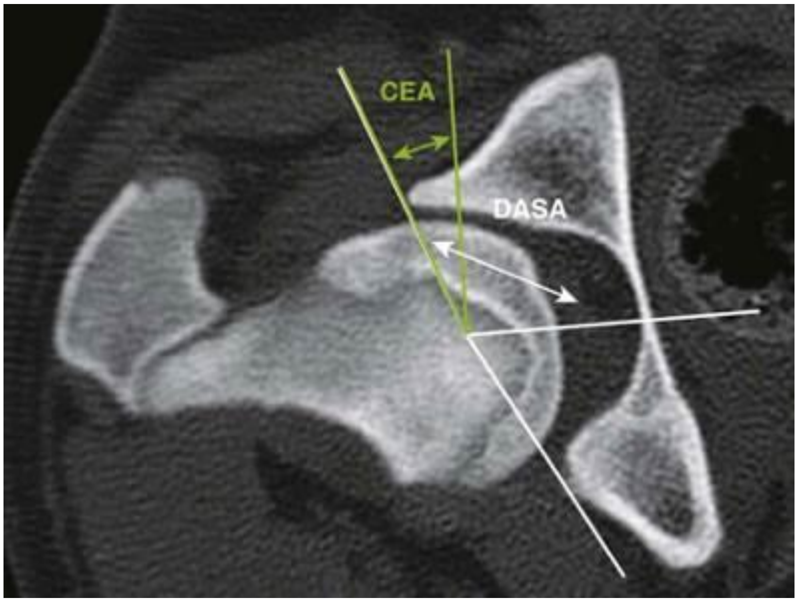


Figure 59-17 Ultrasonographic measurements of passive hip laxity: α-angle and β-angle. *Green line:* baseline, parallel and tangential to ilial silhouette. *Red line:* bony rim line, connecting the caudal edge of the ilium in the acetabular fossa to the osseous convexity of the bony acetabular rim. *Blue line:* cartilage roof-line, connecting the osseous convexity of the bony acetabular rim to the cartilage roof triangle. A-Angle is the angle between the baseline and the bony rim line. None of the ultrasonographic parameters assessed was ultimately linked to the development of canine hip dysplasia, but because ultrasound is the standard of care in human medicine, it may be an area of future study.

(From Fischer A, Flöck A, Tellhelm B, et al: Static and dynamic ultrasonography J Small Anim Pract 51:582, 2010.)

Dynamic ultrasonography between 8 and 16 weeks appears to permit joint laxity assessment, but the subjectivity of scoring leads to imprecision in repeated measures and the absence of reference ranges precludes clinically relevant interpretation. Additionally, Fischer et al.[37] showed that ultrasonographically measured variables, including α-angle, joint laxity, and distraction value, between 16 and 49 days are not correlated with the diagnosis of canine hip dysplasia at 12 to 24 months of age, based on the hip-extended radiograph (Figure 59-17).[37] Ultrasound is not routinely used as a diagnostic or screening method for canine hip dysplasia in puppies.

Figure 59-18 Representative two-dimensional computed tomography (CT) image obtained from a dog indicating dorsal acetabular coverage. The DASA *(white angle)*—dorsal acetabular sector angle—is measured between a line from the center of the femoral head to the dorsolateral edge of the acetabular rim and the horizontal pelvic axis. The CEA *(green angle)*—center-edge angle—is used to assess dorsolateral coverage by the bony acetabular rim, and is measured between a line from the center of the femoral head to the dorsolateral edge of the acetabular rim and a line perpendicular to the horizontal pelvic axis. Both of these angles may be indicators of joint laxity; in a study by Lopez et al.,[164] both were shown to correlate significantly with PennHIP distraction index and cartilage microdamage at 30 months of age. These measurements, along with others based on CT and magnetic resonance imaging (MRI), are promising areas of future study for the diagnosis of hip dysplasia.



Computed Tomography and Magnetic Resonance Imaging

Computed tomography is used routinely in immature and mature human hips for establishing diagnoses, planning surgery, and assessing therapeutic outcomes of treatment.[85,90,124,125,187] In the dog, CT (and MRI) has not been used routinely, largely because of its high cost and limited availability. These methods, however, have been applied in research settings to image joint changes associated with geometry-modifying surgical treatment,[32,136] to detect joint laxity (subluxation) associated with the dorsolateral subluxation test, and to view and correlate an array of indices of hip scoring in an attempt to predict cartilage microdamage (Figure 59-18).[93] MRI was used to demonstrate a relationship between joint laxity, as measured by distraction index in 7- to 9-week-old puppies, and the synovial fluid volume index; however, a poor association was seen between hip laxity at 7 to 9 weeks compared with laxity measured later in life, corroborating previous reports.[47,169]

Kinematic and Force Plate Studies

Several studies have investigated gait using kinematic and force plate analysis of dogs with hip dysplasia.* Kinematic changes consistent with hip dysplasia may be subtle and may include increased coxofemoral extension at the end of the stance phase, increased femorotibial flexion throughout the stance and early swing phase, coxofemoral deceleration early in the stance phase, and increased stride length with decreased peak vertical force.[74,142] In immature dogs (16 weeks) with moderate passive hip joint laxity and no hip osteoarthritis, no relationship between distraction index and joint kinematics was noted. Ground reaction forces in these dogs were consistent with those of clinically normal dogs.[94] Other studies using kinematics and force plate analysis show varying results, depending on the extent of lameness in the dogs examined. For example, when dogs with radiographic hip osteoarthritis were compared with those without, no difference in ground reaction force was noted, but significant differences in joint kinematics were observed.[14,80] Joint kinematic analysis and force plate analysis are areas of future study, but to date they have not been shown to have early diagnostic value for canine hip dysplasia.

References 13, 14, 34, 74, 80, 91, 94, and 142.

Full Reference List: (Following Chapter 3)

Chapter 3: Controlling Canine Hip Dysplasia

Ideal Hip Screening Requirements

Two principal strategies are used to control/prevent a complex trait like canine hip dysplasia. The first, genetic control, is aimed at reducing canine hip dysplasia prevalence in future generations by optimally selecting breeding dogs free of susceptibility (and, it is hypothesized, free of the genes) for canine hip dysplasia. The second, more recent, approach is to prevent, delay, or mitigate the expression of canine hip dysplasia in dogs in the current generation (e.g., pet and service dogs). This new approach is termed *predictive medicine,* and involves determining the risk or susceptibility for disease followed by implementation of measures to lower that risk. Whether the test is molecular (genomic) or phenotypic, our task is to apply evidence-based methods to lower disease risk or reduce disease progression. In the process, we need to understand the characteristics of an ideal hip screening/diagnostic test and to ask how popular methods compare with these ideals.

Many hip diagnostic/screening techniques from radiography to palpation to newer modalities, such as ultrasound, CT, and MRI, have been described. However, a sense of confusion remains among practicing veterinarians, dog breeders, and the dog-owning public as to which is the best hip screening method, and how rapidly it will work to reduce the incidence of this highly prevalent disease. Some of this confusion stems unintentionally from the complexity of canine hip dysplasia, the complexity of research into canine hip dysplasia, and the difficulty involved in getting useful information to the public.

The holy grail of disease detection would be discovering the entire array of genes and gene products that can explain all of the phenotypic variation associated with expression of the disease. A simple blood sample would contain the answer. Although this is a worthy objective, its achievement is years, if not decades, away. Such research must and will continue, but it is important for dog breeders and practicing veterinarians to understand that tools currently are available that can be used to make rapid genetic progress toward control of canine hip dysplasia. Also, it is only through association with well-characterized “screening phenotypes” that genomic progress will be made.

Knowledge of the principles of quantitative genetics is important for understanding how current screening tests can produce significant genetic change toward improved hip phenotype; some of the more recent literature has emphasized these important concepts.[62,86,184] This section briefly describes the more basic principles of quantitative genetics.

Let's examine critical characteristics of the ideal hip screening tool.

First, the ideal metric should be accurate meaning it is closely associated with the unwanted phenotype. It should have a high positive and negative predictive value, giving one confidence that when the metric is low, the risk of disease is low, and when the metric is high, the corresponding risk of disease is high. In the case of hip dysplasia, the phenotype to be predicted and appropriately avoided is osteoarthritis because it is the osteoarthritis (joint inflammation and cartilage damage) of hip dysplasia that is closely associated with long-standing pain. Multiple studies from multiple institutions have shown a high correlation between distraction index and later osteoarthritis.[18] Hip-extended score and Norberg angle from hip-extended radiography have lower correlations with the development of osteoarthritis, particularly when the test is performed in a patient younger than 2 years of age.[169,178,194]

Second, the metric should be *precise*. Precision means that if multiple examiners are given the same set of radiographs, the resulting hip scores will be similar across examiners. Several studies have documented poor precision of subjective hip scoring with hip-extended radiographs.[72,178,194] Accuracy and precision are often incorrectly considered synonymous. Accuracy is the ability to hit the bull's-eye; precision is the ability of all examiners to arrive at the same diagnosis without regard to the bull's-eye. Underemphasized in the literature is an adequate and plausible definition of the bull's-eye. In terms of hip dysplasia diagnosis, what is the bull's-eye? For now, we will define the center of the diagnostic target, the phenotypic bull's-eye, as the hip metric with the highest *heritability*, which, when used as a means to apply *selection pressure*, will yield the most rapid genetic change toward improved hip status of the offspring. This definition can be expressed by a mathematical formula that will be introduced in Box 59-2. It is important to appreciate that the concepts of *heritability* and *selection pressure* have immense importance in controlling or eliminating canine hip dysplasia through appropriate selection of breeding dogs. They constitute criteria 5 and 6 to be followed and will receive greater elaboration in the genetics section.

Third, it is desirable to seek a metric that is represented as a continuous ratio scale—which is more desirable than an interval scale, such as the Norberg angle or percentage of femoral head coverage, or a noncontinuous, ordinal scale. A continuous ratio scale means that, for instance, a dog with a distraction index of 1 has twice the laxity of a dog with an index of 0.5 or 4 times the laxity of a dog with a distraction index of 0.25. A similar proportionality does not exist for an interval scale (e.g., an Norberg angle of 50 degrees is not twice as loose as an Norberg angle of 100 degrees), and percentage of femoral head coverage similarly does not have a fixed zero point. A percentage of femoral head coverage of 50% is not exactly half the percentage of femoral head coverage of 100% (an anatomically unachievable position). It needs to be recognized that an ordinal scale such as that used in most hip dysplasia scoring systems worldwide has no proportionality. It is unclear whether there is an incremental diagnostic difference, if any, between Excellent and Good or Good and Fair, and so on. This reality creates insurmountable obstacles in attempts to assess the degree of applied selection pressure or the extent or rate of genetic improvement, to be discussed in a later section.

Fourth, the ideal metric should be measurable as early as possible in life and should remain constant throughout life. The distraction index has been shown to have superior repeatability and predictive value for osteoarthritis in longitudinal studies within a fixed cohort of dogs in contrast to the OFA-type score and the Norberg angle.[169] Also, the distraction index was shown to be reliably measured at an age as young as 16 weeks (r_i = 0.85) when compared with 2-year hip scores. To our knowledge, no similar studies of longitudinal reliability in a fixed cohort of dogs over a period of 3 years have been reported for other hip screening tests.

The fifth requirement of a hip screening phenotype is rooted in the principles of quantitative genetics.[33] For a phenotype to have utility as a selection criterion within a given population, it must have optimal heritability. The heritability of a test is a population metric that quantifies the relationship of a dog's phenotype (e.g., the hip score of the parents) as an estimate of its genotype (the hip scores of the offspring of the parents). It is a number between zero and 1 with a heritability of 1 meaning that all variation of a phenotype within a given population is attributable to the genes. A heritability of zero means that the variation observed in a specific phenotype within a population is due to non-genetic causes, such as environmental influences.

The sixth, and perhaps least emphasized, requirement of a hip screening metric involves another important principle derived from quantitative genetics—and that is selection pressure. To make genetic change toward better hips, there must be range in the phenotype, the hip metric, sufficient to permit selection of breeding dogs that are much better than average for the breed.

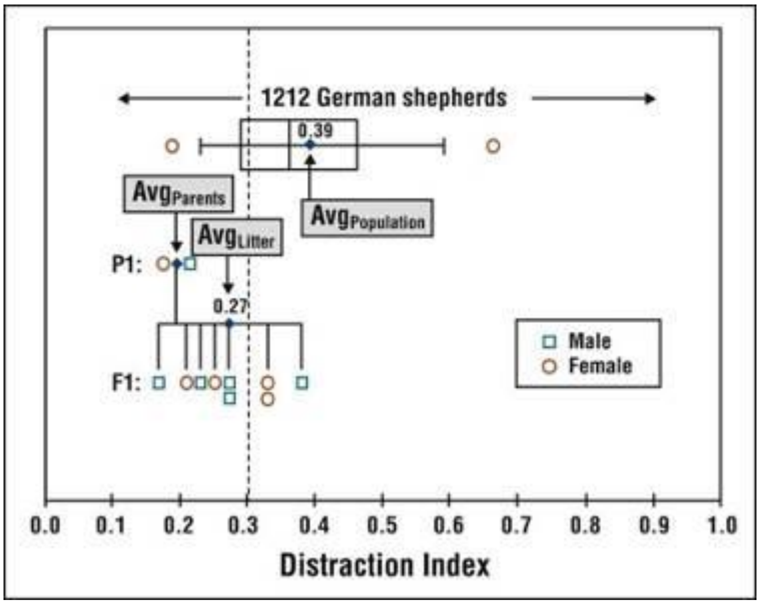
It is important to recognize that all hip screening methods, new and old, must be tested against these ideals, to permit meaningful comparisons among methods.

Genetic Change: The Importance of Heritability and Selection Pressure

The predominant mode of choosing breeding stock is to make selection decisions based on the individual dog's hip phenotype. This process is known as *mass selection* and should be differentiated from the use of *estimated breeding value*. Calculating estimated breeding value is a superior selection strategy that incorporates not only an individual dog's hip phenotype, but also that of its relatives. More rapid genetic change can be expected when estimated breeding values are used, but the requirements of extensive record keeping coordinated with accurate pedigree information are impediments to its common use by breeders. *Mass selection* is selection of breeding candidates based on the individual dog's phenotype without consideration of the phenotype of the dog's relatives. It is an acceptable tool for making genetic improvement, but, to optimize genetic improvement, the heritability of the hip screening phenotype must be high (>0.5) so that environmental (nongenetic) factors have a smaller role in obscuring the phenotype of interest. As mentioned, heritability denotes the reliability of the phenotype in predicting genotype. A high heritability (e.g., approaching 1) means that the phenotype accurately reflects the genotype. In other words, all variation in the phenotype within the population is explained by the genes, and environmental (nongenetic) factors have little to no influence on the phenotype. Quantitative traits such as hip dysplasia, however, typically have estimates of heritability much lower than 1, meaning that environmental (nongenetic) factors, such as nutrition or body weight, may play an important role in causing variation of expression of the phenotype. From the lifespan study, it can be seen that overfeeding Labrador Retrievers compared with gender-matched lean littermates[75–77,79,139,174,176,186] had a profound influence on accelerating the development of osteoarthritis and radiographic canine hip dysplasia, even though the dogs were genetically very similar. By 2 years of age, 4% of lean dogs showed radiographic evidence of hip osteoarthritis compared with 25% in the overweight group. This environmental effect was maintained for the life of the dogs (see Figure 59-9).[79,176]

Heritability is mathematically defined as the ratio of additive genetic variation to overall phenotypic variation of a given trait ($h^2 = V_G/V_P$). The total phenotypic variation is made up of genetic and nongenetic components. Environmental factors such as diet, age, or diagnostic error increase the variance components in the denominator of this relationship (V_P); therefore, such factors have the effect

Figure 59-19 Estimated heritability. Box plot of the calculation of estimated heritability from an actual mating. The figure shows the relative relationships of passive hip laxity in the German Shepherd Dog breed at large, of the dog and bitch (P1), and of the litter (F1). Extreme selection pressure was applied in this actual mating, as shown by the position of the sire and dam relative to the population of German Shepherd Dogs from which they were derived. The dogs are drawn from tightest 5th percentile of the breed. By plugging the values from this sample mating into Relationship 1, we can estimate the "heritability" of distraction index, which was 0.63 for this mating.



(From Kapatkin AS, Mayhew PD, Smith GK: Genetic control of canine hip dysplasia. Compend Contin Educ Pract Vet 24:681, 2002.)

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of lowering estimates of heritability. Lower heritability means that the phenotype of offspring has reduced association with the phenotype of parents. Often, complex traits, formerly called *quantitative or polygenic traits*, are influenced by the complex interplay of environmental and genetic effects. For example, a dog's weight is influenced in part by how much food it consumes (an environmental factor), but also by the genes of its parents (obese parents tend to have obese offspring). As emphasized earlier epigenetic factors can also add considerable variation to the nongenetic components.

Heritability is an essential principle of quantitative genetics; those dedicated to breeding for improvement in hip quality must understand the concept. Of equal importance is an understanding of selection pressure. *Selection pressure* is defined as deviation of the parental mean hip score from the overall population mean hip score from which the parents were derived ($Avg_{parents} - Avg_{population}$). See Figure 59-19 for results of an actual mating of two tight-hipped German Shepherd Dogs, illustrating both selection pressure and heritability. Why are these two concepts so important? Because, for a complex trait, the rate of expected genetic change (ΔG) in the ensuing generation is equal to the heritability (h^2) of the hip score times the selection pressure applied through the choice of parents. See Relationship 1 in Box 59-2. At the time of the mating shown in Figure 59-19, descriptive statistics for the German Shepherd Dog population had an average distraction index of 0.39. The parental average distraction index was 0.2; therefore, the selection pressure applied was 0.19 distraction index units. The average distraction index (litter mean) for the nine puppies born to these two parents was 0.27. Therefore, the estimate of heritability from this single mating can be found by rearranging terms and solving Relationship 1, where ΔG is the difference in average distraction index of the offspring minus that of the mean distraction index of the parents:

Box 59-2 Relationship 1: Determining Genetic Change per Generation

$$\Delta G = h^2 \times (\text{Avg}_{\text{parents}} - \text{Avg}_{\text{population}})$$

in which:

ΔG = expected change in average litter phenotype after one generation

$\mathbf{h^2}$ = heritability of phenotype (e.g., distraction index or subjective hip score)

$\mathbf{Avg_{parents}}$ = average hip phenotype of the parents

$\mathbf{Avg_{population}}$ = average hip phenotype of the population from which the parents were derived

$\mathbf{(Avg_{parents} - Avg_{population})}$ = selection pressure applied

Then solving for h^2 yields:

$$h^2 = \Delta G \div (\text{Avg}_{\text{parents}} - \text{Avg}_{\text{population}})$$

and,

$$h^2 = (0.39 - 0.27) \div (0.39 - 0.20) = \mathbf{0.63}$$

This formula could be applied to the calculation of heritabilities for the Orthopedic Foundation for Animals (OFA) score, the Norberg angle, or dorsolateral subluxation (DLS), but the results would be less interpretable because of the absence of proportionality and fixed zero points for these metrics. Note that the mean litter distraction index (0.27) moved 63% of the way from the mean of the German Shepherd Dog breed (0.39) to the mean of the parents (0.20). Therefore, the estimated heritability from this one mating is 0.63. As previously mentioned, more accurate estimates of heritability by breed are derived from incorporation of pedigree data into sophisticated statistical software.

Therefore, the higher the heritability of a quantitative trait and the greater the selection pressure applied, the more rapid the expected genetic change per generation of breeding. These concepts are exquisitely important in directing breeding practices and must be understood by both dog breeders and veterinarians.

Heritability estimates are best determined by examining the variation in phenotype of animals, with knowledge of their pedigree. Until recently, scant information was available on some of the most popular hip screening methods available worldwide. In 2000, the OFA published the first estimates of heritability of that phenotype in four breeds of dog: English Setter, Portuguese Water Dog, Chinese Sharpei, and Bernese Mountain Dog. Estimates of heritability varied, ranging from a low of 0.17 for English Setters to a high of 0.31 for Chinese Sharpeis.[145] These estimates are similar to older data from an analysis of a more popular breed, the German Shepherd Dog, showing heritability of the OFA-type score to be 0.22.[86] A more recent analysis of OFA data[89] estimated the heritability of OFA score in the Labrador Retriever to be 0.21; this is considered low heritability. A study from Finland suggests similar low heritability of subjective hip score when used as a selection criterion in German Shepherd Dogs.[87] In this study, best linear unbiased prediction (BLUP) procedures were used to analyze 10,335 German Shepherd Dogs from 1985 to 1997. Subjective hip scoreing produced no genetic improvement when used as a selection criterion. This contrasts with two studies showing statistically significant improvements in hip score using OFA selection over 13 years[68] and 37 years.[62] In the latter study, the average hip scores of Labrador Retrievers after 37 years of selection improved from OFA 2.0, where 2 corresponds to an "OFA Good" score, to 1.91, still "OFA Good" and statistically significantly better but of doubtful clinical significance. Though statistically significant, it is doubtful that an improvement of 0.09 OFA units over 37 years would be clinically significant.

