Universidade de Évora - Escola de Ciências e Tecnologia

Mestrado Integrado em Medicina Veterinária

Dissertação

Canine Hip Dysplasia: Radiographic Evaluation of German Shepherds

Raquel Lopes da Costa Ferreira de Almeida

Orientador(es) | Sandra Maria Branco

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A dissertação foi objeto de apreciação e discussão pública pelo seguinte júri nomeado pelo Diretor da Escola de Ciências e Tecnologia:

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Évora 2021

ACKNOWLEDGMENTS

Firstly, I want to thank the University of Evora, especially to my supervisor Professora Sandra for all the patience and availability.

To all the staff of Centro Veterinário Conimbricense who helped me evolve and improve. Professor Nuno, you were the best mentor I could have asked for. Sofia, Raquel, Maria, Mariana, Nicole, and Fred, it would not have been the same without you. Thank you for welcoming me and making me feel like part of the family. I will always be grateful for your support. Thank you, Evelyn, for the opportunity.

A journey as impactful as this had to be lived in the company of exceptional people.

I would like to address a special thank you to the people who started this journey alongside me but unfortunately can no longer witness its progress. To my grandfather. Thank you for always believing in me and spoiling me. I hope you are still betting on me. To my uncle Nuno. I sincerely appreciate how you taught me how easy it could be to make other people feel loved because you did it naturally. I miss you. To my grandmother Vó Lica. I cannot begin to describe your importance in my life. I especially miss the way you laughed at all my jokes, funny or not. Also, the way you were always proud of me, and how you could find the time to show me how much you loved me even on your worst days.

To my father, who has been as good as a parent as anyone can ever aspire to be. Thank you for supporting all my decisions and for being proud of me even when you tried to conceal that fact. I am proudly a daddy’s girl.

To my mother, who always believed in my capabilities and deeply understood the dream of becoming a veterinarian. Thank you for all the reassuring hugs and for your never-ending love.

To my brother, who has the ability to be my best friend and at the same time the most annoying person in the world. I wouldn’t have it any other way. You make me a better human being, and I am immensely proud of you, my big brother.

To my grandmother Vó Béu, for supporting my studies and my dreams for acknowledging that I am on my path, not because it is hard or easy but because it is what I consider to be correct.

A special acknowledgment to my family who lives across the globe. To my uncle João for always being available to discuss veterinarian subjects or to be an emotional support, I love you for both. To my aunt Rita for the endless conversations about everything and for all the love. To my aunt Simone for the laughs, the dialogues, and the support. To my cousin, Ana, for being a "Jumenta" who loves and feels deeply and always has time for her younger cousins who are invariably going through something. And to my cousin Laura who is such a wonderful human being who is constantly encouraging others to pursue their dreams. I am the luckiest person to have such amazing people in my life.

To my best friend Maria for all the understanding and love throughout these 14 years of friendship. I would be a worse person had I not known you and your family. And of course, thank you to your dogs who let me practice on them and are so dear to me.

To all my university friends. For making this journey a lot more fun. Especially to my academic family, from my godmother to my godchild and, of course, my university sister Mafalda. I gained a sister and a best friend for life. Thank you to my classmates from "Turma D," who are also beautiful people I had the pleasure to have by my side during these years, Bruna, Maria, Tita, Pacheco, Dentinho, Gui, Miguel, "Tio" Luís e Niche I'm grateful for your friendship. To the friends who integrated this group later, Pipa, Nassar, and Miguel Lopes, I adore you, "Ramiros".

Thank you to all my friends from my hometown who are always down for a good time and help me unwind when it is needed, Madalena, Andreia, Catarina, Mochila, Mendonça, Grenha, Arromba, Piteira, Laura, and many more names that have a permanent space in my heart.

Thank you all, I am sincerely grateful for your presence in my life, always.

ABSTRACT

Canine hip dysplasia is a common orthopedic disorder that affects dogs of all ages and breeds. The exact cause and hereditability of this condition remain unclear. However, good progress has been made in recent years. It is described as a polygenic multifactorial condition. Different treatments are available, whether a surgical or conservative approach is pursued.

This dissertation includes a literature review considering the topic of canine hip dysplasia and a preliminary, exploratory study that has the objective of evaluating different radiographic measurements and investigating their correlations and their possible value to help diagnose and differentiate German Shepherds with or without hip dysplasia. For this purpose, acetabular measurements were made in radiographs obtained in the standard hip-extended ventrodorsal view.

The results suggest statistically relevant differences between dysplastic and non-dysplastic and also between male and female dogs. However, further investigation on these measurements and their utility is warranted.

Keywords: Canine Hip Dysplasia, Diagnostic, Treatment, Radiographic Evaluation, Norberg Angle.

RESUMO

DISPLASIA DE ANCA EM CÃES: AVALIAÇÃO RADIOGRÁFICA DE PASTORES ALEMÃES EM PORTUGAL

Displasia de anca em cães é um problema ortopédico comum que afeta cães de todas as idades e raças. As causas e heritabilidade exata desta condição continuam obscura. Apesar de se ter registado um bom progresso ultimamente. É descrita como uma doença poligénica e multifatorial. Diferentes tratamentos médicos e cirúrgicos estão disponíveis.

Esta dissertação inclui uma revisão bibliográfica sobre displasia de anca em cães e um estudo preliminar e exploratório que tem como objetivo avaliar diferentes medidas radiográficas e investigar as suas correlações e o seu potencial valor para ajudar no diagnóstico e diferenciação de Pastores Alemães com ou sem displasia. Assim, foram realizadas diferentes medidas acetabulares foram realizadas em radiografias obtidas na vista ventrodorsal com os membros em extensão máxima.

Os resultados sugerem diferenças estatisticamente relevantes entre cães com e sem displasia e entre machos e fêmeas. Contudo, mais estudos sobre estas medidas e a sua utilidade são necessários.

Palavras-chave: Displasia de Anca em Cães, Diagnóstico, Tratamento, Avaliação Radiográfica, Ângulo de Norberg.

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LIST OF SYMBOLS AND ABBREVIATIONS

ADc – Acetabular Depth Measured using the Acetabular Circle

ADk – Acetabular Depth Measured as when obtained by Computed Tomography

AFRc – Ratio between Acetabular Depth And Femoral Head Portion Measured Using the Acetabular Circle

AFRk - Ratio between Acetabular Depth And Femoral Head Portion Measured as when obtained by Computed Tomography

AIc – Acetabular Index Using the Acetabular Depth Measured Using the Acetabular Circle

AIk – Acetabular Index using the Acetabular Depth Measured as when obtained by Computed Tomography

ADSCs – Adipose-Derived Stem Cells

AW – Acetabular Width

BFX – Biological Fixation

BVA/KC – British Veterinary Association and the Kennel Club

CHD – Canine Hip Dysplasia

COX - Cyclooxygenase

CT – Computed Tomography

DI – Distraction Index

DJD – Degenerative Joint Disease

DLS – Dorsolateral Subluxation

DPO – Double Pelvic Osteotomy

FCI – Fédération Cynologique Internacionale

FHNE – Femoral Head and Neck Excision

FHPc – Femoral Head Portion of Acetabular Depth Measured Using Acetabular the Circle

FHPk – Femoral Head Portion of Acetabular Depth Measured as in Computed Tomography

GABA - Gama-Aminobutyric Acid

GS – German Shepherd Dog

HA – Hyaluronic Acid

JPS – Juvenile Pubic Symphysiodesis

LOX – Lipoxygenases

MSCs - Mesenchymal Stem Cells

NA – Norberg Angle

NSAIDs – Non-Steroidal Anti-Inflammatory Drugs

OA – Osteoarthritis

OFA – Orthopedic Foundation for Animals

PennHip – Pennsylvania Hip Improvement Program

THR – Total Hip Replacement

TPO – Triple Pelvic Osteotomy

SD – Standard Deviation

SEM – Standard Error of the Mean

I. Canine Hip Dysplasia: Literature Review

1. Introduction

Canine hip dysplasia (CHD) represents a challenge for owners and veterinarians, being the most common non-traumatic orthopedic pathology found in growing dogs [1]. Although the inheritance and development of this disease are not yet fully understood, it is considered a polygenetic and multifactorial disease [2].

It is thought that the pathogenesis of this disease is related to the joint laxity that allows for joint subluxation, followed by catastrophic reduction of the femoral head into the acetabulum [3]. It is known that the dogs are born with normal hips, but by two weeks of age, conformational changes have already occurred [4]. However, joint laxity alone does not seem to be sufficient for the development of CHD [5]. In cats, a shallow acetabulum has been associated with hip dysplasia, and as it happens in dogs, excessive body weight seems to contribute to the onset of the disease [6]. The most critical issue with CHD is the development of osteoarthritis because it is the cause of the high morbidity associated with this disease [5]. The progressive loss of cartilage results in pain and loss of quality of life due to functional limitation [7–10].

The diagnosis of this disease is made by a thorough physical examination followed by radiographic imaging [11]. The physical examination is of utter importance because radiographic severity of osteoarthritis (OA) does not correlate well with its clinical effects, and it is possible that a dog with radiographic signs of canine hip dysplasia might exhibit discomfort due to other problems [12]. Still, radiographic imaging has a crucial role in diagnosing the disease and the follow-up and measurement of the rate of evolution [13]. Newer methods of diagnosis are being investigated or are already in use [14]. However, the four most important grading systems, The Fédération Cynologique Internacionale, The Orthopedic Foundation for Animals, The British Veterinary Association/Kennel Club, and The Pennsylvania Hip Improvement Program, still rely on radiographs [15–18]. An earlier diagnosis is important because more treatment options are available and, also, because recent studies suggest that OA progression is faster and more significant in young dogs [19].

Each individual patient has their specific needs. Therefore the management of CHD should be based on those needs, this means that it is not the same for every patient [20]. When pursuing the conservative management of the disease, a multimodal approach is recommended [21]. This approach needs to be supervised and adjusted constantly. A wide variety of treatments is available, from non-steroidal anti-inflammatory drugs to opioids, passing through chondroprotectors, supplementation, weight loss, exercise restriction, physical therapies, and others [22].

Different surgery options are also available. Two different types of surgeries can be performed in a dog suffering from hip dysplasia, preventive surgeries that aim to limit the onset of osteoarthritis and palliative or salvage procedures that seek to reduce the pain after osteoarthritis has developed [12]. In the preventive surgeries group, juvenile pubic symphysiodesis and triple and double pelvic osteotomy are the most relevant [12]. In the palliative group, femoral head and neck excision and total hip replacement are the ones with higher preponderance [12].

A study conducted in humans concluded that pharmacological treatment, rehabilitation, physical therapy, and other methods appeared to be inefficient in patients with hip osteoarthritis awaiting a total hip replacement, moreover the cost of conservative management could be almost twice than that of the surgical management [23]. However, humans have a much longer lifespan than dogs and present less tolerance to pain. Therefore, no linear conclusion can be drawn solely relying on the conclusions of this study.

2. Anatomy of the Hip Joint

The pelvic girdle is composed of two symmetrical hip bones meeting ventrally at the pubic symphysis [24]. On each side of the body, the head of the femur articulates with the acetabulum, which is a deep socket cotyloid cavity, forming the hip joint [24]. Anatomically the canine hip is very similar to the human hip, apart from the obvious difference that the dog is quadrupedal [25].

Three bones fuse in order to form the hip bone, these are the ilium (*os ilium*), the ischium (*os ischi*), and the pubis (*os pubis*) [24,26]. In carnivores the acetabular bone (*os acetabult*) can also be found [24,26]. Figure 1 displays the anatomy of the ventral and caudodorsal aspects of the pelvis.

The dorsocranial part of the pelvic is formed by the ilium, which can be divided into the cranial portion composed by the wing and the caudal portion composed by the columnar body [24]. The ileal wings in the dog are orientated in an almost sagittal position [24]. Composed by tuber sacrale and tuber coxae, the iliac crest (*crista iliaca*) forms the cranial border of the ilium between these two tubers [26]. The lateral surface (*facies glutea*) is excavated, and it is where the origin of the muscle gluteus medius is located [24,27].

The medial iliac surface (*facies iliaca*) has several pelvic muscles insertions [24]. Its mediodorsal part is composed of the roughened auricular portion (*fascies auricularis*) and the iliac tuberosity (*tuberositas iliaca*), which forms the sacroiliac joint by articulating with the sacrum [24].

The great ischiatic notch (*incisura ischiadica major*), over which the sciatic nerve runs, is formed at the junction of the iliac body and the dorsomedial border of the iliac wing, where it is deeply concave [24,26].

Divided into the body (*corpus ossis pubis*), the transverse acetabular branch (*ramus cranialis ossis pubis*), and the sagittal symphysial branch (*ramus caudalis ossis pubis*), the pubis extends from the ilium and ischium laterally to the symphysis pubis medially where the pubis from each side fuse [24,26]. The two branches account for about 50% of the obturator foramen through which the obturator nerve passes [27]. Where the cranial edge of the acetabular branch joins the ilium is located the iliopubic eminence (*eminentia iliopubica*) [24,26].

The ischium is composed of the body (*corpus ossis ischii),* the caudal plate (t*abula ossis ischii*), and the medial branch (*ramus ossis ischii*) [24]. The caudal circumference of the obturator foramen is formed by a symphysial branch and an acetabular branch of the cranial portion of the caudal plate [24]. The caudal portion of the pelvic symphysis is composed of the medial branch of the ischium [24]. The dorsal border of the body of the ischium continues with the dorsal border of the ilium to form the ischiatic spine (*spina ischiadica*), while another portion of it forms part of the acetabulum [24]. The caudomedial border of the body of the ischium forms the deep ischial arch (*arcus ischiadicus*) with the contralateral body of the ischium [24,26]. The caudolateral part of the caudal ischiatic plate thickens to constitute the ischial tuber (*tuber ischiadicum*), ending in the lateral side in a pronounced rough hemispherical eminence [24,26].

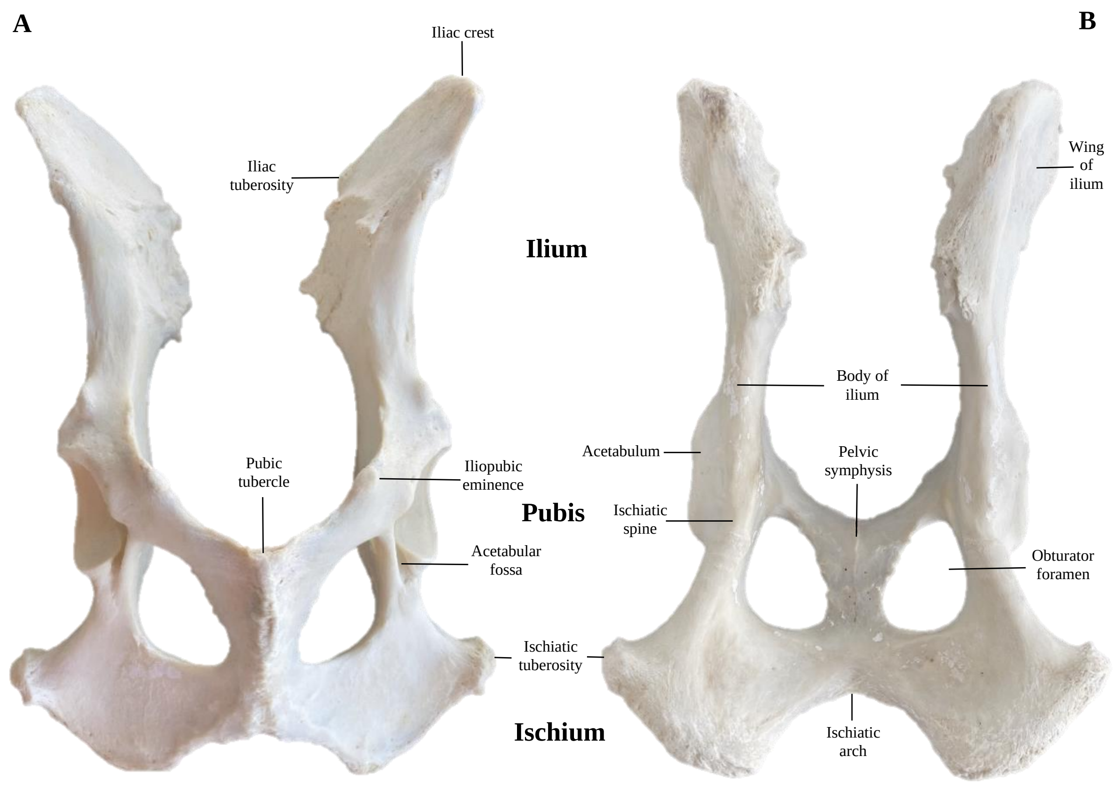

Figure 1 - A Ventral aspect of the pelvis. B Caudodorsal aspect of the pelvis. (Author)

The acetabulum is composed of parts of the body of ilium, the body of ischium, and the body of the pubis, and there is also the contribution of the small acetabular bone [24,26]. It is a deep cotyloid cavity that is reciprocal to the head of the femur, in medium-sized dogs, it is approximately 1 centimeter deep and 2 centimeters of diameter [24,26]. It is divided into a peripheral lunate surface (*facies lunata*) and the acetabular fossa (*fossa acetabuli*) [24,26]. The widest part of the lunate surface is cranial, and the narrowest is midlateral. The lunate surface is indented medially by a notch, the deep acetabular notch (*incisura acetabuli*) [24,26]. The acetabular fossa is the thin, non-articular, depressed area that extends from the acetabular notch.[24,26] A lateral aspect view of the acetabulum is represented in figure 2.

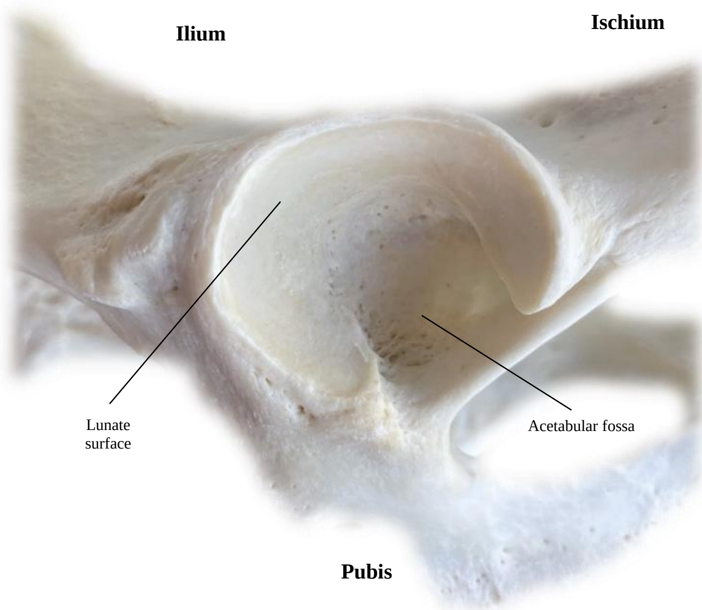

Figure 2 - Lateral aspect of the left acetabulum. (Author)

The proximal end of the femur that consists of the head, neck, and two trochanters, articulates with the acetabulum forming the coxofemoral joint or hip joint [24,26]. The head is smooth and nearly hemispherical and has a circular pit in the middle named the fovea (*fovea capitis*) that serves as the attachment of the ligament of the femoral head (*Ligamentum capitis ossis femoris*), previously known as the round ligament [24,26]. Figure 3 displays the caudal and cranial aspects of the proximal epiphysis of the femoral bone.

