DEPARTMENT AND CLINIC OF SURGERY AND OPTHALMOLOGY

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Approaches to Canine Hip Joint Laxity: Trochanter Major Transposition as a Reduction Method

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Abstract

Despite decades of considerable research efforts, concerns regarding the prevalence of hip dysplasia in dogs persist to this day worldwide. A strong correlation has been shown between increased laxity of the hip joint, the occurrence of hip dysplasia, and associated degenerative changes and clinical signs. The purpose of this paper is a systemic review of the current approaches to hip joint laxity in the canine population, with particular emphasis on diagnostic techniques, palpation, and radiology, in addition to applicable treatment options. A cadaver study on young canine candidates was carried out to assess the prospect of laxity reduction in the hip joint by trochanter major transposition, evaluated and quantified by PennHIP imaging and the application of the Distraction Index.

Introduction

Hip joint laxity is a concept of increasing importance within orthopaedic veterinary medicine and goes hand in hand with canine hip dysplasia, an ongoing concern amongst many dog owners, breeders, and kennel clubs. Canine hip dysplasia was first described by Gerry B. Schnelle in 1935 (King, 2017; Schnelle, 1935) and to the present day exists with a high prevalence in large breed dogs, with continuously increasing incidence (Ginja et al., 2015) – despite extensive research efforts from both veterinarians and breeders on national and international levels. Prior to the works of Schnelle, poor hip conformation was merely associated with congenital dysplasia in humans. One of the earliest publications describing the specific correlation between canine hip dysplasia and hip joint laxity was in 1966, '*On the etiology and pathogenesis of hip dysplasia: A comparative review*,' concluding that there is "overwhelming evidence that hip dysplasia in the dog is caused by a laxity of the joint early in life" (Henricson et al., 1966). It is therefore of interest to explore this correlation further.

Screenings at early ages and follow-up interventions are perhaps the clinical keys to defining and addressing the symptoms of laxity-associated hip dysplasia. A variety of diagnostic measures are in practice, with varying degrees of sensitivity and specificity. Likewise, an array of treatment options exists with varying prognoses; however, there is a significant divide in the objective of therapy, i.e., being of preventative or symptomatic means. A study by Ginja et al. (2015) suggests this focus categorization be an underlying difference between veterinary and human medicine, supported by the works of Wenger and Bomar (2003). As of today, the majority of the therapeutic options, both conservative and surgical, are focused on symptomatic treatment of an already present clinical picture. An approach aimed at specifically tackling increased hip joint laxity, as prophylactic management, is yet to be determined and universally adopted into common practice.

Prior to the discussion of diagnostics and therapy, the concept of hip joint laxity in canine species and its subsequent consequences requires a thorough understanding of the hip joint's fundamental and functional anatomy, with a primary focus on musculoskeletal structures, elaborated in the following section.

Anatomy of the Canine Hip Joint

The hip joint, articulatio coxae, also known as the coxofemoral joint, is a spheroidal, diarthrodial articulation and the primary weight-bearing structure of the hind limb. It is composed of two articular surfaces forming the joint capsule, namely the femoral head, caput ossis femoris, and the cotyloid cavity, more commonly termed the acetabulum. The acetabulum, the socket of the hip joint, is a complex structure formed by the union of the bodies of the three pelvic bones; os ilium, os ischii, and os pubis, as well as the acetabular bone, os acetabuli. The fusion and ossification of these bones occur approximately 12 weeks postpartum (Evans and de Lahunta, 2013). In the centre of the cotyloid cavity, fossa acetabuli, serves as the attachment point of the resilient lig. capitis ossis femoris, formerly the round ligament, lig. teres. A crescent-shaped articular surface, facies lunata, surrounds the fossa acetabuli. Medially, in the direction of the foramen obturatum, facies lunata is divided by the acetabular notch, incisura acetabuli, a structure continuous with the acetabular fossa. The acetabular notch is spanned by lig. transverum acetabuli completing the acetabular rim as well as creating a foramen-like opening for the passage of lig. capitis ossis femoris and accompanying vessels. Additional reinforcing structures include the lig. iliofemorale in the cranial aspect and lig. ischiofemorale in the caudal aspect of the joint capsule (Schaller and Constantinescu, 2007). The rim of the acetabulum is lined by fibrocartilage, known as labrum acetabulare, expanding the surface area and thus deepening the cavity space.

The femoral head, extending from the neck of the femur, collum ossis femoris, incorporates the fovea capitis medially, as the origin of insertion of the above-stated lig. capitis ossis femoris, one of the primary stabilizing structures. Further proximally located structures on the femur, such as the prominent trochanter major, trochanter minor, fossa trochanterica, and the roughened surface of tuberositas glutea, serve as attachment points for the muscles connecting the pelvic girdle to the distal extremities. Refer to figures 1.1-1.4 for illustrated anatomical representation.

The numerous muscles acting on the hip joint provide both restriction in movement as a means of stability, as well as a wide range of directional movement. The hip joint, and to a lesser degree the shoulder, are multi-axial joints. This refers to the ability to move along several planes; median, sagittal, dorsal, and transverse planes, and consequently in six directions, creating angular changes, i.e., extension, flexion, supination (the lateral rotation of the limb), pronation (medial rotation of the limb, primarily associated with the distal limb), abduction and adduction (Dyce et al., 2009). Table 1 outlines the muscles acting on the canine hip joint, with their origin and insertion sites, and primary actions, based on details provided in *Illustrated Veterinary Anatomical Nomenclature* (Schaller and Constantinescu, 2007).

Muscle	**Origin**	**Insertion**	**Action**
mm. adductors (m. adductor longus, m. adductor magnus et brevis)	Ossis pubis, tendo symphysialis	Facies aspera, labrium mediale	Adduction, hip extension
m. articularis coxae	Adjacent to rectus femoris on Os ilium	Proximal os femoris, between lat. and med. vastus mm.	Hip flexion (minimal)
m. biceps femoris	Lig. sacrotubercale, tuber ischiadicum	Radiates into fascia lata, fascia cruris	Hip extension
mm. gemelli	Lateral ischium border	Fossa trochanterica	Hip supination
m. gluteus medius	Fascia glutea of ilium, crista iliaca	Trochanter major	Hip extension
m. gluteus profundus	Ilium, spina ischiadica	Trochanter major, cranial aspect	Hip abduction
m. gluteus superficialis	Facies glutea, Os sacrum, 1st caudal vertebra, lig. sacrotuberale	Tuberositas glutea	Hip extension
m. iliopsoas (m. psoas major, m.iliacus)	Facies iliaca, ventral surfaces of lumbar vertebral bodies and transverse processes	Trochanter minor	Hip flexion, supination
m. obturatorius internus	Internal surface of ischium, pubis, around for. obturatum	Crossing incisura ischiadica to Fossa trochanterica	Hip supination
m. pectineus	Pecten ossis pubis, eminentia iliopubica	Labrium mediale	Adduction
m. piriformis	Os sacrum, lig. sacrotubercale	Trochanter major	Hip extension

m. quadratus femoris	Ventral ischium	Distal to fossa trochanterica	Hip supination
m. rectus femoris (cranial head of m. quadriceps femoris)	Cranial to acetabulum	Tuberositas tibiae by patellar ligaments	Hip flexion (primarily extension of stifle joint)
m. sartorius (pars cranialis, pars caudalis)	Tuber coxae	Proximal tibia medially via Fascia cruris	Hip flexion
m. semimembranosus	Tuber ischiadicum	Medial condyles of femur & tibia	Hip extension, abduction
m. semitendinosus	Tuber ischiadicum	Tibial crest	Hip extension
m. tensor fasciae latae	Proximal ilium, tuber coxae	Radiates into Fascia lata	Hip flexion

Table 1. *Muscles acting on the canine hip joint*

The schematic illustrations below, Figures 1.1-1.4, courtesy of *Miller's anatomy of the dog* (Evans and de Lahunta, 2013), demonstrate the anatomical locations of muscle attachment, as detailed in table 1, of those muscles relevant to hip joint mobility and stability.