Similar slow genetic improvement was observed in the hips of Labrador Retrievers in the United Kingdom using a different scoring system (previously described) to evaluate the same hip-extended radiograph made from dogs 1 year of age or older (discussion to follow).[89]

Higher estimates of heritability have been found for other radiographic methods, including PennHIP distraction index (>0.46 to 0.83)[50,86] and the dorsolateral subluxation method (0.54),[86,206] suggesting that if these phenotypes were applied, more rapid change would be observed, but only if the metric has a good correlation with osteoarthritis. When heritability is low, genetic change can still be accomplished but very slowly. Genetic change can be sped up by employing the technique of estimated breeding value (EBV).[62] The heritability of the PennHIP distraction index is sufficiently high (>0.5) in the breeds tested thus far to permit rapid genetic progress without invoking estimated breeding values. Of course, if estimated breeding values are utilized, genetic progress will occur even faster.[86,185]

Heritability of a given phenotypic trait is a property of the population under study. Therefore, the heritability of each trait or diagnostic phenotype must be calculated for each breed and each population of dogs. A simple example for estimating heritability was discussed previously (see Figure 59-19); however, more accurate estimates of heritability are typically calculated by combining the observed variance of the trait of interest within a population with the pedigree of that population. Based on data collected over decades at The Seeing Eye, Inc., the heritability of the distraction index and the hip-extended score, based on Bayesian analysis, ranges from 0.56 to 0.60 for distraction index and from 0.16 to 0.32 for hip-extended score for Labrador Retrievers, Golden Retrievers, and German Shepherd Dogs, respectively (Leighton, unpublished data, 2011). Similarly, the heritability of the distraction index in Estrela Mountain Dogs has been estimated at 0.83.[50] High heritability alone, however, does not ensure that hip dysplasia will be easily eliminated. One must be able to apply selection pressure also (see Box 59-2 and Figure 59-19), and, probably most important, the metric of interest (whether OFA score, Norberg angle, distraction index, or dorsolateral subluxation score) needs to be shown to have high association with the disease phenotype, which in the case of hip dysplasia is osteoarthritis (see ideal #1).

Although many studies have correlated the various scoring schemes with each other,[*] only the PennHIP distraction index has been shown to have high correlation with osteoarthritis in both short-term and long-term studies[†] (see Figure 59-7). Corroborating evidence showing the importance of hip laxity in the prediction of osteoarthritis was found in a study of the nine components of hip scoring in the BVA/KC system derived from the hip-extended radiograph.[89] The scoring components descriptive of joint laxity were the most valuable early age predictors of osteoarthritis. However, as found in earlier investigations, these signs were not visible in very young dogs. A study of the chronology of the radiographic components of hip laxity, specifically subluxation,[174] showed that hip subluxation from the hip-extended radiograph occurred up to 2 years of age and not thereafter. More specifically, 66% of dogs showing hip subluxation did so by 1 year of age, and the remaining 33% developed hip subluxation on the hip-extended radiograph by 2 years of age. This means that when the BVA/KC system of hip scoring of 1-year-old dogs is used, a 33% false-negative rate is built into it, at least for Labrador Retrievers. This figure perfectly parallels data from the Jessen and Spurrel study reported in 1972.[65] Other breeds need to be similarly investigated.

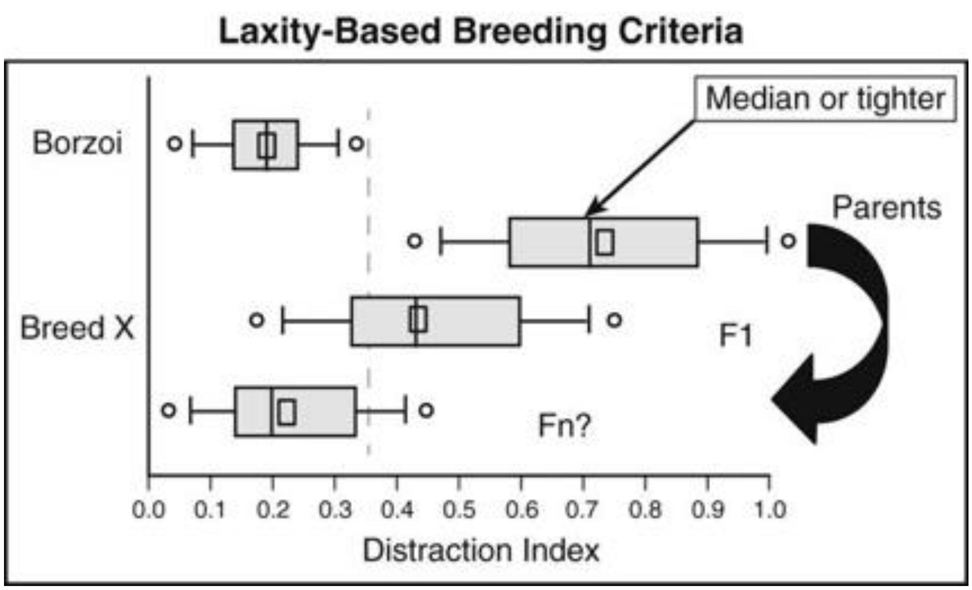
Selection Pressure and Its Role in Genetic Change

Breeders cannot influence the magnitude of heritability of the phenotype, but they can control the magnitude of applied selection pressure (i.e., the difference between the mean of the parents and the mean of the population at large; see Box 59-2). Therefore, to the extent that breeders select breeding candidates, they control the rate of improvement in hip phenotype in each generation. This of course assumes that the phenotype of interest is not so skewed toward uniformity that there exists no ability to apply selection pressure (discussed in a later section).

For the most rapid genetic change, the breeder would mate only dogs with the extreme best hips (for OFA scoring, dogs having Excellent scores; in the case of PennHIP distraction index, dogs having the tightest hips [e.g., better than the 95th percentile]) and then continue to inbreed and line breed in pursuit of better hips. An example in Figure 59-19 shows extreme selection pressure using distraction index on a pairing of German Shepherd Dogs. This approach of breeding the extremes would maximize the difference between the parent average and the population average—the selection pressure—and therefore would maximize the expected genetic change in each generation. This approach, however, has potential pitfalls. Founding a breeding program on only a few dogs—followed by inbreeding on these dogs—would increase the coefficient of inbreeding and may contribute to the loss of some desirable traits or cause the expression of some undesirable traits. A requirement that all breeding candidates should come from this small pool of “best dogs” not only would seriously reduce genetic diversity, it would be unacceptable to breeders, because most members of any breed would not be considered suitable candidates for breeding.

To avoid potential problems associated with inbreeding and the systematic application of extreme selection pressure, a moderate approach has been suggested.[71] The application of moderate selection pressure is particularly indicated in breeds with few or no members having hips free of susceptibility to osteoarthritis. In such breeds, it is more acceptable if breeders have the option of selecting breeding candidates from the tightest half or, better, the tightest 40% of the breed, thereby maintaining a reasonable level of genetic diversity while still applying positive selection pressure (Figure 59-20). The PennHIP report ranks each dog relative to other members of the breed, making it possible for the breeder to identify which specific dogs, when bred, will allow application of positive selection pressure. By applying at least moderate selection pressure, eventually the average of the population will shift toward tighter (better) hips with each generation, systematically changing the minimum standard for breed (average distraction index by birth year or generation) toward better hips. With successive generations, fewer and fewer dogs will be at risk for developing osteoarthritis. Of course, more rapid genetic change could be achieved by imposing greater selection pressure or by using estimated breeding values obtained from incorporation of the pedigree. Even without these measures, however, the principle of mass selection, if linked to a highly heritable phenotype, is the simplest means and therefore holds the greatest potential to reduce the frequency and severity of osteoarthritis in future generations of dogs.

Figure 59-20 Box plot of proposed laxity-based breeding criterion. By selecting from the tightest 40% of a breed (60th percentile or better) as the minimum criterion, meaningful genetic change can be expected to occur without creating a genetic bottleneck. Breed X displays a range and distribution of hip laxity similar to the current status of the Golden Retriever breed. The goal of this strategy is to tighten the hips of breed X until the breed approximates the mean and distribution of hip laxity approaching that of the Borzoi. The tighter the means of the candidate parents' hips, the greater the selection pressure, and the faster this change will occur.



(From Kapatkin AS, Mayhew PD, Smith GK: Genetic control of canine hip dysplasia. Compend Contin Educ Pract Vet 24:681, 2002.)

* References 2, 30, 35, 46, 101, 140, 143, 190, and 206.
† References 2, 41, 138, 143, 159, 169, 174, 175, and 177.

Reported Improvements in Hip Phenotype

Hip screening methods have been around for decades, so an important question is this: “Do we have scientific evidence that the methods have improved the quality of canine hips?”

Only recently has well executed trial evidence become available, from two trials pertaining to the OFA system of hip screening (OFA score)[62,68] and two related to the BVA/KC system of hip scoring.[88,89] The authors of another study reported the relationship of official OFA score to PennHIP distraction index in a pool of 439 dogs undergoing both evaluations.[140]

The first study (2009) evaluated OFA hip screening and improvement in hip phenotypes of many breeds of dogs over the interval from 1989 to 2003.[68] This study included data from the official OFA database for all breeds of dogs (431,483 dogs) with descriptive statistics on the most popular breeds—Labrador Retriever, Golden Retriever, German Shepherd Dog, Rottweiler, and Bernese Mountain Dog. For comparison between studies, this discussion will focus largely on the Labrador retriever breed (N = 102,960), the most common breed in the study and in the United States. The study's authors conceded an indeterminate selection bias in the OFA database due to voluntary film submission, making it not possible to accurately determine whether there was any reduction in the frequency of hip dysplasia over this interval. However, the authors did believe that changes in the distribution of dogs scored "OFA Normal" (Excellent, Good, or Fair) were accurate, reasoning that all owners of dogs undergoing OFA hip radiographs at the local veterinarian would submit the radiographs that appeared normal, and therefore the bias within the "OFA Normal" submissions would be uniform and negligible. This assumption was questioned by a study[135] showing that of dogs undergoing radiography for OFA submission, 53% were submitted to OFA and 47% were not.[135] Of hip films submitted to the OFA, 92% were scored as "Normal," as anticipated. Unexpectedly, however, was the finding that of those not submitted, 50% were normal as judged by a board-certified radiologist.[135] The authors of this study did not explain how this nonsubmission rate varies by breed or time interval. The indeterminate bias caused by voluntary radiograph submission (influencing both normal and abnormal diagnoses) makes all estimates of genetic progress drawn from such databases, whether domestic or global, suspect. Considerations of bias aside, results of the investigation of official OFA data over the interval 1989 to 2003 showed that Labrador Retrievers had an increase in "OFA Excellent" hip scores of 1.5%, an increase in "OFA Good" scores of 3.3%, and a decrease in "OFA Fair" scores of 2.1%.[68] This rate of improvement, if the numbers are reliable, is extremely slow.

The slow pace of hip improvement in the Labrador retriever was corroborated by a more comprehensive analysis of 154,352 dogs drawn from the OFA database from 1970 to 2007 combined with pedigree information from an additional 104,499 dogs. It was concluded that small but statistically significant hip improvement had occurred over the 37 years of selection based on OFA scoring. The authors suggested that quicker improvement would be appreciated by invoking estimated breeding values. Breeding value by year decreased linearly from 0 in 1970 to -0.095 OFA units in 2007, representing change in the desirable direction.[62] The rate of change, however, was not impressive. Similarly, mean OFA hip scores for Labrador Retrievers went from 2.0 (OFA Good on a scale of 1 to 7, with Excellent being 1) in 1970 to 1.91 in 2007—a 0.09 OFA unit change over 37 years of selection. The heritability of OFA score in Labrador Retrievers was found to be low at 0.21, which helps to explain the slow observed progress in improving hip phenotypes in this breed.[62]

However, in addition to the low heritability of OFA score in Labrador Retrievers is the inability to apply further significant selection pressure. Based on Relationship 1 (see Box 59-2), if the average Labrador Retriever has a hip score of OFA Good, then the only means to make further genetic progress is to breed OFA Excellent dogs—which is a fairly small percentage of the breed at 21.8%, based on the OFA database.[62]

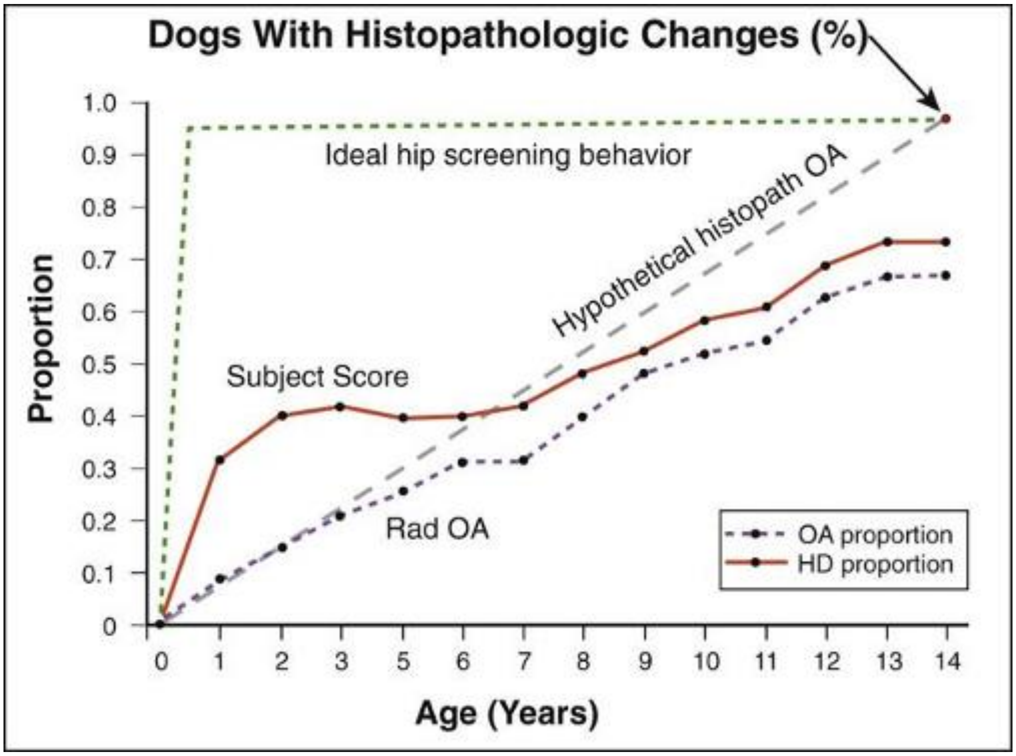
Similar slow genetic improvement was observed in the hips of Labrador Retrievers in the United Kingdom using a different scoring system (see BVA/KC section) applied to the hip-extended radiographs taken of dogs 1 year of age or older. Hip radiographs (25,243) of Labrador Retrievers were evaluated from 2000 to 2007. The mean hip score for the breed was 13.2 and the median was 10 (out of a total score of 106 points per dog); the heritability of the BVA/KC hip score was higher at 0.35[88] than that found using OFA scoring (0.21).[62] Using "average" hip score excluded from breeding only the dogs in the worst 15% of the overall population of Labrador Retrievers. The small genetic improvement observed over this interval was thought to be a consequence of the skewness of the data—most dogs are given hip scores in the low numbers, indicating better hips. It was suggested that to speed up genetic improvement, estimated breeding values, rather than just individual phenotypic hip scores, should be calculated in making selection decisions. It was estimated that at the current rate of progress using mass (phenotypic) selection, it would take 44 years to move the median hip score for Labrador Retrievers from 10, its current value, to 5. However, using estimated breeding values for breeder selection would reduce the period to 37 years.[88] It is interesting to note that a related study from the United Kingdom of 11,928 Labrador Retrievers showed that among the nine traits making up BVA/KC scoring paradigm, those descriptive of joint laxity had value as early-age predictors of osteoarthritis.[89] This finding is consistent with those of other studies showing the importance of joint laxity in the ultimate development of hip osteoarthritis, even on the hip-extended radiograph.* Studies from OFA and BVA/KC data show extremely slow genetic progress toward a desirable phenotype: "Excellent" OFA score and in the BVA/KC system, 5 or less. However, an essential question was not addressed in these reports: If these endpoints were reached, how osteoarthritis resistant would the hips of those dogs be? Are we selecting for the best target phenotype, the bull's-eye?
* References 1, 51, 114, 138, 158, 159, 169, 174, 175, 177, and 186.

Are We Hitting the Bull's-Eye?

An important point discussed earlier is the definition of the bull's-eye. Specifically, the bull's-eye or best target phenotype represents the interplay of (1) the heritability of the selection phenotype, (2) the selection pressure that can be applied, and (3) the "value" of the target outcome (phenotype) and how it relates to the disease or trait of interest, in this case, hip osteoarthritis. For all hip screening methods, the phenotypic goal is to breed for dogs that are both free of hip dysplasia at the time of examination and, more important, free of the susceptibility to acquire hip dysplasia throughout life. The purpose of selective breeding is to maximize the proportion of dogs within a population that have the target phenotype. For OFA score, the target phenotype is an "OFA Excellent" score; for the BVA/KC system (similar to the Australian hip scoring system), the target phenotype is a score of "0" out of a total of 106. For the PennHIP system, the target outcome would be to have dogs receiving hip scores of distraction index <0.3. The rate at which, or even the possibility, that dogs can achieve these targets depends on satisfying the requirements of the bull's-eye. Of extreme importance is the necessity for the hip score (OFA, BVA/KC, or PennHIP) to have a clear and definable relationship to the disease of interest—hip osteoarthritis. It is the absence of research into this relationship that represents a common weakness of most hip dysplasia screening systems but for PennHIP.

The hip-extended radiograph and the various subjective methods used worldwide to score this radiograph for the presence of and susceptibility to hip dysplasia have been largely a product of empiricism. The relevant research is typically short term, usually involving dogs younger than 3 years of age but some as young as 8 months of age.[101,102,190] Only one study evaluated dogs up to 5 years of age, but this study did not differentiate canine hip dysplasia from its underlying diagnostic components—hip laxity (subluxation) and hip osteoarthritis.[65] It has been shown in a 3 year study that a correlation exists among OFA score, Norberg angle, and distraction index, with distraction index having the best correlation with osteoarthritis as expressed by 3 years of age.[169] However, osteoarthritis occurring after 3 years of age was not investigated in this study. In all hip-extended evaluations, dogs without obvious hip laxity (subluxation) and without radiographic hip osteoarthritis would be scored as "normal" by subjective scoring at the time of evaluation. Such "normal" dogs that develop hip osteoarthritis later in life are "false-negative" diagnoses. A lifespan study of Labrador Retrievers showed a high number of false-negative diagnoses associated with both OFA-type scoring and official AVA/ANKC scoring.[72,174] See Figure 59-21 for how scoring at various ages relates to end-of-life data. Two-year subjective scores (OFA scores) had a negative predictive value of 48% when compared with end-of-life radiographic score, and a very low, 8% negative predictive value when compared with end-of-life gross and microscopic histopathologic findings. For 1-year AVA/ANKC scoring, negative predictive values for the three radiologists in the study ranged from 43% to 56% compared with end-of-life radiographic scoring, and from only 6.7% to 10% for end-of-life gross and histopathologic scoring. The PennHIP distraction index predicted at 2 years of age that all Labrador Retrievers in the study were susceptible to the osteoarthritis of hip dysplasia, and 98% of the dogs manifested osteoarthritis radiographically or histopathologically by end-of-life (mean age, 12.1 years). From the linear cumulative prevalence of osteoarthritis observed in the study

Figure 59-21 Hip screening: Real versus Ideal. Cumulative prevalence of subjective scoring of hip dysplasia and radiographic osteoarthritis compared to ideal hip screening behavior. The screening performance of the subjective criteria method is an attempt to interpret radiographic hip laxity (subluxation) as an indicator of susceptibility to osteoarthritis. Note that an "ideal hip screening system" would predict at a very early age the susceptibility to develop histopathologic evidence of osteoarthritis later in life. In the life span study 98% of the dogs developed radiographic or histopathologic evidence of OA by end of life. The *dashed line* labeled "Hypothetical Histopath OA" is included to give an idea of how radiographic osteoarthritis *(dashed blue line)* may lag behind histopathologic osteoarthritis with age (because end-of-life histopathologic osteoarthritis was the only data point). The cumulative prevalence of histopathologic osteoarthritis is assumed to be linear from the observed linear cumulative prevalence of radiographic osteoarthritis. The obvious bump in the Orthopedic Foundation for Animals (OFA) prevalence curve at 2 years of age represents the sum of dogs having both subluxation and osteoarthritis. After 2 years of age, no new subluxation was observed; therefore, the curve became horizontal leading to the conclusion of a previous study[65] that no new canine hip dysplasia occurred after 5 years of age. However, after 6 years, age-dependent osteoarthritis became the single criterion for increasing canine hip dysplasia diagnoses. By the end of the lifespan study, 98% of dogs showed radiographic or histopathologic osteoarthritis. Subjective scoring (subluxation or osteoarthritis) at 2 years of age missed 58% of dogs that would ultimately develop osteoarthritis of canine hip dysplasia. Such dogs are currently being certified for breeding.