The ligament of the femoral head is a complex structure that is cylindrical at its origin in the fovea of the femoral head and fans out to form multiple fascicules [28]. Studies have established that elongation of this ligament co-exists with hip dysplasia [28]. However, it is still not known whether it is a primary cause or a secondary effect of the pathology [28].

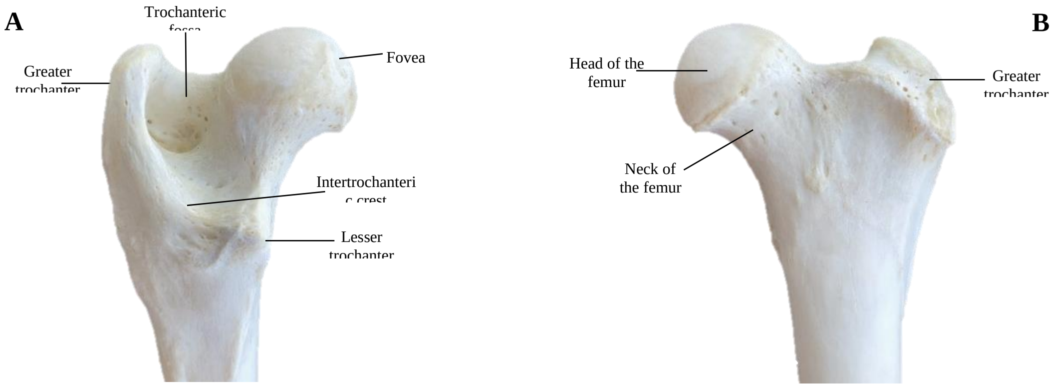

Figure 3- **A** Left femur caudal aspect. **B** Left femur cranial aspect. (Author)

The pelvic muscles can be divided into three groups: the lumbar hypaxial, the lateral pelvic, and the medial pelvic [26].

The lumbar hypaxial group is composed of the muscle small psoas (*psoas minor*), the iliopsoas that can be divided into the psoas major and the iliacus muscle, and the quadrate lumbar muscle (*quatratus lumborum*) [24,26].

The lateral pelvic group includes the superficial gluteal muscle (*gluteus superficialis*), gluteofemoral muscle (*gluteofemoralis*), middle gluteal muscle (*gluteus medius*), piriform muscle (*piriformis*), deep gluteal muscle (*gluteus profundus*), and tensor muscle of the fascia lata (*tensor fasciae latae*)[24,26].

The medial pelvic muscles group is composed of internal obturator muscle (*obturatorius internus*), external obturator muscle (*obturatorius externus*), gemellus muscles (*gemelli*), quadrate muscle of the thigh (*quadratus femoris*), and articular muscle of the hip joint (*articularis coxae*) [24,26]. Table 1 explains the different muscles and their function.

Table 1- Name and function of the pelvic muscles (adapted from König HE, Liebich H-G, 2020)

Name	Function
Small psoas	Steepens the pelvis when the vertebral column is fixed and flexes the vertebral column in the stance.
Iliopsoas	Flexes the hip joint and rotates outward the stifle joint, thus advancing the pelvic limb
Quadrate lumbar	Stabilizes the lumbar vertebral column and, in dogs, also causes ventroflexion of the sacroiliac joint.
Superficial Gluteal	Extends the hip joint
Middle Gluteal	Extends the hip, causes medial rotation of the hip, and prevents lateral rotation during weight-bearing
Deep Gluteal	Extends the hip joint, with some abduction of limb and causes medial rotation of the hip and prevention of lateral rotation on weight-bearing
Piriform	Extends the hip joint
Tensor Muscle of The Fascia Lata	Flexes the hip, abducts the limb, and extends the stifle joint
Internal Obturator Muscle	Rotates the femur Laterally and assists in extending the hip
External Obturator Muscle	Acts as a supinator of the femur and adductor of the limb
Gemellus Muscles	Assists in rotating the limb laterally
Quadrate Muscle of The Thigh	Assists in extending the hip and retracting the limb
Articular Muscle of The Hip Joint	Tenses the joint capsule, thus preventing damage to the peri-articular structures

The thigh muscles are divided into groups according to their position in caudal, cranial, and medial [26]. The caudal group is comprised of biceps muscle of the thigh (*biceps femoris*), abductor muscle of the thigh (*abductor cruris caudalis*), semitendinous muscle (*semitendinosus*), and semimembranous muscle (*semimembranosus*) [24,26].

The medial muscles of the thigh are the sartorius muscle (*sartorius*), gracilis muscle (*gracilis*), pectineal muscle (*pectineus*), and adductor muscles (*adductores*) [24,26]. In dogs, the adductor muscle is divided into greater adductor muscle(*adductor magnus*) short adductor muscle (*adductor brevis*) [24,26].

The group of the cranial muscles of the thigh is comprised of the quadriceps muscle of the thigh (*quadriceps femoris*) and the popliteal muscle (*popliteus*) [24,26]. The quadriceps muscle of the thigh can be divided into lateral vastus muscle (*vastus lateralis*), medial vastus muscle (*vastus medialis*), intermediate vastus muscle (*vastus intermedius*), and straight muscle of thigh (*rectus femoris*) [24,26]. Table 2 summarizes the high muscles and their functions.

Table 2 - Thigh muscles and their functions (adapted from König HE, Liebich H-G, 2020)

Name	Function
Biceps Muscle of The Thigh	Extends the hip and the stifle, and the caudal pelvic head also extends the hip but flexes the stifle.
Abductor Muscle of The Thigh	Assists the biceps muscle of the thigh in the abduction of the limb.
Semitendinous	Extends the hip, stifle, and tarsal joints when in a weight-bearing position. Flexes the stifle and rotates the leg outward and moves it backward in the free limb.
Semimembranous	Extends the hip and stifle joints in the weight-bearing position, supporting propulsion of the trunk. However, it adducts and retracts the limb in the opposite situation.
Sartorius	Flexes the hip and advances and adducts the limb. It also extends the stifle.
Gracilis	Adducts the limb. It can also move the whole rump sideways when the foot is placed firmly on the ground. It assists the extension of the stifle.
Pectineal	Flexes the hip and adducts and supinates the limb.
Adductor	Adducts the limb but also retracts it and moves the rump forward and sideways.
Lateral Vastus	Extends the stifle joint
Medial Vastus	Extends the stifle joint
Intermediate Vastus	Extends the stifle joint
Straight Muscle of Thigh	Extends and flexes the stifle joint
Popliteal	Flexes the stifle and pronates the leg

According to Huang C. *et al.* (2012), the hip joint capsule is enervated by branches of the cranial gluteal nerve, muscular branches of the sciatic nerve, femoral nerve, obturator nerve, although some individual differences might be present [29].

3. Pathogenesis

Canine hip dysplasia (CHD) exact cause remains unknown, yet joint laxity appears to play an important role because animals with a bigger degree of joint laxity have a higher risk of developing osteoarthritis [5].

It has a polygenic and multifactorial origin, amongst the environmental factors, there is nutrition, body score, and exercise [18]. A polygenic disease involves the impact of at least two genes working together in order to create clinical presentation [2]. CHD is most often bilateral [2]. It is known that puppies are born with normal hips, but by two weeks of age, conformational alterations have occurred, predisposing the joint to excessive laxity and to changes of shape of the articular components [4].

Many theories exist to explain the development of canine hip dysplasia, with joint laxity and irregular or delayed ossification being among the most popular [18]. Uneven load-bearing, incongruity, and instability predispose to osteoarthritis because it leads to inflammation in the joint that results in the attempt of stabilization by the organism with bony proliferation [30]. Although it is observed in cats and toy breeds, their unstable hips usually do not produce the same changes in the joints as in heavier dogs [31]. Also, larger active pelvic muscle mass has been associated with a lower incidence of hip dysplasia, maybe because it inhibits the transformation of passive laxity into functional laxity, decreasing the level of stress on articular cartilage [32].

When laxity of the femoral head exists, the femoral head shifts laterally during weight-bearing, causing the force to be concentrated on the dorsal acetabular rim [33]. Until the dogs are 6-month-old, the dorsal acetabular rim is cartilaginous and very plastic [33]. Hence the result of the concentration of weight-bearing forces is microfractures and remodeling of the acetabulum [33]. When the dogs become older than six months, changes in the joint are only possible through the production and absorption of bone [33]. The period of maximum growth and development of the hip occurs between the third and eight months of age [5]. When there is hip subluxation due to excessive laxity, a concentration of mechanical load on the dorsal acetabular might cause variations in the cartilage development [5]. These variations are most critical in the period of maximum growth and development [5].

Abnormal joint loading is a result of laxity, plus it causes osteochondral damage and initiation of degenerative and inflammatory processes [21]. Inflammatory mediators such as tumor necrosis factor α, interleukin-1, and free radicals are released into the joint [21]. The release of matrix metalloproteinases from chondrocytes is caused by inflammatory cytokines that result in loss of proteoglycan and break-down of the cartilage matrix [21]. This leads to distorted cartilage mechanics and additional joint injury [21]. These degenerative processes become a vicious cycle with subsequent cartilage erosion, subchondral bone sclerosis, joint capsule thickening, periarticular new bone formation, and associated pain and loss of function [21].

Even though there are dogs that are affected by hip laxity itself and show clinical signs at an early age, that usually resolves until later in life [5]. The main cause of morbidity of CHD is the presence of osteoarthritis that occurs with the progression of the disease [5]. The leading cause of osteoarthritis in dogs is canine hip dysplasia [34]. Additionally, canine hip dysplasia is one of the most common orthopedic diseases in dogs [34].

Synovial joints allow for movement and are the most commonly affected by osteoarthritis [35]. The deterioration of the joint cartilage causes osteoarthritis that is a form of chronic joint inflammation [36]. The degradation of the articular cartilage results in a loss of proteoglycans from the extracellular matrix and the subsequent release of inflammatory mediators and degradative enzymes [22]. Cells residing in the damaged joints release pro-inflammatory cytokines, worsening the inflammatory process [35]. This leads to more breakdown of the cartilage collagen type II and proteoglycans, which perpetuates the destructive cycle [35]. Like humans, dogs with OA or pre-osteoarthritis reveal significantly elevated values in cartilage oligomeric matrix protein in the synovial fluid [25].

Recently, Kiefel and Kutzler (2020) [37] suggested that the increase in luteinizing hormone receptors might play a role as a contributory factor to the increased incidence of hip dysplasia in gonadectomized dogs.

Obesity also plays an important role in the development of osteoarthritis [38]. It is a problem that has been growing amongst domestic dogs [39]. There is evidence to support that diet restriction can impact the frequency and severity of canine hip dysplasia [40]. Theories to explain this obesity-induced OA exist. One hypothesis is that the overloading of weight-bearing joints results in biochemical effects that lead to OA [38]. Hip joints form obese dogs that suffer from CHD have already altered biomechanics and have to support the excess weight from obesity, dealing with a greater amount of stress due to that reality. Obesity might lead to altered joint kinematics, combined with the increase of the ambulatory load, can play an important role in the initiation and progression of osteoarthritis [39]. Both CHD and OA seem to be multifactorial [41,42].

However, in humans, obesity has been correlated as a risk factor for hand joint osteoarthritis [39]. These joints are non-weight-bearing, which might suggest a metabolic influence [39]. Adipocytes are not just energy reserve cells [39]. They are capable of synthetizing and releasing a panoply of molecules [39]. Specifically, adipokines that are released by adipocytes are thought to have a role in the OA progression by causing low-grade inflammation when in high concentrations [38]. A peptide hormone produced by adipocytes, leptin, also is thought to play an important role by having a detrimental effect on articular cartilage [39].

The progression of CHD and of OA leads to chronic pain, lameness, stiffness, loss of joint functions, and mobility, thus decreasing quality of life [36]. However, genetically predisposed dogs may not express osteoarthritic changes related to CHD until later in life or may not show any signs at all, it depends on the cumulative effects of environmental factors [40].

4. Diagnostic

Presentation differs from patient to patient. Some patients will show signs of hip dysplasia earlier in life, others will present them later in life, and some never do at all, or at least they are not perceived by the owner [18]. There are different severities of the disease. This might also explain the different presentations [18]. Natural variability, such as individual response to environmental influences, likely results in the lack of a single predictable pattern for joint degeneration [18].

Canine hip dysplasia can affect dogs of any size or breed, although it is more commonly diagnosed in large and giant breed dogs [43]. Prevalence of CHD has been reported to vary significantly between breeds and even within breeds in different countries [44]. There has also been reported an increased incidence in gonadectomized dogs when compared to intact dogs [37].

According to the Orthopedic Foundation for Animals (OFA), which was founded in 1966 with the goal of lowering the incidence of CHD, the most affected breed is the Pug with a prevalence of 71,8%, followed by the English Bulldog with a prevalence of 70,6% [45]. On the other end of the spectrum, the breeds with the least prevalence, are the Chinese Crested and the Italian Greyhound [46]. Although dogs that weigh less than 12 kilograms might have incongruity, it does not progress to osteoarthritis [31].

Age at presentation varies. Consequently, a bimodal presentation is suggested, dogs presenting as juveniles (juvenile form) and dogs presenting as middle-aged dogs (chronic form) [47]. Moreover, there are the dogs that are submitted to evaluation for breeding purposes presenting no clinical signs, with approximately one year of age (in Europe) often leading to an accidental discovery of hip dysplasia.

The juvenile form presents in young dogs between four and twelve months of age, frequently showing sudden signs of unilateral disease (occasionally bilateral) [31]. Sometimes the only sign that the owners notice is a “click” or a “clunk” when the dog walks or runs. Acute onsets often mean more severely affected hips [43]. The differential diagnosis that should be considered in the juvenile patient includes panosteitis, osteochondrosis, physeal separation, hypertrophic osteodystrophy, and partial or complete cranial cruciate ligament injury [48].

Adult patients with age over fifteen months present with signs associated with chronic disease [31]. Presentation is often associated with osteoarthritis of the hip joint and degenerative joint disease (DJD), whereas young patients show signs associated with laxity and subluxation of the joint [43]. Older patients who suffer from CHD often present signs of osteoarthritis, which is a degenerative joint disease [7]. Dogs will present with decreased activity, stiffness when rising, difficulty lying down, reluctance to jump, worsening lameness with intense physical activity, gait abnormalities (bunny hoping and others), and muscle atrophy of the pelvic region [43,47]. The differential diagnosis for adult dogs includes neurological conditions, such as cauda equina, it also includes polyarthritis, bone neoplasia, and cranial cruciate ligament injury [48].

For a long time, efforts have been made in trying to find the perfect diagnostic test to detect hip dysplasia in dogs and in humans [49]. In 1937, Dr. Ortolani discovered that a "click" occurred with the abduction-adduction motion of the thigh of human babies, thus introducing the now-famous "Ortolani sign" [49].

For now, there is no perfect test. The recommendation is to perform a thorough orthopedic examination, combined with radiographic imaging of the pelvis [50]. As the disease progresses, it becomes easier to note radiographic changes because they become more apparent [50]. Computed tomography (CT) is becoming increasingly popular, although radiographs remain the most widespread diagnostic method [18].

4.1. Physical Examination

When performing the orthopedic examination, the observer must start by examining gait abnormalities [43]. However, traditional gait analysis is subjective even with the existence of lameness scoring scales [51]. After, a systematic examination discomfort should be localized in the hip region [43]. Pain on hip extension is a sign of CHD, yet it must be differentiated from other conditions such as iliopsoas strain [43]. Patients with advanced osteoarthritis may reveal crepitus on motion of the hip, decreased coxofemoral range of motion, and muscle atrophy [43].

In the juvenile patient evaluating hip laxity is of utmost importance, hip joint laxity can be accessed with specific tests, like the Ortolani maneuver, the method of Barden's, and the Barlow's maneuver [31,47,52]. The three tests are based on hip joint instability and demonstrate hip joint laxity when a positive sign is present [11]. Ortolani and Barlow's tests were originally developed for the screening of hip dysplasia in infants. Both tests can be performed in lateral or dorsal recumbency [43].

When performing the Ortolani maneuver in lateral recumbency, the limb should be placed perpendicular to the spine [53]. One hand of the clinicians is placed on the dorsal aspect of the pelvis and spine to stabilize them, while the other hand is placed on the stifle [47]. Placing gentle pressure proximally and adducting the stifle allows the femoral head to subluxate or luxate above the dorsal acetabular rim, thus the hip joint becomes subluxated [47]. While firmly holding the stifle, the limb should be slowly abducted [54,55]. In dogs with coxofemoral laxity, a click can be felt or even heard as a result of the sudden reduction of the femoral head back into normal position [54,55]. This is a positive Ortolani sign, suggesting excessive hip laxity [54,55]. It can be used to determine the angle of reduction and the angle of subluxation [31]. When the hip joint becomes subluxated, the angle of the femur from vertical is the angle of subluxation [31]. When the test proceeds and the femur falls back in place, the angle of reduction can be determined [31]. Figure 4 presents a scheme on how to perform the Ortolani maneuver.

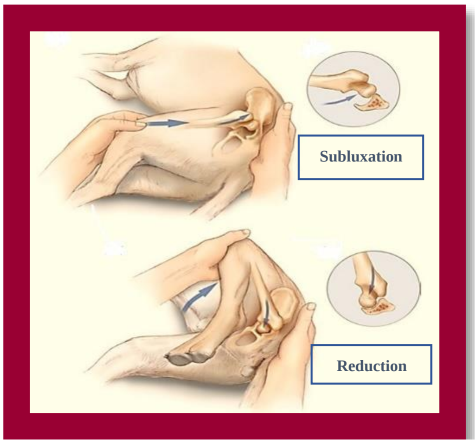

Figure 4 -The Ortolani Maneuver (adapted from Duerr 2016)

Some dogs with CHD do not have a positive Ortolani test [18]. Thickening of the joint capsule and joint tissue that occur during the development of hip dysplasia might interfere with the displacement required for a positive Ortolani sign [18]. The sensitivity of the Ortolani test, can be up to 92%, yet it has a relatively low specificity [56]. Recently a study suggested that it is possible to predict the FCI scores by performing the Ortolani maneuver at approximately 35 weeks of age [11].