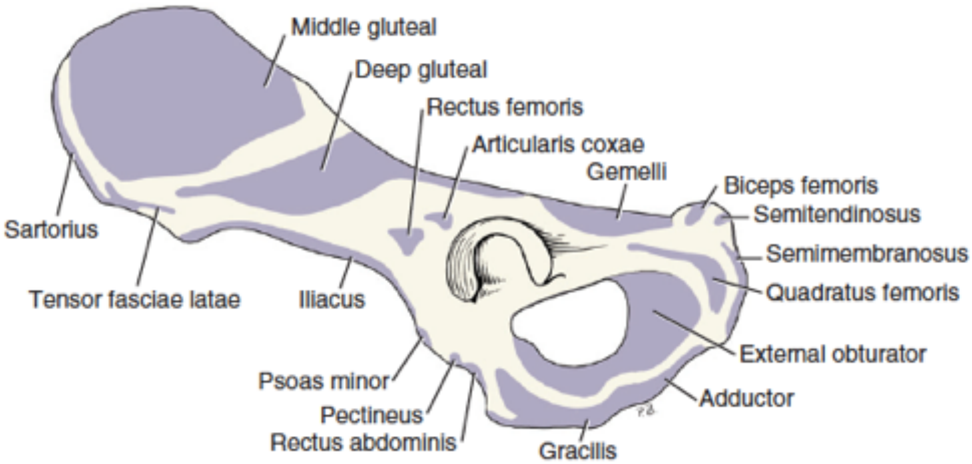

Figure 1.1. *Attachment points of hip joint muscles on os coxae sinister, shown from the lateral aspect. Source: Miller's anatomy of the dog, illustrator Marion Newson (Evans and de Lahunta, 2013, pg. 255)*

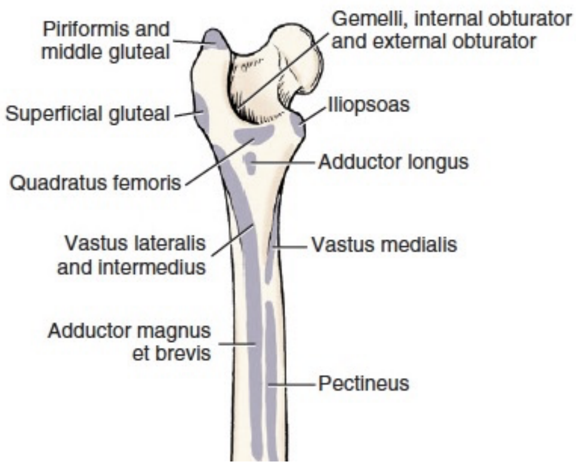

Figure 1.2. *Attachment points of hip joint muscles on os femoris sinister, shown from the caudal aspect. Source: Miller's anatomy of the dog, illustrator Marion Newson (Evans and de Lahunta, 2013, pg .258)*

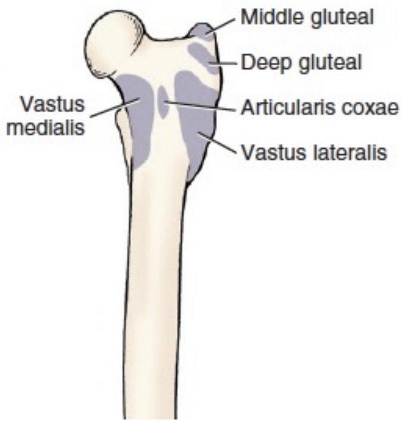

Figure 1.3. *Attachment points of the hip joint muscles on os femoris sinister, shown from the cranial aspect. Source: Miller's anatomy of the dog, illustrator Marion Newson (Evans and de Lahunta, 2013, pg.258)*

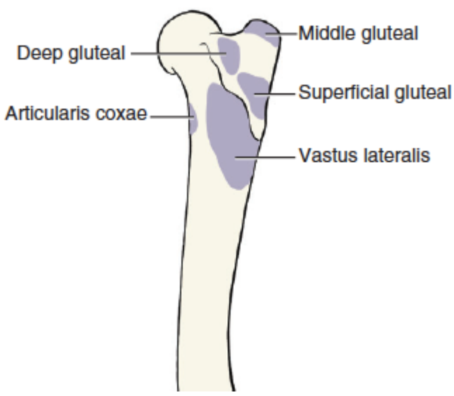

Figure 1.4*. Attachment points of hip joint muscles on os femoris sinister, shown from the medial aspect. Source: Miller's anatomy of the dog, illustrator Marion Newson (Evans and de Lahunta, 2013, pg.258)*

Aetiopathogenesis of Laxity

Laxity, or the state of being lax, can be defined as looseness, originating from the Latin word *laxus*; 'loose, lax' (Oxford English Dictionary, 2012). Within the context of the hip joint, laxity can be defined as a quantifiable amount of subluxation of the femoral head from the acetabulum. Subluxation refers to a partial separation, dislocation, or misalignment of the joint. In directional terms, the majority of femoral head luxation is craniodorsal (Wardlaw and McLaughlin, 2018). Laxity, to a certain extent, is physiological, allowing for the intended free movement of the joint; however, in case of increased laxity, hyperlaxity, or pathologic laxity, there is increased elasticity or lengthening of the joint restraints (i.e., ligaments, tendons, joint capsule). As such joint laxity can be considered a precursor to joint instability, which in turn may result in points of increased pressure, microfractures, strain, and over-compensation, expressed as clinical signs ranging from mild to severely debilitating.

Increased hip laxity is often directly associated with or as a predisposing factor of canine hip dysplasia and further secondary degenerative musculoskeletal disorders, i.e., degenerative joint diseases, such as osteoarthritis and arthrosis (Kapatkin et al., 2002; Smith et al., 2001). Despite over five decades of continuous research, the description provided by Henricson et al. (1966), " the main feature of hip dysplasia is 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," has not been disproved, and has become the focus of diagnostic practices.

Hip dysplasia is one of the most common orthopaedic developmental disorders seen amongst canine species (Gulanber, 2006). Therefore, the determination of laxity at an early stage, i.e., less than one year of age, can provide possible means for improvement, if not full correction, prior to the development of clinical signs and irreversible structural changes. Investigating laxity at later stages of life may prove false negative if secondary changes such as remodelling have already occurred and consequently may mask the expression of laxity. It is important to note that hip laxity may likewise present in the absence of secondary degenerative changes and clinical signs.

The aetiology of hip joint laxity is multifactorial (Schachner and Lopez, 2015), i.e., a single cause cannot be pinpointed. Polygenic inheritance plays an underlying role, indicating that a "large, but unknown number of alleles are involved, scattered throughout the genome" (King, 2017); a multifactorial mode of inheritance (Soo and Worth, 2015). Additionally, a wide range of non-genetic, environmental factors can influence the degree of progression, and in turn, the degree of clinical severity. Lack of client education comprising inappropriate feeding regimes favouring high-calorie loads, promoting elevated body condition scores is a strongly supported external factor (Kapatkin et al., 2002). Evidence shows that dogs subjected to restricted feeding have "lower prevalence and later onset of hip joint osteoarthritis" (Smith et al., 2006). Increased laxity is predominantly seen in large and giant breed dogs (Runge et al., 2010), which are subject to more rapid growth rates and weight gain when compared to smaller breeds. Such development is characterized by skeletal growth exceeding the rate of muscular development in the early stages of life, i.e., often termed skeletally immature dogs. In other words, the soft tissue related to the joint is unable to hold it in a congruent position, resulting in increased laxity. Furthermore, dogs associated with extensive physical work with high activity levels and thus greater strain on joints, i.e., working dogs, are even more predisposed. A study carried out in Norway evaluating puppy husbandry (Krontveit et al., 2012) established that exercise conditions should exclude access to stairs and include moderate outdoor activity, off-leash, during the first three months of age. Commonly named breeds associated with hip joint instability include, but are not limited to; German Shepherds, Labrador Retrievers, Golden Retrievers, and Rottweilers (Adams et al., 1998). Smaller dog breeds are infrequently mentioned in the discussion of joint laxity, primarily due to the absence of clinical signs and are demonstrated to be at lower risk of developing osteoarthritis (Arnbjerg, 2017). Moreover, the study conducted by Arnbjerg (2017), suggests that joint laxity in small dogs may be "over-diagnosed as a pathological finding, when the radiographs are taken under some traction." Other named aetiologies include increased volume of synovial fluid, resulting in increased intra-articular volume, which causes joint instability through lateral femoral head displacement (Leighton et al., 2018; Lust et al., 1980). Specific to canine hip dysplasia, one study determined that castrated male dogs in particular are at higher risk of developing the disease (Witsberger et al., 2008). It is clear that continued efforts are required to identify etiological patterns and variability to further understand the multifactorial background.

Joint Incongruence

When discussing the aetiology of canine hip laxity and hip dysplasia, the terminology of *congruency* should also be mentioned. The coxofemoral joint is normal at time of the birth and assumed to continue normal development "if complete congruity between the femoral head and the acetabulum is maintained" (Leighton et al., 2018). Under normal circumstances, there is proper femoral head coverage, also termed femoral overlap, of greater than 50% (Leighton et al., 2018). Where the articular surfaces are in precise alignment with each other, the term *congruency* is used; defining a healthy, congruent hip joint. When congruency is below optimum, the femoral head conforms poorly to the acetabulum, whether due to developmental dysplasia or increased laxity, instability of the joint develops in the form of abnormal friction, i.e., points of increased local abrasion. The term *incongruency* is then of relevance. Consequently, the integrity of the labrum acetabulum is affected, and further local periarticular osteophyte reactions can occur. In relation to laxity, it can be stated that an abnormal degree of laxity will result in joint incongruence, similarly, the presence of joint incongruence will lead to abnormal stretching of the joint restraints and further increase laxity. As such, it can be said that increased joint laxity and incongruence negatively impact each other.