(see Figure 59-21), it was concluded that all osteoarthritis, even at 12 years of age, was secondary to laxity and not primary. The linearity of the onset of osteoarthritis in this cohort of dogs suggests one rate constant and, therefore, a single cause of the osteoarthritis—joint laxity. This conflicts with the current empirical understanding that old dogs develop primary hip osteoarthritis because the cartilage wears out. Further evidence that osteoarthritis in this study was secondary to laxity and not primary is derived from a subsequent study[115] showing that both geriatric Greyhounds and geriatric non-Greyhounds with DI ≤0.35 (mean age of 8.33 years) show little to no hip osteoarthritis.[115] The lifespan study, the only one of its kind, demonstrated the profound importance of hip laxity in predicting the susceptibility of dogs to develop, at some point in their lives, the osteoarthritis of hip dysplasia. A 3-year, 5-year, or even 10-year study would not have been long enough to arrive at these conclusions.

The question remains as to whether the target phenotype (the bull's-eye) has absolute value; specifically, whether OFA Excellent hips (or BVA/KC score of 0) do actually represent dogs free of susceptibility for hip osteoarthritis later in life. Unfortunately, the lifespan study had the limitation that there were no dogs with excellent hips at 2 years of age, so direct inference could not be made from that pool of dogs. However, evidence was derived from an investigation of 439 dogs having both official OFA scores and official PennHIP scores.[140] It was found that of the dogs receiving OFA Excellent hip scores, 52% had a PennHIP distraction index that put them into the osteoarthritis-susceptible range (DI >0.3). Similarly, of the dogs receiving OFA Good scores, 82% had DI >0.3 and 94% of OFA Fair scores had DI >0.3. The relationship appeared to be breed-specific, because among Labrador Retrievers with OFA Excellent hips, 80% had hips with DI >0.3 and therefore were susceptible to the osteoarthritis of hip dysplasia. Similar results would be expected from all hip scoring systems that rely on the hip-extended radiograph to determine hip phenotype.

This evidence suggests that slow genetic progress can be explained by both low heritability of the subjective hip-extended phenotype and a breed distribution of hip scores that leaves little room for applying further meaningful selection pressure Labrador Retrievers have an average hip score of OFA Good. One must breed to dogs having OFA Excellent hips to make further genetic improvement of hips. The matter is additionally complicated because the best target score achievable, Excellent, is associated with at least a 50% chance of a dog getting the OA of hip dysplasia at some point in its life.

Summary

AIS PennHIP is the only method that satisfies all the requirements to be an effective tool to reduce the frequency and lower the severity of canine hip dysplasia.

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See www.veterinarysurgerysmallanimal.com for a complete list of references.

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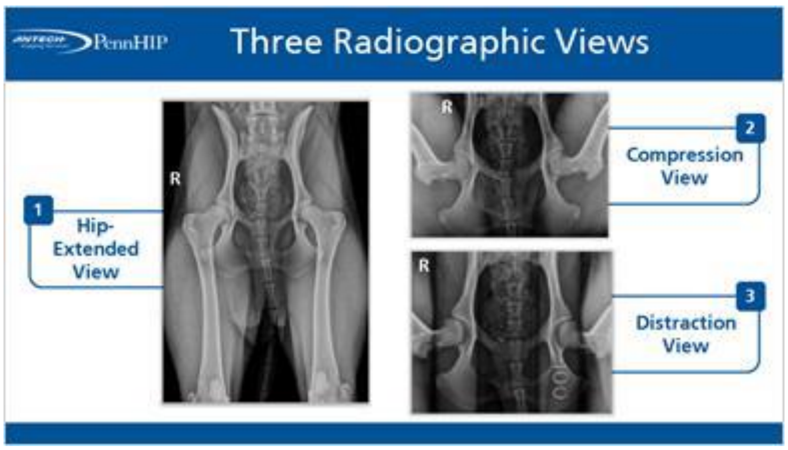
Chapter 4: How to Perform the AIS PennHIP Procedure

(This Chapter covers material presented in Online Course 3)

Course Overview

This chapter will describe the preparation for, and execution of the AIS PennHIP procedure. You will learn the levels of anesthesia necessary to permit optimal positioning of the patient for the procedure while minimizing discomfort to the patient. Step by step instructions to perform the procedure will be covered as well as quality control standards and troubleshooting techniques to assure submission of diagnostic quality radiographs.

Three Radiographic Views



An AIS PennHIP exam consists of three radiographic views. The radiographs should be made in the exact order you see in the illustration; first, the hip-extended view or conventional ventrodorsal view, next the compression view, and then last, the distraction view.

These are not your typical hip radiographs. The views are complementary, each view contributing unique information to the overall hip evaluation.

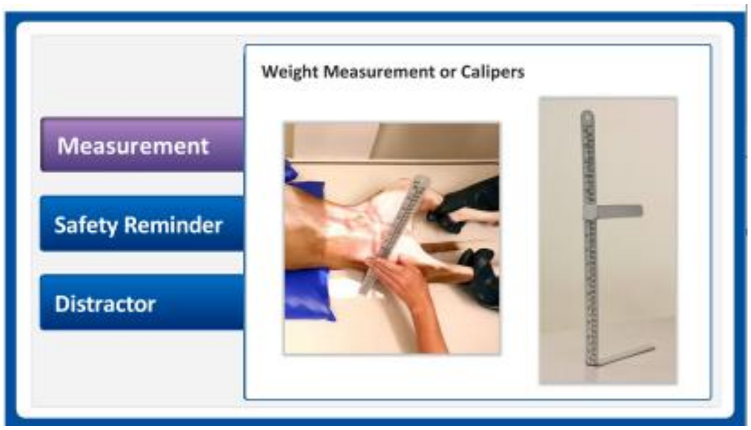
- The hip-extended view is used to assess the overall state of the hip joints and to obtain supplementary information regarding the existence of osteoarthritis.
- The compression view is used to identify key landmarks for measurements and also gives an indication of how well the femoral head sits in the acetabulum.
- And the distraction view is the key view to demonstrate the dog's maximum passive hip laxity.

Both the compression and distraction views are used in determining the distraction index.

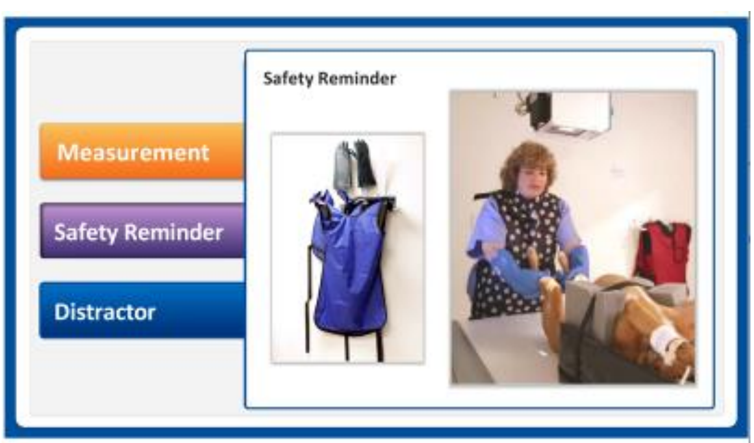
Preparation

As for all radiographic procedures, appropriate preparation, awareness of radiation safety requirements, and safe and effective use of anesthesia or sedation are essential.

For digital radiographs, an accurate body weight is needed for the appropriate machine setting. For film radiographs, caliper measurements are to be taken at the thickest part of pelvis. For an accurate measurement to be obtained, the bottom and the moveable portion of the calipers should be parallel. The soft tissue should not be compressed by the calipers. The measurement reading is taken at the bottom of the moveable bar and is usually read in centimeters. Remember to refer to your technique chart.



When restraining the patient for the radiographs, you should wear appropriately fitting personal protective equipment including lead apron, gloves, thyroid shield, dosimeter and lead glasses if required. Positioning aids should also be used whenever possible to help limit the number of people in the room. This is an ALARA principle and helps limit personnel exposure. Remember gloved hands should never be in the primary beam because gloves are only meant to protect you from scatter radiation. When in the room, stay out of, and distance yourself as far as possible from, the primary beam thereby lessening exposure to scatter radiation.



Have the appropriate sized distractor for the patient nearby and ready to use. Make sure the distractor is assembled correctly and in working order so that the bars can be adjusted as needed using the knobs on either end.

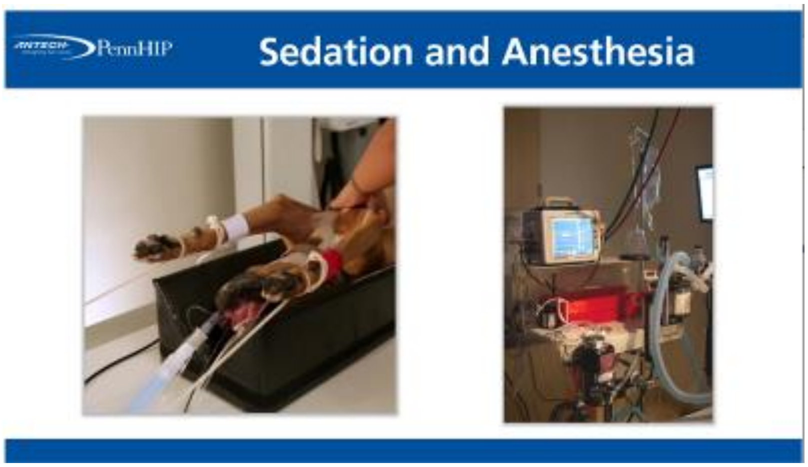
Record Keeping

Enter in all of the information for the patient and the radiographs. The radiographs should be properly labeled and include the patient and owner name, registration number and date. If your software allows, include a unique identifier such as microchip, AKC or tattoo number for further identification. Verify the accuracy of the information and ensure that it doesn't obscure or overlap any of the critical anatomy.

The example radiographs you will see used in the courses of this program will not contain patient identification information to protect patient privacy.

Also, make sure that the positioning marker is present and visible in the collimated view. Ensure that it is appropriately placed for proper orientation of the film for evaluation and interpretation. And, just like the label, it should not obscure any of the important anatomy. A complete description of the information to submit PennHIP radiographs will be covered in greater detail in Chapter 7.

Sedation and Anesthesia



Adequate sedation is necessary to obtain a diagnostic AIS PennHIP study. Sedation not only ensures a cooperative patient but also prevents the reflex muscle contraction that pulls the femoral head into the acetabulum. This reflex muscle contraction conceals maximal passive laxity in the hip joint and decreases the measured distraction index.

Use the anesthesia or sedation with which you are most comfortable, with the understanding that the patient must be at or near a surgical plane of anesthesia. Incorporating pain management into your overall anesthetic plan may be indicated. This indication is not due to the procedure being painful but that if the patient has any hip disease, preemptive pain management is always preferable to symptomatic pain management.

Proper monitoring equipment to monitor all patient parameters, including heart rate, pulse, respiration and temperature, should be used. Thermal support should also be used if needed.
The patient's health, safety and comfort are of the highest priority.

Patient Positioning

Positioning devices will be used to help obtain the desired radiographic images. Have various sandbags, foam wedges, ties and tape available. A soft v-trough or deep, square trough with foam wedges should be used to keep the patient stable while on its back. A shallow, hard sided v-trough can make it difficult to position the patient and is not recommended. Please remember that sandbags, troughs, or other positioning devices, shouldn't obscure any important anatomy in the images submitted.

Following proper sedation, the patient will be placed into dorsal recumbency on the radiology table. Gently place the dog into the trough. Be sure the entire pelvis extends beyond the rear portion of the trough so that it is not superimposed on the hips. Use positioning devices to help position the patient with the sagittal plain perpendicular to the radiographic table, the spine straight and the pelvis not rotated. Ties can be used and placed using a cow-hitch knot over the front limbs ensuring circulation to the limbs is not restricted. The thoracic limbs can be extended over the head being sure not to over extend them or they can be crossed over the head for stability. Care must be taken not to impart extreme traction on the limbs as it can cause patient discomfort.

Sandbags or foam wedges can be placed on either side of the chest to hold the patient in position but not of a weight or position that would increase respiratory effort keeping patient comfort and safety in mind. Again, make sure these are not superimposed over the hips. Other positioning devices can be utilized to achieve diagnostic quality films in addition to those demonstrated here. Verify that the sternum and spine are straight and parallel to each other and to the radiology table before taking radiographic films.

Hip-Extended View

The first radiograph you will obtain is the hip extended view. This view allows the hips to be screened for evidence of osteoarthritis. As discussed in the science course, traction on the thoracic and pelvic limbs produces hip extension which winds up the joint capsule. The effect conceals the maximum passive hip laxity.

For collimation of the hip-extended view, the x-ray beam will be centered on the pubis to start. Open the collimator enough to include from the cranial edge of the wing of the ilium to the entire femurs and stifle joints. You may move the beam and collimated light distally as needed depending on the conformation of the patient. However, it is better to eliminate a portion of the stifles rather than the cranial aspect of the pelvis.

The stifles are included in order to provide information about potential rotation of the femurs.

Place the positioning marker on the table just lateral to the superficial tissues of the pelvic limbs. Collimate and palpate for appropriate landmarks and make sure the collimator is wide enough to include the positioning marker. For the hip-extended view, you will place moderate traction on the thoracic limbs cranially and pelvic limbs caudally. Ensure that the pelvis is not rotated: trochanters and tuber ischia should be equidistant from the table.

Grasp the hocks or distal tibias firmly and flex both the hip joint and the stifles to approximately 90 degrees (as shown). The femurs should be pointing at the ceiling and parallel to each other.

The tibial tuberosities should be level establishing that the pelvis is not rotated. From this position pull the hips and stifles into full extension while at the same time applying slight internal rotation to each tarsus causing pronation at the hip. Gently hold the stifles together making the femurs parallel and push downward on the stifles extending them maximally.

Radiograph 1: Hip-Extended 15 month, F, Golden Retriever

Verify the position by palpating the greater trochanters as each should be the same distance above the table. The hips should be in full extension with the long axis of each femur parallel to each other. Also, palpate the patellas to ensure they are on the center or top of the femurs and not rotated to one side or the other.

Then, make the exposure.

Review your films for quality and proper technique before moving on to the next image.

When performing a quality control check on the hip-extended view you will:

- Verify the anatomical boundaries. The area cranial to the wings of the ilium and the area just to the level of the stifles should be included.
- Verify that the wings of the ilium and obturator foramen are symmetrical. The patellas must be centered in the trochlear grooves and the femurs and tibias parallel to one another. There should be a slight pronation of the femurs.
- Verify that the technique is correct. You should see all the important anatomy including soft tissues.
- Verify that the positioning marker and patient ID are present and correct.

Compression View

The compression view is the second radiograph you will obtain in this three part series. The goal of this view is to identify key landmarks for measurements and the view also gives an indication of how well the femoral head sits in the acetabulum.

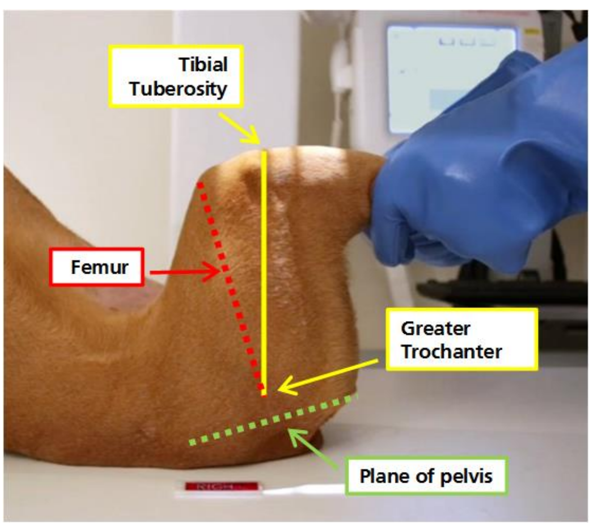
For collimation of the compression view, the primary x-ray beam will be centered on the pubis to start. Open the collimator just enough to include the wing of the ilium cranially to the tuber ischia caudally. In most dogs it's possible to palpate the cranial pubis to verify landmarks. Collimation should be enough to include the proximal half of the femurs but the stifles do not have to be included in the image. It is acceptable to cut off the cranial edge of the wing of the ilium as you see in this example image. The longitudinal cross-hairs of the collimator will be centered on the midline between both hips and the transverse cross hair should cross the cranial pubis and simultaneously, both tibial tuberosities. The hips should be in the center of the image, as shown.

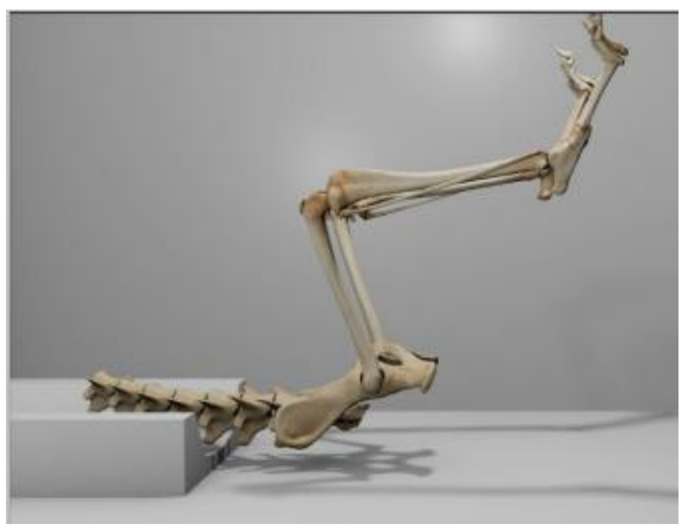
Note collimation

For the compression view the patient is still in dorsal recumbency with the pelvis not rotated, looking symmetrical. Verify that the patient is still completely stabilized with positioning devices and that the level of anesthesia or sedation is appropriate for limb manipulation.

Visualize and palpate the external landmarks for proper collimation and positioning. The transverse collimator line should cross the pubis and both tibial tuberosities simultaneously while the longitudinal collimator line should be on the midline of the patient. This is nicely shown in the picture of the dog in compression position. Verify that the positioning marker is appropriately placed.

Place the femurs into a stance phase position as shown, slightly angled forward. As viewed from the side, the tibial tuberosity (TT) should be directly vertical to the greater trochanter (GT). Both the compression and the distraction view start with this position shown below.





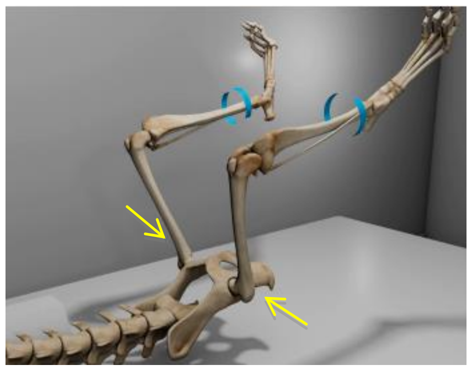
Assess positioning prior to performing the compression maneuver. Palpate the greater trochanters (GT) to confirm that they are the same distance above the table and the pelvis is not rotated

It is important to remember that the stifles are to be kept at a stance phase distance apart during the compression maneuver with the tibial tuberosities level with each other.

Irrespective of dog size, position hands as proximally on the tibias as possible short of having gloved hands in the primary beam. Now the compression force will be applied. Without changing position, externally rotate the tibias with hands at hock or mid-tibia depending on the size of the dog. The stifles will be abducted enough to avoid superimposition over the femoral heads. This maneuver creates a medially directed force (yellow arrows) at the hips fully seating the femoral heads into the acetabula.

Then, make the exposure.

Radiograph 2: Compression View



Review the compression radiograph for quality and proper technique before moving on to the next image.