The Barlow's sign is detected when performing the first half of the Ortolani maneuver until subluxation of the femoral head is achieved [53]. A careful examiner might detect joint laxity with this examination [53]. However, it is recommended to continue the manipulation and perform the Ortolani maneuver completely [53]. It is considered positive when the head of the femur luxates during abduction of the neck [52]. In sum, Barlow's test dislocates the joint, and the Ortolani reduces it [25].

Barden's technique can be painful in young adult dogs [31]. It is recommended in dogs between 6 and 8 weeks of age [53]. The clinician stands in the rear, and the animal must be heavily sedated or anesthetized and placed in lateral recumbency [53]. One hand palpates the greater trochanter, while the other holds the femoral diaphysis [55]. The femur is adducted, attempting to lift the femoral head out of the acetabulum, the mobility of the great trochanter is accessed [55]. It is a subjective test that depends on the experience of the examiner and that it is done on small puppies, moreover the mobility of the great trochanter is evaluated in millimeters making it less reliable [55].

All the tests described above have value. The Ortolani test has a higher sensitivity, up to 92%-100%, when performed in dogs with ages slightly over 4 months [43]. Nevertheless, it has low specificity in younger dogs (with ages ranging from six-to-ten weeks and sixteen-to-eighteen weeks) [57]. Therefore, it can be useful as a screening method in young dogs, where a positive Ortolani sign is significant, and the dog is at high risk of developing degenerative joint disease, but a negative test should not rule out hip dysplasia [43]. Other diagnostic tests should be used to confirm the diagnosis, such as radiographs [43]. In older dogs, all the tests that access hip laxity become less valuable because the dorsal acetabular rim wear and acetabular infilling increase in severity, making the reduction of the joint less distinct or palpable, although some crepitus might be felt during the manipulation of the hip [43].

The range of motion of the hip joint is another parameter that can be evaluated. Subluxation, fixed luxation, capsular fibrosis, and osteophytes might cause a decrease in the range of motion [55]. Two different steps are required to evaluate the range of motion. Firstly, with the dog in lateral recumbency, flexion and extension of the hip are measured [58]. Afterwards, with the animal in dorsal recumbency, the adduction and abduction of the limb are measured, as are the internal and external rotation [58]. Newton described the normal range of motions of a dog hip: flexion 70º-80º; extension 80º-90º; abduction 70º-80º; adduction 30º-40º; internal rotation 50º-60º; external rotation 80º-90º [58].

The physical examination is of extreme importance because there are dogs with degenerative joint disease due to CHD that have concomitant problems, like cauda equina syndrome, and it is very important to distinguish the origin of the pain. At the same time, radiographs are of extreme importance to confirm the diagnosis and to rule out other causes of hip pain like septic arthritis [47].

4.2. Diagnostic Imaging and Grading

Since 1935 radiographs have been used to diagnose hip dysplasia [50]. A series of different radiographic projections can be used in order to diagnose hip dysplasia [50]. The most commons include hip-extended radiography, distraction-stress radiography, and dorsal acetabular rim view [50]. Computed tomography is becoming more available in veterinary medicine [50]. However, it is not commonly used for the screening of hip dysplasia in dogs [50]. The standard ventrodorsal hip-extended radiographic view is the worldwide recommended technique since 1960 for canine hip dysplasia screening [59]. The positioning is exemplified in figure 5, this image was obtained for exemplification purposes only.

Figure 5 - Positioning for the standard ventrodorsal hip-extended radiographic view. (Author)

The ventrodorsal hip-extended view allows for excellent evaluation of osteoarthritis, although it can underestimate hip laxity [45]. In 1993, the Pennsylvania hip improvement program was created, which introduced compressed and distracted views to the early detection of hip dysplasia, as well as the hip-extended view [45]. Distraction stress estimates better the degree of passive laxity of the coxofemoral articulation [50].

The five most widespread and investigated screening approaches the Fédération Cynologique Internacionale (FCI), the Orthopedic Foundation for Animals (OFA), the British Veterinary Association/Kennel Club (BVA/KC), the Pennsylvania Hip Improvement Program (PennHip), and the Dorsolateral Subluxation Score (DLS) [60].

4.2.1. The Fédération Cynologique Internacionale

On May 22nd, 1911, the Fédération Cynologique Internacionale was created with the purpose of protecting cynology and purebred dogs [61]. The FCI hip grading method is used in more than 80 national kennel authorities, mostly located in western European countries, South America, and Asia [62]. Other classification systems have derived from the FCI, such as the Swiss evaluation and grading system [63].

There are requirements that must be met in order to evaluate a dog according to this method, such as a minimum age for evaluation, which is one year for most breeds and 18 months for large and giant breeds [64]. Other requirements are animal identification, the fact that the dog has not been exposed to surgical treatments to improve hip joint quality, among others [64].

The official radiographic positioning is the hip-extended view where the dog is deeply sedated or anesthetized to ensure complete muscle relaxation [65]. While holding the hind limbs at the tarsi region, the operator adducts the stifles and pronates the hind limbs, then the limbs are extended, pulled caudally, and pushed down. Inward rotation of the tip of the paws is also required [65].

The radiograph must show the entire pelvis, parallel femora, iliac wings, and obturator foramina equal in size, similar sacroiliac joints, and the marker for the left or right side of the dog [65].

Table 3 - FCI scheme for grading (adapted from Flückiger, 2007)

A	**No signs of hip dysplasia** There is congruency between the femoral head and the acetabulum. The craniolateral acetabular rim is sharp and slightly rounded. The joint space is narrow and even. The Norberg angle is about 105°. In excellent hip joints, the craniolateral rim encircles the femoral head slightly more in the caudolateral direction.
B	**Near normal hip joints** There is a slight incongruity between the femoral head and the acetabulum, and the Norberg angle is about 105° or the femoral head and the acetabulum are congruent, and the Norberg angle is below 105°.
C	**Mild hip dysplasia** There is an incongruity between the femoral head and the acetabulum, the Norberg angle is approximately 100°, and/or there is slight flattening of the craniolateral acetabular rim. Only slight signs of osteoarthrosis on the cranial, caudal, or dorsal acetabular edge or on the femoral head and neck may be present.
D	**Moderate hip dysplasia** The incongruity between the femoral head and the acetabulum is obvious, and subluxation is present. The Norberg angle is superior to 90° (only as a reference). Flattening of the craniolateral rim and/or osteoarthritic signs are present.
E	**Severe hip dysplasia** Marked dysplastic changes of the hip joints, such as luxation or distinct subluxation, are present. The Norberg angle is inferior to 90°. Notorious flattening of the cranial acetabular edge, deformation of the femoral head (mushroom-shaped, flattening), or other signs of osteoarthrosis is noted.

There is another radiographic position that is not mandatory. It is the abducted hind limb position [65]. In this radiographic position the femurs are abducted, and again there is complete visualization of the pelvis [65]. Five different scores are used from A to E, and they represent the severity of the disease. Being A and B attributed to nondysplastic hips and C, D, and E dysplastic [60]. The worse side of the hip is the one used for scoring [60]. Grades are attributed taking into account the Norberg angle, the degree of subluxation, shape, and depth of the acetabulum, and signs of degenerative joint disease [62]. As explained in table 3.

Individual kennel clubs decide if a dog can or not be used for reproduction based on the score they get [60]. Most ban from breeding dogs with moderate and severe hip dysplasia.[62] The general recommendation is that only animals categorized as “A” or “B” are used for breeding, but some breeding clubs enable exceptions [66].

The Norberg angle is of great importance when using the FCI method because it represents a means to objectively quantify the degree of subluxation [50]. This angle is obtained by drawing a line between the center of the femoral heads and then a line from the center of the femoral head to the ipsilateral cranioacetabular rim [47].

4.2.2. The Orthopedic Foundation for Animals

The Orthopedic Foundation for Animals grading system has been used in the United States and Canada since 1966 [60]. It uses the standard hip-extended view with heavy sedation or general anesthesia, like the FCI method [60].

The radiographs are submitted to the OFA via e-mail for grading [67]. The grading depends on the evaluation of nine different anatomic areas [67]. Those are the craniolateral acetabular rim, cranial acetabular margin, femoral head fovea capitis, acetabular notch, caudal acetabular rim, dorsal acetabular margin, junction of femoral head and neck, and trochanteric fossa [67].

After evaluating the nine anatomic areas, congruency and confluence of the hip joint are also accessed in the radiographic image [67]. Then the hip joint is graded into one of the following seven categories: Excellent, Good, Fair, Borderline, Mild hip dysplasia, Moderate hip dysplasia, Severe hip dysplasia [68].

The Excellent classification is assigned to animals presenting superior conformation of the hip joint in comparison to others of the same breed and age, and when there is almost complete coverage of the femoral head that sits tightly into the acetabulum [68].

The Good classification is attributed to hip joints when good femoral head coverage is present, and a well-formed congruent joint is visualized, although it is not considered superior to breed and age standards [68].

The Fair grade is given when the hip joint has minor irregularities, a minor degree of incongruency, and the acetabulum might appear slightly shallow due to a minor inward deviation of the weight-bearing surface of the dorsal acetabular rim [68].

The borderline grade is assigned if there is no clear consensus between the radiologist to consider the hip normal or dysplastic [68]. No arthritic changes are present, which would mean a definite diagnosis of CHD [68]. However, more incongruency is showed than in fair graded hips [68]. The recommendation is to repeat the radiographs at a later date (usually six months) [68]. This allows for the progression of arthritic changes in case the dog is truly dysplastic [68].

A dog is considered to have mild hip dysplasia when there is significant subluxation meaning the femoral head is partially out of the acetabulum. Generally, young dogs (below 30 months of age) with this grade do not show arthritic changes [68]. Hence a reevaluation, once the dog is older, might be recommended.[68]

Moderate hip dysplasia is assigned to hip joints where significant subluxation is present with the femoral head almost barely seating on the acetabulum [68]. The femoral neck and head and the acetabular rim reveal secondary arthritic bone changes, and sclerosis is often present as well [68].

Severe hip dysplasia is the worst grade, and it is given to hip joints that show marked dysplasia [68]. Significant subluxation is present with the femoral head partly or completely out of the acetabulum, and a large amount of arthritic bone changes [68].

The OFA database shows that from 1974 through 2020, the breeds with the highest percentage of dysplastic dogs are: Pug with 71,8% being dysplastic, English Bulldog with 70,6%, and the Olde English Bulldog with 67,4% [46].

4.2.3. British Veterinary Association/Kennel Club

The British Veterinary Association and the Kennel Club (BVA/KC) created the Hip Dysplasia Scheme in 1965 in an attempt to reduce the incidence and severity of hip dysplasia in dogs [69]. A ventrodorsal hip-extended radiographic view is submitted to be analyzed and scored by appointed scrutineers [69].

Each hip joint is given a score that ranges from 0 to 53, meaning that an animal score range is from 0 to 106, where the lowest score ensures a better hip joint quality [69]. Nine separate features are evaluated by the scrutineers in order to score each hip joint [69].

The nine criteria evaluated are Norberg Angle, degree of subluxation, cranial acetabular edge, cranial effective acetabular rim, dorsal acetabular edge, acetabular fossa, cranial acetabular edge, femoral head and neck exostosis, and femoral head recontouring [60].

This method recommends breeding concerning the breed mean score [60]. Therefore only a dog with 10-20 points below the average breed score, which means a dog that is in the 40%-30% best hips for the breed, cannot breed [60].

According to the statistical data provided by the BVA/KC, the breeds with the worse mean score in the period from 2005-2019 are the Otterhound with a mean of 44,4, the English Bulldog with 40,0, and the Sussex Spaniel with 39,7 [70]. When the data analyzed is from the period of 2015-2019, the breeds with worse mean score are the English Bulldog with 43,8, the Sussex Spaniel with 39,9, and the Griffon Fauve De Bretagne with 35,8 [70]. The differences between the BVA/KC and the OFA score might be explained by the numbers of individuals accessed, the different breeders (ones are from the UK, the others are from the USA), the different classification method and the different time periods.

4.2.4. The Pennsylvania Hip Improvement Program

Doctor Gail Smith, a professor at the University of Pennsylvania School of Veterinary Medicine, developed a new method for early diagnosis of CHD in 1983 [71]. The PennHip was established 10 years later [71].

Three different radiographic views while the dog is sedated are required in the PennHip grading systems, one to evaluate signs of osteoarthritis the hip-extended view, another to identify critical anatomic landmarks and to determine how well the femoral head fits into the acetabulum, which is the compressed view, and finally, the distraction radiograph that evaluates the joint laxity [72]. The radiographs should be submitted for evaluation to the PennHip Analysis Center [73].

The compression radiograph is obtained with the hind limbs of the dog in a neutral position, with a weight-bearing orientation and the femoral heads gently seated into the acetabula [72].

An adjustable distractor is used in order to obtain the distraction radiograph [73]. The device is placed in the proximal femurs, and the femurs are levered against the device resulting in lateral displacement of the femoral head [45]. With this radiographic view, a distraction index (DI) can be obtained [50].

The distraction index is obtained by measuring the distance between the femoral head center and the center of the acetabulum and divide it by the femoral head radius [11]. Thus, the DI measures maximum passive hip joint laxity where a value of 1 represents complete joint luxation and a value of 0 absolute joint congruity [45]. Usually, a distraction index between 0,3 and 0,5 is considered to represent mild joint laxity, 0,5-0,7 moderate joint laxity, and greater than 0,7 is considered to represent severe joint laxity [45]. Although not linearly, the chances of developing degenerative joint disease later in life increase with the value of the DI increase [60]. Moreover, the same DI value in different animals might not mean the same risk for developing DJD, as a heavily muscled dog might tolerate higher values [50].

The PennHip method has the ability to predict the development of DJD at an early age (16 weeks) [50]. Therefore it can be used to screen patients for preventive procedures like pubic symphysiodesis [50]. It can be a very useful tool when selecting animals for breeding [16]. However, its popularity outside the United States of America is limited, perhaps due to the costly mandatory training and certification process, the evaluation fees, and the necessary wait for the official PennHip report [16].

For a dog to be considered dysplastic, it must have signs of OA in the hip-extended view radiograph [45]. The breeding recommendation is that only dogs with no evidence of osteoarthritis and that are in the 60th percentile for that breed are used. The recommendation is not the DI below 0,3 because this might cause extreme selection pressure and cause a severe restriction of the gene pool [45].

4.2.5. The Dorsolateral Subluxation Approach

The dorsolateral subluxation approach (DLS) aims to evaluate hip laxity in a weight-bearing position, therefore evaluating functional laxity, while the PennHip method evaluates passive laxity [60]. Both methods try to access hip laxity, which has been described as an important trait for OA development [60]. Nevertheless, the PennHip method has shown to be predictive and repeatable in animals with four months or more, while the DLS recommends evaluations at eight months of age [74].

For this method, the dogs must be heavily sedated or anesthetized, but no manual restrain is needed [55]. The dogs are placed in sternal recumbency in a kneeling position, and foam-rubber mold with openings for the hind limbs is placed, being the hind limbs adducted and fixed with medical tape [55]. Then the dorsolateral subluxation score is calculated, it corresponds to the percentage of the femoral head medial to the most lateral point of the cranial acetabular rim [75].

A higher percentage in the DLS score means a reduced probability of having OA in the future, being scores above 64% considered unsusceptible and scores below 39% considered highly susceptible [76].

Even though it is not used as much as the PennHip or OFA and FCI method for breeding purposes, the DLS test is commonly used as one of the traits in genetic studies, therefore it is included in this review.

4.2.6. Other Radiographic Projections

The dorsal acetabular rim view (DAR) was first described in 1990 it allows for an unobstructed view, from a craniocaudal perspective, of the dorsal rim of the acetabulum [77]. This area of the acetabulum receives a considerable amount of stress when there is subluxation of the femoral head during ambulation [50].

The patient must be anesthetized or heavily sedated, the animal is placed in sternal recumbency with the hind limbs being pulled cranially while being held against the dog's body [50].

Even though the visualization in fine detail might be compromised due to the overlapping of anatomical structure, the DAR view can help access the shape and degree of sclerosis of the acetabular rim, articular congruence, and presence of osteophytes on the femoral neck [78]. Thus the DAR view can help in the evaluation of CHD when used as a complement to the hip-extended view, and it also is useful when accessing a dog for the possibility of being submitted to surgery to improve hip joint congruity like the triple pelvic osteotomy and the double pelvic osteotomy [78].

The Vezzoni modified Badertscher distention device view is another type of positioning that allows measurement of hip joint laxity [16]. Again the dog needs to be anesthetized or heavily sedated, the device is placed between the animal's hindlimbs, and the femurs are extended, and adduction force against the device is applied [16]. It uses the laxity index to access hip joint laxity, and only two radiographs are necessary [78]. One is the ventrodorsal hip-extended view, and the other is the distention projection [78].

In 2020, a different view was suggested, the hip flexed not distracted ventrodorsal view, that does not require human operators or special devices [79]. However, further investigation is warrant.

4.2.7. Ultrasound, Computed Tomography, and Magnetic Resonance Imaging

In humans, a dynamic ultrasound at birth is able to detect joint laxity that usually leads to developmental dysplasia of the hip [80]. In dogs, an analogous technique has been described but presenting mixed results [50]. Variables investigated have shown poor correlation to the development of CHD, and its utility is considered operator-dependent [50].

Computed tomography usage to diagnose CHD has been growing in popularity, although radiographs are still the preferred method [18]. Research indicate that it can be important for the evaluation of dysplastic changes, allowing for accurate and easy evaluation of coxofemoral joint indices [50].

For now, the exposition to ionizing radiation and the higher cost when compared with radiography is a disadvantage, but, in the future, CT can be used as a more important tool for the diagnosis of CHD [50]. In recent years, the availability of multi-slice CT scanners allowed for an increase in the speed in which CT scans are performed, which translated into the ability to perform CTs using light sedation only [47].

Magnetic Resonance Imaging (MRI) has been occasionally used in studies, a correlation between higher volumes of synovial fluid and hip joint laxity and the later development of canine hip dysplasia [55]. It is costly, less available than radiographs and CT, also the main advantage of MRI is the soft tissue detail [47]. Given that CHD is more an osseous condition, it is not the most relevant diagnostic tool, although it can be interesting to use in a research setting. It has been used to demonstrate a relationship between the quantity of synovial fluid and joint laxity [3].

4.2.8. Kinetic and Kinematic Gait Analysis and Thermography

Kinetic and kinematic analysis tools have evolved in recent years, allowing for a more accurate reading of lameness than the clinical observation [34]. Kinetic gait analysis system can measure ground force reactions conducted by individual steps of the dog in locomotion [51]. There are two systems used in veterinary medicine that assume a bigger preponderance, these are force plates/platforms and pressure-sensitive walkways [47].