Diagnostics & Screening

Expression of laxity, and simultaneously incongruence, can be achieved with different physical examination methods as a primary approach. Focus is placed on joint palpation, manipulation, and radiographic imaging for confirmation, with varying specificities, advantages, and disadvantages. As of today, no one single golden standard is used in veterinary practice. Furthermore, the current diagnostic tools are not all specific to the evaluation of laxity alone. There is a division of diagnostic focus: firstly, the subjective assessment of hip joint laxity, and secondly, the signs of secondary degenerative joint diseases. Additionally, the age of the patient at the time of evaluation plays a distinguishing role.

In a conscious animal, joint palpation and the range of motion (ROM) should be evaluated as part of an orthopaedic examination. Three bony prominences, the spina iliaca dorsalis cranialis, the tuber ischiadicum, and the trochanter major, are palpable landmarks that form a triangle with an obtuse central angle at the trochanter major (Englar, 2017).

Bilateral symmetry is primarily assessed superficially, focusing on bone structures, muscle mass, or lack thereof (King, 2017), and joint surfaces, followed by more profound palpation to assess for crepitation or pain. ROM involves palpation during stationary postures as well as a passive, visual assessment during gaits, specifically in the walk, amble/pace, and trot. Normal ROM for flexion-extension of the hip joint is approximately 110 degrees (Bexfield and Lee, 2014), measured with a goniometer. During gait examination, the practitioner evaluates clinical signs of the hind limbs such as stiffness, pain, unilateral or bilateral lameness, the abnormal swaying of hips, abnormal lengths of stride, bunny-hopping gait, contact of nails with the floor, and decreased ROM (Bell, 2015; Kyriazis and Prassinos, 2016; Piermattei et al., 2006). All of these indicators help determine the clinical severity and provide basis for further diagnostics.

Ortolani test

The Ortolani test or Ortolani sign is a physical manoeuvre frequently incorporated into orthopaedic examinations when increased hip joint laxity characteristic of hip dysplasia is suspected. The test was developed by Marino Ortolani in 1935, an Italian paediatrician who dedicated his life's work to the patho-anatomy of hip dislocation in infants (Mubarak, 2015). This adduction-abduction manoeuvre has since been adopted into veterinary and human medicine alike. The Ortolani test is a two-step, *sensational* demonstration of hip joint laxity; specifically, the detection of two simultaneous sensations by the practitioner during the reduction or relocation of a forced subluxation. Firstly, an *audible* noise, 'click, pop, or clunk' sound, and secondly a *palpable* sensation. Due to the significant amount of force required, the test is most often performed in an anaesthetized or sedated animal, positioned typically in lateral recumbency, with the leg opposite the table or floor examined. In addition to animal comfort, sedation also avoids the influence of tensed muscle tone. Dorsal recumbency can also be used to perform the test on both legs simultaneously, primarily an applied technique in smaller dogs. Figure 2 demonstrates the technique performed in lateral recumbency (Hazewinkel et al., 2009). First, the femur is *adducted*; with one hand, pressure is placed on the stifle, pushing it medially towards the table or floor and simultaneously applying force along the long axis of the femur in a dorsal direction. The other hand stabilizes the sacral region of the back while also palpating the greater trochanter to assess for subluxation of the femoral head. This is detected in case of abnormal laxity, as the femoral head is dislodged past the dorsal acetabular rim. Secondly, the femur is *abducted*, by lifting the femur away from the table, reducing the joint back into the original position. A positive Ortolani test is deduced from the femoral head 'clicking' back into the acetabulum upon reduction.

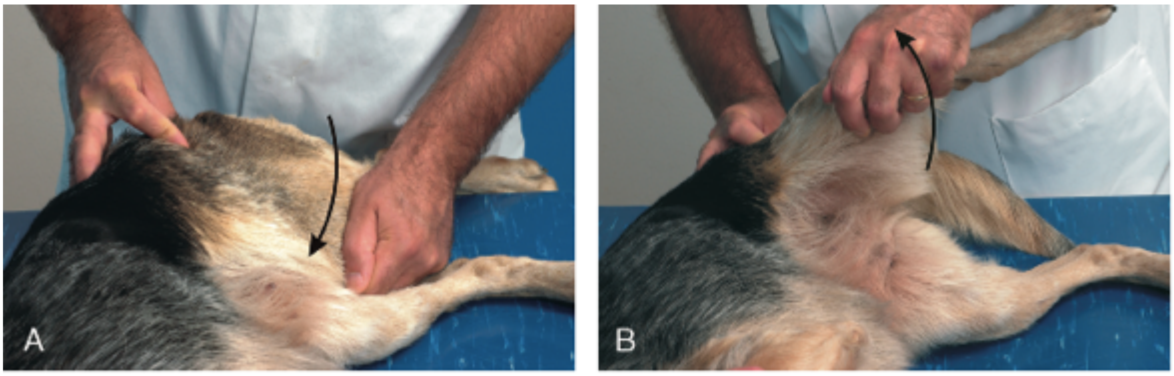

Figure 2. *Technique for performing the Ortolani test. Source: Hazewinkel* et al.*, 2009*

Lack of a positive Ortolani sign does not however, inevitably signify that the hip is normal and healthy (Schachner and Lopez, 2015). As previously stated, secondary joint changes associated with the presence of increased laxity and dysplasia, e.g., fibrosis, remodelling, and capsular thickening, will mask the palpable manoeuvre, rendering the test negative (Read, 2002). The Ortolani test is therefore of most value at younger ages, i.e., below one year of age.

Other clinical palpation techniques include the modified Barlow and the Barden tests, originating and mostly associated with human paediatric medicine. The Barlow maneuver is essentially the first step of the Ortolani sign inducing the subluxation of the femoral head (Farese et al., 1998), described in *Congenital Dislocation of the Hip in the Newborn* (Barlow, 1966). Barden's test, also referred to as the hip lift, is a technique assessing whether or not "the femoral head can be 'bounced' in and out of the acetabulum," through the elevation of the femoral shaft away from the table (in lateral recumbency) and simultaneous pressure on the greater trochanter (Fries and Remedios, 1995). According to Adams *et al.* (1998), "a positive Bardens' maneuver consisted of a 2 mm or greater estimation of palpable hip laxity." Neither the Barlow nor Braden's tests are currently widely used nor universally accepted in veterinary practice. Moreover, these provocative tests, including the Ortolani test, should not solely support the diagnosis of coxofemoral laxity. For a more objective confirmation, further auxiliary examinations are required, with emphasis on radiographic imaging.

Radiographic imaging

Different radiology approaches exist for both the specific expression of passive hip laxity and the general evaluation of hip joint integrity, most commonly as a screening for canine hip dysplasia. It is important to recognize the term *passive* hip joint laxity is used, implying that its expression is achieved during non-weight-bearing positioning, measured and demonstrated with radiographic imaging, as opposed to the pathologic form, *functional* laxity occurring during weight-bearing (ANTECH Imaging Services, 2016; Kapatkin et al., 2002). The radiographic selected method, and scoring thereof, depends on various factors. Such factors include; geographical location and its associated preference or guidelines set by national or international organizations, practitioner or scrutineer competence (and in some cases licensing), and the available equipment. The most standardized and 'traditional' technique has been described by, amongst others, the Federation Cynologique Internationale (FCI), an '*Extended Hind limbs'* radiograph (FCI Scientific Commission, n.d.). The positioning is dorsal recumbency, with ventrodorsal beam alignment; hence, this technique is also called *standard ventrodorsal extended hips/position*. The radiograph is carried out under general anaesthesia or heavy sedation to assure adequate muscle relaxation (Genevois et al., 2006) so that the hindlimbs can be fully extended caudally. The entire pelvis should be visible within the frame, identical size of foramina obturatum, the femurs parallel with slight medial rotation, and the patellae visibly centred in the trochlea ossis femoris. For the official registration of the radiograph, the FCI requires the dog to be a minimum age of one-year-old (18 months for large breed dogs). The FCI also describes a second radiograph, '*Abducted hind limbs'* where the femora are abducted with the tarsi elevated off the table (FCI Scientific Commission, n.d.); however, this is more specific for early diagnosis of femoral neck osteoarthrosis. Figure 3 demonstrates the correct positioning for fully extended hips, courtesy of the FCI.