When performing a quality control check on the compression view, you will:

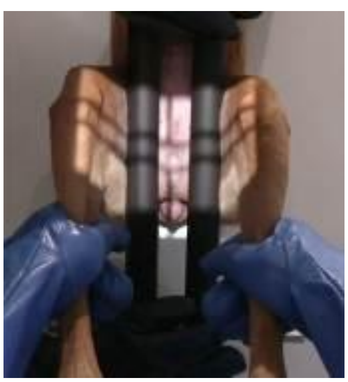
- Verify the anatomical boundaries. The wing of the ilium cranially and the tuber ischia caudally should be included. Also the proximal half of the femurs should be included.
- Verify that the wings of the ilia and obturator foramen are symmetrical. An imaginary line connecting the tibial tuberosities should cross the hips and cranial pubis. Check that the femoral heads are fully seated into the acetabula.
- Verify that the radiographic technique is correct. Contrast and brightness should enable visualization of all the needed anatomy including soft tissues

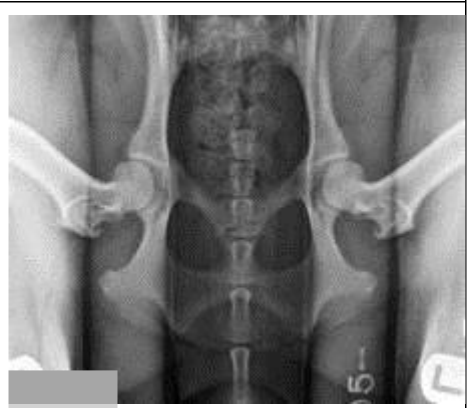
• Verify that the positioning marker and patient ID are present and correct.

Distraction View

The distraction view is the third and final radiograph you will obtain in this three part series. The starting position is the same as for the compression view described above. The goal of this view is to use the distractor and distraction force to measure the maximum amount of passive laxity inherent in the hip joint. As the adduction force is applied to the femurs, the femoral head is distracted from the acetabulum and the foam encasing the distraction rods is compressed approximately 25-50%.


Radiograph 3: Distraction View **DI = 0.37**

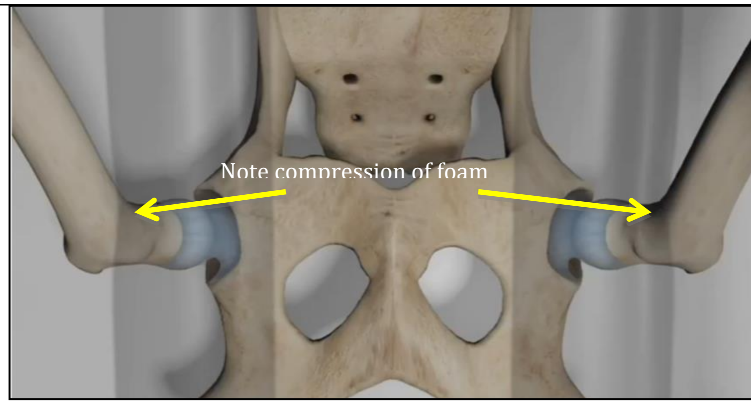




The distractor acts as a fulcrum to impose a lateral distractive force on the hips. It's important the distractor rods are spaced so that the femoral heads lie in the shadow of the rods, as shown. The distraction of the hips occurs in response to the force applied by adducting the femurs until the stifles are at a stance phase distance apart and the foam covering the distractor rods is compressed25 - 50%.

The rods will be placed parallel to the ventral abdomen and pelvis as viewed from the side while keeping the rods parallel to each other. Hold the distractor at each end by the aluminum bars and apply a firm and evenly distributed downward force onto the pubis. Sometimes there is a misconception or confusion that pressing the distractor downward with more force is what actually causes the distraction. That's not true. You cannot create evidence of hip laxity by applying excessive force on the distractor.

It's important to ensure even and perpendicular distribution of pressure for both rods. A common mistake is to apply more force to the near rod which will result in a non-diagnostic image. The aluminum distractor bars at the ends of the rods must be parallel to the table, so that the distractor is not rotated relative to its long axis. The operator should always check that the pelvis is not rotated by observing that the tibial tuberosities remain level while applying the distraction force.



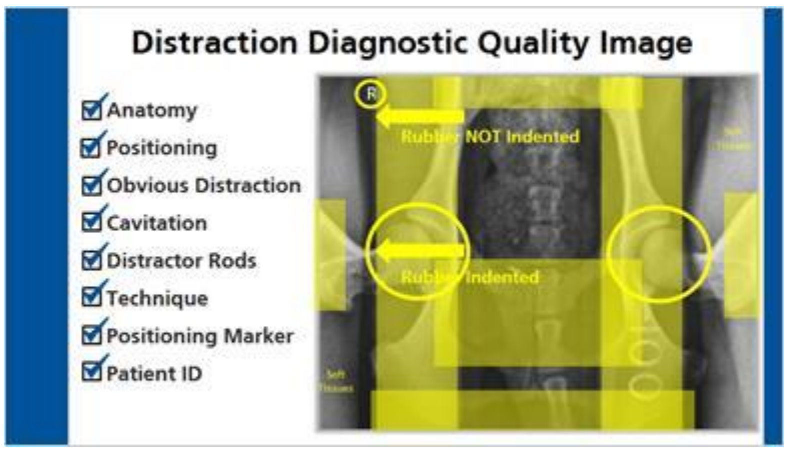
The collimation of the distraction view is similar to the compression view. The x-ray beam will be centered on the pubis. The collimator is open just enough to include the caudal sacrum cranially and the tuber ischia caudally. Lateral collimation should be enough to include the proximal half of the femur. Ensure that the pelvis is not rotated by keeping the tibial tuberosities level.

Step-by-step Instructions for the Distraction View:

- The patient remains in dorsal recumbency for the distraction view. Verify that the patient is still stable and the level of anesthesia or sedation is still appropriate for the radiograph to be obtained.
- Visualize and palpate the external landmarks to ensure proper collimation. Verify that the positioning marker is appropriately placed. The transverse collimator line should cross the pubis and both tibial tuberosities simultaneously while the longitudinal collimator line should be on the midline of the patient.
- For rod spacing, palpate the pectineus muscle as it originates on the iliopubic eminences of the pubis.
- The medial side of the rods are positioned (at least initially) just lateral to this muscle attachment site. Remember to keep the rods parallel to each other while making adjustments.
- Place the distractor onto the dog with rods parallel to the ventral abdomen and pelvis while keeping the rods parallel to one another. Have your assistant hold the distractor at each end and apply a firm downward force on to the pubis. Remember to apply even and perpendicular pressure to both

distractor rods.

- Verify the greater trochanters are the same distance above the table and that the tibial tuberosities are level and are vertical to the greater trochanters. Check that the long axis of each femur is abducted sufficiently so that when the distraction force is applied, the stifles will end up at stance-phase width.
- It is often helpful to do 1 or 2 practice distraction procedures at low applied load to make adjustments in distractor rod spacing if necessary. Assess the positioning of the patient prior to the image being obtained.
- The PennHIP member grasps the hocks firmly and applies the full distractive force, placing the hips in a stance phase position. Maintain the distractive force for duration sufficient to make the exposure.
- Make the exposure

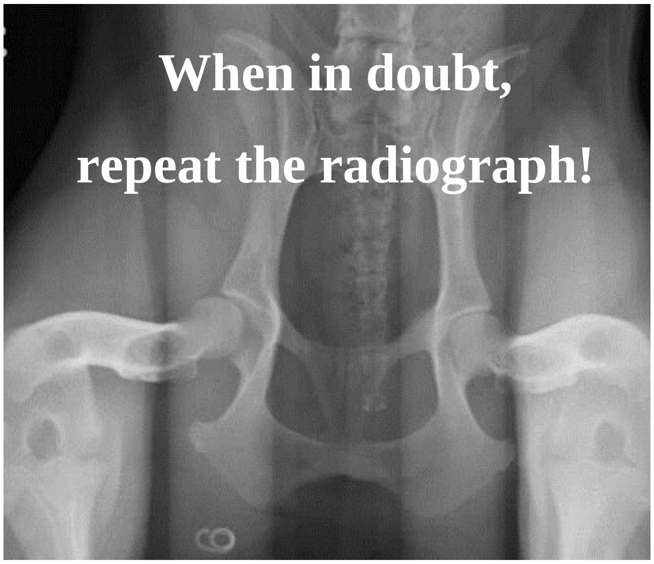


Review your distraction radiograph for quality and proper technique before waking up the patient. When performing a quality control check on the distraction view, you will:

- Verify the anatomical boundaries. The area from the caudal sacrum to the tuber ischium should be included. Laterally, the proximal half of the femurs should be included.
- Verify proper pelvic positioning. The wings of the ilia and obturator foramen should be symmetrical. An imaginary line connecting the tibial tuberosities should cross the hips and cranial pubis. There can be no superimposition of the femurs, stifles or thigh muscles over the hip joints.
- Verify that the femoral head has obvious distraction from the acetabulum.
- If obvious cavitation (description to follow) is seen in both hips, repeat the procedure in 24 hours or more.
- Verify that the distractor rods are over the femoral heads and evaluate the image for the proper distractor rod shadow. The acetabulum does not need to be in the shadow of rods, but the femoral head does. For very lax hips the rods will have to be widened to remain over the femoral heads
- Verify that adequate rubber compression is evident.
- Verify that the radiographic technique is correct. Contrast and brightness should enable visualizing

all the important anatomy including soft tissues.

- Verify that the positioning marker and patient ID are present and correct.
- Make sure there is discernible laxity on the distraction view when compared with the compression view



Before waking the dog from anesthesia or sedation, compare the distraction view to both the compression view and hip-extended view in order to be certain that the distraction view contains more discernible laxity on both hips. Your eye should be able to detect a visible difference in the joint laxity. If little to no laxity is observed, first check the level of sedation. If the dog is deep enough, a trick to try is lifting up on the tibias while applying the distraction force. This often releases the femoral head and more laxity can be observed. The assistant holding the distractor should also be advised to reduce the downward pressure on the distractor.

In the case above there is no laxity seen on the left hip during the distraction procedure. This image should be repeated because it would be rejected if submitted to AIS PennHIP. The guiding principle is to repeat any distraction image where there are no signs of distraction. When in doubt repeat!

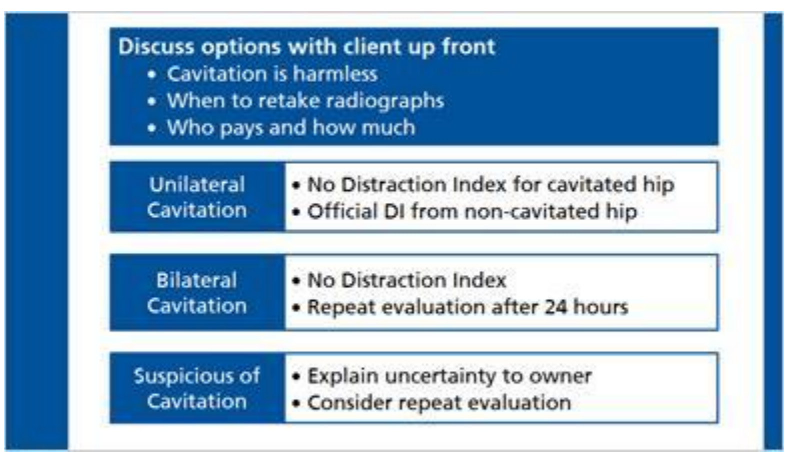
Keep in mind that all dogs, even Greyhounds and Borzois, have measurable joint laxity under conditions of distraction. If your radiographs show no joint laxity or only slight joint laxity when compared to the compression view, something in your technique needs adjustment or correction.

Cavitation

In the quality control review process, one of the things you will be looking for is cavitation, or lucencies in the synovial fluid caused by low intra-articular pressure. The appearance, however, of cavitation is often subtle and easy for the inexperienced to overlook, so most times the phenomenon of cavitation will only be diagnosed upon evaluation of the images at AIS PennHIP.

If you've ever cracked your knuckles, you've created cavitation. This phenomenon can occur during the distraction procedure. The intra-articular pressure is lowered enough that voids can form in the synovial fluid. This void appears as bubbles on the radiograph as you can see here in this example. Cavitation is not painful and doesn't cause any short or long term damage to the joint.

Cavitation occurs infrequently while performing the distraction view and resolves itself within 24 hours.



Cavitation is problematic only because it causes the distraction index to be unreadable or can cause a false increase in the distraction index. Cavitation can take on a variety of appearances. Only the most obvious cavitation will be detectable. The potential for cavitation to occur is the reason the distraction view is performed last in the series of views. It's also the reason that distraction radiographs are read by highly trained readers at Antech Imaging Services.

- If cavitation is unilateral, no distraction index will be generated for the cavitated hip. An interpretation will be given from the non-cavitated hip and the report will state that unilateral cavitation was observed. If repeating the distraction radiographs is desired, wait at least 24 hours to permit the bubbles to go back into solution.

- If cavitation is bilateral, no distraction index will be generated for either hip and the procedure will have to be repeated again after 24 hours have passed. Bilateral cavitation occurs infrequently (1 every 400 submissions) nonetheless, it may be wise to discuss it with the pet owner because the procedure will have to be repeated.

- Sometimes there is only suspicion of cavitation. If so, make sure that you talk with the pet owner about the situation and consider repeating the radiographs at a later date to confirm the true hip laxity. A designation "Suspicion of cavitation" does not appear on the official report, only on our notes to you, the PennHIP member. Because a DI will be issued for a hip with suspicion of cavitation, it is possible that the true laxity of that hip could be better than the DI indicates. Hence, we recommend speaking with the owner about the desirability of repeating the distraction radiograph.

Recommendations for Those Who Cavitate Frequently

For PennHIP members who experience frequent cavitation, we have a few recommendations to avoid it:

- Back off on the amount of force applied. If the dog is sufficiently anesthetized/ sedated it takes very little force to create maximum laxity.
- If cavitation continues to be a problem in the face of reducing applied force, try doing a "half strength – full strength" procedure. On the first distraction radiograph use only an estimated half the amount of applied force. Then follow up with a full strength distraction radiograph. You will note that the amount of observed laxity will be very similar despite the difference in applied force, assuming of course that cavitation did not occur on the full strength image.
- Cavitation seems to occur more frequently when the hips are too extended; that is, the stifles are too caudal. As demonstrated in the proper technique section above, position the hips so that the transverse collimation line traverses the both the tibial tuberosities and the cranial pubis simultaneously (as shown above for both compression and distraction positions).

Helpful Hints and Tidbits

1. One of the Plexiglas rods of each distractor has an identifying radiolucent number etched into the rod. Try to avoid superimposing the number over the hip making the reading of the distraction index difficult. To mark the location of the distractor number, simply slide the foam sleeve up the plexiglass rod and measure the distance where the number is engraved into the rod. Slide the sleeve back down. Next, measure this same distance and using adhesive tape, mark the spot where the number is under the foam. Knowing where the distractor number is located allows you to place it away from the hip joint.

2. Ortolani, Barden's and other hip manipulation tests should be performed AFTER the AIS PennHIP film series is completed. Any hip joint palpation technique could potentially create cavitation. Even applying too much tension on the dog when performing the hip-extended view can cause cavitation.

Moderate force is all that is necessary.

3. Estrus has been shown to have no effect on hip laxity in either the distraction or the hip-extended radiographs. Pregnancy and lactation however, are associated with elevated relaxin levels which have been shown to increase laxity of fibrous tissue. Do not do the AIS PennHIP procedure during pregnancy. Although the duration of relaxin's effects are not known, we suggest waiting at least 2 months following the end of lactation.

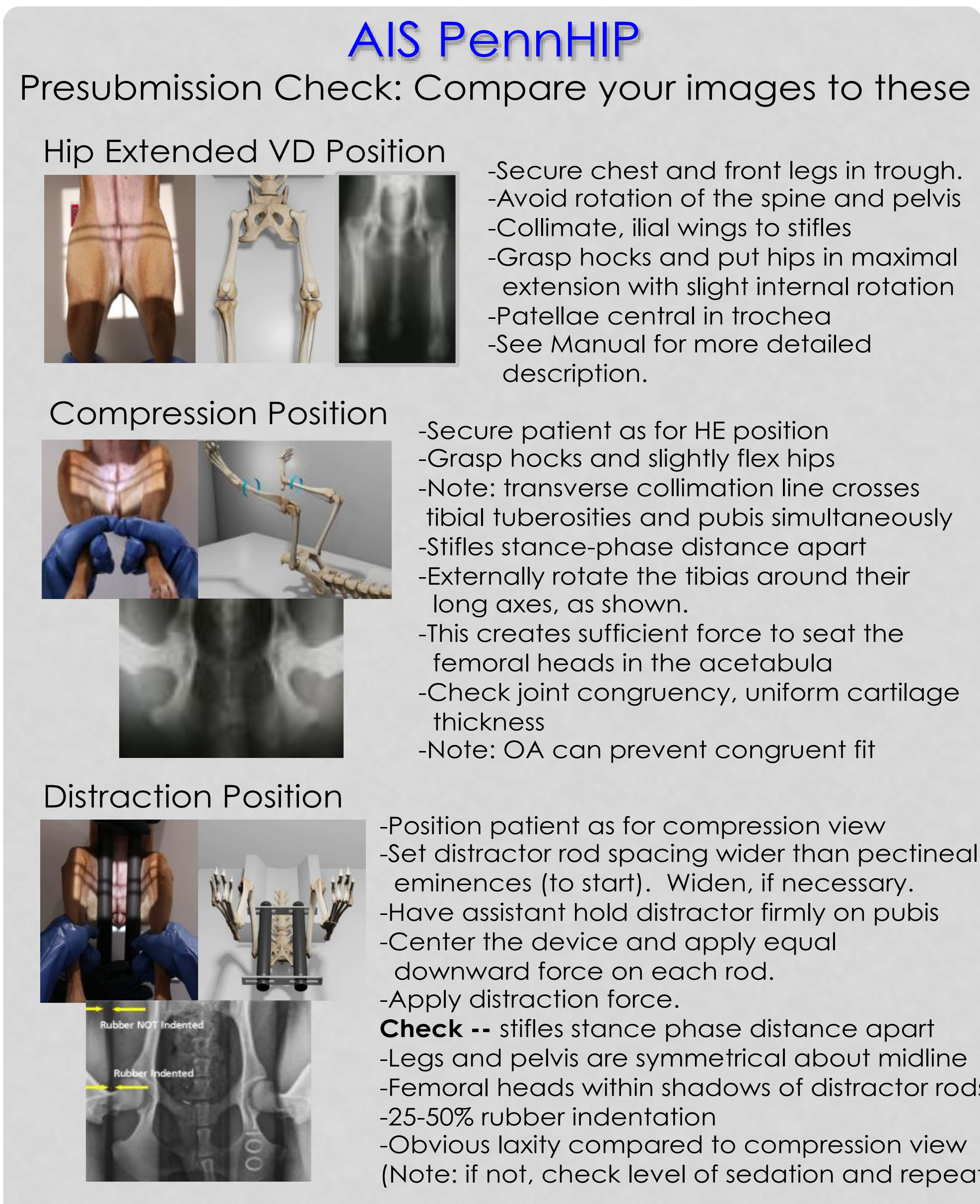
4. When making the compression and distraction views on large or long-legged dogs, it helps to grasp the middle of the distal tibias rather than the hocks. For giant breed dogs, such as Irish Wolfhounds, better leverage can be obtained by clamping the dog's feet under your armpits. This usually requires that the certified member will need to stand on a stepstool to obtain suitable height for proper positioning and leverage.

5. For very muscular dogs, it's often difficult to position the distractor close to the pubis because the adductor musculature is well developed. The distractor tends to migrate toward the stifles when the distraction force is applied. The assistant may have to make greater effort to stabilize the distractor and may have to apply a bit more downward force to do that. In addition, the certified member may have to apply more distraction force. Ensure the dog is sufficiently sedated or anesthetized because any reflex muscle contraction will make it impossible to distract the hips.

Chapter 5: The Good, the Bad, and the Ugly: Reasons for Rejecting Submissions

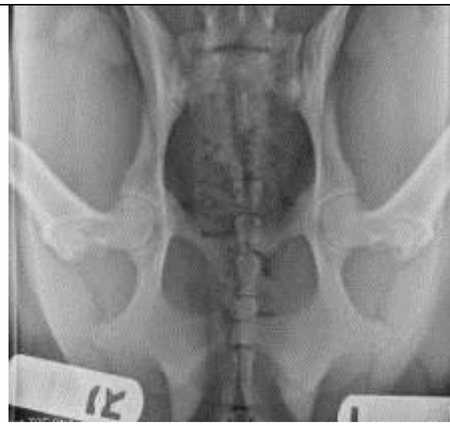
Good PennHIP Technique

This figure summarizes and reviews how to perform the AIS PennHIP Procedure. Print it out and keep it in your radiographic suite.



It is important to learn to critique your images prior to submitting to AIS PennHIP. The next 2 cases are examples of nearly perfect AIS PennHIP technique.

Case 1: These three PennHIP radiographs are of a 15 month old, female Golden Retriever. All three images represent near-perfect technique. The distraction index for this dog is 0.37. Study them. PennHIP radiographs do not have to be perfect to be readable, however these are the images you should strive to produce. To follow, we will review some images that do not meet PennHIP criteria.