Force plate systems measure forces from three different directions, vertical force is the largest, craniocaudal force is a biphasic force, and mediolateral force is the smallest force in dogs moving in straight line [47]. These variables translate into peak force, impulse, and percentage of body weight distribution [47]. One of the limitations of force plate systems is the inability to accurately collect data from small animals [81]. Although, a new modified force plate has been designed in order to allow the collection of data in animals of any size, thus withdrawing the need to purchase different sized plates [81]. Dogs that suffer from hip dysplasia tend to have reduced peak vertical force and vertical impulse [34].

On the other hand are the pressure-sensitive walkway systems, based on paw pressure [47]. Clinically these systems allow the record of several consecutive foot strikes and provide semiautomated analysis [47]. They allow for the measurement of pressure in the vertical direction, percentage of body weight distribution, and temporospatial variables such as stance time, swing time, stride length, stride velocity, stride acceleration, and gait cycle time [47].

Both of the systems provide dynamic kinetic analysis and can be of value to understand alterations associated with orthopedic diseases and their treatment [81].

A different approach was suggested in recent years, a stance evaluation of weight distribution and off loading at stance [82]. The weight distribution platform is similar to a veterinary scale [82]. However, the readings take a few minutes to be done, thus, more hyperactive patients may not be suitable for this measurement [82]. Currently, it is still a method that needs further study and improvement of the current limitations that include the lack of studies relating to the use of weight distribution platforms and their ability to detect subtle orthopedic diseases and to track their progression [47].

When it comes to kinematic measurements, two different systems can be used, one in two dimensions with motion occurring in a single plane and one in three dimensions with motion occurring in multiple planes [47]. It is based on the acquisition of video during motion, and the animal is using superficial skin-markers [83].

When evaluating the hindlimb, usually five different markers are placed over different anatomical landmarks, one is placed on the iliac crest, the other on the greater trochanter of the femur, other on the femorotibial joint between the lateral epicondyle of the femur and the fibular head, the lateral malleolus of the tibia and the distolateral aspect of the fifth metatarsal bone [83].

Fur should be clipped, and care must be taken in order to fixate the markers when the limb is in a normal stand, thus not caudally or cranially extended, a consistent limb position during the placing of the markers is also of utter importance [83,84].

The kinematic analysis allows the clinicians to measure the range of motion by subtracting the minimum joint angle from the maximum joint angle, both variables measured by the kinematic systems [47]. Kinematics analysis of the dysplastic dog revealed that a decreased range of motion is present and it is exacerbated when performing tasks like sitting down and climbing stairs [34].

The sensitivity of kinematic methods to external factors like skin movement, the difficulty of acquiring motion data in three planes, the need to limit the movement of the dog in order to keep in the plane are disadvantages of this testing tool, making it for now mostly limited to research laboratories [84]. For this reason, an alternative to optical kinematic evaluation has been suggested but still needs further investigating as the size of the animal seems to be a limitation for this tool [84].

As equipment for kinetic and kinematic analysis becomes affordable and more profoundly studied, it is beginning to be used in an everyday practice setting and not only in research and specialty setting [47]. Unfortunately, not all practitioners are acquainted with these tools meaning it might take longer for them to be seen as an everyday diagnostic method [47].

Recently thermography has been studied as a diagnostic tool for a panoply of pathologies, being a non-invasive, contactless, and non-radiating diagnostic tool that relies on temperature changes to indicate inflammation [85]. However, it is a tool that requires perfecting in order to be used in hip OA in dogs, further research must be conducted to understand the influence of different hair coats, different breeds, and different views [85].

4.2.9. Genetic Testing

Since the 1950s, canine hip dysplasia has been considered a hereditable condition [33]. Initially, it was believed that it was related to a single gene with a recessive or dominant pattern of transmission [33]. Nowadays, it is believed that a complex inheritance with multiple genes and environmental factors being responsible for the phenotypic manifestation of the disorder [86].

Genomic selection accelerates the rate of progress due to a higher accuracy it also allows for earlier selection [33]. However, the existence of undesirable complex traits determined by multiple genes makes genetic screening more difficult than a single-gene trait [87]. Different loci were associated with CHD, such as the noggin gene, a bone and joint developmental gene on chromosome 9, and nanos C2HC-type zinc finger 1, a regulator of matrix metalloproteinase 14 on chromosome 28 [88]. Furthermore, genes are related to the presence of osteoarthritis also need to be considered important as they may play a role in canine hip dysplasia [88].

Great progress has been made in recent years in an effort to identify the risk loci responsible for CHD [89]. However, their validation and replication have been difficult [89]. The difference in the populations of dogs affected by CHD is also a challenge [90]. A test was created in 2015, but last year a study realized in Denmark wasn’t able to replicate the results, concluding this test had no value in the prognostic of CHD development in Danish Labrador Retrievers [91]. The existence of dogs with mild dysplasia is also a challenge when it comes to the task of identifying genes responsible for the presence of CHD, although they are at a lower genetic risk to develop the disorder [92].

Because age and diet restriction can influence the phenotypical expression of CHD, a genetic test would allow for better screening as it would limit the influence of environmental factors [40]. A quantitative leap can be achieved when a genomic test is made available to accurately provide a prognosis for CHD and possibly solve the problem of an entire population [93].

5. Conservative Management

Depending on the age at presentation, different approaches of conservative management are recommended. In immature patients, exercise control, weight management, physical therapy, and analgesics are the main recommendations [22]. In mature patients, a multimodal approach is recommended aiming to improve function, reduce clinical signs of pain, improve hip range of motion and strength, hence trying to reduce OA progression [94]. The goal of conservative management of CHD is to improve the coxofemoral joint environment [94]. Therefore many of the recommendations are similar to the management of osteoarthritis [94]. Osteoarthritis cannot be cured, but it can be managed [30].

The objective of the treatment is not only to relieve pain, but also to prevent further cartilage degradation [36]. Therefore, there is a need to use a treatment modality that is safe in the long-term [36]. Because OA causes chronic pain that is neurobiologically complex, the multimodal pharmacological approach seems to be the preferable [95].

5.1. Pharmacological Options

Non-steroidal anti-inflammatory drugs (NSAIDs) are used to treat symptoms of OA and have a representative role in the therapeutic management of OA [36]. Before beginning

NSAIDs treatment, bloodwork, and urinalysis should always be performed to rule out dehydration and renal insufficiency [30].

Non-steroidal anti-inflammatory drugs exert their effect via inhibition of the cyclo-oxygenase (COX) enzymes, blocking the synthesis of prostanoids [96]. This blocking might cause side effects, especially at a gastrointestinal level [36]. An increased expression of COX-2 was found in joints with OA [22]. Two forms of COX are well-known COX-1 and COX-2. Therefore preference should be given to COX-1-sparing drugs [22].

The action of lipoxygenases (LOX) on arachidonic acid also promotes the inflammatory response because it leads to the formation of leukotrienes [22]. Non-steroidal anti-inflammatory drugs inhibition of COX enzymes may lead to a shift in arachidonic acid metabolism to the LOX pathway, resulting in increased production of leukotrienes [22]. This might clarify why most NSAIDs may not offer complete relief of pain and inflammation [22]. Tepoxalin inhibits both COX-1 and COX-2, and it also affects 5-LOX activity, which might make it the most appropriate for use in OA [22].

Analgesics that can be considered and administered in conjunction with NSAIDs include amantadine, gabapentin, tramadol, acetaminophen, and codeine and tricyclic antidepressants such as amitriptyline and clomipramine [22]. However, tramadol has been found to lack efficiency when administered orally in a 5mg/kg dosage in the relief of pain that results from osteoarthritis, specifically elbow and stifle joint OA [97].

Gabapentin is gama-aminobutyric acid (GABA) analog and it can be used both as a an anticonvulsant and analgesic [22]. It shows minimal side effects, although there is the possibility of mild sedation when beginning the treatment, the doses can be increased over time, and it can be used in the long-term [30].

Amantadine can is synergic with NSAIDs, and it exerts its effect by turning off receptors within the nervous system, called N-methyl-D-aspartic acid receptors responsible for amplifying pain signals sent to the brain for pain perception [30].

The individual and across species variability of bioavailability and half-life of tramadol, a synthetic opioid, make it unreliable alone for long-term management of OA pain [30].

Corticosteroids are synthetic analogs of the natural adrenocortical hormones and can be used in an attempt to reduce inflammation [2]. They can be administered orally or locally through intra-articular that can be combined with local anesthetics [22]. Corticosteroids do not represent the safest treatment option, therefore, they should only be used in refractory patients or ones presenting with end-stage disease [22]. The administration of intra-articular triamcinolone hexacetonide has an impact on reducing pain due to the high anti-inflammatory effect it possesses [98]. The results showed improvements in weight-bearing up to the 90-days [99].

In 1992 a study suggested that oral administration of doxycycline reduced the severity of OA [100]. Dogs have been reported to show significant signs of improvement when medicated with oral doxycycline [35]. However, further studies should be conducted, bearing in mind that doxycycline is an antibiotic, therefore, its use should be limited in order to limit bacterial resistance [35].

5.2. Biomodulators and Supplements

Per os administration of glucosamine and chondroitin sulfate are popular supplements, also known as chondroprotectants, that have shown significant improvement in pain scores in different studies [36]. Glucosamine and chondroitin sulfate are synergetic supplements or dietary complements [22]. Glucosamine is a precursor of glycosaminoglycan, and chondroitin sulfate is a sulfated glycosaminoglycan that is predominantly present in articular cartilage [22,31,101]. Supplementation with glucosamine and chondroitin sulfate can provide the same results as the administration of carprofen, yet a longer period of time might be needed to do so [101]. Using a combination of those two with omega-3 fatty acids can improve joint status [101].

Polysulfated glycosaminoglycan is a semisynthetic product that can be obtained from bovine lung and tracheal tissue that can protect against extracellular matrix degradation, therefore slowing down the OA progression process [22,102]. It is very safe and has few adverse effects when administered in the long term, especially when compared to NSAIDs [103]. Evidence supports the ability to prevent and modify the progression of degenerative changes associated with canine hip dysplasia [103]. The typical protocol involves an intramuscular injection administered twice-weekly for four weeks [22].

Omega-3 fatty acids present in fish oil, such as eicosapentaenoic acid, and docosahexaenoic acid can reduce the inflammatory environment [104]. The administration of a triglyceride form of the two can improve clinical markers of OA [104].

Green-lipped mussels may have an anti-inflammatory and chondromodulatory effect and, for this reason, have been investigated and revealed the ability to improve arthritis scores, joint swelling, and signs of joint pain [101].

A supplement composed of glucosamine sulfate, krill oil, chondroitin sulfate, *ribes nigrum*, krill flour, *Lentinus edodes, Equisetum arvense*, and products obtained from the transformation of herbs *(Curcuma longa, Boswellia serrata, Harpagophytum procumbens*) revealed good results in improving joints and reducing pain [36]. Each component of this supplement has different actions but are mainly used for their anti-inflammatory or antioxidant action [36].

Cannabidiol exerts immunomodulatory, antihyperalgesic, antinociceptive, and anti-inflammatory effects, it can be administered via oral transmucosal route, and its use combined with NSAIDs, gabapentin, and amitriptyline enhance pain relief [95]. Furthermore, the administration of cannabidiol may allow for a reduction in the dosage of the other drugs, thus preventing and reducing the severity of side effects [95]. A previous review pointed out that cannabidiol products are not regulated nor standardized, this means a wide variation in the concentration of the active ingredient is possible [105].

5.3. Intra-Articular Injections

A relatively recent treatment modality is the intra-articular administration of exogenous hyaluronic acid (HA) or hyaluronic acid derivates in order to provide pain relief and improve joint mobility, this is also called viscosupplementation [106].

Being normally present in mammalian bone marrow, articular cartilage, and synovial fluid, HA is an important component of the extracellular matrix [107]. Hyaluronic acid is a naturally occurring non-sulfated glycosaminoglycan non-protein compound that has excellent viscoelasticity, high biocompatibility, high moisture retention capacity, and hygroscopic properties [107].

The use of intra-articular viscosupplementation has shown lameness score improvement and even orthopedic evaluation improvement in dogs with osteoarthritis [106]. In humans, this therapy is becoming increasingly popular [108]. A study conducted by Carapeba *et. al.* in Brazil in 2016 suggests greater improvement of hip OA associated signs when intra-articular hyaluronic acid is administered than when using conventional treatment using oral nutraceuticals and NSAIDs [108].

A study conducted by Alves *et. al.* in Portugal in 2021 compared the effects of intra-articular administration of triamcinolone hexacetonide, Hylan G-F 20, stanozolol, and a platelet concentrate [98]. This study concluded that the 4 treatments were able to improve clinical signs of hip OA and that the platelet concentrate and Hylan G-F 20, which is a viscosupplement, effects lasted longer [98].

Mesenchymal stem cells (MSCs) have gained importance as a regenerative treatment of OA in recent years, especially due to their self-renewal properties, multilineage differentiation potential, immunomodulatory capacity, and anti-inflammatory effects [109]. They can be obtained from multiple sources such as bone marrow, periosteum, umbilical cord blood, dermis, muscle, infrapatellar fat pad, synovial membrane, and adipose tissue [110]. Their use is safe and well-tolerated [111].

Adipose-derived stem cells (ADSCs) are abundant, can be easily collected, and have rapid expansion and high proliferation potential [110]. However, when compared to bone marrow, the mesenchymal stem cells ability to differentiate into the chondrogenic, and osteogenic lineage is weaker [112]. Younger donors ADSCs show a higher proliferation rate, nonetheless, the differentiation capacity was maintained with aging [113].

Dogs with osteoarthritis in the coxofemoral joints treated with autologous adipose-derived stem cells have exhibited improvement of lameness, pain, and range of motion [114]. Data support the MSCs ability to reduce synovial inflammation and to protect cartilage degradation [111]. Thus, MSCs based treatments represent an important breakthrough in the treatment of osteoarthritic conditions in dogs [115].

In 2021 a new study concluded that MSCs genetically engineered to overexpress platelet-derived growth factor represent a superior alternative to the previously mentioned MSCs when aiming to improve of patient outcome [116]. Those particular MSCs might be synergetic to hyaluronic acid, scaffolds, specific exosomes, or disease-modifying OA drugs [116].

5.4. Weight Loss and Physical Therapy

Obesity plays an important role in the development of OA as a consequence of CHD because the rate of OA development depends greatly on the amount of stress the joint is subjected to, thus weight management is of utter importance [22,117]. Studies have revealed that a lower incidence of hip OA is found on limited-fed dogs with lower body condition score [22,38,39]. Weight management might be achieved by limiting caloric intake with or without the use of microsomal triglyceride transfer protein inhibitors that decrease the uptake of dietary lipids such as mitratapide and dirlotapide [22]. Weight reduction unaided results in substantial improvement in clinical lameness in dogs with hip OA [21].

The environment in which the dog is inserted plays an important role and can be modified to aid the treatment of signs related to CHD and OA [22]. Slippery floors are to be avoided, as are stairs [22]. Moreover, protecting joints from cold is a great way to help maintain and improve patient mobility [22].

Nonpharmacological anti-inflammatory options can be considered to reduce peripheral pain, such as cold therapy and massage [94]. Besides the pain relief associated with the decrease in nerve conduction velocity, icing also provides pain relief through the reduction of edema and by limiting the overactivity of catabolic enzymes [94]. When a chronic injury is present thermal modification through heat can improve function and comfort [118].

In recent years the hydrotherapy industry has shown a marked increase, two modalities are more commonly used a pool or a water treadmill [119]. The water treadmill represents a smaller investment in terms of space and money [119]. Water-based veterinary physiotherapy has evolved from human aquatic therapies [120]. Water treadmill exercises can be altered by modifying the variables water depth and treadmill speed [121]. The temperature of the water must be between 27,5ºC and 31ºC [122].

Acupuncture is a minimally invasive treatment with solid evidence of efficacy in pain management in veterinary medicine [118]. Acupuncture points are associated with specific anatomic locations, usually being the vicinity of major nerves, blood vessels, or lymphatic vessels [123]. Many locations are associated with regions that generate muscular dysfunction and pain [123]. Electroacupuncture is being used with the purpose of enhancing treatment outcome and durability [123]. Evidence suggests that acupuncture can be effective and useful, especially when integrated into a multimodal approach and performed by a trained practitioner [123].

Two forms of electrical stimulation are most often used in canine rehabilitation the neuromuscular electrical stimulation and transcutaneous electrical nerve stimulation [124]. In humans, neuromuscular electrical stimulation has shown the ability to increase pain modulation associated with OA [125]. It has given the ability to accelerate recovery time after knee arthroplasty, as well as increasing the walking distance and quality of life [126]. The procedure is simple, place the electrodes over the muscle to be stimulated, there is no need for sedation in most animals, the frequency should be increased gradually [124]. Dogs with a thicker coat might need to be clipped in the area where the electrodes will be placed [124]. The frequency applied should range between 25 and 50 Hz, with a pulse duration between 100 and 400 μs, as the muscle becomes stronger, higher frequencies should be used, and the treatment should be done 3 to 7 times a week [124].

The transcutaneous electrical nerve stimulation has been used in combination with medication to provide relief of inflammatory, neuropathic and musculoskeletal pain [127]. It has shown the potential to manage neuropathic pain in humans allowing for a decrease in the analgesic administration dosage or frequency [127]. Used in combination with stretching exercises, it can help in the increase of the range of motion [124]. Thus, it can be useful when a dog suffers from hip dysplasia. Differently from the neuromuscular electrical stimulation, the electrodes for the transcutaneous electrical nerve stimulation should be placed over the area of pain [124]. The frequency range is between 30 and 150 Hz, with a pulse duration ranging between 50 and 100 μs [124].

In both modalities of electrical stimulation, there are some precautions to consider, such as treatment over areas of decreased sensation, treatment directly over skin irritation areas or wounds, in patients with osteoporosis (since there is a fracture risk), and in patients with obesity (excessive fat is a poor current conductor) [124]. Also, it is not indicated to stimulate directly over the heart, in areas of cancer or infection, over the trunk during pregnancy, over areas of thrombosis or thrombophlebitis, over the pharyngeal area or the carotid sinus, in patients with seizure disorders, or when the active movement of the body part is contraindicated [124]. The practitioner must observe the skin looking for skin irritations and burns below the electrodes after each session [124].

Light amplification by stimulated emission of radiation or laser therapy has been growing in popularity in recent years [128]. The specific use of low-level laser therapy may have an effect on the activation of respiratory chain enzymes, oxygen production, formation of proton gradients across the cell and mitochondrial membranes, adenosine triphosphate production, deoxyribonucleic acid production, cell proliferation, reduced cyclooxygenase, and prostaglandin E2 production [128]. The theory behind these effects is called photobiomodulation, and it suggests that a certain wavelength at a particular energy density applied to cells of the body will cause a predetermined reaction [129]. It has shown promising results, having the ability to improve lameness and decrease NSAIDs use in canine patients with elbow osteoarthritis [130]. Promising results are being achieved, yet more prospective clinical trials are needed to demonstrate the usefulness of laser therapy to treat pain associated with OA [131]. It is a treatment modality that has potential, but further investigation is warranted because different wavelengths have shown different results, and it appears to make more difference when used in the long-term [132]. Without training and proper settings, laser therapy may fail to deliver the therapeutic dose [133]. A study has demonstrated that the darker the coat color of the dog, the less transmission is achieved [133]. Shaving the area where the laser is to be applied is also an important factor, this gains more relevance in darker coated dogs [133]. An example of a dog being submitted to laser therapy is shown in figure 6.