Figure 3. *Correct positioning for an 'Extended hind limbs radiograph.' Source: FCI.*

Evaluation and Scoring of radiographs

The standard *extended hind limbs* radiographic image is utilized by most scoring schemes to evaluate canine hip conformation worldwide. Internationally there are three main credible organizations used in practice (Flückiger, 2007); however, there is minimal assessment of hip laxity; primary focus falls upon the determination of canine hip dysplasia. In Europe, the most widely used classification scheme for canine hip dysplasia is set by the previously mentioned FCI, using a five-point scale of A-E, with A representing normal canine hip conformation and E representing severe hip dysplasia. The FCI scoring is based on the assessment of compiled radiographic findings, including bone structure and shape, pathological changes such as periarticular osteophyte reaction and osteoarthritis, and the Norberg angle (NA), as an indicator for hip laxity (Klever et al., 2020). The Norberg Angle is deduced by marking the centres of both femoral heads with a line connecting the two and drawing an additional line from each centre to the craniolateral acetabular margin on the respective side (Klever et al., 2020). The angle produced between the two is the NA, represented in units of degrees. A NA of 105 degrees has been described as the universal threshold mark for normal hip joint conformation (Culp et al., 2006). The larger the angle (>105°), the more congruent the hips are considered, whilst the smaller the angle (<105°), the more indicative of a shallower acetabulum, abnormal hip conformation, and "consistent with increasing degrees of subluxation" (Butler and Gambino, 2017). As such, the NA is considered a subjective parameter for hip conformation. Figure 4 demonstrates the NA on a radiograph.

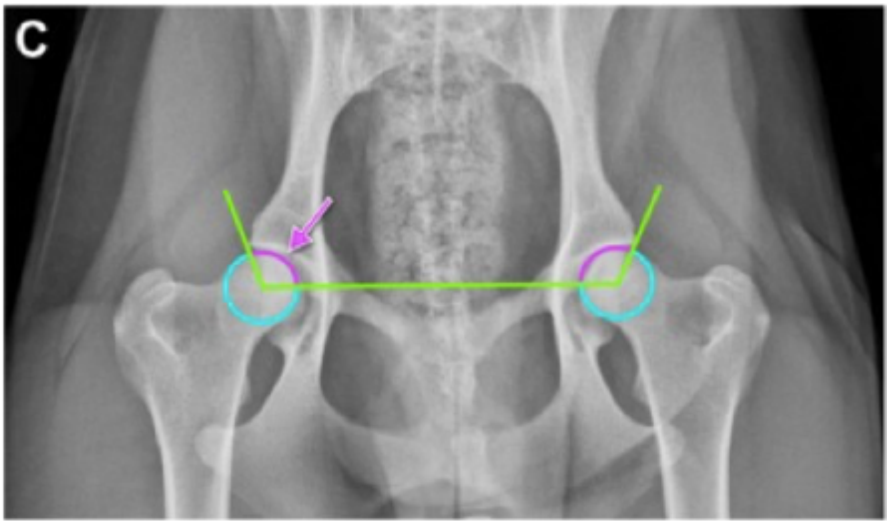

Figure 4. *Norberg Angle. Source: (Schachner and Lopez, 2015)*

PennHIP radiography

Another more novel radiographic approach with its own unique scoring scheme is the Pennsylvania Hip Improvement Program (PennHIP), which can be considered an individual entity in veterinary radiology, developed by Dr. Gail Smith in 1993 and adopted by the University of Pennsylvania in 2013 (AIS PennHIP, n.d.). The initial research behind the method was based on the understanding that the "displacement of the femoral head from the acetabulum was maximized in the neutral position and was largely independent of the distraction force" (Leighton et al., 2018). The PennHIP method provides a more specific approach to quantifying hip joint laxity, based on three separate radiographs:

1. A standard, conventional *Ventrodorsal/Extended hips* radiograph, as previously described, to evaluate degenerative changes such as osteoarthritis, and to obtain a general overview of hip status.

Figure 5.1. *Extended hips positioning and radiograph. Source: PennHIP training manual (PennHIP, 2015).*

2. A *Compression* view radiograph to evaluate congruency and to determine markers for measurement taking, in which the dog is positioned in a neutral position simulating weight-bearing (the femoral heads fully seated and pressed into the acetabula)

Figure 5.2. *Compression positioning and radiograph. Source: PennHIP training manual (PennHIP, 2015).*

3. A custom *Distraction view* radiograph, also termed a stress-radiograph, to specifically evaluate the maximal passive hip joint laxity, with the femoral heads displaced laterally with the use of a special distraction device, i.e., acrylic fulcrum distractor, placed between the proximal femurs (ANTECH Imaging Services, 2016; Butler and Gambino, 2017; Powers et al., 2010). The distraction view position is illustrated in Figure 5.3 below, as provided in the AIS PennHIP training manual.

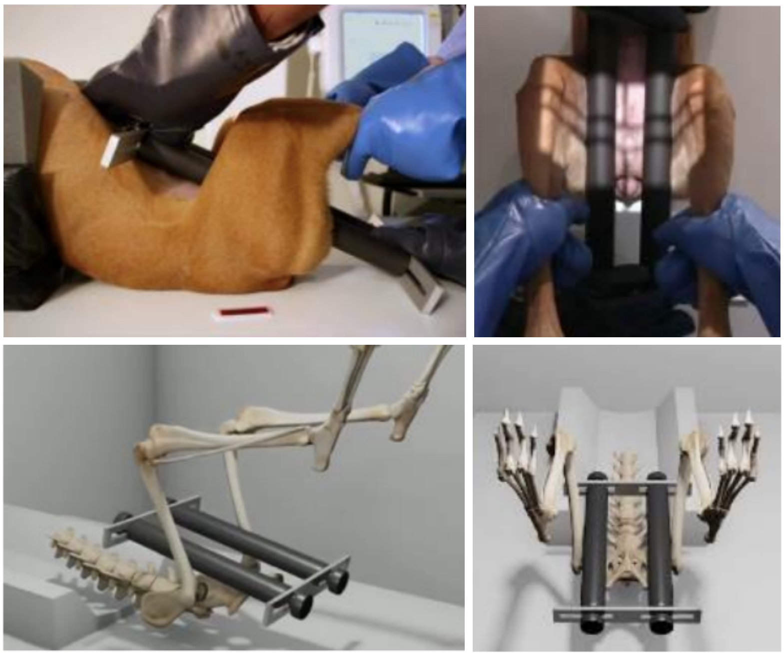

__Figure 5.3.__ Distraction view positioning with placement of distractor device. Source: PennHIP training manual (PennHIP, 2015)

The resulting radiograph from the distraction view is illustrated in Figure 5.4. The less radiopaque parallel areas overlapping the femoral heads and necks demonstrates the correct placement of the distractor device.

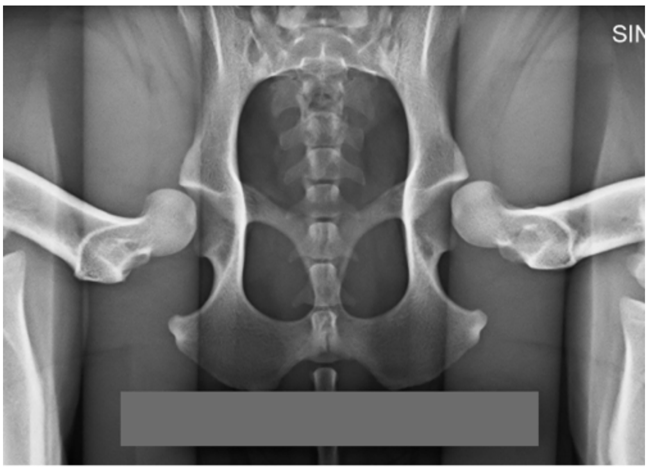

__Figure 5.4.__ Distraction view radiograph. Source: PennHip training manual (PennHIP, 2015).

The additional two views of PennHIP provide a more thorough insight to how well the femoral heads are seated within the acetabulum, compared to the standard extended hips radiograph as a sole reference. This may "mask subtle hip dysplasia because the joint capsule is taut when the hips are hyperextended" (Englar, 2017). The AIS PennHIP training manual provides a checklist for further details, refer to Appendix 1.

In contrast to the primarily qualitative grading systems of the FCI, the Orthopaedic Foundation for Animals (OFA), and the British Veterinary Association/The Kennel Club (BVA/KC), the PennHIP technique involves the calculation of a distraction index (DI), measured on the distraction view radiograph, as a quantification of the relative femoral head displacement. The DI is calculated as the distance, d, between the centre of the femoral head and the centre of the acetabulum during the induced distraction, divided by the radius, r, of the femoral head, i.e. $Distraction\ Index(DI) = d/r$ (PennHip, n.d.). Figure 6 illustrates the measurements for calculation.