Case 2: A 15 month old female, Labrador retriever. Very good technique. The only criticism might be that there is not quite enough rubber compression on the left hip in the distraction view. However, there is optimal rubber compression on the right hip and the apparent hip laxity is equal on both hips. Therefore a distraction index was measured, DI = 0.31.

Reasons for Rejecting AIS PennHIP Consults

We reviewed 3888 of the most recently submitted AIS PennHIP cases and found that 77 consults (2%) were rejected and had to be repeated. Although 2% is not a high failure rate, we recommend explaining to prospective clients that there are circumstances, though rare, that may require that the procedure be repeated. The most common reasons for rejection include:

- Inadequate hip distraction (distraction view shows no more laxity than the compression view)
- Inadequate rubber compression (often assoc. with inadequate distraction)
- Incorrect positioning:
  - Stifles too caudal (hips too extended)
  - Stifles too cranial (hips too flexed)
  - Excessive leg abduction
  - Excessive leg adduction
  - Excessive pelvic rotation
- Distractor:
  - Rods too narrow
  - Rods too wide
  - Not centered
- Thigh muscles or stifles superimposed on hips
- Both hips cavitated
- Poor radiographic technique (contrast, brightness, resolution)

A submission can be rejected for more than one reason. In the analysis mentioned above, 9 % of the rejected cases were rejected for 3 reasons; 36%, for 2 reasons; and, 55% for one reason.

Before submitting your images, review them for the common mistakes mentioned. Note: bilateral cavitation is technically not a mistake. It occurs at no fault of the practitioner. See “Cavitation” in Chapter 4 for tips as to how to avoid it.

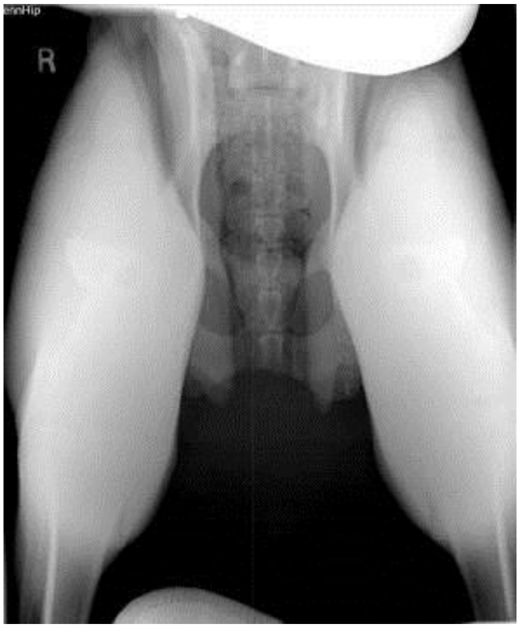
Self-Critiquing PennHIP Radiographs:

Note: Review the Images before reading the legends. Try to identify problems in technique.

Case 1R:

This distraction view is not of diagnostic quality. It was rejected for several reasons. Most importantly the image itself has poor detail. Note the pixilation. It was not possible to measure a reliable DI. Also, the pelvis is rotated (see obturator foramen), the distractor rods are too wide, the distractor is not centered, and overall the positioning is not symmetric about the midline.

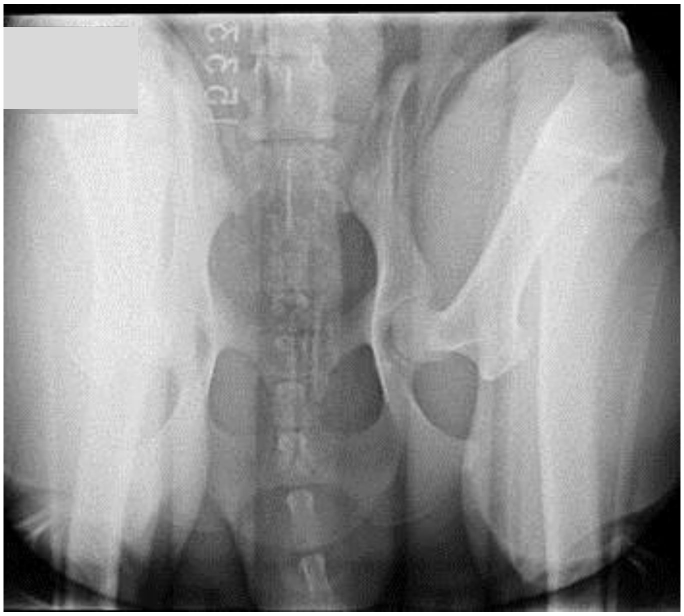
Case 2R:



This consult failed for multiple reasons. The distractor rods are too narrow, therefore thigh musculature is superimposed over the hips. There is no obvious joint laxity (although it is very difficult to see the hips with this radiographic technique). The hips are too extended (stifles too caudal). The hips are internally rotated (tibia not parallel). This hip extension and internal rotation seriously reduces the amount of hip laxity on the distraction view.

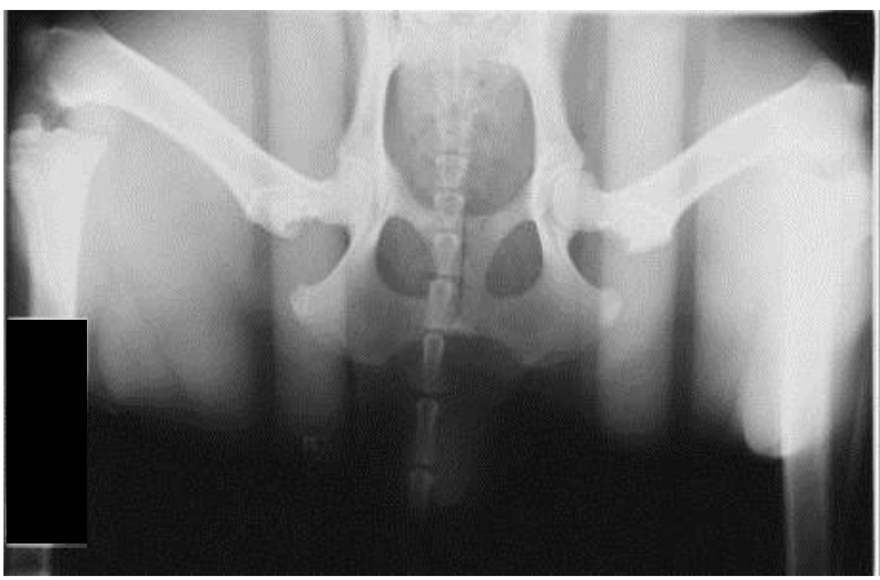
A recommendation (but not grounds for failure) is that gloves are in the primary beam. A comment will be included on the report to keep gloved hands out of the primary beam.

Case 3R:



This distraction view would not be acceptable. The principle reason is that there is no discernible hip distraction. Also, the stifles are too far cranial. A line drawn between the tibial tuberosities should cross the cranial pubis. Here such a line crosses the caudal sacrum. The distractor rods are too narrow and the distractor is not properly centered. The tibia and musculature are superimposed over a portion of the right hip. The overall appearance of the legs and pelvis is not symmetrical. Although not grounds for rejection, the tibias are internally rotated (note the fibulas are silhouetted out against the soft tissue). The stifles should be in neutral position rotationally for the distraction view. Recall that for the compression view the tibias should be internally rotated to apply the compressive force.

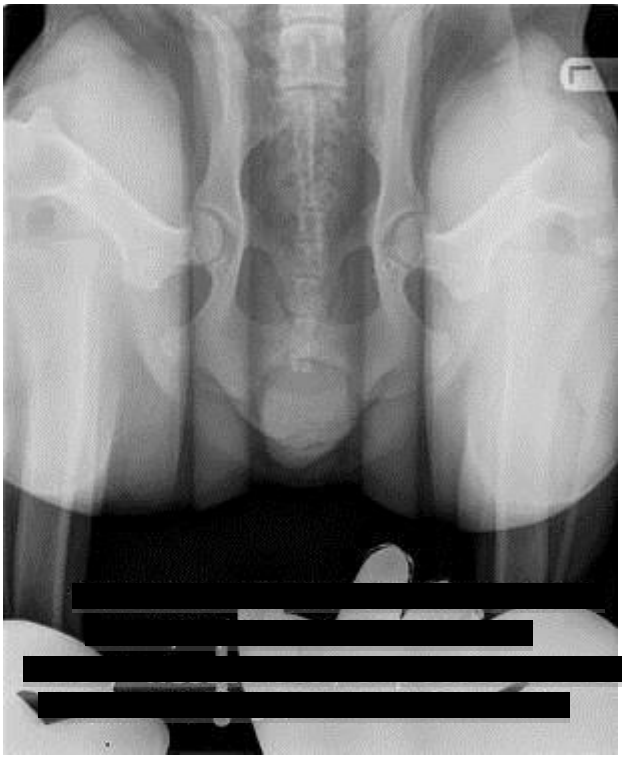
Case 4R:



Rejection Reasons: No distraction, legs too abducted, insufficient rubber compression, distractor rods too wide.
Note: When distractor rods are too wide the knees cannot be adducted to a stance phase distance. This abducted positioning combined with the distractor being pushed down by the assistant tends to capture the femoral head in the acetabulum, particularly in hips that have no remodeling changes.

Also, with the rods being too wide, the rubber compression occurs on the bottom side of the distractor and doesn't appear on the lateral side where we assess it. In this example this pelvis is rotated but not enough to reject.

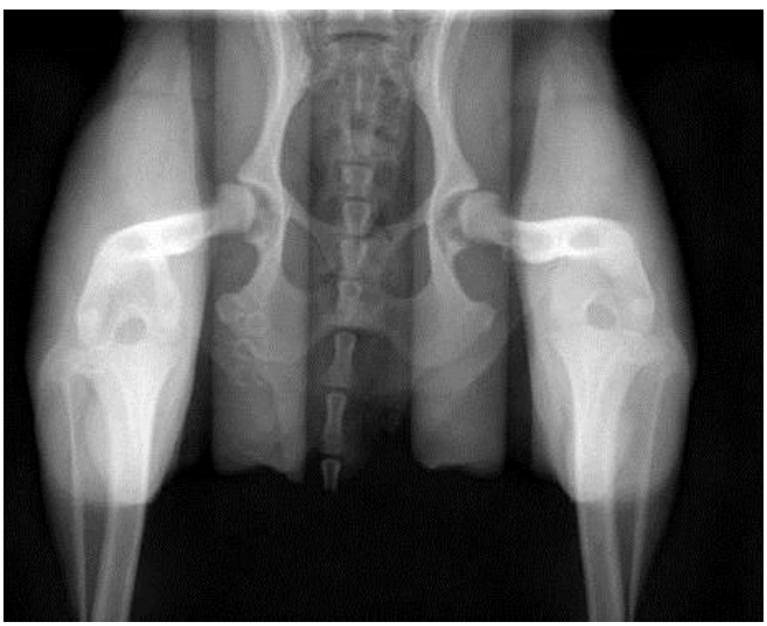
Case 5R:



Rejection Reasons: Rods too narrow, inadequate rubber compression (Therefore uncertain max laxity was achieved). Femoral heads should be entirely in the shadows of the rods.
Other recommendations: Try to keep the engraved numbers away from the hip area. Collimate more and keep gloves out of primary beam.

There is good symmetrical positioning. Stifles could be a bit more forward (hips more flexed)

Case 6R:



Rejection Reason: Bilateral Cavitation
Other recommendations: Knees should be more craniad. We tend to see cavitation more commonly associated with this caudal positioning of the stifles. There should be greater collimation, and we don't recommend internally rotating the tibias while applying the distraction force, (Note how the fibulas are prominently silhouetted indicating internal tibial rotation).

Chapter 6: AIS PennHIP Client Communication

This chapter will introduce several tools to use to help educate your clients about the AIS PennHIP procedure. For pet owners it will cover risk assessment, early detection, and preventive treatment for osteoarthritis of the hips. For breeders the chapter will introduce some time-tested principles of quantitative genetics: tools you can use to help breeders make more informed selection decisions. The new PennHIP report will be fully described so you can share this important information with your clients, whether pet owners or breeders. Some typical clinical case examples will be presented.

Tools for Communication

Now that you know the current information about AIS PennHIP - the history, the science behind the procedure and what the procedure involves - the next step is talking to your client. Facts and figures can be overwhelming when talking about medical care of any family member. Emphasizing the benefits always makes it easier to understand. Let's look at a few tools that can help you better communicate with your clients. We will look at the Chunk & Check method, using the AIS PennHIP Report as a communication tool and using a video as an educational tool.

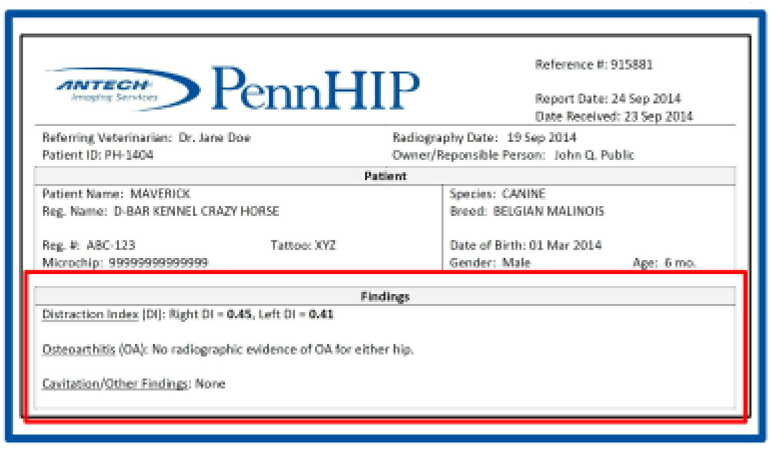
When communicating this information to a client, you want to ensure that they understand what you are talking to them about so that they can make good, sound health decisions for their pet. When presenting a new procedure or technique, the tendency is to focus on the facts and "data dump" information on the client all at once. Unfortunately, that's often the way information is presented in the medical field. The goal would be to move away from this type of one-way communication style because it only serves to overwhelm the client and ensures they will not remember all that you just discussed with them. A good tool to use is the Chunk and Check method. Basically this involves giving information in small, easily understood, bite size pieces or chunks and then checking that the client understands using pauses between chunks. You can then ask open-ended questions and demonstrate active listening before moving on to the next chunk.

AIS PennHIP Report

The AIS PennHIP report is a tool that is useful for you and your client. Two reports will be issued to you: one for the client and one for the veterinarian. The veterinarians report will contain the same information as the client's report plus additional comments relevant to patient positioning in the radiograph or image quality. As for all diagnostic tests it will be your responsibility to pass the results of PennHIP testing on to the pet owner. Breaking down the information in the report into sections will help when discussing the results with your client.

All submitted radiographs are interpreted at Antech Imaging Services by personnel trained specifically in the AIS PennHIP evaluation method. The reference range for this report is based on the data from previously submitted AIS PennHIP evaluations that have been entered into a comprehensive medical database. This includes the distraction index, information pertaining to radiographic evidence of osteoarthritis and the patient data for each evaluation.

Findings


ANTECH Imaging Services PennHIP

Reference #: 915881
Report Date: 24 Sep 2014
Date Received: 23 Sep 2014

Referring Veterinarian: Dr. Jane Doe
Patient ID: PH-1404
Radiography Date: 19 Sep 2014
Owner/Reponsible Person: John Q. Public

Patient

Patient Name: MAVERICK
Reg. Name: D-BAR KENNEL CRAZY HORSE
Reg. #: ABC-123
Tattoo: XYZ
Microchip: 99999999999999
Species: CANINE
Breed: BELGIAN MALINOIS
Date of Birth: 01 Mar 2014
Gender: Male
Age: 6 mo.

Findings

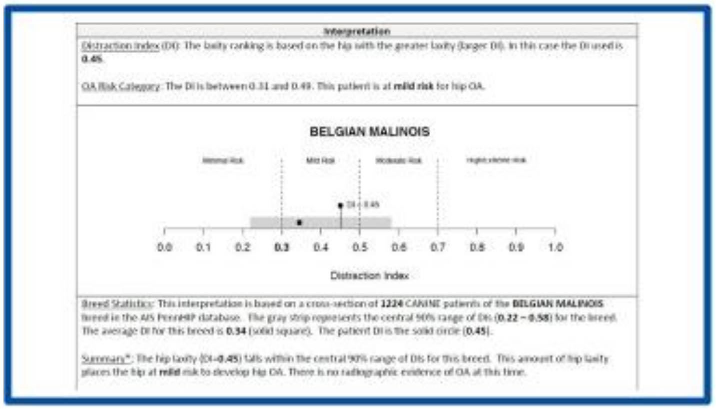
Distraction Index (DI): Right DI = **0.45**, Left DI = **0.41**

Osteoarthritis (OA): No radiographic evidence of OA for either hip.

Cavitation/Other Findings: None

The Findings section of the report will contain the results with a separate evaluation of each hip including the distraction index, an assessment of osteoarthritis from the hip-extended view and the presence or absence of cavitation. This particular Belgian Malinois had hip laxity DI = 0.45, no evidence of osteoarthritis on the hip-extended radiograph and no other findings that would influence this report or its interpretation.

Interpretation


Interpretation

Distraction Index (DI): The laxity ranking is based on the hip with the greater laxity (larger DI). In this case the DI used is **0.45**.

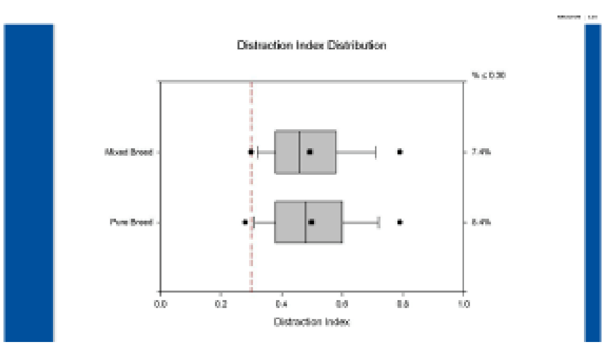
OA Risk Category: The DI is between 0.31 and 0.49. This patient is at **mild risk** for hip OA.

Breed Statistics: This interpretation is based on a cross-section of **1224** CANINE patients of the **BELGIAN MALINOIS** breed in the AIS PennHIP database. The gray strip represents the central 90% range of DIs (**0.22 – 0.58**) for the breed. The average DI for this breed is **0.34** (solid square). The patient DI is the solid circle (**0.45**).

Summary*: The hip laxity (DI=**0.45**) falls within the central 90% range of DIs for this breed. This amount of hip laxity places the hip at **mild** risk to develop hip OA. There is no radiographic evidence of OA at this time.

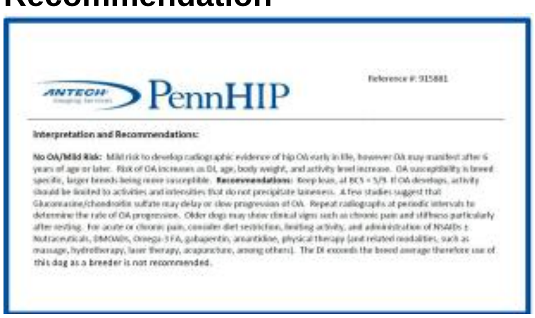
The Interpretation section is based on the AIS PennHIP database information.
This will allow you to compare your patient to other dogs of the same breed whose evaluations were previously submitted to AIS PennHIP. The data allows assessment of the genetic aspects of hip laxity, which is especially important for use in responsible breeding programs. This information allows the client or breeder to make decisions based on the data collected from other dogs of the same breed both within and across generations. This Belgian Malinois has hip laxity markedly looser than the average for the breed. The significance of this laxity is explained in the Recommendation section of the report.

Mixed breed dogs will also get information in this section based on overall dog data.



From this box and whisker plot, one can see that the distribution of hip laxity of mixed breed dogs is almost identical to the averaged hip laxity of all pure dogs lumped together. Hence the latter distribution is used to interpret the DIs of mixed breed dogs. Whether it's a mixed breed dog or a pure breed dog, the distraction index is directly correlated to the occurrence of osteoarthritis. As the distraction index increases, the risk for osteoarthritis increases in both groups.