Figure 6 - Low-level laser therapy (Author)

Ultrasound therapy has been in use for a long time, and it is a modality approved by the United States Food and Drug Administration [134]. It can exert a positive influence on inflammatory processes, and it can also aid in bone reparation and remodeling [134]. It works by converting electricity into sound waves, and the sound waves are used to heat tissues [122]. The principles are the same as thermal heat therapy, but the ultrasound can reach deeper structures [94]. Its thermal effect may increase collagen extensibility, blood flow, pain threshold, and enzyme activity [94]. Thus, it can be used in dogs suffering from CHD to improve stretching and range of motion [94].

In human medicine, extracorporeal shockwave therapy is used as a common therapy for different orthopedic diseases [135]. Two modalities of this treatment exist, focused and radial shockwave therapy. There is some evidence that indicates that treatment with radial shockwave therapy can be beneficial in the long term in dogs suffering from hip OA [135]. Shock wave therapy has resulted in larger callus and more cortical bone following internal fixation of induced tibial fractures [132]. However, sedation is often required in order to apply the shockwaves, and discomfort, swelling, or erythema can be observed after administration [132].

Recently, clinical canine massage therapy has shown promising results regarding the possibility of being a treatment for myofascial/musculoskeletal pain in dogs [136]. Thus, it is a promising therapy that can be included in the multimodal management of CHD.

Thus, the conservative treatment for OA caused by hip dysplasia is evolving. For now, it relies on a multimodal approach aiming to improve patient's life quality by reducing pain scores and improving or maintaining the range of motion of the coxofemoral joint. The multimodal approach includes pharmaceutical options, nutraceuticals, weight management and control, nonpharmacological options, rehabilitation, physical therapy, and regenerative therapies [22].

6. Surgical Management

Early surgical intervention can improve long-term prognosis, although, as discussed before, early conservative management can provide a good outcome as well [48]. Patient selection is important because a house or yard pet might benefit from conservative management, while a sporting or working dog might need an earlier and more aggressive approach [31]. Generically, surgical treatment can be divided into two different groups, one that englobes therapies that prevent or lessen the development of degenerative joint disease, and another that is composed of therapies that provide relief from pain due to an already present osteoarthritic process [31].

6.1. Juvenile Pubic Symphysiodesis

Juvenile pubic symphysiodesis (JPS) is a surgical option for young patients, with best outcomes when performed at 12 to 16 weeks of age [31]. It is a minimally invasive procedure that has been reported to have an average operative time of 30 minutes [137,138]. Based on the three-dimensional anatomy of the acetabulum, JPS produces progressive ventrolateral rotation of the acetabula and consequently achieves better dorsal femoral head coverage through the induction of premature closing of the pubic symphysis [1,138]. The premature closure of the pubic symphysis can be achieved by the application of electrocautery to induce thermal necrosis of the growth plate [139]. To reliably achieve thermal necrosis of the germinal chondrocytes and arrest of endochondral bone growth, a unipolar needle electrocautery can be used at 40W while concurrently performing trans-rectal palpation in order to move the urethra and the rectum away from the high temperatures that can be produced [140]. With the growth prevention of the pubic symphyseal cartilage, there is a ventromedial constrain to acetabular growth, while dorsally, the ischium and ilium continue to grow, resulting in bilateral ventrolateral acetabular rotation or acetabular ventroversion [138]. After undergoing JPS, some morphological changes are observable through radiographs, such as fusion of the pubic symphysis, arrest of the growth of the pubic rami giving it a stocky appearance, ventroflexion of the acetabula, and widening of the obturator foramina [141].

Juvenile pubic symphysiodesis is a simple technique. Performed with the dog lying in dorsal recumbency, the skin, subcutaneous tissue, rectus abdominis muscle, adductor muscle, and aponeurosis of the gracilis muscle are incised in order to expose the pubic portion of the pelvic symphysis [31]. Then an electrosurgical instrument is used to apply a current for 10 to 30 seconds every 2 to 3 mm along with the cranial one-third to one-half of the symphysis [142].

Because it is a minimally invasive procedure, juvenile pubic symphysiodesis also has minimal postoperative morbidity [139]. Better results can be achieved when the surgery is performed before 18 weeks of age [143]. In fact, Dueland *et al. (2015)* obtained results that showed that JPS surgery is 5 times more effective when performed at 12 weeks of age rather than at 24 weeks of age, also when performed at 16 weeks of age, it is twice as effective as when performed at 24 weeks of age [144]. Age is important because about 82% of pelvic growth is complete at 17 weeks of age [138]. Furthermore, Vezzoni *et al.* (2008) supported the importance of age at the time of intervention but suggested other factors that can have significant importance in the outcome of patients subjected to JPS, such as the severity of susceptibility signs to CHD present at the first orthopedic examination [1]. A preoperative distraction index between 0,4 and 0,6 seems to be the ideal to restore normal joint congruity, with degenerative changes occurring after JPS when a preoperative DI greater than 0,7 is observed [138].

Juvenile pubic symphysiodesis has its benefits and its contraindications. Thus, patient selection is of utter importance and of some degree of difficulty. The advantages of JPS include it being relatively inexpensive, simple, rather painless, and less invasive, especially when compared to other preventive surgeries that can provide similar effects like triple pelvic osteotomy and double pelvic osteotomy [31,145]. Moreover, JPS allows for the treatment of both hips at the same time, as the closure of the pubic symphysis results in bilateral acetabular rotation, and it is an effective method of prevention of secondary effects related to CHD when applied in young patients [138].

The disadvantages of this technique are mainly related to patient selection [137]. When patients have more severe preoperative hip laxity and signs of OA, the outcome is limited, as it is when the patient is older than 18 weeks [137]. The patients subjected to JPS should not breed [141]. Therefore spraying should be done at the time of surgery [141]. However, when the animals remain intact, it is rather difficult to distinguish them from animals not subjected to JPS [141]. Because patients with mild to moderate hip laxity remain asymptomatic during the first weeks of their development, they usually do not present to the clinic in time to be subjected to JPS, for they are often older than 18 weeks[138]. As mentioned before, juvenile patients often show signs between 4 and 12 months of age [138]. A possible approach is to perform the Ortolani maneuver in dogs considered to be at risk for CHD when they present for the first time, and if a positive sign is registered, then further imaging and possibly surgery can be suggested, particularly in dogs that are not meant for breeding [138].

As it does not exclude the patient from later being submitted to other surgeries that aim to prevent the onset of OA related to CHD like TPO and DPO, juvenile pubic symphysiodesis can be a very useful tool if the owners are educated to bring their dogs for early screening and if the dogs are not meant for breeding purposes. Given that JPS can mask the occurrence of CHD and, therefore, leave in the gene pool a dog that has a more severe grade of CHD than it appears, it is important to inform the owners that such dogs cannot breed.

6.2. Triple and Double Pelvic Osteotomy

Triple pelvic osteotomy and the most recently developed double pelvic osteotomy are two surgeries that, like juvenile pubic symphysiodesis, fit in the group that aims to prevent joint damage and consequent osteoarthritis that derive from CHD [146]. A triple osteotomy of the pelvis is performed in humans and has reports of over 80% of hips presenting pain-free 15 years post-surgery [147]. Dogs have been purposed as a natural model to human hip dysplasia, yet in humans, a more wide variety of pelvic osteotomies is described [148]. TPO has shown satisfactory results and therefore has to be considered one of the alternatives to treat human development dysplasia of the hip [148]. In dogs, the triple pelvic osteotomy is meant to achieve better acetabular coverage of the femoral head through ventrolateral rotation of the dorsal acetabular rim [149]. The ventrolateral rotation is achieved by performing osteotomies of the pubis, ischium, and ilium and then stabilizing the iliac osteotomy with a pre-angled TPO plate [150]. The plates typically have angles that range from 20 to 45 degrees and are available in locking and non-locking styles [151]. The use of these plates allows for an increase in the femoral overlap. Generally, hips before undergoing TPO surgery have a femoral overlap of about 30%, and this increases to 70-75% post-surgery [152]. The most common complication of this surgical technique is screw loosening, procedures done using Slocum canine pelvic osteotomy plate have reported an incidence of screw loosening from 29 to 62,5% [153]. This can be prevented by using locking TPO plates [153]. Figure 7 allows for a visualization of the intraoperative placement of DPO plate.

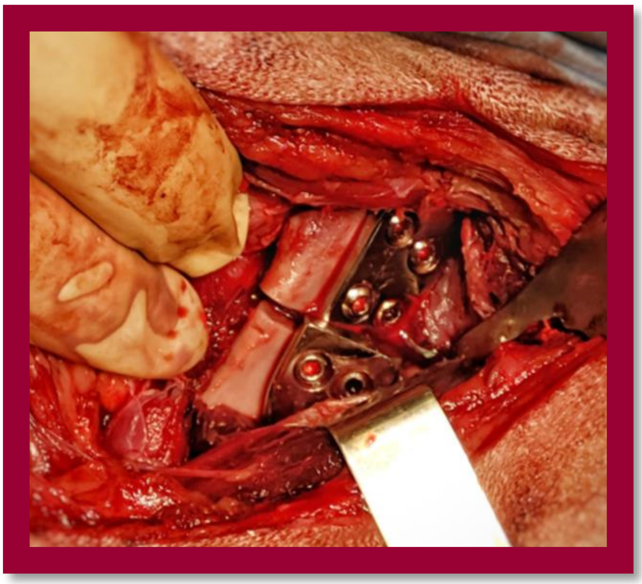

Figure 7 - Intraoperative placement of a DPO plate (Author)

Bilateral triple pelvic osteotomy can lead to severe pelvic canal narrowing, which can cause symptoms like constipation and obstruction [142]. Urethral dysfunction is also possible to happen, usually resolving with medical management in a matter of days [154]. Cases of dysuria have been reported because the pelvic canal narrowing can provoke urethral compression [155]. Obturator nerve impingement has been reported as a late and severe complication of the TPO procedure [156]. It can manifest as severe lameness years after surgery, and a surgical approach to excise a segment of the pubis and fibrous callus tissue can be made to manage this complication [156]. Also, there is a case report of a dog who developed osteosarcoma 11 years post-surgery, at 12 years of age [157]. This can be explained because some osteosarcomas develop associated with fractures, and some may form secondary to chronic loosening of orthopedic implants [157]. It is an orthopedic surgery that requires three different incisions and approaches that take a certain amount of time.

Therefore, the possibility for infection is present. Implant failure, decreased range of motion of the coxofemoral joint, and continued degenerative changes in the hip are all potential complications following TPO surgery despite surgery [154]. The failure to control hip dysplasia can happen due to bad patient selection and insufficient acetabular ventroversion [142].

The double pelvic osteotomy has been shown to produce similar outcomes and fewer complications than TPO [146]. Brian Beale, during the 2014 Meet the Experts sessions, described the double pelvic osteotomy as "A technique that provides acetabular ventroversion . This is provided by a pubic and ilial osteotomy" [158]. The fact that the ischium is not osteotomized may be the reason that DPO provides a greater degree of immediate postoperative stability, therefore improving comfort [146]. A cadaveric study concluded that a DPO performed with 25º plate results in an acetabular ventroversion similar to the obtained by performing a TPO with a 20º plate [159].

The double pelvic osteotomy can be considered a more challenging technique when compared to the triple pelvic osteotomy, mainly because of the difficulty handling and rotating the acetabular iliac segment [160]. A study performed to assess the long-term effectiveness of the DPO technique reported that it substantially reduces the radiographically confirmed progression of coxofemoral osteoarthritis in juvenile dogs diagnosed with canine hip dysplasia [161]. An additional ventral plate fixation can be performed, and it has the potential to reduce screw loosening and the failure of the double pelvic osteotomy technique in correcting hip dysplasia [162].

There is the option of performing bilateral TPO or DPO in the same surgery, this approach has some benefits and some disadvantages. If the surgeon chooses to perform the bilateral approach, the dog will only undergo one anesthetic event [146]. Furthermore, the risk of progressive joint damage in an unoperated limb is mitigated [146]. However, performing bilateral surgery can lead to higher rates of screw loosening [146].

In 2012, Petazzoni described a different pelvic osteotomy approached that he named 2.5PO [163]. This technique involves the typical ilial and pubic osteotomies plus a dorsal ischial mono-cortical osteotomy [163]. Petazzoni concluded that this technique could provide increased acetabular ventroversion when compared to double pelvic osteotomy [163]. This dorsal ischial osteotomy may minimize the tensile forces on the ischium, thus reducing the likelihood of fractures [146]. However, at the same time, it can also weaken the bone and predispose it to fracture [146]. It is a more complex technique, and there is a lack of clinical results published [146].

Regardless of the chosen technique, they share two steps in common. Typically, the pubic osteotomy is the first to be performed [142]. This osteotomy is generally performed with the dog in dorsal recumbency and the limb held in vertical position [31]. The pectineus does not need to be severed or released. In fact, A. Vezzonni *et al*. described the DPO technique mentioning the pectineus muscle remained intact [160]. Some authors describe a small ostectomy, others only osteotomy [31]. Nevertheless, care must be taken to protect the obturator nerve [31]. The iliopubic eminence is used as an anatomy reference, with some authors referring the osteotomy or small ostectomy should be performed medially to the eminence, and others mentioning it should be performed abaxial to it and axial to the acetabulum [31,146].

If a triple osteotomy is going to be performed, the second osteotomy is the ischial osteotomy [142]. After closing the incision made for the pubic osteotomy, the patient can be placed in lateral recumbency, and an incision is made over the caudal aspect of the ischium, medial to the ischial tuberosity [146]. The pudendal nerve courses along the dorsal surface of the internal obturator muscle [142]. Thus when the subperiosteal elevation of the muscle from the dorsal surface of the ischium is performed, the nerve is elevated as well [142]. On the ventral aspect of the ischium, the musculature is also elevated until the obturator foramen is reached [146]. The osteotomy is then performed and preferably extends from nearly the caudolateral border of the obturator foramen through the ischiatic table medial to the ischiatic tuberosity [146].

The last osteotomy to be made is also common to the two techniques. With the dog in lateral recumbency, the approach to the ilium is made with the gluteal muscles being elevated from the body and ventral wing of the ilium [31]. Care must be taken in order to protect the obturator, sciatic, and cranial gluteal nerves [31]. Typically, the ilial osteotomy is performed immediately caudal to the sacrum [146]. When performing a DPO, because of the preservation of the ischial bone, it may be harder to achieve the desired rotation [160]. This issue can be overcome by releasing the sacrotuberous ligament at its insertion over the ischial tubercle [160]. After rotation is possible, the plate and screws are applied. Some discomfort has been associated in DPOs with the tip of the caudal osteotomy because it impinges the gluteal muscle [158]. Therefore it is advisable to cut that tip after the plate and screws are in place [158]. The different osteotomy sites are represented in figure 8.

Figure 8 - Osteotomies performed in DPO and TPO techniques, the red lines correspond to both DPO and TPO techniques while the yellow is exclusive of TPO. (Author)

6.3. Darthroplasty and Femoral Neck Lengthening

Other surgical procedures that may limit or prevent the development of degenerative joint disease are darthroplasty and femoral neck lengthening [164]. The purpose of darthroplasty is to create additional dorsal bone support of the femoral head and prevent the pain associated with joint capsule tears from the dorsal acetabular rim by providing a bony extension of the dorsal acetabular rim of the acetabulum [165]. These changes significantly reduce dorsal subluxation and often substantially reduce the tendency for lateral translation [165].

The darthroplasty has a low cost, and it can be performed in dogs in which juvenile pubic symphysiodesis, triple pelvic osteotomy or double pelvic osteotomy, and total hip replacement have been precluded by cost, age, or degree of laxity [166]. However, some contraindications exist, such as signs of advanced DJD, breakdown of the dorsal acetabular rim, or neurological disease, furthermore only an expert surgeon should perform this advanced technique [166].

The surgical procedure can be divided into two parts. The first part involves the harvesting of the bone graft, it has been described as being harvesting a cortical and cancellous bone graft from the wing of the ilium or rib bone allograft with platelet-rich plasma and mesenchymal stem cells [165,166]. However, more studies are warranted before recommending the latter. After the bone graft harvesting, one, two, or even three corticocancellous strips can be used [165]. These bone strips are tied together and subsequently anchored to the dorsal hip joint capsule using strong absorbable sutures [165]. These sutures are passed through drill holes in the bone strips, and the strips are placed next to or overlapping the original dorsal acetabular rim [165]. Holes are drilled into the original dorsal acetabular rim, and the new shelf is coated with cancellous bone graft [165]. Temporary sciatic dysfunction is the main complication that can be observed, it can be diminished by severing the sacrotuberous ligament at the time of surgery [165]. The limitations to this procedure are lack of cartilage and possibly patients with completely luxated hips [165].

Although femoral neck lengthening nowadays is rarely used, there are rare cases that have an indication for this procedure [31]. This technique aims to increase the distance from the femoral head to the greater trochanter, and it can be considered an adjunctive procedure in breeds that have an elevated incidence of a shortened femoral neck in order to improve the mechanical function of the gluteal muscles [12]. Some breeds are more prone to have short femoral necks, such as the *Akita*, *Chow-chow*, and *Tibetan mastiff* [12]. The procedure can be suggested in the aforementioned breeds or in cases of TPO where a rotation of over 30 degrees is needed [31]. An osteotomy cuts free the greater trochanter from the femoral head [165]. A hole should be made before performing the osteotomy to mark the place where it is intended to end, thus preventing cracks beyond this point when the trochanter is dislocated laterally [31]. Three different screws must be placed, one immediately distal to the osteotomy a 3.5 mm cortical-thread lag screw placed transversely to ensure additional protection against cracking the lateral cortex [31]. The second is placed in the greater trochanter, threaded only in the initial cortex [31]. This second screw allows for the lateral distraction of the trochanter [31]. When the laxity of the femoral head is abolished, a third 3.5 mm cortical screw is placed 1 cm distal to the second screw, this one is threaded in both cortices, and it helps to maintain the lateralized position of the trochanter [31].

6.4. Femoral Head and Neck Excision

When there is a progression of osteoarthritic disease, fewer surgical options are available, and the options that exist are salvage procedures such as femoral head and neck excision and total hip replacement. There are also palliative surgeries available, one of the most reported involves the denervation of the hip joint capsule [12].