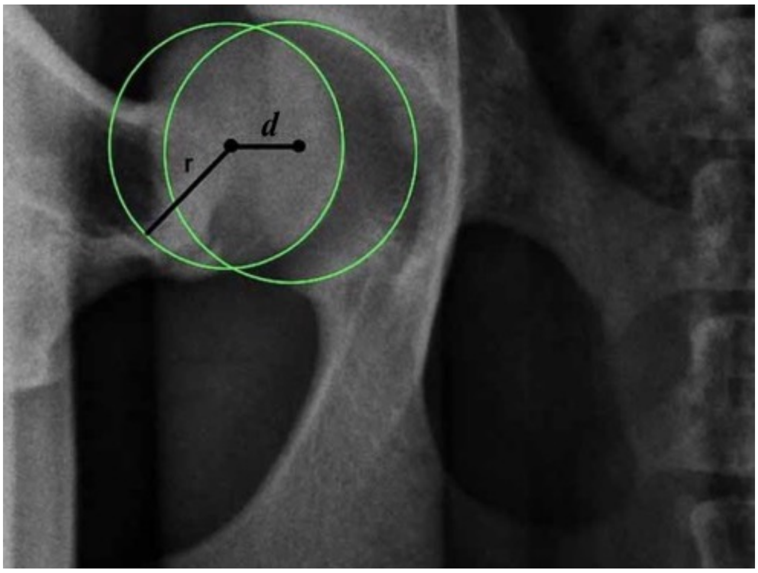

Figure 6. *Distraction Index, adapted from M Soo & AJ Worth (2015)*

The DI is a unitless number on a continuous scale between 0 and 1.0, or higher, where a score of 0 represents perfect congruency and, as such, the tightest hip joint, and 1.0 or higher is indicative of severe hip joint laxity, i.e., an extremely loose hip joint. There has been shown to be a strong correlation between the DI and microstructural changes in cartilage (Lopez et al., 2008), supporting the association of laxity and degenerative joint diseases. Furthermore, the DI of the assessed animal can be related to the laxity scores of the breed in question, provided in the regularly updated AIS PennHIP Breed Laxity Report. Another distinguishing and advantageous factor of the PennHIP method is that it can be reliably performed in dogs at younger ages, as young as 16 weeks. However, a disadvantage of the PennHIP evaluation is that an expense for training and certification, receiving the title of a PennHIP-certified veterinarian, is required for its official application (ANTECH Imaging Services, 2016; Broeckx et al., 2018). Despite this, the PennHIP method is receiving international acceptance and more frequently being applied to orthopaedic evaluations.

Further Laxity-based Diagnostics

A relatively new laxity-based diagnostic method, the Vezzoni-Modified Badertscher Hip Distension Device technique, developed in 2008 (Bertal et al., 2019; Broeckx et al., 2018), applies a distraction view to determine a Laxity Index (LI), similarly to the DI. The Broeckx et al. study (2018) concluded that the LI approximates the DI provided by the PennHIP evaluation centre very closely, and as such, is "less expensive as two instead of three radiographs are made." Nevertheless, this method's acceptance and application is largely limited to Italy and Belgium and does not yet hold global recognition. In fact, the Vezzoni-Modified Badertscher Hip Distention method was highly scrutinized in *'Imitation is the Sincerest of Flattery'…Except When It Negatively Impacts Canine and Client Welfare*' (Smith, 2018), deeming it invalid. Further studies are required to confirm the method's legitimacy.

Dorsolateral subluxations (DLS) test is another diagnostic method specific to the determination of hip joint laxity, effectively the radiologic expression of the Ortolani sign. The dog is placed in sternal recumbency on a custom foam pad with a cut-out section for the placement of the flexed hind limbs, with the stifles in contact with the table surface (Farese et al., 1998). This method aims to produce a weight-bearing projection radiograph, simulating functional hip laxity, as the femoral heads subluxate in a dorsolateral direction. The degree of DLS is converted into a quantifiable unit by calculating the percentage of femoral head coverage (Leighton et al., 2018). The DLS technique can be compared to the PennHIP compression radiograph achieved in sternal recumbency, as previously described by Farese et al. in 1998.

Regardless of the method of radiographic imaging, there are several variables that hold substantial influence on the evaluation of the radiographic findings, e.g., individual examiner variability, individual animal variability "including periarticular soft tissue changes and muscle atrophy" (Schachner and Lopez, 2015), radiograph quality, and the type and degree of chemical restraint used for anaesthesia or sedation eliciting muscle relaxation (Malm et al., 2007). In other words, radiographic evaluation is inevitably subject to subjectivity.

Therapy options

Non-surgical approaches

Within the framework of laxity-associated hip dysplasia, medicinal, and non-medicinal conservative treatment options exist; however, these have limited preventative properties. Increased laxity as a physical deviation requires primarily physical manipulation, and as such, can only be minimally addressed by nonsurgical approaches. However, secondary clinical signs associated with increased laxity, e.g., osteoarthritis, may be subject to symptomatic treatment. Medicinal palliative strategies are focused on pain management, alleviating discomfort, involving non-steroidal anti-inflammatory drugs (NSAIDs), i.e., cyclooxygenase (COX) inhibitors (Aragon et al., 2007; Johnston and Budsberg, 1997). Some of the most preferred drugs of choice in today's clinics include, but not limited to:

- Oxicams e.g. meloxicam (*Metacam*)
- Carprofens (*Rimadyl vet.)*
- Coxibs e.g. robenacoxib (*Onsior*), firocoxib (*Previcox*), mavacoxib (*Trocoxil*), cimicoxib (*Cimalgex*)
- Pentosan polysulphate sodium, PPS (*Cartophen*)
- Selective prostaglandin E4 (EP4)-receptor antagonist, grapiprant (*Galliprant vet.*)

The aforementioned drug choices were supported by consultation with Mjøsa Hesteklinikk and Sinsen Dyreklinikk in Norway, and cross-referenced with the Norwegian Veterinary Formulary (Søli et al., 2018). Additionally, chondroprotective agents, also termed chondroprotectants, such as glycosaminoglycans (GAGs) and their precursors, are used in various combinations in veterinary practice. One mode of action involves the concept of substitution, as described by Hawks (2002), "replacing declining amounts of GAGs in degenerating joints". Frequently mentioned constituents include glucosamines, which are involved in collagen, GAG and proteoglycan synthesis, and chondroitin sulphate, a significant GAG (Piermattei et al., 2006). Hyaluronic acid is another GAG and component of synovial fluid, influencing its viscosity. As the majority of GAGs are sulphated, methylsulphonylmethane (MSM) is often incorporated as a synergistic precursor acting as a sulphate donor (Hawks, 2002). One naturally occurring source of such chondroprotective agents, as well as omega-3 polyunsaturated fatty acids having anti-inflammatory activity, is the New Zealand green-lipped mussel, *Perna canuliculus* . Chondroprotective agents are not strictly considered medicinal, rather nutritional additives or nutraceuticals, and are usually incorporated into prescription food diets e.g., Hill's j/d®, or administered as dietary supplements in both liquid and solid forms e.g., Glycoflex®.

Other conservative management practices for symptomatic treatment of laxity-associated hip dysplasia include physiotherapy, hydrotherapy, chiropractic, and acupuncture (Hawks, 2002). Of preventative measures, the previously stated and well-recognized concept of restricted feeding regimes to achieve optimum body weight is of importance, supported by several studies (Anderson, 2011; Witte, 2019). As described by Smith et al. (2006) and Kapatkin et al. (2002), excess body mass as a joint stressor may be one reason for the conversion of passive hip laxity into pathologic functional hip laxity and sequential degenerative changes. For greater efficacy, combination of the various nonsurgical management practices is recommended. Furthermore, prospective studies with increasing importance focus on selective breeding programmes, especially with the incorporation of estimated breeding value analyses based on laxity-specific diagnostics (Soo and Worth, 2015) to bring about genetic change. This may prove beneficial in the future by reducing the prevalence.