Recommendation

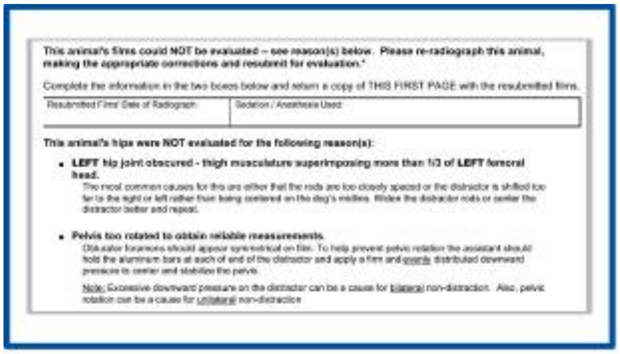

Reference #: 915881

Interpretation and Recommendations:

No OA/Mild Risk: Mild risk to develop radiographic evidence of hip OA early in life, however OA may manifest after 6 years of age or later. Risk of OA increases as DI, age, body weight, and activity level increase. OA susceptibility is breed specific, larger breeds being more susceptible. **Recommendations:** Keep lean, at BCS = 5/9. If OA develops, activity should be limited to activities and intensities that do not precipitate lameness. A few studies suggest that Glucosamine/chondroitin sulfate may delay or slow progression of OA. Repeat radiographs at periodic intervals to determine the rate of OA progression. Older dogs may show clinical signs such as chronic pain and stiffness particularly after resting. For acute or chronic pain, consider diet restriction, limiting activity, and administration of NSAIDs ± Nutraceuticals, DMOADs, Omega-3 FA, gabapentin, amantidine, physical therapy (and related modalities, such as massage, hydrotherapy, laser therapy, acupuncture, among others). The DI exceeds the breed average therefore use of this dog as a breeder is not recommended.

The Interpretation and Recommendations area will have an explanation about what the test values mean to the patient. The dog's DI tells us where the dog ranks within its breed regarding hip laxity. If the hips are better than the median for the breed and if there is no apparent OA, the dog may be considered a candidate for breeding. If the DI indicates the dog is at risk to get OA, preventive and palliative measures may be discussed.

Resubmission



This animal's films could NOT be evaluated – see reason(s) below. Please re-radiograph this animal, making the appropriate corrections and resubmit for evaluation.*

Complete the information in the two boxes below and return a copy of THIS FIRST PAGE with the resubmitted films.

Resubmitted Films' Date of Radiograph:	Sedation / Anesthesia Used:

This animal's hips were NOT evaluated for the following reason(s):

- **LEFT hip joint obscured - thigh musculature superimposing more than 1/3 of LEFT femoral head.**
  The most common causes for this are either that the rods are too closely spaced or the distractor is shifted too far to the right or left rather than being centered on the dog's midline. Widen the distractor rods or center the distractor better and repeat.
- **Pelvis too rotated to obtain reliable measurements.**
  Obturator foramens should appear symmetrical on film. To help prevent pelvic rotation the assistant should hold the aluminum bars at each of end of the distractor and apply a firm and evenly distributed downward pressure to center and stabilize the pelvis.
  Note: Excessive downward pressure on the distractor can be a cause for bilateral non-distraction. Also, pelvic rotation can be a cause for unilateral non-distraction

If for some reason the radiographs cannot be evaluated, a report will be sent to inform you that the radiographs will need to be made again and resubmitted. As you can see in this example, an explanation is provided so that you will have an understanding of why the views were rejected and what you can do to correct the issues.

A review of Chapter 4 of this Manual or the "How to Perform an AIS PennHIP Procedure" course will provide guidance in how to improve your technique.

Client Education Video

A short AIS PennHIP client education video is available to help explain the AIS PennHIP procedure. We recommend that you have your clients watch the video when the AIS PennHIP procedure is offered. You can have your clients watch this video by visiting the AIS PennHIP website. The video contains an overview of the procedure and will be able to help answer some client questions. This video is also a good resource for clients to share with family members who may not be present at the time the recommendation is made. For those that are visual learners, this is a great way to comprehend this information. Consider making it available in your waiting room.

Controlling Canine Hip Dysplasia: Prevention and Breeding

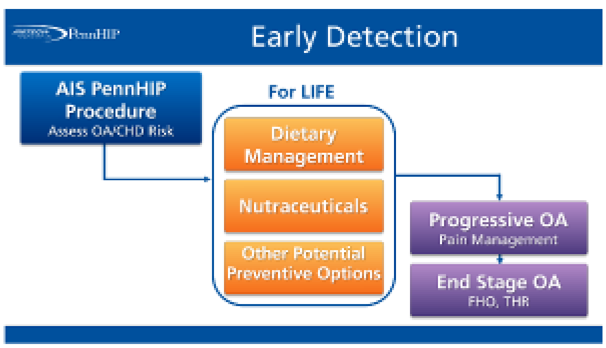
The AIS PennHIP procedure is recommended as a preventive screening tool for canine patients and for those dogs that are or will be included in a breeding program. If Woody is scheduled for a wellness exam, the emphasis of the visit will be centered around preventive medicine. Chase, on the other hand, is part of a breeding program for service dogs. While preventive medicine also pertains to him, it's important to communicate specific information to his owner that applies to him and future generations he may sire.

Some examples will be presented later in this chapter.

Preventive Care and Early Detection

Let's start with preventive care. AIS PennHIP can be used to assess a dog's risk for developing the osteoarthritis of canine hip dysplasia. Since the AIS PennHIP procedure can be performed as early as 16 weeks, it can provide the information needed to begin an early conversation with a pet owner about what activities are suitable, what signs to anticipate, and what can be done to help his or her dog to offset the risk of getting the painful OA of hip dysplasia.

Hip screening is suggested for all dogs, so that a pet owner can learn the predicted hip status of his or her dog and make good decisions about preventive care.



Understanding the risk of canine hip dysplasia can lead to implementation of appropriate preventive and/or therapeutic measures to control or manage this highly prevalent and painful disease early in the disease process. Some measures may be life-long. Clients want to make educated decisions about their pets' wellness and the AIS PennHIP procedure is a great tool to help them do that. With early detection you can help to improve the quality of a patient's life as they age.

A conversation about the benefits of the procedure can begin with a puppy's first wellness visit but can be discussed during any wellness visit. Wellness exams are an opportunity to talk about the advantages of the AIS PennHIP procedure.

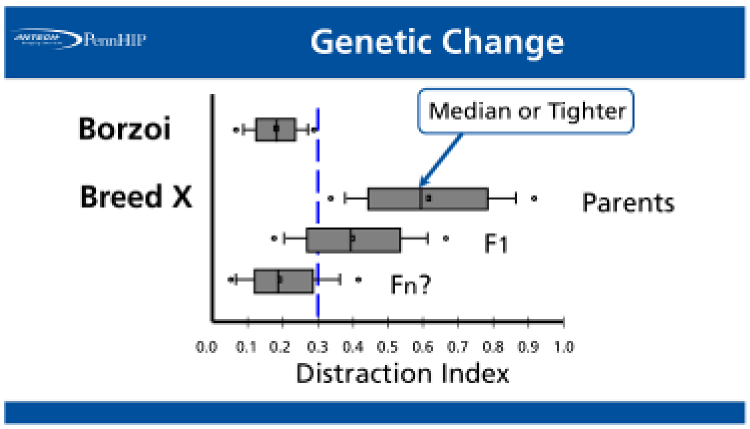
A good time to schedule the AIS PennHIP exam would be in conjunction with another procedure requiring anesthesia such as a spay or neuter or a professional dental cleaning. The dog is already anesthetized so adding a set of AIS PennHIP radiographs provides additional important diagnostic information and decreases the cost of performing the procedure alone.

Prospective Breeding Dogs

The distraction index can be used to assess a dog's risk for developing canine hip dysplasia. If screening is done on dogs before they are bred, breeders will know the predictive hip status for their dogs and can use the information to make educated breeding decisions.

Since the distraction index has been shown to have high heritability, in fact, highest of all the hip scoring metrics, it allows breeders to apply selection pressure to breed for tighter, more osteoarthritis-resistant hips. This will ultimately benefit the entire breed. The breeder can share the AIS PennHIP report with those who purchase puppies or dogs and explain the importance of the parents' hip status within the database. Breeders should also encourage clients to have their dogs screened as well to encourage continued improvement of the breed.

Breeders can help make a difference in the fight to lessen the incidence and severity of canine hip dysplasia because with regular PennHIP testing they can control the rate of improvement in hip phenotype in future generations. The guiding principle is "tighter hips are better hips."



In general, a reasonable plan would be to breed a dog that has a distraction index tighter than the breed median (as shown in the illustration). By doing this year after year (or generation after generation), one should see a steady tightening of the hips in subsequent generations. Obviously, the most rapid improvement in hips could be achieved by breeding only the tightest-hipped dogs within the breed and then inbreeding and line breeding using these dogs and close relatives of these dogs. However, this practice is to be discouraged because it seriously reduces genetic diversity, creating so-called ‘genetic bottlenecks’, potentially leading to the loss of desirable traits and possibly the expression of undesirable traits or disorders.

Effect of Estrus and Whelping on Hip Laxity

A common question from breeders is how long to wait to perform the PennHIP procedure after a bitch whelps. We consulted a theriogenologist and were informed that the hormone relaxin is still present 8 weeks post whelping (although it varies by breed). It persists throughout lactation. Relaxin is a hormone shown to affect fibrous tissue making it in essence ‘relax’ or stretch. We know of no study to show whether relaxin has an effect on DI or any other hip scoring method. However, to be on the safe side, we have been advising breeders to wait 8 weeks post lactation or 16 weeks post whelping.

Estrus, however, has been investigated as to its impact on hip laxity, and it has been shown to be of no consequence to hip scoring irrespective of method used (PennHIP or hip-extended radiography like that used by the OFA, See reference #55 in Chapter 3).

Client Communication

Please review the "Client Communications" video on the AIS PennHIP web site. It gives an example of how one veterinarian speaks with her client about the AIS PennHIP method as a preventive procedure, one part of a routine wellness exam.

Please review the "Client Communications" video on the AIS PennHIP web site. It gives an example of how one veterinarian speaks with her client about the AIS PennHIP method as a preventive procedure, one part of a routine wellness exam.

In discussing the AIS PennHIP procedure with your clients here are a few questions you may get followed by some suggested answers.

Q: It looks like my dog's hips will be popped out of joint. Is that what's happening?
A: Your dog's hips will not actually be popped out of joint. Your dog will be sedated and placed on his back and the hips will be positioned as though standing. A small harmless force will be used to distract the ball from the socket. The distance that the ball moves is related to the risk of hip dysplasia. The greater the distance, the greater the risk. The distance measured is similar to what occurs when your dog is awake and standing or running around. It is your dog's inherent hip laxity.

Q: Is this procedure painful?
A: For the vast majority of dogs, even those with moderate hip laxity and mild osteoarthritis, there are no signs of pain and lameness following the procedure. However, for dogs with advanced OA, the hips may be painful for a day or two following the procedure much like they would be with any hip manipulation technique. We preemptively address pain for these patients by administering analgesics prior to the performing the procedure.

Q: Does the procedure cause damage to the hips? Will it increase the chance of issues with the hips down the road?
A: There have been no observed long-term ill effects of performing the AIS PennHIP procedure.

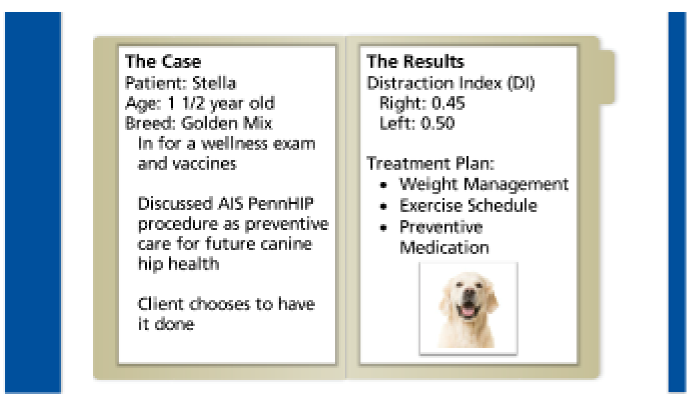
Q: If you find evidence of osteoarthritis on the first radiograph you take, will you stop there and not take the other two views?
A: The hip-extended radiographic view is only the first step in the AIS PennHIP process. Similar to chest x-rays we have to take images in multiple positions to get a full picture to arrive at an accurate assessment of the patient. Scientific studies have clearly shown that all three views are needed to make a complete assessment of the hip health of the patient.

Q: My dog is young. Why do I need to be concerned?
A: Early detection allows us to take preventive action now instead of waiting until he shows symptoms of the disease.

Q: My dog has a DI that indicates he will get OA later in life. What do we know now?
A: We need to create a treatment plan and implement preventive strategies to offset the genetic risk. We will work together to find the right combination for him and one that works for you too. We can begin by discussing how to maintain an appropriate body weight and if necessary we will prescribe medication to help his joints manage any pain so he can live a long and active life.

Q: Will I need to have this procedure done again?
A: We suggest repeating the radiographs to determine, particularly in high-risk dogs, whether the osteoarthritis of hip dysplasia has indeed begun so that we can monitor the rate of disease development. If osteoarthritis is progressing rapidly, we want to make sure that we tailor the treatment options to meet his needs

Case Example #1: Pet dog



Clients understand the importance of preventive care and want to know their options. In this case example, the client brings in her newly adopted dog for a wellness exam. When you explain the AIS PennHIP procedure to her, she enthusiastically agrees to have the procedure done on her new dog and explains why. Her previous dog had osteoarthritis and canine hip dysplasia and she tells you about what the severity of hip pain was like as the dog aged and how difficult it was for her dog and for her. If she can do something to help ensure that her new dog will not suffer the same pain, then she wants to do it!

You can identify at-risk dogs early in life and help to educate clients on the steps they can take to care for their aging pet through diet, medications or other procedures. The hip laxity for this particular dog is average for the breed and puts it at mild to moderate risk of developing OA. The owner feels some relief that her new dog does not have terrible hips but she is understandably concerned that her dog’s hips will likely develop OA during its lifetime. Your approach would be to inform her of the importance of keeping her dog lean. Keeping the body condition score at 5/9 or below will delay the onset and diminish clinical signs. You may caution her to avoid extremely strenuous activity particularly for long periods of time. Nutraceuticals or DMOADS may be considered for preventive benefit. Commercial joint formula diets can also be prescribed. At present, the science does not support any type of preventive surgery in a 1.5 year old dog. While having a conversation with the dog’s owner over the PennHIP results, you can mention that if clinical signs develop there are pain medications that are effective in keeping most dogs comfortable and that yearly visits are necessary to assess the health of the hips. It is not all doom and gloom. You can offer that it is extremely unlikely that a dog with a DI of 0.5 will go on to develop end stage hip disease that for example may require total hip replacement.

Case Example #2: Working Dog

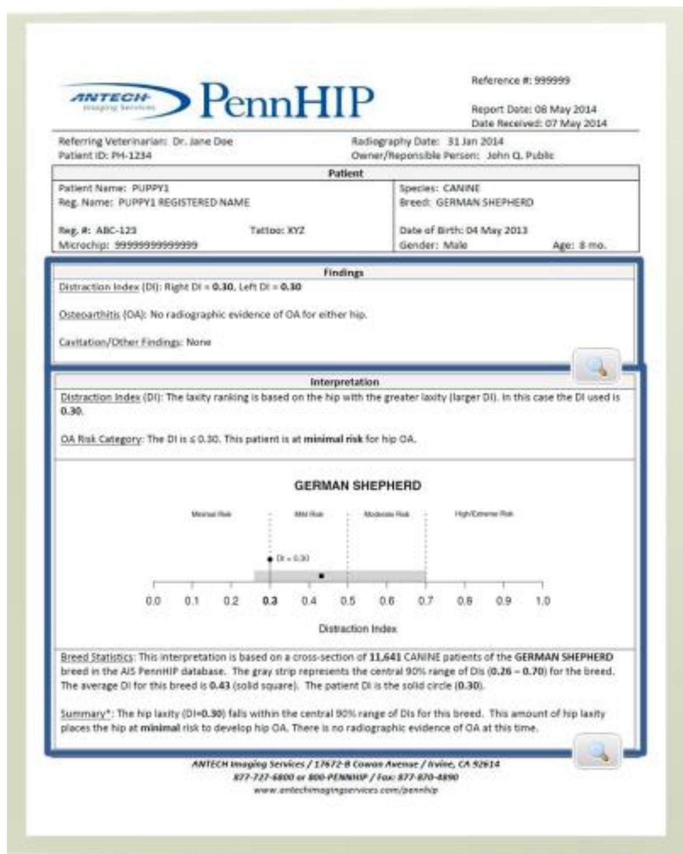
OWNER
Police Force Dog Unit

ANIMAL
Canine/ German Shepherd
Date of Birth: 5/4/2013
Sex: M
Weight: 63 lbs.
Age: 8 mo.

Hip-Extended View

Compression View

Distraction View



ANTECH Imaging Services PennHIP

Reference #: 999999

Report Date: 08 May 2014
Date Received: 07 May 2014

Referring Veterinarian: Dr. Jane Doe
Patient ID: PH-1234
Radiography Date: 31 Jan 2014
Owner/Reponsible Person: John Q. Public

Patient

Patient Name: PUPPY1
Reg. Name: PUPPY1 REGISTERED NAME
Reg. #: ABC-123 Tattoo: XYZ
Microchip: 999999999999999
Species: CANINE
Breed: GERMAN SHEPHERD
Date of Birth: 04 May 2013
Gender: Male Age: 8 mo.

Findings

Distraction Index (DI): Right DI = **0.30**, Left DI = **0.30**

Osteoarthitis (OA): No radiographic evidence of OA for either hip.

Cavitation/Other Findings: None

Interpretation

Distraction Index (DI): The laxity ranking is based on the hip with the greater laxity (larger DI). In this case the DI used is **0.30**.

OA Risk Category: The DI is ≤ 0.30. This patient is at **minimal risk** for hip OA.

Breed Statistics: This interpretation is based on a cross-section of **11,641** CANINE patients of the **GERMAN SHEPHERD** breed in the AIS PennHIP database. The gray strip represents the central 90% range of DIs (**0.26 – 0.70**) for the breed. The average DI for this breed is **0.43** (solid square). The patient DI is the solid circle (**0.30**).

Summary*: The hip laxity (DI=**0.30**) falls within the central 90% range of DIs for this breed. This amount of hip laxity places the hip at **minimal** risk to develop hip OA. There is no radiographic evidence of OA at this time.

ANTECH Imaging Services / 17672-B Cowan Avenue / Irvine, CA 92614
877-727-6800 or 800-PENNHIP / Fax: 877-870-4890
www.antechimagingservices.com/pennhip

Hip radiographs show no evidence of OA. There is very good joint congruity on the compression view, and tight-appearing hips on the distraction view. A DI of 0.3 means that this dog has minimal to mild risk of acquiring hip OA later in life. The findings from the AIS PennHIP procedure would indicate that this dog is a good candidate to put into training as a working dog. The DI is much better than the breed median, and therefore this dog is also a candidate for breeding purposes.

Case Example #3: Pet Dog

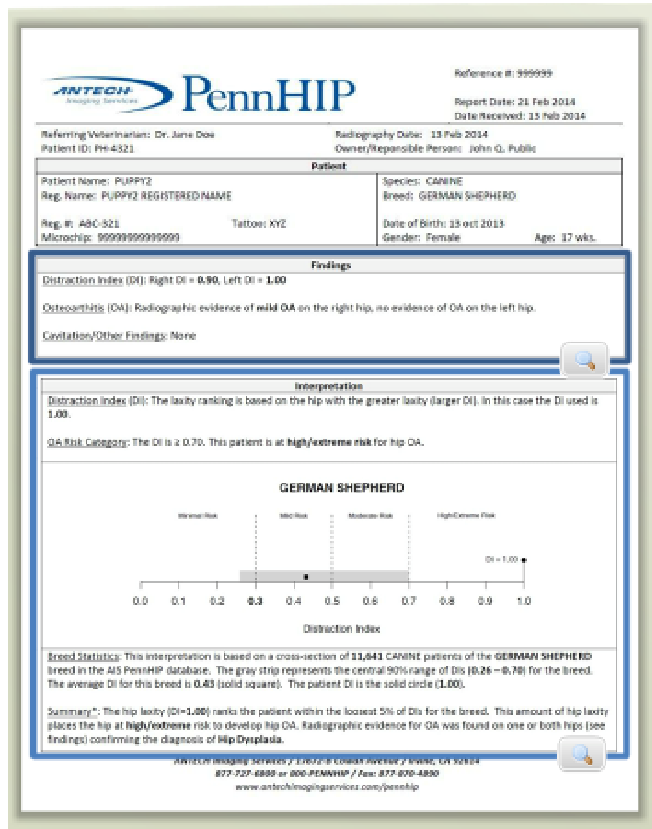
OWNER
Individual Owner

ANIMAL
Canine/ German Shepherd
Date of Birth: 10/13/2013
Sex: F
Weight: 34 lbs.
Age: 17 wks.

Hip-Extended View

Compression View

Distraction View



PennHIP

Reference #: 999999
Report Date: 21 Feb 2014
Date Received: 13 Feb 2014

Referring Veterinarian: Dr. Jane Doe
Patient ID: PH-4321
Radiography Date: 13 Feb 2014
Owner/Reponsible Person: John Q. Public

Patient

Patient Name: PUPPY2 Reg. Name: PUPPY2 REGISTERED NAME Reg. #: ABC-321 Tattoo: XYZ Microchip: 999999999999999	Species: CANINE Breed: GERMAN SHEPHERD Date of Birth: 13 oct 2013 Gender: Female Age: 17 wks.