The femoral head and neck excision (FHNE) is a surgical procedure used to reduce pain and restore mobility [167]. Therefore, this surgical technique is used to treat painful conditions involving the hip joint such as aseptic necrosis of the femoral head, chronic hip luxation, osteoarthritis secondary to hip dysplasia, non-reconstructable acetabular fractures, and capital physeal and femoral neck fractures [168]. However, anatomical and biomechanical modifications of the hip joint, such as limb-length difference and restriction in range of motion, femoral head, and neck excision, can lead to gait abnormalities and pain [169]. Consequently, careful patient selection is warranted, yet D. Piermattei wrote in 2010, “I have never regretted performing this procedure, even on giant breeds, as long as the owner is well educated about the procedure and expected long-term function” [170]. Smaller and non-overweight animals may benefit more from this procedure, although with good postoperative care and physical therapy, satisfactory results can be achieved on large and giant breeds [171]. The fact that weight might influence the success of FHNE is based on the capacity to compensate for the mechanical disadvantages of an absent coxofemoral articulation before the pseudoarthrosis is formed, yet functional disabilities have also been reported in small dogs [172].

The craniolateral approach is considered the standard for this procedure, although several different approaches to the coxofemoral joint have been described [171]. The ventral approach is also commonly used and can have advantages, such as sparing the gluteal muscles and dorsal joint capsule, which may enable a more precise resection of bone up to but not including the lesser trochanter [168]. Nevertheless, this technique has its problems, such as the proximity to the medial circumflex femoral artery and vein and reduced exposure of the coxofemoral joint [168].

When performing the craniolateral approach, a partial tenotomy of the deep gluteal muscles tendon can improve visualization of the hip joint if necessary [173]. After the incision of the joint capsule, the femoral head is visible, and some steps are important to ensure surgery success. One is the transection of the ligament of the head of the femur if it is still present [20]. Exposure of the cranial surface of the proximal femur is important and is aided by rotating the femur and the use of retractors [20]. Moreover, the identification of the osteotomy site is of utter importance as well, and it is located at the junction of the femoral neck and the femoral metaphysis [20]. The osteotomy site should commence just medial to the greater trochanter proximally and end just proximal to or bisecting the lesser trochanter distally [20]. The osteotomy site is usually smoothed with a bone rasp [174]. It is important to suture the joint capsule before closing the surgical site using standard methods [20]. After surgery, it is important to begin a physical therapy protocol in order to provide a satisfactory effect on the functional recovery of the limbs submitted to FHNE [175].

6.5. Total Hip Replacement

Although FHNE presents satisfactory results, total hip replacement seems to be a better option because it has a lower incidence of pain, movement restrictions, limb shortness, and muscle atrophy when compared to femoral head and neck excision [176]. Thus, it is considered to be the most effective salvage procedure in the treatment of hip OA, providing the best pain relief and best performance [12]. Associated with low perioperative mortality, a low incidence of euthanasia dictated by implant failure, no neoplasia at the total hip replacement site, and no adverse impact on longevity or cause of death, it is a relatively safe procedure [177]. The complication rate of this procedure is reported to be between 5% and 20% [178]. The technique consists of implanting a stainless steel or titanium femoral head and femoral stem component after the removal of the femoral head and neck and implanting a high-density polyethylene acetabular cup after the preparation of the acetabulum [31]. The first method for implant fixation available was cemented [142]. However, at the beginning of the XXI century, cementless implants have experienced exponential growth in popularity [142]. There also is a hybrid approach available, with promising results, that uses a cementless acetabular component and a cemented femoral stem [179]. When using cemented prostheses, polymethyl-methacrylate cement is used to stabilize the implant [180]. The cementless techniques usually rely on osseointegration to achieve long-term stability [142]. The differences between the techniques demand a careful patient evaluation and also an assessment of the surgeon's training and experience before choosing a cemented or cementless procedure [181]. For instance, an older patient might have a questionable bone quality or non-ideal anatomic features and therefore benefit more from a cemented implant [12]. In contrast, a younger dog with a more active lifestyle and longer lifespan expectation might benefit from the biological fixation of the cementless implant [12]. Thus, age, temperament, bone structure, anatomic shape, secondary disorders, and owner compliance should be evaluated before making a decision on whether the type of implant used is cemented or cementless [182].

Different cemented implants are available to use, such as *Biomécanique* and its derivative, *Porte*, yet the most commonly used it's the BioMedtrix CFX™ [183]. Since the appearance of the first cemented implant, research efforts were made in order to improve the cement application technique [179]. This led to the introduction of cleaning and drying of the recipient bone surfaces, plugging of the femoral canal, retrograde injection of cement in the liquid phase, and cement pressurization [179]. These alterations in the cement application technique are meant to increase the resistance to shear stress [142]. At the turning of the century, Kurt Schulz in 2000 had already described the existence of 1st, 2nd, and 3rd generation cementing techniques [184].

Multiple challenges arise when performing a cemented total hip replacement, such as the time of surgery that should not overcome the 2 hours period because of the possibility of infection, extreme care with the aseptic conditions is also necessary [31]. To avoid complications, care must be taken when applying the cement, and the technique is important, as is the thickness of the mantle [185]. Also, there are important factors related to the implant, such as its shape, size, and position, as well as implant contact with the endosteal cortex of the femur [185]. The surgery is performed through a craniolateral approach to the hip joint [31]. An osteotomy of the femoral head and neck is performed, taking special attention to the neck cut angle [181]. As it is in FHNE, if the ligament of the head of the femur is intact, it has to be transected in order to allow for the luxation of the femoral head [142]. The preparation of the femur is extensive, involving the enlargement of the femoral canal using a powered drill and tapered reamer [31].

After the preparation of the femur, the prosthesis is placed to verify if it is the correct size [31]. Curettage, pulsatile lavage, and suction can be used to clean the femoral canal [179]. The acetabular preparation is of utter importance requiring thorough assessment of radiographs and recognition of the true acetabular center [142]. The reaming involves two stages, the first removes subchondral and cancellous bone and allows the achievement of appropriate depth and approximate width [181]. The second step only finishes the prepared bed surface and width to within the 1 mm tolerance needed [181]. Usually, and regardless of the technique used, the acetabular cup is placed first, being placed with an approximately 45-degree angle of lateral opening and 15 to 20-degree retroversion, in a cemented technique, a positioner can be used to ensure proper orientation as the cup is cemented into place [3,31]. Usually, when using a cemented acetabular cup, defects in the bone are created to allow for cement intrusion and anchoring because bone cement is cohesive and not adhesive [181]. After the placing of the acetabular cup, liquid-phase cement is introduced into the femoral canal and the prosthesis is placed, with care to avoid anteversion [31]. The cement placing technique is important because the most common complication in cemented total hip replacement is thought to be aseptic implant loosening [185]. A composite cement containing low content bioactive titania fillers dispersed among specific polymethylmethacrylate polymers has been created and investigation suggests that, because of its biocompatibility and bioactivity, it can have greater bonding strength values and affinity indices with bones [186].

Different cementless options are available, with the biological fixation BFX® from BioMedtrix and the Zurich Cementless THR being the more commonly known [187]. The HELICA implant or The INNOPLANT Total Hip Replacement system is an alternative to the two aforementioned [187]. These three systems use different mechanisms to achieve short-term stability, specifically and respectively press-fit, locking screw fixation, or screw-in implants [188]. Figure 9 provides a visualization of the three different systems.

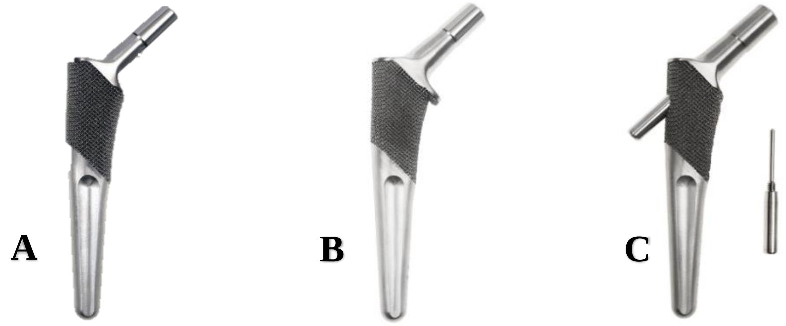

Figure 9 - The three different biological fixation implants from BioMedtrix. Adapted from https://biomedtrix.com/total-hip-replacement-2/ (Accessed on 30/06/2021)

A - BFX® EBM Titanium Stem. B - BFX® EBM Collared Stem. C - BFX® EBM Lateral Bolt Stem

Since the introduction of BFX®, different modifications have been made in order to prevent and limit stem subsidence in the postoperative period [189]. This lead to the presentation of the collared stem and, more recently, the lateral bolt stem [189]. The original titanium stem is the preferred material for human hip replacement, the collared stem is recommended for large breed dogs, German Shepherds, and dogs with a low canal flare index [189]. Cases with an increased concern for stem position changes, or where calcar bone is absent, or when the use of a collared BFX stem is not recommended should all use the lateral bolt [189].

These three implants developed by BioMedtrix rely on initial press-fit within the femoral canal to provide initial femoral stem stability and posterior osseointegration to offer long-term stem stability [189]. The use of the lateral bolt stem has been associated with less postoperative subsidence compared with the other two stems provided by this company, this might translate to less implant loosening [189]. Noel Fitzpatrick *et al*. in 2014 suggested that a cementless total hip replacement can be safely performed in juvenile patients, and it might mean a less demanding technique because there aren't as many anatomical alterations as in an adult dog with a more advanced stage of hip OA [190]. Furthermore, the loss of musculature isn’t as severe, moreover, a reduction in the challenge of the technique also means less time of surgery, making it less likely to have infections, thus providing a window of opportunity for an uncomplicated arthroplasty [190].

The Zurich Cementless THR (Kyon, Zurich, Switzerland) is different as it uses a locking screw implantation system for the application of the implant, combined with a distinctive micro interlock bone on-growth for the long-term stability of the femoral component, while the acetabular cup uses an initial press-fit stabilization with a posterior bone in-growth through a porous design of the cup [188]. Bone in-growth implies a firm fixation through bone growth into the porous surface of metal implants, while on-growth fixation occurs through bone growth on the rough surface of an implant [191]. The main difference of the Zurich technique is screw insertion for initial stability, and once the femoral stem is placed, after the acetabular cup, screws should be inserted in the following order 3-1-5-2-4 (1 denotes most proximal, 5 most distal), it is recommended that the screw placed in the most proximal position is a bicortical screw [188].

The INNOPLANT Total Hip Replacement system (INNOPLANT Veterinary, Hannover, Germany), similarly to the BioMedtrix system, also has both cemented and cementless components [187]. However, it has unique components the screw-in cementless femoral stem (HELICA TPS stem) and acetabular (Screw Cup) [187]. Two generations are available, the second generation implant allowed for a reduction in implant loosening [192]. The first generation implant had a 37.5 percentage of cases needing revision surgery one year postoperatively, thus it wasn’t broadly recommended [193]. However, the introduction of Helica Three-Part Stem appears to have greatly reduced the incidence of aseptic loosening of the femoral stem [192]. The advantages of the screw-in endoprosthesis are the ease of implantation, a shorter learning curve, less intraoperative time, femoral neck anteversion is preserved because the femoral neck is preserved during the procedure, and the threads provide an increased surface area and, hence, improved stability [191].

Overall, the techniques for the three different cementless systems described above are similar to each other and also similar to the cemented technique [142]. Steps that are common to all the techniques are the excision of the femoral head and differing degrees of the femoral neck, and some degree of femoral canal preparation (except the

INNOPLANT system, which is a screw-in femoral prosthesis) [142]. Also, the preparation of the acetabulum must be precise regardless of the type of implant chosen, with the acetabular cup being placed before the femoral stem [142].

Complications also can arise regardless of the technique used, even though some techniques can have higher incidences of certain complications. A study has related the higher possibility of complications to an increased body condition score, especially if the dogs gained weight in the postoperative period [188]. Also, when the procedure is done in juvenile patients, different complications are expected than when performed in adults [188]. Described complications include luxation, femoral fracture, infection, problems associated with wound healing, aseptic loosening, acetabular fracture, sciatic paresis, femoral pain, femoral subsidence, *protrusio acetabuli* (intrapelvic displacement of the acetabulum), sciatic pain, femoral pain, and cardiac arrest [178]. Infection has been described as the third most common cause for revision of THR [194].

Even though complications do exist, the rate of owner satisfaction is usually good to very good after their dog underwent a THR surgery [178,188,195,196]. Thus, total hip replacement surgery has been evolving, with more techniques available, from cemented to cementless and even hybrid possibilities, it can offer dogs with canine hip dysplasia a better life quality, and it is associated with a high success rate.

6.6. Denervation of the Joint Capsule and Pectineal Myectomy

Denervation of the joint capsule is presented as a palliative procedure, it aims to reduce pain associated with hip OA through sectioning local sensory nerves [197]. In 2017, Giebels *et al*. concluded that the denervation of the cranial region of the acetabular rim is crucial to reduce capsular inflammation and joint-related pain because the craniodorsal region of the hip joint capsule is an influential origin of pain [198]. A lateral approach has been recommended after the aforementioned study [199]. Another study that was performed in sheep and reached the same conclusions regarding the importance of the craniodorsal region [199]. It can be performed combined with a pectineal myectomy and help alleviate pain and symptoms associated with CHD and hip OA [199].

The surgical technique to perform denervation of the joint is relatively simple [142,200]. After a lateral approach, a retractor is used in order to retract the middle gluteal muscle, and a strip of periosteum is excised from the dorsal surface of the acetabulum [142,200]. A study from 2002 reports a success rate of 90% with dogs that were submitted to this procedure showing improvement of their symptoms [200].

The pectineal myotomy is not a commonly used technique by veterinary surgeons nowadays [142]. It is thought that it relieves pain by increasing the load-bearing areas of the femoral head and neck [31]. However, as it does not address the joint and the latter is still unstable, progression of OA still happens [31]. It still results in symptomatic improvement, yet only for a limited and variable period of time [31]. It is also a relatively simple technique [31]. After a ventral approach at the hip joint, the pectineal tendon is undermined, and its origin cut [31]. After that, the leg is abducted and adducted, extruding the muscle through a proximal incision where the distal tendon is incised, and the whole muscle is removed [31].

Thus, hip denervation combined or not with pectineal myotomy can be a relatively simple and cheaper option to total hip replacement, also it is important to know that doing this procedure does not exclude the patient from undergoing a total hip replacement in the future.

II. Canine Hip Dysplasia: Radiographic Evaluation of German Shepherds in Portugal

1. Introduction

Canine hip dysplasia is one of the most commonly diagnosed orthopedic diseases in dogs, and it is a complex developmental disorder with a polygenic and multifactorial etiology [18,55]. The hip extended standard view is frequently used to diagnose hip dysplasia in dogs. It is also the radiographic view that the Orthopedic Foundation for Animals, the *Fédération Cynologique Internationale,* and the British Veterinary Association/ Kennel Club use to screen for CHD [79,201]. In Portugal, the German Shepherd breeders club is affiliated and recognized by the FCI [202]. The German Shepherd Association (*Verein Für Deutsche Schäferhunde*) has established the necessity to evaluate hips since 1996 to obtain a breeding license, and dogs with medium and serious hip dysplasia cannot be used for breeding [203]. Dogs must be over 12 months to be evaluated for breeding purposes, this norm is in agreement with the FCI requirements [64,203]. Thus, the hip condition of the breed has been through more scrutiny over the last years. Acetabular parameters have interest in order to adjust acetabular components when performing total hip replacements procedures [204]. These parameters can also have importance when diagnosing CHD, computed tomography and MRI can obtain more accurate information [47,204]. However, radiography is more commonly available [47,204].

In the clinical setting other reasons exist to radiograph hips before 12 months of age. Thus, animals with less than 12 months were included in this study.

2. Objective

The objectives of this study were to understand and compare the hip dysplasia status of German Shepherds dogs in Portugal with the available statistics from OFA, and to evaluate how the acetabular index [(Acetabular Depth/Acetabular width)*100] correlates with the dysplasia status, and to determine if it can be a reliable and measure. Furthermore, two different methods were used to obtain acetabular depth, and the portion of the femoral head concurrent to those depths was also registered and analyzed in order to discern how valuable and reliable those references can be.

For these purposes hip radiographs obtained in the clinical setting were used, regardless of the reason the dogs why were submitted to such evaluation.

3. Materials and Methods

Standard hip-extended ventrodorsal radiographic views of 33 German Shepherds (10 males and 23 females) were evaluated. Dogs were evaluated at the Centro Veterinário Conimbricense. Most radiographs were obtained during the period between September 2020 and February 2021, although some precede that period, hence, being retrospective data. The radiographs were performed for different purposes and were included in this study afterward. All dogs were sedated in order to perform the radiography, the protocol used was Dexmedetomidine (0,1mg/kg/IV) and Butorphanol (0,1mg/kg/IV). The radiographs were performed by an experienced veterinary surgeon assisted by an intern. Each dog had one radiograph taken that was then measured. Some data from this study is retrospective, thus, not all the body weights were registered, which led to the exclusion of this parameter from the statistical analysis.

The radiographs were analyzed, and measurements were made as described in Radiographic Examination. The radiographic measurements of the Norberg angle, acetabular depth, acetabular width and femoral head portions were performed 3 times in each radiograph than the average value was used in order to obtain ratios and indices, and also for most of the statistical analysis apart from the intraclass correlation. Overall statistics were evaluated using IBM SPSS Statistics®.

Two different groups were then formed, the dysplastic (9 animals, 18 hips) and the non-dysplastic (24 animals, 48 hips) based on the FCI classification scheme. Also, two groups that separated males from females were established.

3.1. Radiographic Examination

Six different measurements were obtained from each coxofemoral joint. Those were repeated 3 times on three different days, with an interval of three days between each repetition. All 33 radiographs were evaluated on the same three days. One of the measurements was the Norberg Angle as exhibited in figure 10 (NA) and the acetabular width (AW) as described in figure 11.