Surgical Approaches

As with the diagnostic approaches to hip joint laxity, there is currently no single preferred surgical approach. Surgical procedures can be categorized into their respective objective, either preventing the development of clinical signs associated with hip dysplasia, or as a salvage procedure (Anderson, 2011). Neither is exclusively specific to decreasing joint laxity. Furthermore, the various surgical procedures are strictly age-specific. Juvenile pelvic symphysiodesis (JPS), performed in dogs 3-6 months of age (Dueland et al., 2010), and triple pelvic osteotomy (TPO), performed in dogs 6-12 months of age with well-conformed hips and no signs of osteoarthritis, are procedures involving the reduction of the pelvic inlet diameter aimed at increasing "femoral head coverage by ventrolateral rotation of the acetabulum" (Schachner and Lopez, 2015). Potential complications related to pelvic inlet narrowing exist, including dystocia, dysuria, constipation, and screw loosening in TPO (Anderson, 2011). A study by (Manley et al., 2007) established that neither TPO or JPO successfully eliminate passive hip joint laxity. Total hip replacement, applicable only in skeletally mature dogs, and femoral head osteotomy, are current salvage procedures that omit the concept of laxity altogether.

Cadaver Study

A canine cadaver study was carried out aimed at establishing the effect of a trochanter major transposition on hip joint laxity. A trochanteric transposition is most commonly associated with the treatment of traumatic craniodorsal coxofemoral luxation, chronic luxation, and pre-existent hip dysplasia (Ash et al., 2012). However, to the author's knowledge, it is scarcely mentioned as a preventative measure tackling joint instability prior to clinical signs. As an open reduction method, it can be hypothesized that the given effect may likewise induce the reduction of hip laxity and thus improve joint stability through the medial and distal pull of gluteal mm., with resulting pronation, flexion, and abduction of os femoris.

Pilot study

The aim of the preliminary pilot study was to imitate functional hip joint laxity in a canine cadaver through incising the lig. capitis ossis femoris from a medial aspect, without severely damaging joint capsule integrity. Laxity is assessed by palpation and radiographic imaging pre- and post-incision. The chosen method of radiology is PennHIP, and thus the use of a distraction device, due to its universally growing acceptance. The cadaver candidates used for both the pilot and full-scale study were chosen according to the following criteria; medium to large breed of dog, below 1.5 years of age and without the presence of osteophytes and arthrosis development. During collection, the cadaver candidates were preserved at -18°C in a commercial chest freezer and thawed prior to manipulation.

Initial pilot study results: Incision of the lig. capitis ossis femoris was insufficient to demonstrate laxity alone. Further attempts were made by incising the medial aspect of the joint capsule, followed by the tendon of the m. iliopsoas, and m. pectineus. With these points of incision, adequate laxity was demonstrated. It was later determined that incision of the m. iliopsoas could be omitted. Once an adequate demonstration of laxity was achieved in test candidates, a full-scale cadaver study could proceed, comparing the DI measured on intact, laxity-induced and trochanter major transposition hips. Ventrodorsal and compression view radiographs where taken as initial radiographs in each case, as defined by the PennHIP method, to evaluate joint integrity and to determine markers for measurement.

Full-scale study

Materials: Kirschner wire (K-wire), spongiosa screws, oscillating saw, PennHIP distraction device, fully equipped radiology facilities.

Software: New computer software specifically aimed at the evaluation of hip laxity radiographs are underway (Alves-Pimenta et al., 2020), other than the PennHIP Analysis center; however, these are not yet available for communal use. Therefore, the determination of DI in this cadaver study was carried out using the subscription-based program vPOP PRO, a veterinary preoperative orthopaedic planning tool.

Surgical Technique of Trochanter Major Transposition: Supported by details outlined in *An Atlas of Surgical Approaches to the Bones and Joints of the Dog and Cat* (Piermattei, 2004).

The osteotomy of the trochanter major is performed from a craniodorsal approach, through a craniolateral incision. The cadaver patient is positioned in lateral recumbency, and the uppermost trochanter major palpated. The initial skin incision is placed at this level and continued distally along the femoral shaft's cranial aspect. Incised skin margins are retracted, and the underlying m. tensor fasciae latae (superficial layer) revealed, which is further incised adjacent to m. biceps femoris, as illustrated in figure 7.1. Caudal retraction of m. biceps femoris reveals the sciatic nerve, deep layer of m. tensor fasciae latae and m. gluteus superficialis. Transection of m. tensor fasciae latae is followed by tenotomy and retraction of the tendon of m. gluteus superficialis, at the level of trochanter major, illustrated in figure 7.2. Next, osteotomy is performed with an oscillating saw placed at a 45° angle (Piermattei, 2004).

The reattachment site of the osteotomized trochanter major is directed distally and caudally to the original location on corpus ossis femoris. The degree of distal placement in case of coxofemoral luxation is approximately 1-2cm (Wardlaw and McLaughlin, 2018). In this study, distal translocation of 8mm was measured from the distal edge of the osteotomy line. Reattachment is commonly performed using two Kirschner wires and stabilized with tension band wire.

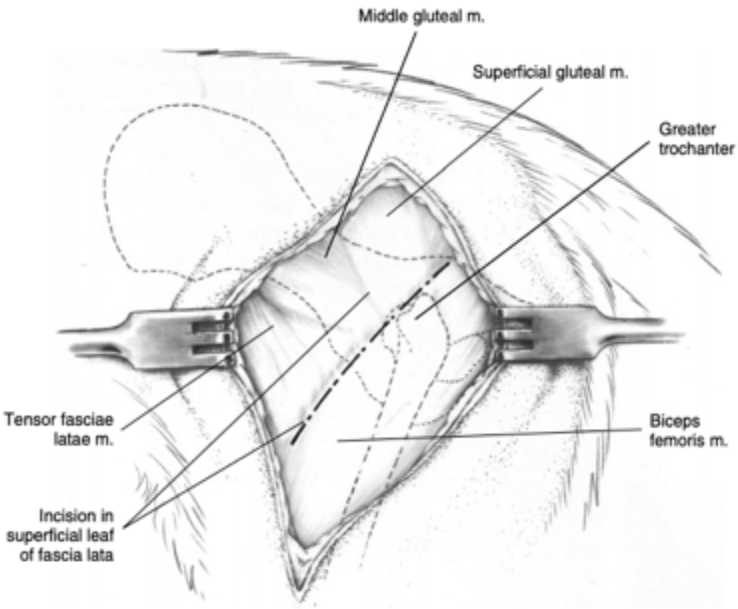

Figure 7.1. *Primary steps to osteotomy of trochanter major, craniolateral approach. Source: (Piermattei, 2004)*

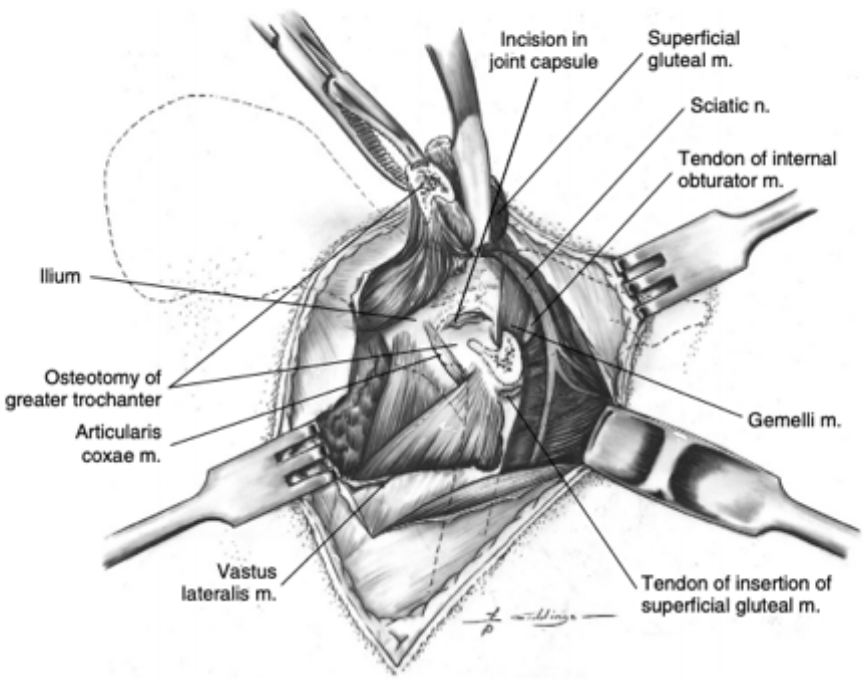

Figure 7.2. *Tenotomy of m. gluteus superficialis and osteotomy of trochanter major. Source: (Piermattei, 2004)*

Case 1

Initial radiographs, figures 8.1-8.3, were taken on an intact hip according to the PennHIP method; firstly, a standard ventrodorsal position, secondly a compression view, and thirdly a distraction view from which the DI could be measured. This was followed by a second distraction view radiograph, figure 8.4, after the incision of the medial part of the joint capsule, lig. capitis ossis, and m. pectineus, demonstrating induced laxity. Finally, a third comparative distraction view radiograph, figure 8.5, after a trochanter major transposition was taken.