Findings

Distraction Index (DI): Right DI = **0.90**, Left DI = **1.00**

Osteoarthitis (OA): Radiographic evidence of **mild OA** on the right hip, no evidence of OA on the left hip.

Cavitation/Other Findings: None

Interpretation

Distraction Index (DI): The laxity ranking is based on the hip with the greater laxity (larger DI). In this case the DI used is **1.00**.

OA Risk Category: The DI is ≥ 0.70. This patient is at **high/extreme risk** for hip OA.

Breed Statistics: This interpretation is based on a cross-section of **11,641** CANINE patients of the **GERMAN SHEPHERD** breed in the AIS PennHIP database. The gray strip represents the central 90% range of DIs **(0.26 – 0.70)** for the breed. The average DI for this breed is **0.43** (solid square). The patient DI is the solid circle (**1.00**).

Summary*: The hip laxity (DI=**1.00**) ranks the patient within the loosest 5% of DIs for the breed. This amount of hip laxity places the hip at **high/extreme** risk to develop hip OA. Radiographic evidence for OA was found on one or both hips (see findings) confirming the diagnosis of **Hip Dysplasia**.

877-727-6800 or 800-PENNHIP / Fax: 877-870-4890
www.antechimagingservices.com/pennhip

This 17 week old German Shepherd Dog shows extremely loose hips on the distraction view, DI=1 and she has a high/extreme risk for developing hip OA. In fact, signs of remodeling of the hips particularly on the right dorsal acetabular rim can already be seen, confirming the existence of hip OA.

The owner should be told that her dog has the most severe form of canine hip dysplasia but that there is a good prognosis that her dog will experience reasonably comfortable, pet-quality function throughout life if she follows your medical advice. You should inform her of the benefits of proper weight management to slow the degenerative process and to improve clinical function. You should caution her to avoid extremely strenuous activity particularly for long periods of time. Long term nutraceuticals or DMOADS may be considered for preventive or ameliorative benefit. Commercial joint formula diets should also be prescribed.

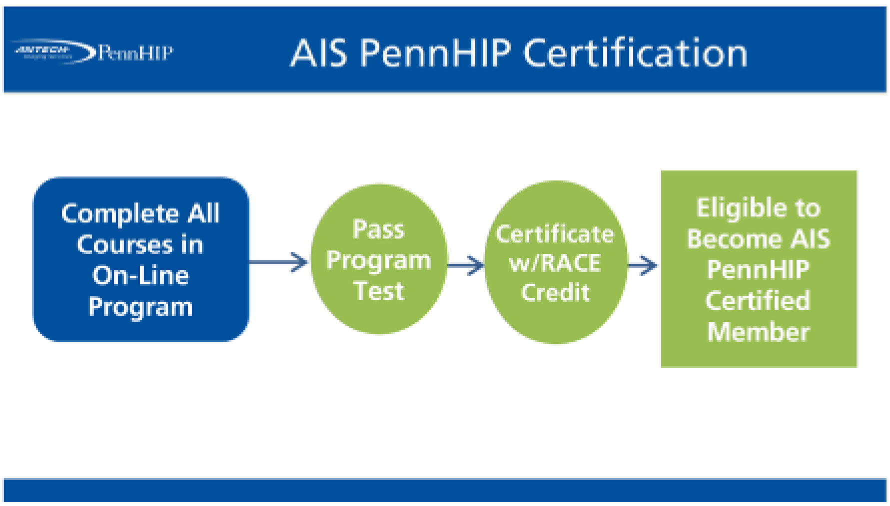
At present, science does not support any type of preventive surgery in a 17 week old dog with this degree of hip laxity although some might argue that a JPS procedure is warranted. While having a conversation with the dog's owner over the PennHIP results, you should mention that if clinical signs develop (and they almost certainly will) there are multimodal pain management protocols that are effective in keeping most dogs comfortable.   Yearly visits are necessary to assess the progression of this condition. You should probably begin the conversation that-end stage osteoarthritis may develop and that a total hip replacement or a femoral head ostectomy may be indicated as salvage procedures should the pain seriously impact quality of life.

This dog's hip laxity falls within the loosest 5th percentile for the breed and therefore obviously she should not be considered for breeding.

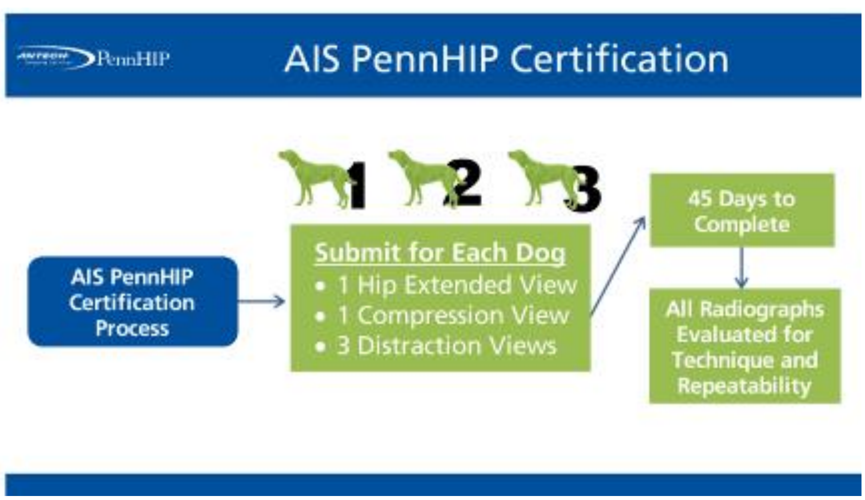
Chapter 7: AIS PennHIP Certification and Membership

(This Chapter covers material presented in Online Course 5)

The final step in the training process toward becoming a Certified Member of the AIS PennHIP Network is to demonstrate your ability to perform the AIS PennHIP procedure in your practice. This chapter covers the certification process and other related topics. You will learn the evaluation criteria used by AIS PennHIP and as well as what to expect when you receive your Quality Assurance report.



Once you have completed the last online course, you will need to complete and receive a passing score on the online program test. At that point, you will receive a continuing education certificate for the RACE credits you have earned for completing all five courses. You will then be eligible to begin the AIS PennHIP Certification process leading to Membership in the program.



Certification is the final step toward membership and it determines clinical competency in performing the AIS PennHIP procedure. Your radiographs will be tested for repeatability and correct technique.

For certification, you will be submitting radiographs for 3 dogs. For each of the 3 dogs you will be submitting 5 radiographs: 1 Hip-Extended view, 1 Compression view and 3 Distraction views.

You will have **<u>45</u>** days from the time you successfully complete the online program to submit your certification radiographs. You may submit as many cases as necessary to get 3 cases that satisfy the criteria of repeatability and image quality. There will be no charge if the cases are submitted within the 45 day window. Beyond 45 days and up to 60 days, you may submit additional cases but you will be charged the going rate. If you don't successfully complete certification by 60 days post online course, you will be required to start over by repeating the online course.

Submission of Cases

Days after Online Course Completion	Goal	What to Do	Cost
0 - 45	3 Passing Cases	As many cases as needed to reach goal	No charge
45 - 60	Complete 45 Day Goal	As many cases as needed to reach goal	There will be a charge
Over 60	Not Reached	Start program over from the beginning	Begin again

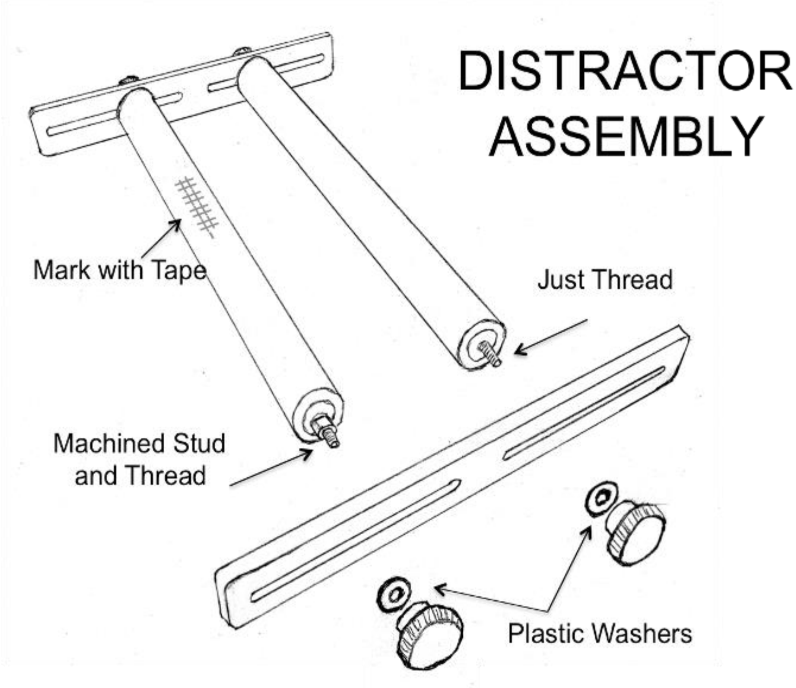
Considering the time constraints to complete the certification process, we recommend that prior to completing the online courses, you identify, 3 or more dogs that you will use for certification purposes. This will make it easier to complete the process within the 45-day period.

We suggest that you use your own or staff-owned dogs for your certification radiographs. Don't wait for a client to request the AIS PennHIP procedure! These films will only be critiqued for technique and repeatability and no individual report will be supplied for each individual dog. The best dogs to use for certification are those that are medium to large in size, weighing 35 to 70 lbs.

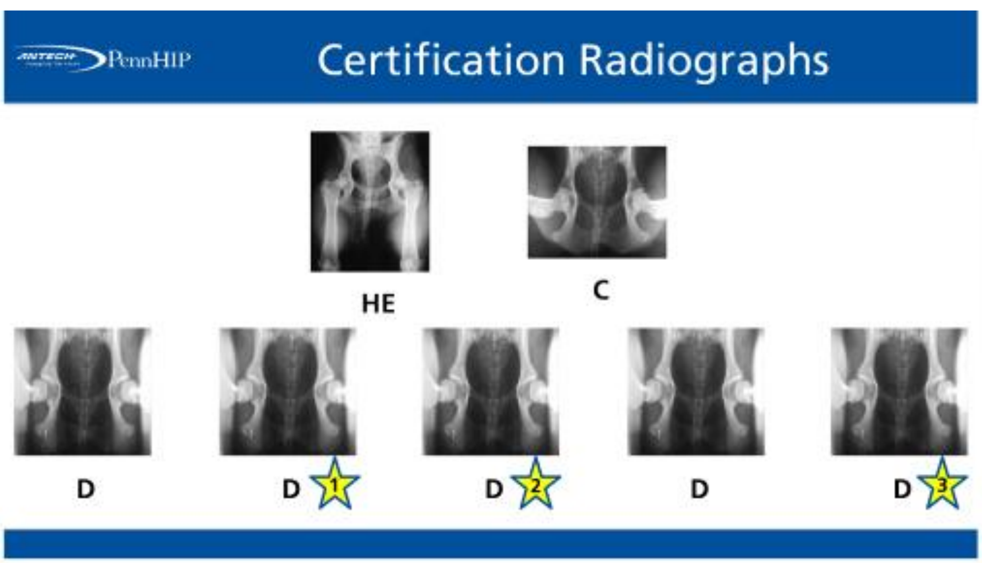
If possible choose breeds or mixes of breeds that are known to have looser hips. Examples include Labradors, Golden Retrievers or Rottweiler's to name a few. Since this is your first attempt at this procedure, try to avoid extremely large or small dogs or deep-chested dogs because they are more difficult to correctly position.

Distractor Assembly

The first step to get certified is to assemble your distractor as shown in the diagram. At one end of each acrylic rod is a machined stud with a threaded portion and at the other end is just a thread. Assemble the distractor as shown with one machined stud and one full thread engaging each Aluminum bar. Before putting the knobs on the threaded portions, find the acrylic rod having the engraved number (pull the rod out of the foam rubber sleeve) and apply a piece of tape on the foam sleeve that overlies the engraved number to mark its location. A plastic washer should go between each knob and the Aluminum bar to make for easy adjustment.

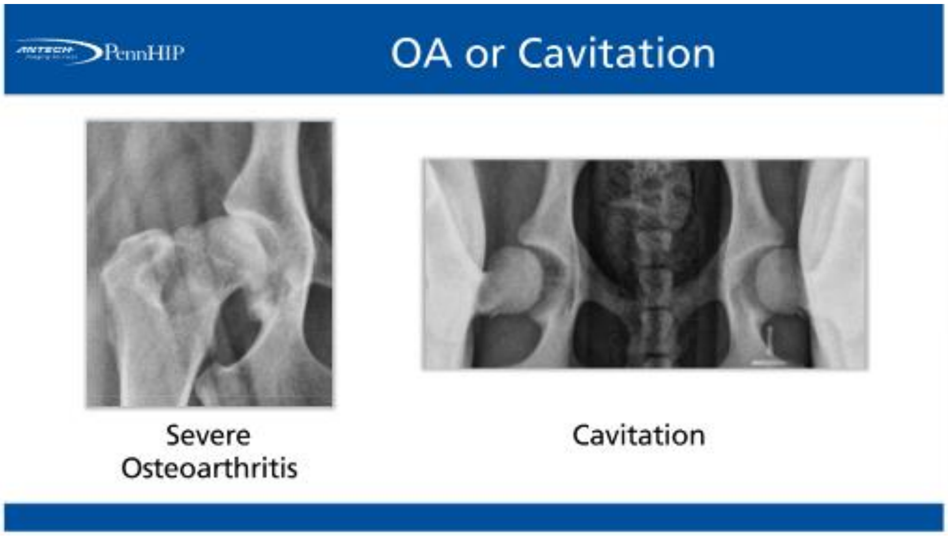


Certification Radiographs



The distraction view is the most difficult to perform proficiently. You may have to take 5 or more distraction radiographs until you find the best 3 that you will submit for certification. Compare your images to the examples of good technique presented elsewhere in this program (and in the Manual). When you go to submit the radiographs, number each distraction view in the order in which it was taken. The AIS PennHIP team needs this information in the evaluation process.

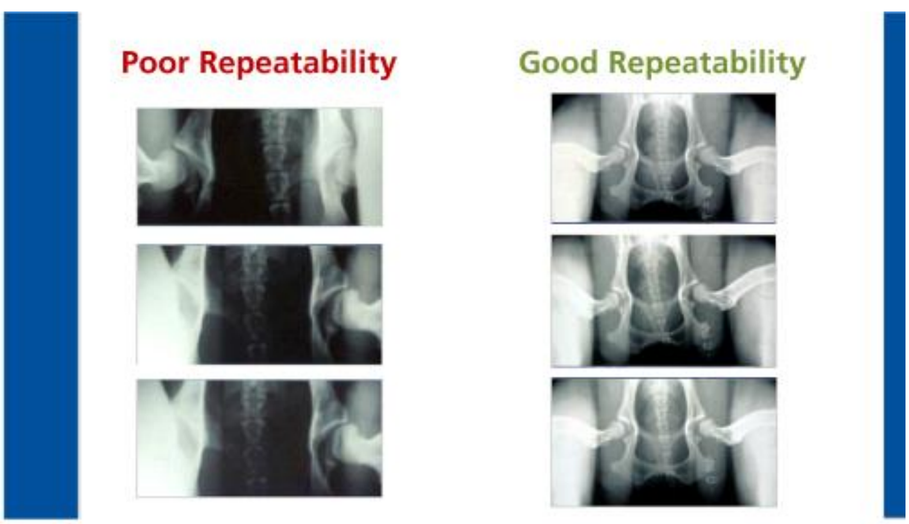
OA or Cavitation



If you detect severe osteoarthritis on the hip-extended view, select a different dog to complete your certification films. Extreme remodeling of the hip precludes an accurate measurement of the distraction index so repeatability cannot be assessed. Mild or moderate osteoarthritis does not affect the accuracy of the distraction index measurement.

If you observe cavitation, we recommend that you repeat the films on a different day or that you select another dog for certification. You will not be denied certification for the random occurrence of cavitation but you may be asked to repeat the evaluation. Often even cavitated hips will have repeatable hip laxity and therefore will count toward your certification.

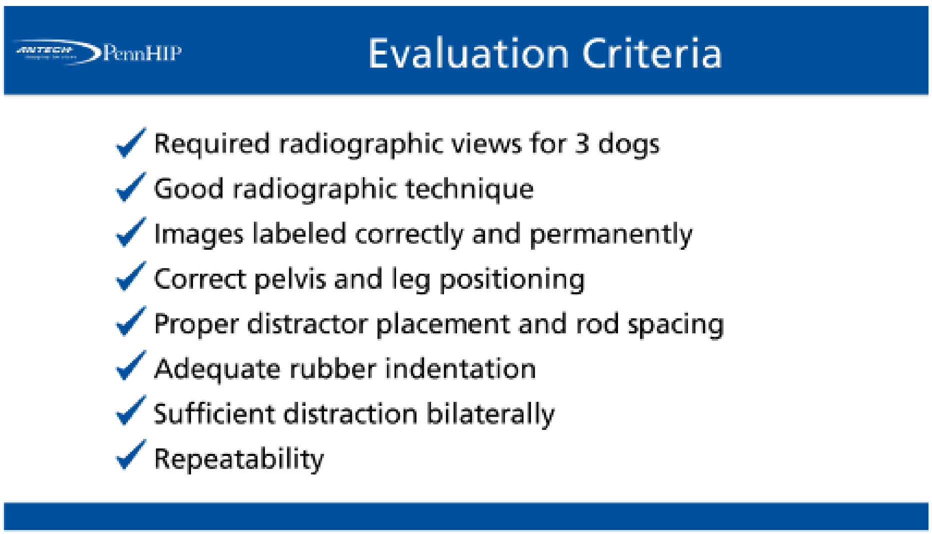
Distraction Index Repeatability



The distraction views are important during the certification process and your goal is to have good technique and good repeatability, which requires practice for proficiency.

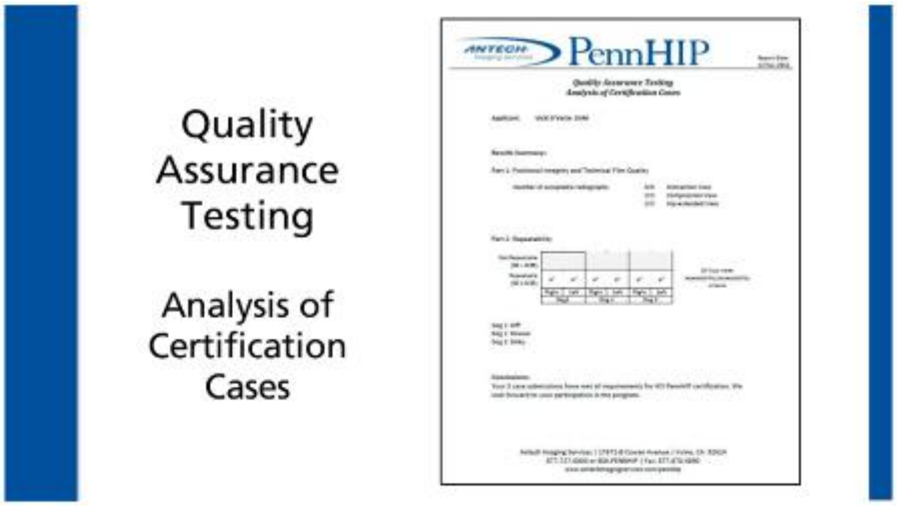
Look for the visible hip laxity for each respective hip on the distraction radiographs of each dog. The hip laxity should appear the same to the naked eye as seen on the three sequential distraction views on the right above. In the illustration showing good repeatability, your eye cannot discern a difference in hip laxity as you scan the 3 left hips and the 3 right hips, respectively. Contrast this to the illustration of poor repeatability. Also, remember that the visualized laxity on the distraction films should be obviously greater than that seen on the compression or hip-extended radiographs. Compare them side-by-side, if possible.