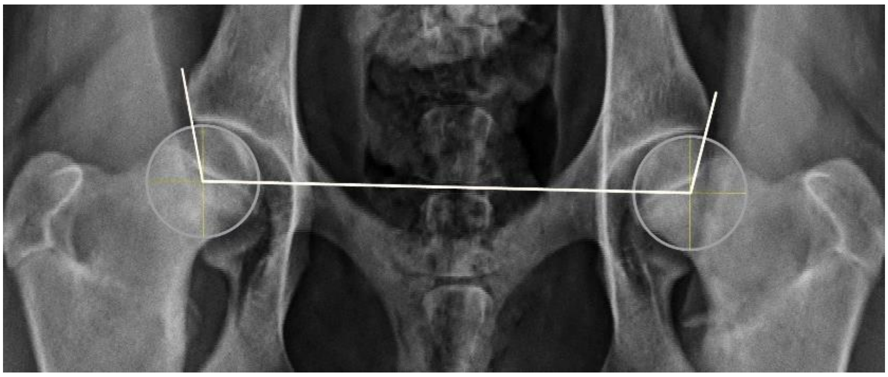

Figure 110 - The Norberg Angle (white lines)

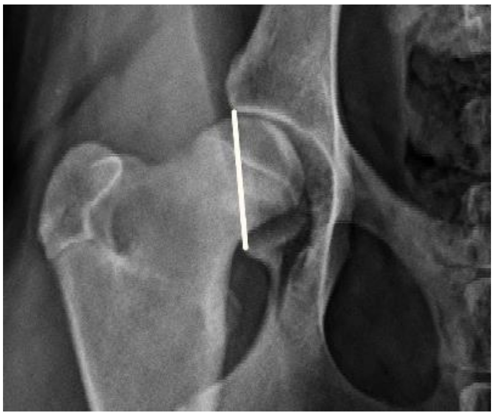

Figure 101 - The Acetabular Width (white line)

Moreover, the acetabular depth using the acetabular circle (ADc) as described by Martins *et al.*[205] and displayed in figure 12, and the femoral head portion (FHPc) that was concurrent with the ADc, also illustrated in figure 12 was also measured in each joint.

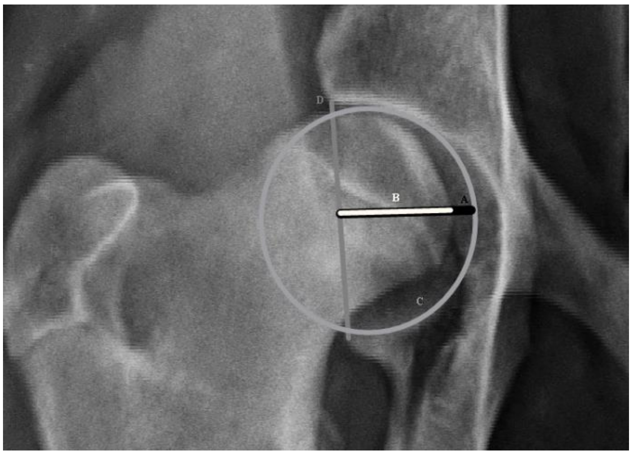

Figure 12 - The Acetabular Depth (**A** black line) measured, using the acetabular circle (**C** grey circle), as the distance from a straight line, tangent to the craniolateral effective acetabular rim and caudal acetabular edge (**D** grey line) and the internal limit of the acetabular circle. And femoral head portion (**B**).

Additionally, the acetabular depth (ADk) as described for CTs by Kanthavichit *et al*. [204] and demonstrated in figure 13, and the femoral head portion (FHPk) concurrent with the ADk were assessed as well.

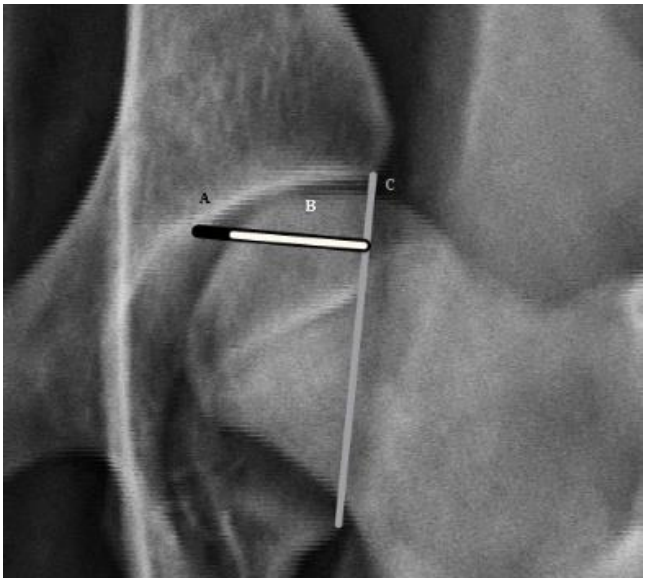

Figure 13 - The Acetabular Depth (**A**), the femoral portion (**B**), and a straight line between the craniolateral effective acetabular rim and caudal acetabular edge (**C**)

4. Results

A total of 1881 values were available for statistical analysis. All the measurements were made three times by the same operator, which allowed for the obtention of intra-rater agreement. The means of the three measured were used to do the statistical analysis. The intra-rater agreements for the NA, ADc, ADk, FHPc, and FHPk were obtained by applying the intraclass correlation coefficients selecting the two-way mixed effects, with absolute agreement and reading the single measurements results as it is described and recommended by Koo and Li (2015) [206]. The intra-rater agreement for the Norberg Angle was 0,981. The ADc had an intra-rater agreement of 0,954, while the FHPc had 0,985. The ADk and the FHPk had 0,963 and 0,984, respectively. Finally, the acetabular width had a 0,955 intra-rater agreement. All the statistical analysis was made with a 95% confidence interval.

The mean age of the dogs was 15,79 months, the maximum was 84 months, and the minimum was 5 months has shown in figure 14.

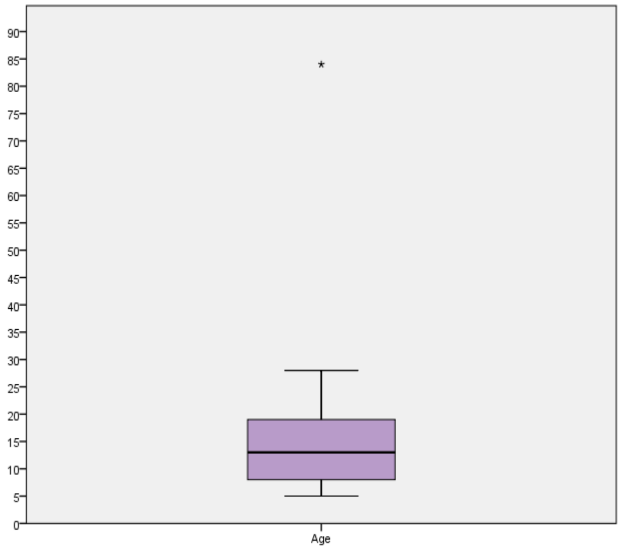

Figure 14 -Boxplot distribution of the animals' age in months.

In what concerns the Norberg Angle, the overall mean was 101,78 degrees with a standard error of the mean of 9,74. The distribution of the NA values is represented in figure 15.

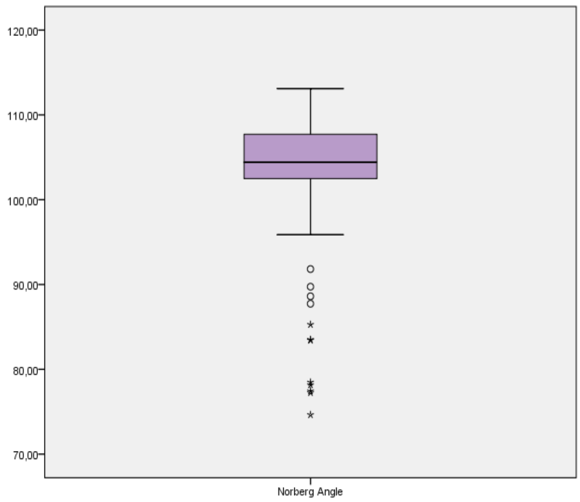

Figure 15 -Boxplot distribution of the Norberg Angle.

The acetabular width showed an average value of 29,34mm with a standard error of the mean of 1,89. Figure 16 reveals the distribution of the acetabular width values.

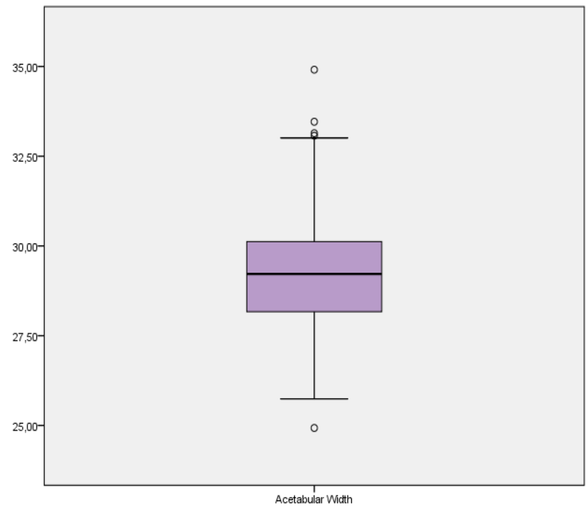

Figure 16 - Box and whisker plots of the acetabular width.

The ADc mean value was 15,50 millimeters with a standard error of the mean of 1,51, whereas the FHPc average was 12,53mm and a standard error of the mean of 2,05. When the acetabular depth was measured as the distance from the medial edge of the sourcil to a straight line between the craniolateral effective acetabular rim and caudal acetabular edge, the mean was 13,671mm, and the femoral head portion corresponded to 10,31mm, the standard error of the mean was 1,47 and 2,03 respectively. The values of acetabular depths and femoral head portions obtained are visible in figure 17.

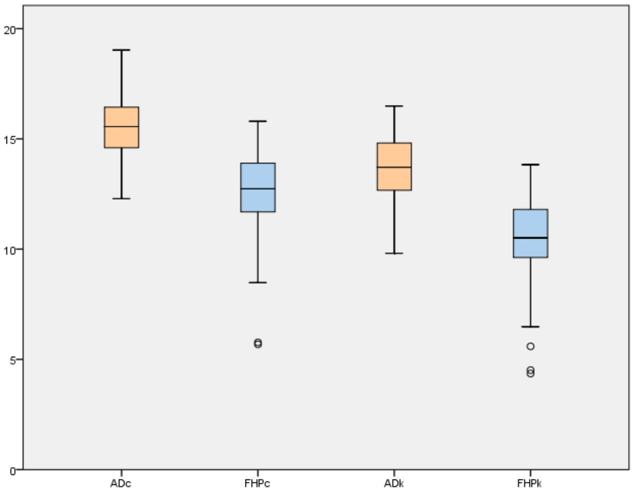

Figure 17 - Boxplot of the acetabular depths (orange) and femoral head portions (blue)

The acetabular indices were calculated using the same formula, although using different acetabular depths measurements, the acetabular width was the same in both cases. The AIc was calculated by dividing the ADc by the acetabular width and then multiplying by 100, while the AIk used the ADk instead of the ADc. Linear regression was drawn in a dispersion graphic comparing both acetabular indices, as is visible in figure 18.

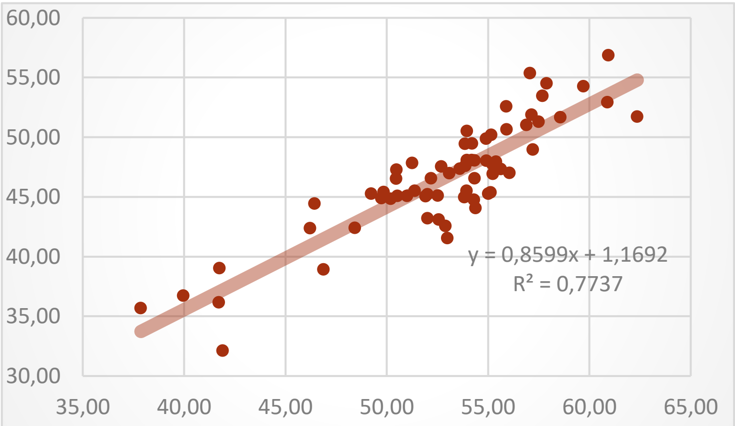

Figure 18 - Correlation between the AIc (X-axis) and AIk (Y-axis).

Similarly to the acetabular indices, the ratios between acetabular depth and femoral head portion were also calculated by dividing the FHPc by the ADc (AFRc) and the FHPk by the ADk (AFRk), and then multiplying by 100. Again dispersion graphics were created, and linear regressions were calculated as illustrated by figure 19.

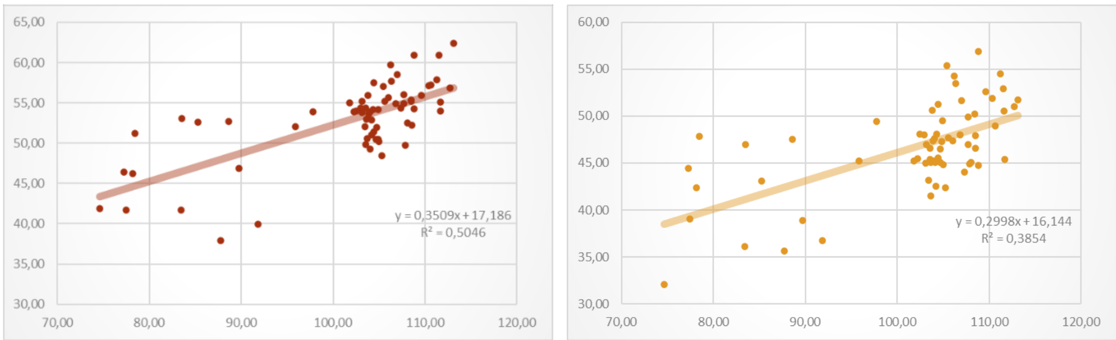

Figure 19 - Correlations between the NA (X-axis) and the AIc (graphic on the left in red), and between the NA (X-axis) and the AIk (on the right in yellow).

Linear regressions were drawn in order to understand the possible relation between the Norberg angle and the two different acetabular indices as figure 20 illustrates.

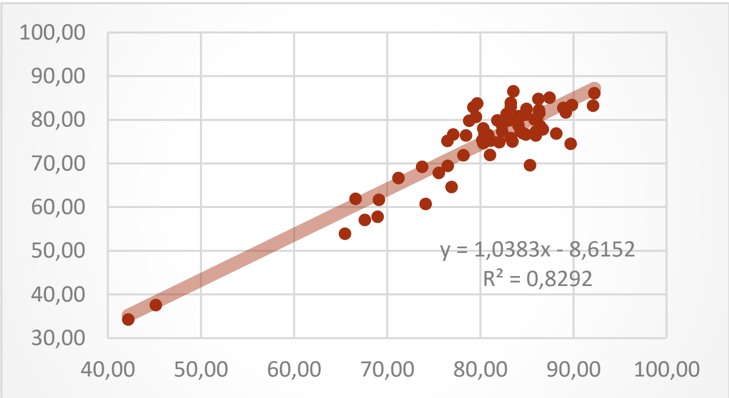

Figure 20 - Correlation between the different acetabular depth and femoral head portion ratios. AFRc (X-axis) and AFRk (Y-axis)

The overall descriptive statistics, such as the Mean, the stantard deviation (SD), and the standard error of the mean (SEM), are exhibited in table 4.

Table 4 - Descriptive statistics of the overall data

	Mean	SEM	SD
Age	**15,79**	**1,66**	**13,46**
Norberg Angle	**101,79**	**1,20**	**9,74**
ADc	**15,50**	**0,19**	**1,51**
ADk	**13,67**	**0,18**	**1,47**
Acetabular Width	**29,34**	**0,23**	**1,89**
FHPc	**12,53**	**0,25**	**2,05**
FHPk	**10,31**	**0,25**	**2,03**
AIc	**52,90**	**0,59**	**4,81**
AIk	**46,66**	**0,58**	**4,70**
AFRc	**80,51**	**1,08**	**8,81**
AFRk	**74,98**	**1,24**	**10,05**

ADc – Acetabular Depth Measured using the Acetabular Circle; ADk – Acetabular Depth Measured as when obtained by Computed Tomography; FHPc – Femoral Head Portion of Acetabular Depth Measured Using Acetabular the Circle; FHPk – Femoral Head Portion of Acetabular Depth Measured as in Computed Tomography; AFRc – Ratio between Acetabular Depth And Femoral Head Portion (related to the circle); AFRk - Ratio between Acetabular Depth And Femoral Head Portion (as in CT)

After the dispersion graphics were drawn, the correlation coefficients were inferred, with results being shown in table 5, in order to evaluate the strength of correlation between different parameters. Using Pearson’s correlation test.

Table 5 - Correlation coefficients between different parameters

Note: The *p*-values represented as ,000 are all considered <0,0001

		Age	NA	ADc	FHPc	AFRc	ADk	FHPk	AFRk	AW	AIc	AIk
Age	Correlation coefficient		-,290	-,395	-,241	,003	-,351	-,274	-,120	,377	-,612	-,560
	p-value		,018	,001	,051	,982	,004	,026	,336	,002	,000	,000
NA	Correlation coefficient	-,290		,601	,822	,765	,527	,830	,864	-,125	,710	,621
	p-value	,018		,000	,000	,000	,000	,000	,000	,317	,000	,000
ADc	Correlation coefficient	-,395	,601		,823	,389	,899	,818	,519	,359	,787	,709
	p-value	,001	,000		,000	,001	,000	,000	,000	,003	,000	,000
FHPc	Correlation coefficient	-,241	,822	,823		,841	,754	,957	,857	,275	,675	,617
	p-value	,051	,000	,000		,000	,000	,000	,000	,026	,000	,000
AFRc	Correlation coefficient	,003	,765	,389	,841		,359	,774	,911	,119	,344	,309
	p-value	,982	,000	,001	,000		,003	,000	,000	,342	,005	,012
ADk	Correlation coefficient	-,351	,527	,899	,754	,359		,818	,428	,369	,683	,823
	p-value	,004	,000	,000	,000	,003		,000	,000	,002	,000	,000
FHPk	Correlation coefficient	-,274	,830	,818	,957	,774	,818		,867	,242	,694	,709
	p-value	,026	,000	,000	,000	,000	,000		,000	,050	,000	,000
AFRk	Correlation coefficient	-,120	,864	,519	,857	,911	,428	,867		,063	,511	,409
	p-value	,336	,000	,000	,000	,000	,000	,000		,613	,000	,001
AW	Correlation coefficient	,377	-,125	,359	,275	,119	,369	,242	,063		-,289	-,220
	p-value	,002	,317	,003	,026	,342	,002	,050	,613		,019	,076
AIc	Correlation coefficient	-,612	,710	,787	,675	,344	,683	,694	,511	-,289		,880
	p-value	,000	,000	,000	,000	,005	,000	,000	,000	,019		,000
AIk	Correlation coefficient	-,560	,621	,709	,617	,309	,823	,709	,409	-,220	,880	
	p-value	,000	,000	,000	,000	,012	,000	,000	,001	,076	,000	

NA – Norberg Angle; ADc – Acetabular Depth Measured using the Acetabular Circle; ADk – Acetabular Depth Measured as when obtained by Computed Tomography; FHPc – Femoral Head Portion of Acetabular Depth Measured Using Acetabular the Circle; FHPk – Femoral Head Portion of Acetabular Depth Measured as in Computed Tomography; AFRc – Ratio between Acetabular Depth And Femoral Head Portion (related to the circle); AFRk - Ratio between Acetabular Depth And Femoral Head Portion (as in CT)

Two groups were formed based on whether the dogs had radiographic signs of dysplasia. These groups revealed some significant differences in the parameters evaluated. Table 6 illustrates the parameters averages, standard deviation, and standard error of the mean.