Figure 8.1. *Case 1. Ventrodorsal view radiograph, intact hip*

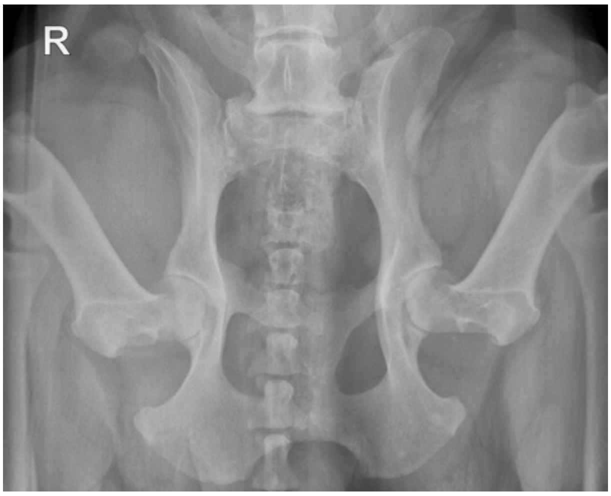

Figure 8.2. *Case 1. Compression view radiograph, intact hip*

Figure 8.3. *Case 1. Distraction view radiograph, intact hip*

Figure 8.4. *Case 1. Distraction view radiograph, induced laxity*

Figure 8.5. *Case 1. Distraction view radiograph, trochanter major transposition*

Case 2

In this case the same procedure and order of radiographs was carried out as in the first case, however the Kirschner wires were replaced with spongiosa screws for convenience of application.

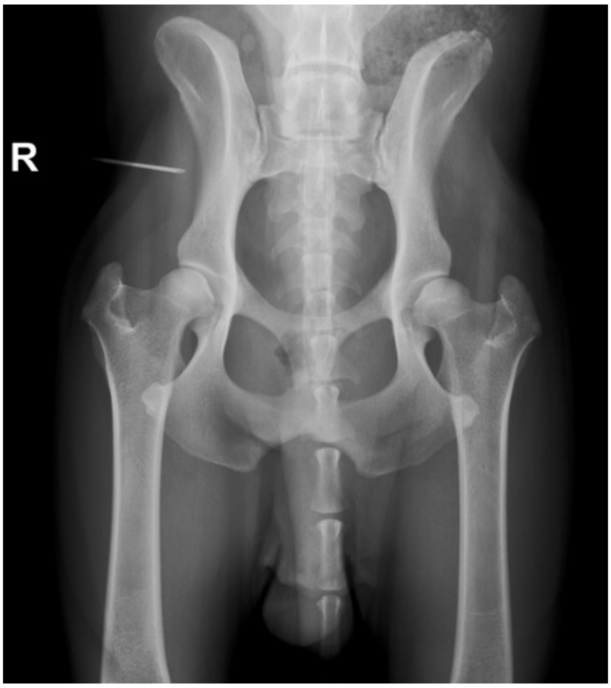

Figure 9.1. *Case 2. Ventrodorsal view radiograph, intact hip*

Figure 9.2. *Case 2. Compression view radiograph, intact hip*

Figure 9.3. *Case 2. Distraction view radiograph, intact hip*

Figure 9.4. *Case 2. Distraction view radiograph, induced laxity*

Figure 9.5. *Case 2. Distraction view radiograph, trochanter major transposition*

Case 3

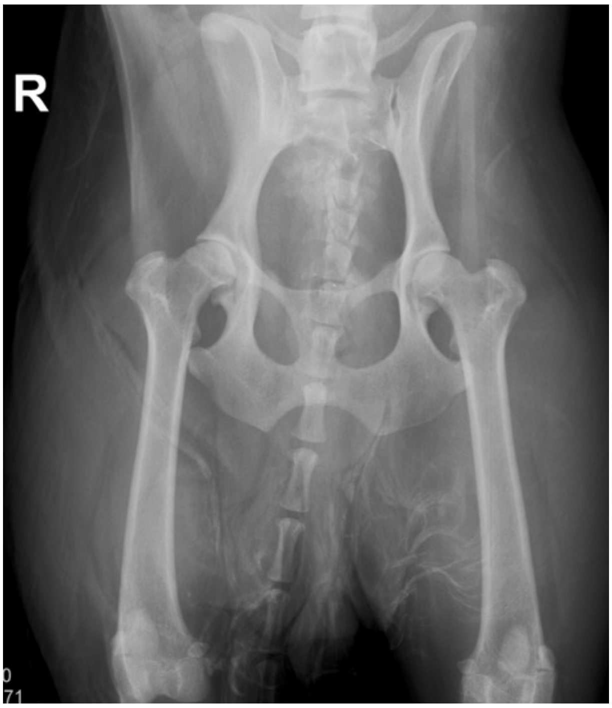

Figure 10.1. *Case 3. Ventrodorsal view radiograph, intact hip*

Figure 10.2. *Case 3. Compression view radiograph, intact hip*

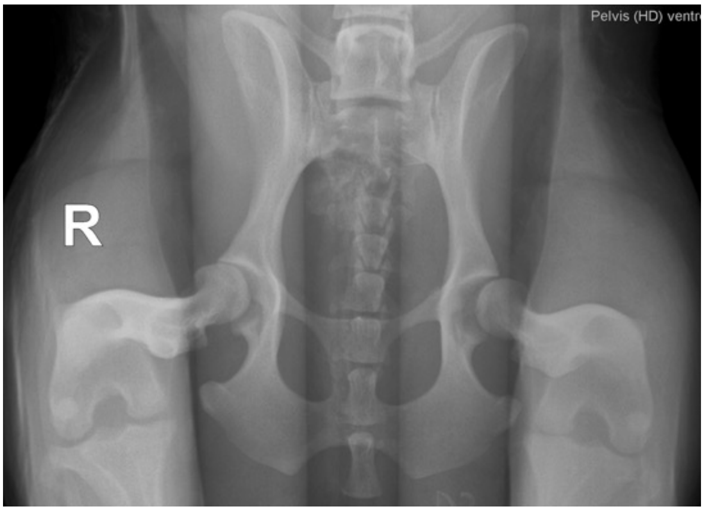

Figure 10.3. *Case 3. Distraction view radiograph, intact hip*

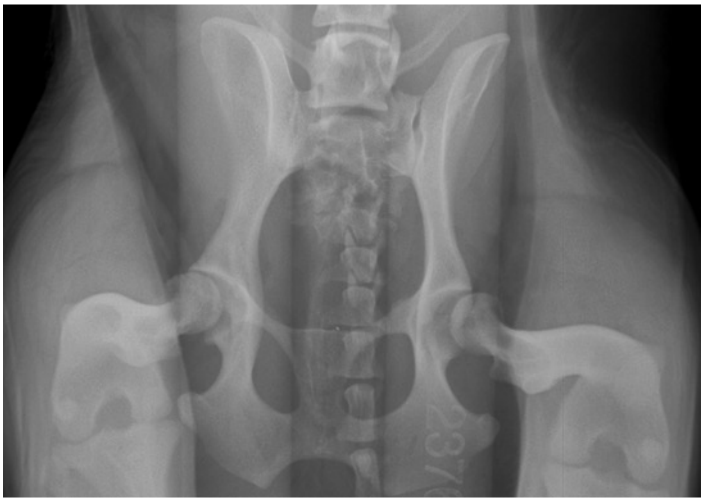

Figure 10.4. *Case. 3. Distraction view radiograph, induced laxity*

Figure 10.5. *Case 3. Distraction view radiograph, Trochanter major transposition*

Results and Discussion

Case 1

Distraction view radiographs	***DI, dexter***	***DI, sinister***
Intact hip	0.28	0.30
Laxity induced hip	0.41	0.41
Trochanter major transposition	0.11	0.34

Case 2

Distraction view radiographs	***DI, dexter***	***DI, sinister***
Intact hip	0.37	0.34
Laxity induced hip	0.58	0.44
Trochanter major transposition	0.14	0.26

Case 3

Distraction view radiographs	***DI, dexter***	***DI, sinister***
Intact hip	0.34	0.51
Laxity induced hip	0.44	0.67
Trochanter major transposition	0.36	0.40

**DI values rounded up to 2 decimal points*

As previously stated, the DIs were derived using vPOP Pro software. Each of the three distraction view radiographs was imported and calibrated to approximately the physical width of the foramen obturatum. Calibration is not a requirement with the DI being a unitless quantity; nevertheless, it was done for ease of calculation. Circle gauges incorporated in the program as measurement tools were used to encircle each femoral head and acetabulum based on the visible cortical margins. Simultaneously radius measurements were given, indicating their respective geometric centres for the subsequent measurement of the distance between them. Figure 11 is a screenshot of the vPOP Pro software during the measurements taken on the trochanter major transposition radiograph in Case 1, arriving at the DI; $\frac{2.4}{22.3} = 0.11$.