Evaluation Criteria

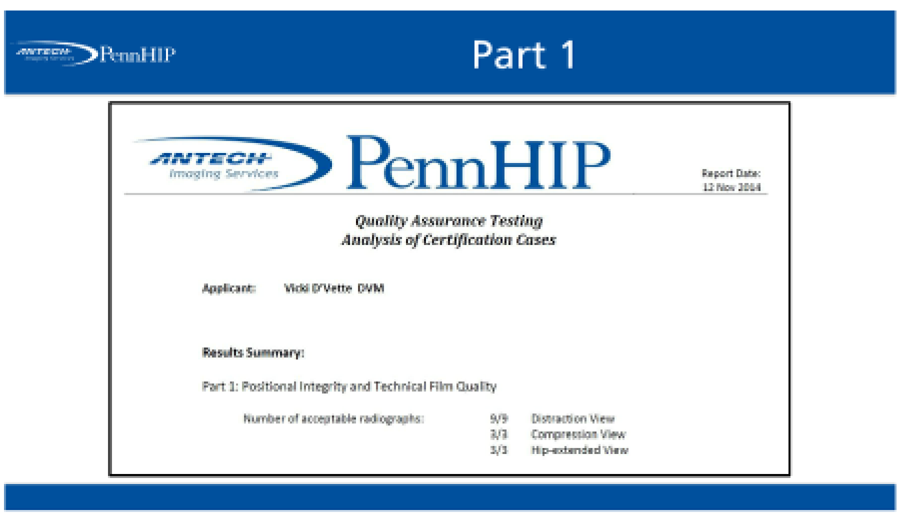


Upon receipt of the certification radiographs from 3 dogs, your submissions will be evaluated. Everything you see listed here will be used to review your submission. From the repeatability of the distraction index on the distraction radiographs, an estimate of your performance of the procedure will be made.

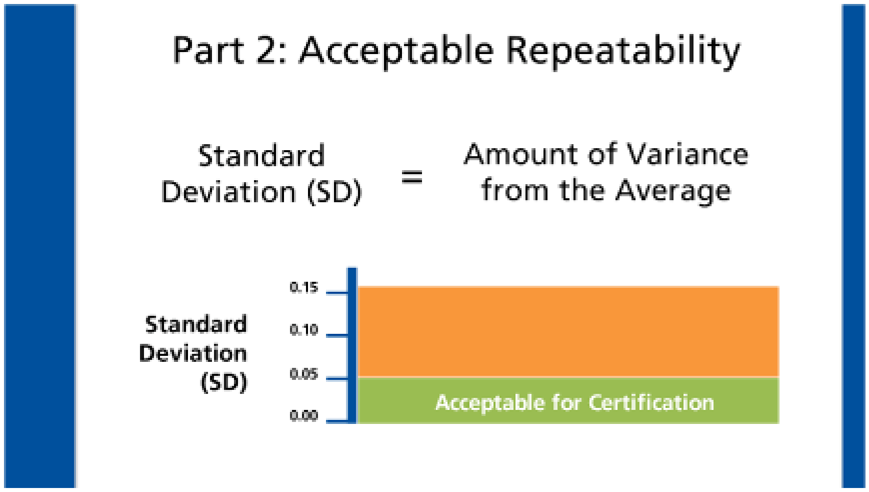
Quality Assurance Testing



Once the evaluation has been completed, you will receive a Quality Assurance report. This is where you will find a summary of the performance evaluation broken up into three sections.



Part 1 is the Positional Integrity and Technical Film Quality section. This is where the number of submitted films meeting the minimum criteria for positioning and radiographic technique is recorded. To be certified, all films must meet the criteria.



The second part is the Repeatability Section. To determine your proficiency in performing the distraction procedure, we evaluate how well you can repeat the distraction index for a given dog.
For each set of distraction images received for certification, a standard deviation or SD of the distraction index will be calculated. Standard deviation is the amount of variance from the average.
We have found that individuals who are experienced with the AIS PennHIP technique can reproduce a distraction index with a standard deviation within ± 0.04. For the certification purposes, the standard deviation is made a little more lenient, set at 0.05 or less.

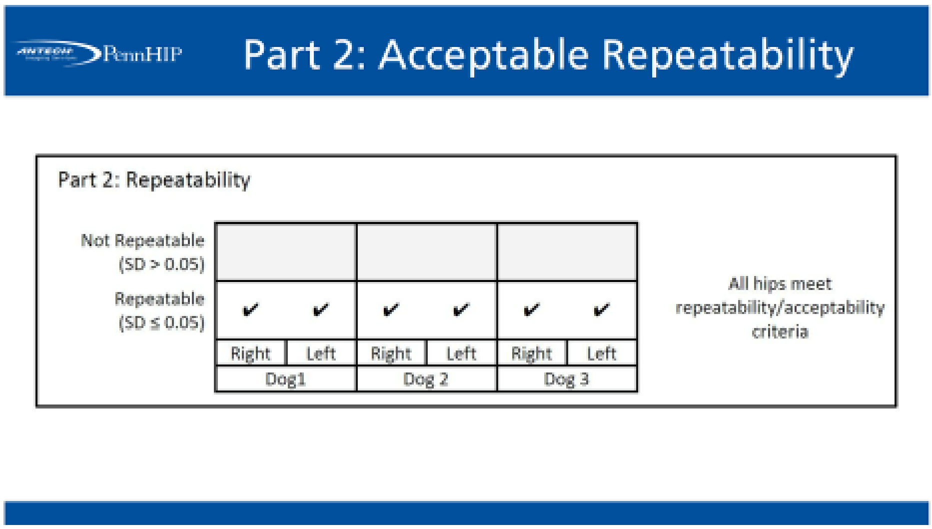
Part 2: Acceptable Repeatability

	Example 1		Example 2	
	Left	Right	Left	Right
Distraction View 1	0.62	0.65	0.28	0.25
Distraction View 2	0.59	0.61	0.43	0.62
Distraction View 3	0.61	0.56	0.59	0.45
Standard Deviation	0.01	0.04	0.13	0.15

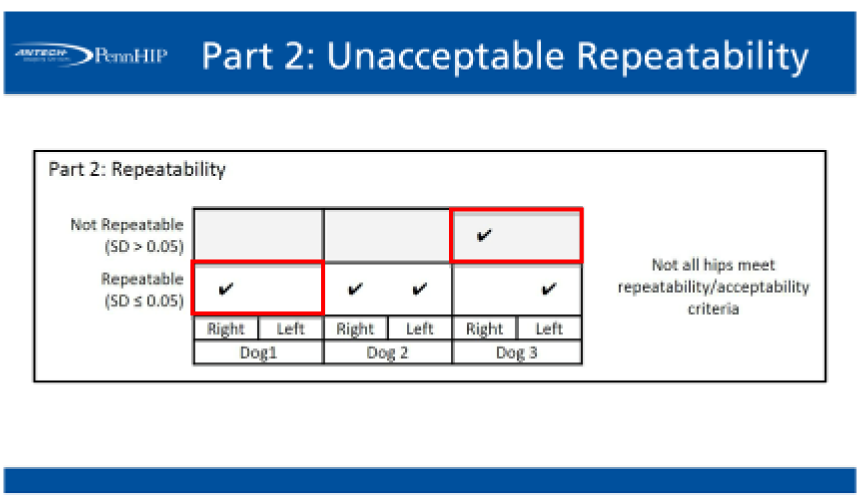
For the 3 distraction images, a standard deviation will be calculated for each hip, the right and left hip, for each dog.

With a low standard deviation as in Example 1, the conclusion is that there is consistency in the performance of the technique.

With a high standard deviation as in Example 2, the true laxity of the hips and the repeatability of the procedure are definitely in question.



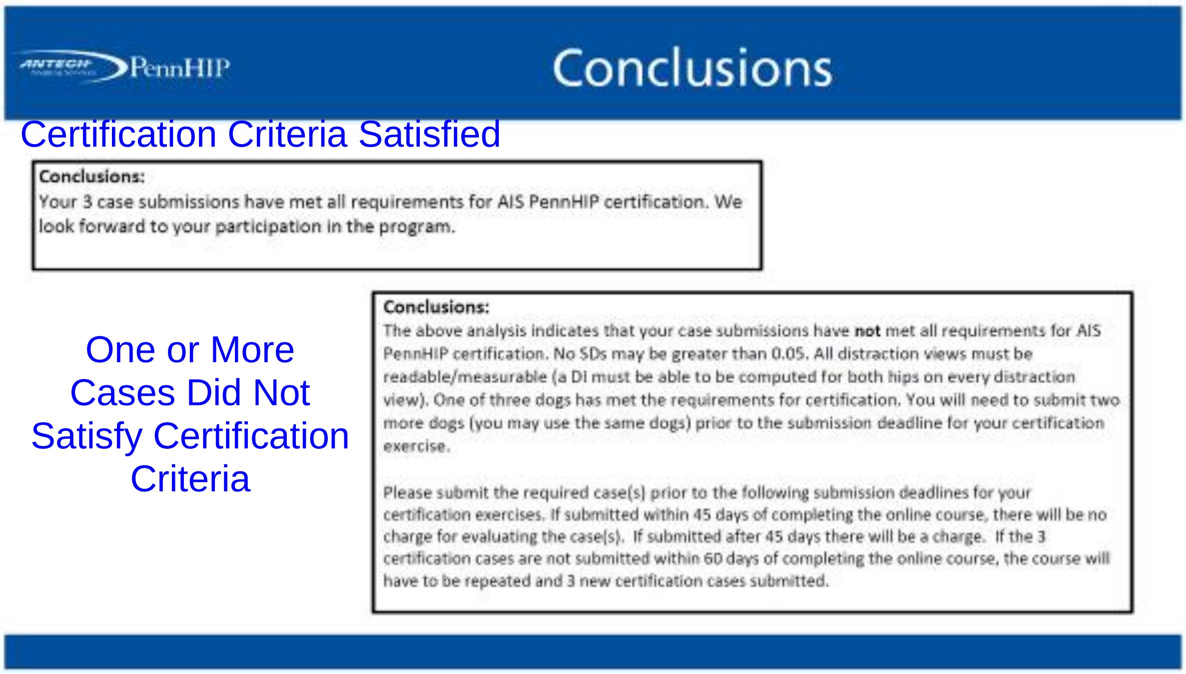
On the report you will see two levels - Not Repeatable and Repeatable - corresponding to the standard deviation intervals for each dog. The check signifies the standard deviation of the right and left hips, one check for each hip for each dog. For certification, 6 checks must appear in the Repeatable row.



AIS PennHIP certification will be withheld if the certification criteria for image quality and repeatability are not met. You will receive a report containing detailed information explaining the reason for the decisions made if certification is withheld.

If a radiograph is unacceptable and no distraction index can be measured, the standard deviation cannot be calculated and no check will appear for that hip of the dog. Another set of films will have to be submitted. The same or a different dog(s) can be used should any case require repeating.

Conclusions: Criteria Satisfied or Criteria Not Satisfied



The conclusion section verifies certification. If all criteria are met, you will be approved as a Certified Member. However, if the quality-assurance criteria are not met, certification will be denied and an explanation will be given. You will then also get additional information about continued submission and time lines.

Certification

If your radiographs meet the established criteria for certification, you will receive a certificate from AIS PennHIP. Your AIS PennHIP Member number is also included on the certificate. This number will need to be included when you submit AIS PennHIP studies moving forward.

Referral Network

Once certified, you become an active participant in the AIS PennHIP Referral Network. With your consent, your member status and name will be listed on our web site and your contact information will be available to prospective clients.

Sending Images: Creating an AIS Account

If you do not have an account already, you will need an AIS account to submit cases for an AIS PennHIP evaluation. You can go to the Antech Imaging Services website to register for an account now. Go to <info@antechimagingservices.com> or phone 877-727-6800.

If you have conventional radiographs, you will first enter the case into the AIS online submission form and then send the films to AIS to be scanned in and digitally recorded.

NOTE: MANDATORY CASE SUBMISSION

The hip- extended, compression and distraction radiographs from all dogs that have the AIS PennHIP procedure performed, must be submitted to AIS PennHIP for interpretation regardless of suspected diagnosis of osteoarthritis or laxity. This helps to ensure the integrity of the AIS PennHIP database. Even if a dog is found to have severe OA, and therefore a DI will not be issued, the case should be submitted to avoid biasing the AIS PennHIP database. Every dog counts. Do not prescreen the hip-extended view and if normal then decide to perform compression and distraction views. This practice will seriously bias the database and, in fact, is grounds for dismissal from the AIS PennHIP network.

Online Submission Form

Once you have an account with AIS, you will use the online submission form to submit the radiographs. Note the Required Fields marked by a red asterisk.

Consultation Type and Radiographic Information Sections

The first section is the **Consultation Type** where you will choose if you are submitting for a standard analysis or for certification. If not yet certified, be sure to check the box, “Certification Submission”.

The next section is the **Radiographic Information** section, which has required fields that need to be filled in.

Clinical Signs

We continue to investigate the extremely important relationship between hip laxity and **clinical signs**. An understanding of this relationship is critical, particularly for those involved in service dog training. **If** an orthopedic examination is performed on the dog as part of the hip evaluation, please indicate whether clinical signs are detected, and if so, the severity of the signs, mild, moderate, or severe. Use the following guidelines to arrive at a severity grade.

- MILD Clinical Signs: No obvious lameness or gait abnormality. May "bunny hop" when playing for extended periods or have mildly reduced exercise tolerance when compared to a normal dog. Little to no muscle atrophy. When palpating without sedation, detectable discomfort in the hip is noticed only at extremes of range of motion. Pet owners typically consider such a dog to be functionally normal. Note: Ignore discomfort that may accompany Barden's test (lateral translation of the femoral head with the hip in a neutral position) because this procedure can elicit discomfort even in normal dogs.
- MODERATE Clinical Signs: Distinct exercise intolerance and "bunny hopping" with activity, however no significant gait abnormality at a walk. Minimal to no hesitation or discomfort noted when rising from a down position. Mild muscle atrophy and notable discomfort at extremes of range of motion and perhaps resentment or conscious limitation to full range of motion. Depending on the dog's activity level, the owners of a dog with moderate signs of Canine Hip Dysplasia may or may not recognize a functional abnormality in their dog particularly if expected activity is that of a typical pet.
- SEVERE Clinical Signs: Obvious gait abnormalities. Lameness and distinct exercise intolerance. Obvious hesitation or discomfort noted on rising, particularly after a long rest or overnight. Hesitation or inability to jump or climb stairs. Wide intertrochanteric distance and perhaps audible clicking when walking. Marked muscle atrophy. Marked pain on manipulating the joint and either conscious or passive limitation to range of motion. Typically, the pet owners are very aware of their dog's pain and functional disability.

Note: It is understood that overlap in clinical signs may occur in the above categories. Clearly, the categories are subjective and only approximate. If an orthopedic examination was not performed as part of the hip evaluation procedure, please indicate by checking the **"Not Evaluated"** box on the Radiograph Evaluation Application.

Use of the comments box for any information you feel may affect the interpretation, such as, difficulties you encountered performing the technique, problems with sedation or anesthesia, uncertainties with identification, evidence of palpable laxity, etc.

Remaining Sections

The next section is for Patient and Client Information and again has required fields.

And the last section is the PennHIP Database section, which asks for additional information and history on the patient. Be sure to check the box indicating whether or not the dog was evaluated before.
Once you have completed all of the information you will submit the selected radiographs either by mail to AIS PennHIP or by web upload.

Review this Certification Checklist Before Submitting Films for Evaluation

Checklist for AIS PennHIP *Certification*

1. **Register for an AIS PennHIP Account**
   You will need an AIS account to submit your certification cases for an AIS PennHIP evaluation. Go to the Antech Imaging Services website www.antechimagingservices.com to register for an account now or contact AIS via <info@antechimagingservices.com> or phone 877-727-6800. If you use radiographic film, you will first enter the case into the AIS online submission form and then send the films to AIS (address below) to be scanned in and digitally recorded. Practices with digital radiography will upload images directly to AIS PennHIP via the web.

2. **Certification Radiograph Identification**
   If using film, permanently label or annotate all images. A permanent marker can be used to add missing and/or unclear information. Minimum required information includes: Owner's last name, Radiograph date, Dog's name and/or registration number as written on the application, and Right or left side marker.
   NOTE: Number all distraction views in the chronological order they are taken (#1, #2, #3, etc). Submit all radiographs but be sure to select and identify your best 3 distraction views (see below).

3. **Review Patient Positioning and Radiographic Images -- Before the dog is recovered from anesthesia, review all images for bilateral distraction, positioning quality, and radiographic technique.**
   A. ***Check for Adequate Sedation/Anesthesia -*** No reflex muscle activity. No withdrawal response when dog's toes are pinched hard.

   B. ***Check Patient Positioning for Distraction View -*** Check Pelvis is not rotated; Pubis symmetrically centered on film and under central beam; Femurs angled craniad (tibial tuberosities should be vertical to the greater trochanters, and should be at level of the cranial pubis viewed from VD); Tibias parallel to each other and to x-ray table, Stifles - approximately 90° flexion and should be stance-phase distance apart when exerting maximal distraction force.

   C. ***Check Distractor Rod Position on X-ray -*** Femoral heads should appear within shadows of rods (indicates proper rod spacing). If rods are too wide or too narrow – adjust and repeat. If thigh musculature superimposes more than 1⁄4 of either femoral head – widen the distractor rods and repeat. Check that the distractor is centered on the dog.

   D. ***Check for Obvious Laxity - MOST IMPORTANT!*** The distraction view always has more measurable laxity compared to the hip-extended or compression view. If one or both hips appear to have **minimal to no** distraction, make necessary adjustments and repeat the distraction view until you detect a visible difference bilaterally from the compression and hip extended view.
   NOTE: No, or Insufficient distraction is the most common cause for failing certification.

   E. ***Check for Distractor Rod Rubber Indentation -*** On the distraction view, look for **25-50% indentation of the rubber** covering the distractor rods. The rubber appears as a linear radiolucent margin just lateral to the rod shadows. Generally, 25-50% rubber indentation at the point where the femurs contact the distractor indicates that sufficient force is being applied during distraction.

   F. ***Check Laxity Repeatability –*** Review the 3 chosen distraction images for respective left hip and right hip laxity repeatability.

   G. ***Check Film Quality -*** Accurate PennHIP measurements require precise identification of key orthopaedic landmarks. Good radiographic technique and attention to proper image brightness and contrast is important.

4. **Submitting Radiographs for Certification -** ***Select Your Best Three Distraction Images and Submit ALL! Number in the order taken (not necessary if time stamped).***
   Part of the certification process involves recognizing and selecting images that best meet the standards as described in the Training Manual and the online courses. Submit ALL distraction view radiographs but identify your best three by labeling/annotating **"USE"** on the image or include a separate note with the exposure time stamp. If you do not identify your best three, we will randomly select any three to evaluate your technique and repeatability.
   A minimum of five images are required for each dog: 1 hip-extended, 1 compression, and 3 distraction views

FOR CERTIFICATION ASSISTANCE: Contact us at pennhip@antechimagingservices.com or call Toll free 1-877-727-6800

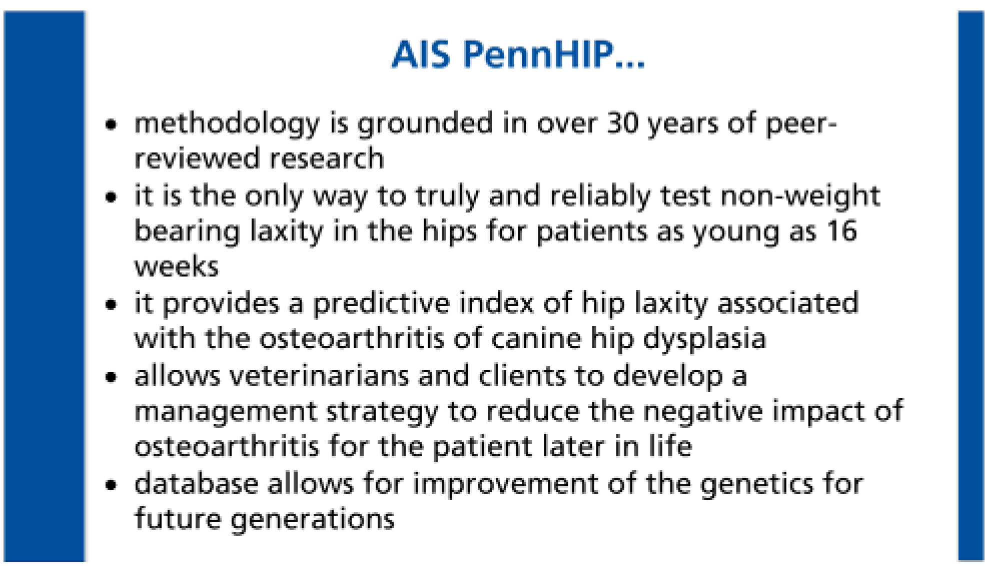
SEND FILMS TO: Antech Imaging Services PennHIP, 17672-B Cowan Ave., Irvine, Ca. 92614

ALL Digital images must be submitted via the AIS website, www.antechimagingservices.com

Getting Help

As an AIS PennHIP member, if you require additional help please phone 1-877-727-6800, or e-mail pennhip@antechimagingservices.com.

Summary and Advantages



Now you know all the advantages of the AIS PennHIP procedure from the methodology to hip laxity and from reducing the negative impact of osteoarthritis to improving the genetics of future generations. This will help you help your clients and patients.

We look forward to having you become a Certified AIS PennHIP Member.