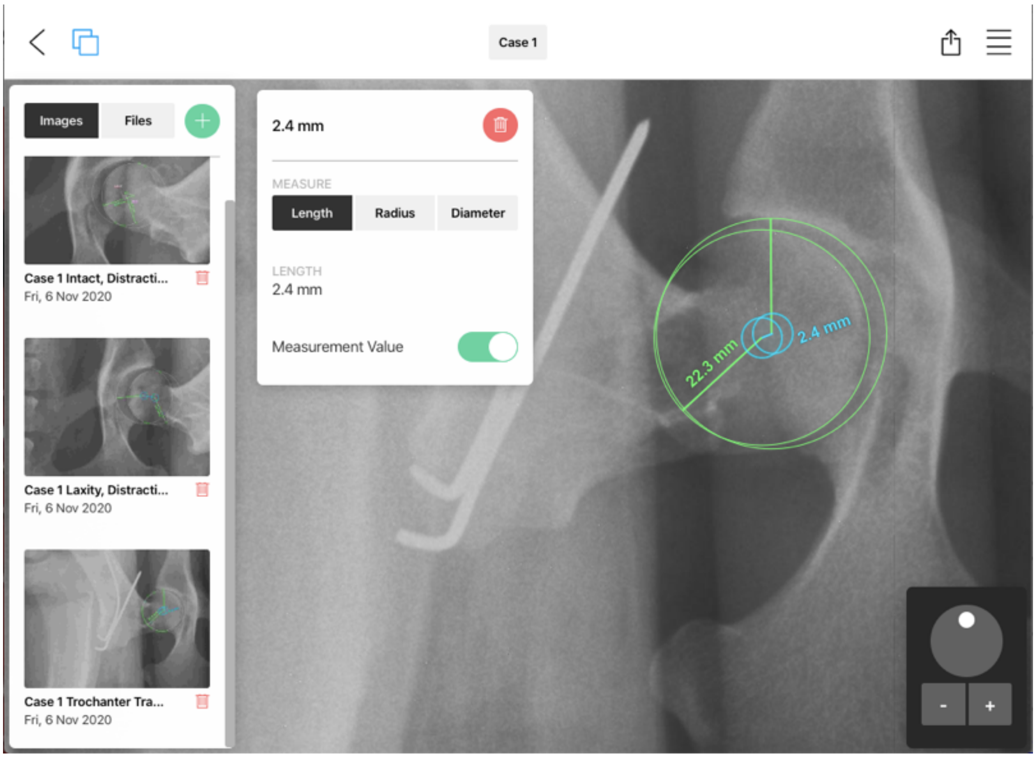

Figure 11. *DI measurement using vPOP Pro software*

It can be established that m. pectineus and lig. capitis ossis femoris are indeed important joint restraints acting against hip laxity, as without their transection, adequate laxity was not achieved in the cadavers. This was demonstrated quantitively by the increased DI value seen in all cases between the intact hip and laxity-induced hip radiographs. Furthermore, stabilization of the hip joint was achieved by the use of a trochanter major transposition, indicated by the decreased DI. The degree of reduction varied between the right and left hip joint, which may be explained by detected looseness of the applied Kirscher wire or spongiosa screw. The commonly anticipated pulling effect on the trochanter major is typically counteracted by the use of tension band wire in live patients. In Case 2 and 3, the Kirscher wire was replaced with spongiosa screws as a rigid fixation method for ease of application and convenience. It is important to note that spongiosa screws are inapplicable in live patients of young age, as they bridge the growing plate of the trochanter major.

Limitations of Study

It is acknowledged that this cadaver study included limited candidates, and conclusions may only vaguely be drawn by the given results. Further cadaver studies are required to broaden the statistical data.

Conclusion

Without a doubt, the field of canine hip joint laxity is open for further studies, as numerous controversies remain unsolved. Radiographic diagnostics and interpretation of joint laxity require a more fine-tuned golden standard aimed at creating a universal and routine application in veterinary clinics. The practice and technique of joint palpation, particularly the Ortolani sign, despite not confirmative, acts as a strong primary indicator for radiology candidates and should not be undervalued as a diagnostic tool, nor as an emphasis in the training of the student clinician. Additionally, raising clinical awareness amongst large breed dog owners is vital to achieving early age screening as standard practice—for instance, an informative discussion with the owner during the puppy's first veterinary visit. With joint laxity being feasibly detectable before the appearance of degenerative structural changes, owner compliance is an essential key for intervention to occur at this stage.

With no indication of a decline in prevalence, coupled with a known genetic predisposition, canine hip laxity research should proceed with more studies in the direction of heritability and genetic screening, especially as identification of phenotypes at earlier stages advances. Nevertheless, until the full application of genotyping is in place, physical efforts to reduce hip joint laxity at an early age to lessen or avoid clinical signs of sequential canine hip dysplasia are of priority. Results obtained through the surgical approach using a trochanter major transposition in this cadaver study provides a promising start. Strengthened results attesting DI reduction may provide a foundation for the application of trochanter major transpositions in clinical trials and information about long-term outcomes.

Desiderius Erasmus stated 500 years ago, "*prevention is better than cure*," a phrase holding unlimited validity to the present day in modern health care and all aspects of veterinary medicine alike. Trochanter major transposition as preventative management to increased hip joint laxity is one such effort, with the potential to outweigh symptom-relief approaches.

Disclosure

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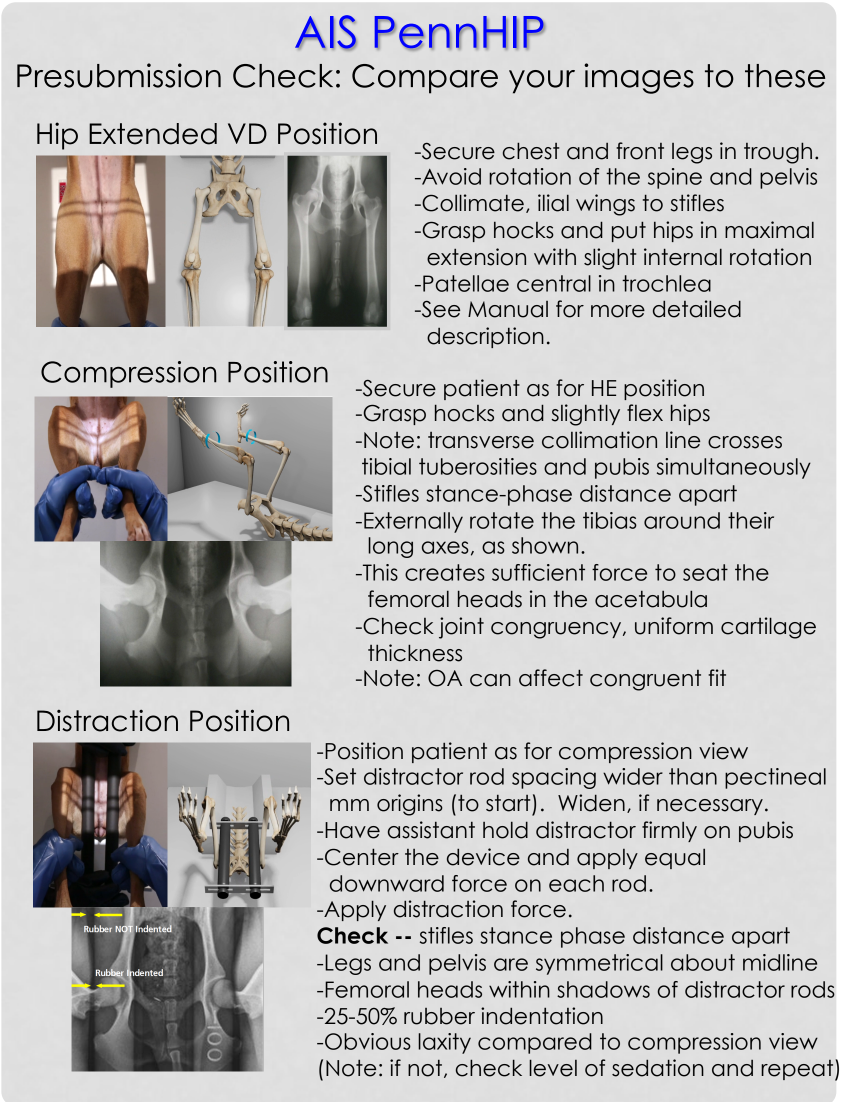
List of Figures

Appendices

Appendix 1. Checklist for performing the PennHIP procedure, as presented in the PennHIP Training Manual, Chapter 5. Recommended as a reference poster for radiology rooms in veterinary clinics.



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