Table 6 - Different mean parameters according to the classification of dysplastic or non-dysplastic.

	Dysplastic	SEM	SD	Non-Dysplastic	SEM	SD
Age	24	5,35	22,71	12,71	0,77	5,34
Norberg Angle	89,75	2,7	11,25	106,3	0,43	3,01
ADc	14,22	0,37	1,56	15,98	0,17	1,19
ADk	12,69	0,35	1,49	14,04	0,19	1,30
Acetabular Width	29,53	0,619	2,63	29,27	0,22	1,55
FHPc	10,23	0,50	2,12	13,39	0,17	1,18
FHPk	8,04	0,47	1,97	11,17	0,18	1,24
AIc	48,40	1,35	5,75	54,59	0,44	3,07
AIk	43,21	1,32	5,61	56,87	0,22	3,60
AFRc	71,77	2,88	12,24	83,79	0,51	3,60
AFRk	62,99	2,81	11,93	79,47	0,51	3,52

ADc – Acetabular Depth Measured using the Acetabular Circle; ADk – Acetabular Depth Measured as when obtained by Computed Tomography; FHPc – Femoral Head Portion of Acetabular Depth Measured Using Acetabular the Circle; FHPk – Femoral Head Portion of Acetabular Depth Measured as in Computed Tomography; AFRc – Ratio between Acetabular Depth And Femoral Head Portion (related to the circle); AFRk - Ratio between Acetabular Depth And Femoral Head Portion (as in CT)

The differences between some parameters observed in the table above were statistically tested using an Independent Samples t-Test, where the groups were comprised of dysplastic and non-dysplastic joints. With a 95% confidence interval, all *p* values were under 0,00013, thus rejecting the null hypothesis, except for the *p*-value of width, which was 0,616. The Independent Samples t-Test concerning the NA as a testing variable and groups formed by the dysplastic and non-dysplastic coxofemoral joints produced the lowest *p*-value 1,03x10E^{-13}. The highest *p*-value (apart from the AW) was obtained when the AIk was a testing variable, and it was 0,00013. Both the AFRc and the AFRk had low *p*-values, although AFRk had an even lower than AFRc. The contrary happened when the acetabular indices were tested. As mentioned, the AIk had the highest yet still low *p*-value, and the AIc was lower than the AIk.

Again, the correlation coefficients were inferred, but this time the data was divided into two groups the dysplastic and non-dysplastic patients. These results are exhibited in Tables 7 and 8. Table 7 has an N of 48, while table 8 has an N of 18.

Table 7 - Correlation coefficients between variables in non-dysplastic German Shepherds

Non-Dysplastic		Age	NA	ADc	FHPc	AFRc	ADk	FHPk	AFRk	AW	AIc	AIk
Age	Correlation coefficient		-,008	-,341	-,287	-,001	-,472	-,448	-,120	-,169	-,302	-,486
	p-value		,958	,018	,048	,994	,001	,001	,415	,249	,037	,000
NA	Correlation coefficient	-,008		,402	,465	,274	,377	,482	,402	,040	,483	,438
	p-value	,958		,005	,001	,059	,008	,001	,005	,785	,000	,002
ADc	Correlation coefficient	-,341	,402		,872	,078	,872	0,789	,136	,652	,707	,63
	p-value	,018	,005		,000	,600	,000	,000	,358	,000	,000	,000
FHPc	Correlation coefficient	-,287	,465	,872		,554	,883	,883	,35	,548	,641	,719
	p-value	,048	,001	,000		,000	,000	,000	,015	,000	,000	,000
AFRc	Correlation coefficient	-,001	,274	,078	,554		,311	,454	,487	,002	,109	,392
	p-value	,994	,059	,600	,000		,032	,001	,000	,988	,461	,006
ADk	Correlation coefficient	-,472	,377	,872	,883	,311		,919	,199	,62	,58	,824
	p-value	,001	,008	,000	,000	,032		,000	,176	,000	,000	,000
FHPk	Correlation coefficient	-,448	,482	,789	,883	,454	,919		,568	,488	,594	,816
	p-value	,001	,001	,000	,000	,001	,000		,000	,000	,000	,000
AFRk	Correlation coefficient	-,120	,402	,136	,35	,487	,199	,568		-,073	,252	,307
	p-value	,415	,005	,358	,015	,000	,176	,000		,621	,084	,034
AW	Correlation coefficient	-,169	,040	,652	,548	,002	,62	,488	-,073		-,073	,068
	p-value	,249	,785	,000	,000	,988	,000	,000	,621		,620	,647
AIc	Correlation coefficient	-,302	,483	,707	,641	,109	,58	,594	,252	-,073		,78
	p-value	,037	,000	,000	,000	,461	,000	,000	,084	,620		,000
AIk	Correlation coefficient	-,486	,438	,63	,719	,392	,824	,816	,307	,068	0,78	
	p-value	,000	,002	,000	,000	,006	,000	,000	,034	,647	,000	

NA – Norberg Angle; ADc – Acetabular Depth Measured using the Acetabular Circle; ADk – Acetabular Depth Measured as when obtained by Computed Tomography; FHPc – Femoral Head Portion of Acetabular Depth Measured Using Acetabular the Circle; FHPk – Femoral Head Portion of Acetabular Depth Measured as in Computed Tomography; AFRc – Ratio between Acetabular Depth And Femoral Head Portion (related to the circle); AFRk - Ratio between Acetabular Depth And Femoral Head Portion (as in CT)

Table 8 - Correlation coefficients between variables in dysplastic German Shepherds.

Dysplastic		Age	NA	ADc	FHPc	AFRc	ADk	FHPk	AFRk	AW	AIc	AIk
Age	Correlation coefficient		-,004	-,266	,148	,381	-,173	,153	,322	,639	-,644	-,537
	p-value		,987	,286	,559	,119	,492	,543	,192	,004	,004	,022
NA	Correlation coefficient	-,004		,422	,747	,650	,455	,798	,754	-,201	,557	,557
	p-value	,987		,081	,000	,003	,058	,000	,000	,425	,016	,016
ADc	Correlation coefficient	-,266	,422		,626	,139	,901	,688	,336	,230	,710	,615
	p-value	,286	,081		,005	,584	,000	,002	,172	,359	,001	,007
FHPc	Correlation coefficient	,148	,747	,626		,858	,526	,955	,921	,346	,324	,229
	p-value	,559	,000	,005		,000	,025	,000	,000	,159	,189	,360
AFRc	Correlation coefficient	,381	,650	,139	,858		,072	,757	,949	,310	-,068	-,131
	p-value	,119	,003	,584	,000		,778	,000	,000	,211	,787	,604
ADk	Correlation coefficient	-,173	,455	,901	,526	,072		,674	,257	,188	,664	,744
	p-value	,492	,058	,000	,025	,778		,002	,304	,455	,003	,000
FHPk	Correlation coefficient	,153	,798	,688	,955	,757	,674		,886	,306	,413	,392
	p-value	,543	,000	,002	,000	,000	,002		,000	,217	,089	,108
AFRk	Correlation coefficient	,322	,754	,336	,921	,949	,257	,886		,289	,121	,045
	p-value	,192	,000	,172	,000	,000	,304	,000		,245	,633	,860
AW	Correlation coefficient	,639	-,201	,230	,346	,310	,188	,306	,289		-,517	-,512
	p-value	,004	,425	,359	,159	,211	,455	,217	,245		,028	,030
AIc	Correlation coefficient	-,644	,557	,710	,324	-,068	,664	,413	,121	-,517		,921
	p-value	,004	,016	,001	,189	,787	,003	,089	,633	,028		,000
AIk	Correlation coefficient	-,537	,557	,615	,229	-,131	,744	,392	,045	-,512	,921	
	p-value	,022	,016	,007	,360	,604	,000	,108	,860	,030	,000	

NA – Norberg Angle; ADc – Acetabular Depth Measured using the Acetabular Circle; ADk – Acetabular Depth Measured as when obtained by Computed Tomography; FHPc – Femoral Head Portion of Acetabular Depth Measured Using Acetabular the Circle; FHPk – Femoral Head Portion of Acetabular Depth Measured as in Computed Tomography; AFRc – Ratio between Acetabular Depth And Femoral Head Portion (related to the circle); AFRk - Ratio between Acetabular Depth And Femoral Head Portion (as in CT)

Because of the higher correlation between AW and ADc and ADk demonstrated in the non-dysplastic data group dispersion graphics were drawn and are displayed in figure 21.

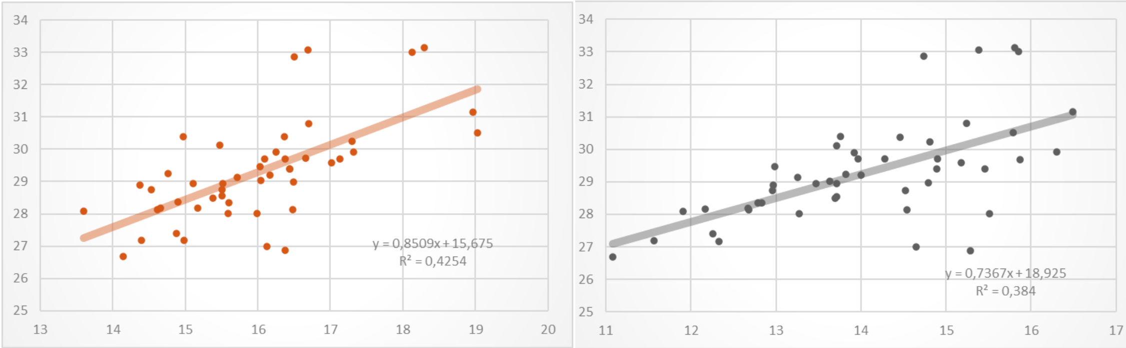

Figure 21 - Dispersion graphics. On the left is the ADc (X-axis) and the AW (Y-axis). On the right is the ADk (Y-axis) and AW (X-axis)

Two groups were once more formed. This time the males were separated from the females. Females composed 66,67% of the sample, while males represented 33,33%. Thus, 22 dogs were female and 11 males. Table 9 demonstrates the parameters means, standard deviation (SD), and standard error of the mean (SEM) obtained when comparing these two groups.

Table 9 - Different mean parameters according to gender

	Female	SEM	SD	Male	SEM	SD
Age	**14,5**	**0,98**	**6,52**	**18,36**	**4,59**	**21,52**
Norberg Angle	**104,49**	**1,11**	**7,37**	**96,37**	**2,49**	**11,68**
ADc	**15,55**	**0,20**	**1,32**	**15,39**	**0,40**	**1,86**
ADk	**13,61**	**0,20**	**1,35**	**13,78**	**0,37**	**1,72**
Acetabular Width	**28,89**	**0,16**	**1,07**	**30,24**	**0,58**	**2,72**
FHPc	**12,8**	**0,22**	**1,45**	**11,97**	**0,61**	**2,86**
FHPk	**10,57**	**0,24**	**1,59**	**9,79**	**0,57**	**2,66**
AIc	**54,84**	**0,64**	**4,24**	**51,02**	**1,15**	**5,41**
AIk	**47,14**	**0,67**	**4,42**	**45,70**	**1,11**	**5,20**
AFRc	**82,24**	**0,75**	**4,95**	**77,05**	**2,79**	**13,09**
AFRk	**77,37**	**0,95**	**6,32**	**70,21**	**2,98**	**13,96**
Percentage of dysplasia	**18%**	**-**	**-**	**45,45%**	**-**	**-**

NA – Norberg Angle; ADc – Acetabular Depth Measured using the Acetabular Circle; ADk – Acetabular Depth Measured as when obtained by Computed Tomography; FHPc – Femoral Head Portion of Acetabular Depth Measured Using Acetabular the Circle; FHPk – Femoral Head Portion of Acetabular Depth Measured as in Computed Tomography; AFRc – Ratio between Acetabular Depth And Femoral Head Portion (related to the circle); AFRk - Ratio between Acetabular Depth And Femoral Head Portion (as in CT)

The factors listed in the table above were then tested using an Independent Samples t-Test with a 95% confidence interval to better understand how the gender influenced the mean values observed. With a *p*-value of 0,001, the Norberg angle seems to be influenced by gender. The same is true for the acetabular width and the AFRc, both with *p*-values of 0,005, and the AFRk and the AIc with *p*-values of 0,023. Having or not having dysplasia also seemed to be affected by gender in this study with a *p*-value of 0,019. All the other parameters had *p*-values greater than 0,05, thus not allowing for the rejection of the null hypothesis.

Once more correlation coefficients were calculated, this time the data was divided by gender. The data obtained is displayed in table 10 and table 11. Table 10 corresponds to the results of correlation coefficients of the different parameters in each coxofemoral joint of females, thus having an N of 44 (22 German Shepherds females). Table 11 corresponds to the male coxofemoral joints data. Hence the N is 22 (11 German Shepherds males).

Table 10 - Correlation coefficients based on Gender (Female)

Female		Age	NA	ADc	FHPc	AFRc	ADk	FHPk	AFRk	AW	AIc	AIk
Age	Correlation coefficient		-,421	-,462	-,529	-,374	-,529	-,600	-,489	-,092	-,453	-,528
	p-value		,004	,002	,000	,012	,000	,000	,001	,554	,002	,000
NA	Correlation coefficient	-,421		,639	,789	,652	,592	,776	,800	-,147	,742	,670
	p-value	,004		,000	,000	,000	,000	,000	,000	,340	,000	,000
ADc	Correlation coefficient	-,462	,639		,865	,262	,875	,815	,477	,352	,894	,778
	p-value	,002	,000		,000	,086	,000	,000	,001	,019	,000	,000
FHPc	Correlation coefficient	-,529	,789	,865		,708	,846	,923	,724	,177	,833	,816
	p-value	,000	,000	,000		,000	,000	,000	,000	,250	,000	,000
AFRc	Correlation coefficient	-,374	,652	,262	,708		,385	,626	,740	-,177	,360	,471
	p-value	,012	,000	,086	,000		,010	,000	,000	,251	,016	,001
ADk	Correlation coefficient	-,529	,592	,875	,846	,385		,892	,456	,344	,772	,925
	p-value	,000	,000	,000	,000	,010		,000	,002	,022	,000	,000
FHPk	Correlation coefficient	-,600	,776	,815	,923	,626	,892		,806	,121	,811	,893
	p-value	,000	,000	,000	,000	,000	,000		,000	,433	,000	,000
AFRk	Correlation coefficient	-,489	,800	,477	,724	,740	,456	,806		-,230	,612	,565
	p-value	,001	,000	,001	,000	,000	,002	,000		,133	,000	,000
AW	Correlation coefficient	-,092	-,147	,352	,177	-,177	,344	,121	-,230		-,104	-,037
	p-value	,554	,340	,019	,250	,251	,022	,433	,133		,503	,809
AIc	Correlation coefficient	-,453	,742	,894	,833	,360	,772	,811	,612	-,104		,853
	p-value	,002	,000	,000	,000	,016	,000	,000	,000	,503		,000
AIk	Correlation coefficient	-,528	,670	,778	,816	,471	,925	,893	,565	-,037	,853	
	p-value	,000	,000	,000	,000	,001	,000	,000	,000	,809	,000	

NA – Norberg Angle; ADc – Acetabular Depth Measured using the Acetabular Circle; ADk – Acetabular Depth Measured as when obtained by Computed Tomography; FHPc – Femoral Head Portion of Acetabular Depth Measured Using Acetabular the Circle; FHPk – Femoral Head Portion of Acetabular Depth Measured as in Computed Tomography; AFRc – Ratio between Acetabular Depth And Femoral Head Portion (related to the circle); AFRk - Ratio between Acetabular Depth And Femoral Head Portion (as in CT)

Table 11 - Correlation coefficients based on Gender (Male)

Male		Age	NA	ADc	FHPc	AFRc	ADk	FHPk	AFRk	AW	AIc	AIk
Age	Correlation coefficient		-,216	-,406	-,131	,141	-,337	-,144	,034	,465	-,768	-,667
	p-value		,334	,061	,561	,531	,125	,521	,881	,029	,000	,001
NA	Correlation coefficient	-,216		,629	,860	,818	,611	,889	,888	,094	,625	,580
	p-value	,334		,002	,000	,000	,003	,000	,000	,678	,002	,005
ADc	Correlation coefficient	-,406	,629		,825	,491	,941	,837	,594	,455	,707	,631
	p-value	,061	,002		,000	,020	,000	,000	,004	,033	,000	,002
FHPc	Correlation coefficient	-,131	,860	,825		,894	,761	,981	,922	,451	,547	,461
	p-value	,561	,000	,000		,000	,000	,000	,000	,035	,008	,031
AFRc	Correlation coefficient	,141	,818	,491	,894		,433	,857	,964	,364	,275	,195
	p-value	,531	,000	,020	,000		,044	,000	,000	,096	,216	,384
ADk	Correlation coefficient	-,337	,611	,941	,761	,433		,811	,519	,428	,672	,728
	p-value	,125	,003	,000	,000	,044		,000	,013	,047	,001	,000
FHPk	Correlation coefficient	-,144	,889	,837	,981	,857	,811		,918	,440	,569	,525
	p-value	,521	,000	,000	,000	,000	,000		,000	,041	,006	,012
AFRk	Correlation coefficient	,034	,888	,594	,922	,964	,519	,918		,361	,380	,281
	p-value	,881	,000	,004	,000	,000	,013	,000		,099	,081	,206
AW	Correlation coefficient	,465	,094	,455	,451	,364	,428	,440	,361		-,304	-,306
	p-value	,029	,678	,033	,035	,096	,047	,041	,099		,168	,167
AIc	Correlation coefficient	-,768	,625	,707	,547	,275	,672	,569	,380	-,304		,926
	p-value	,000	,002	,000	,008	,216	,001	,006	,081	,168		,000
AIk	Correlation coefficient	-,667	,580	,631	,461	,195	,728	,525	,281	-,306	,926	
	p-value	,001	,005	,002	,031	,384	,000	,012	,206	,167	,000	

NA – Norberg Angle; ADc – Acetabular Depth Measured using the Acetabular Circle; ADk – Acetabular Depth Measured as when obtained by Computed Tomography; FHPc – Femoral Head Portion of Acetabular Depth Measured Using Acetabular the Circle; FHPk – Femoral Head Portion of Acetabular Depth Measured as in Computed Tomography; AFRc – Ratio between Acetabular Depth And Femoral Head Portion (related to the circle); AFRk - Ratio between Acetabular Depth And Femoral Head Portion (as in CT)

The age parameter was also studied and its relation to other parameters can be seen in figure 22.

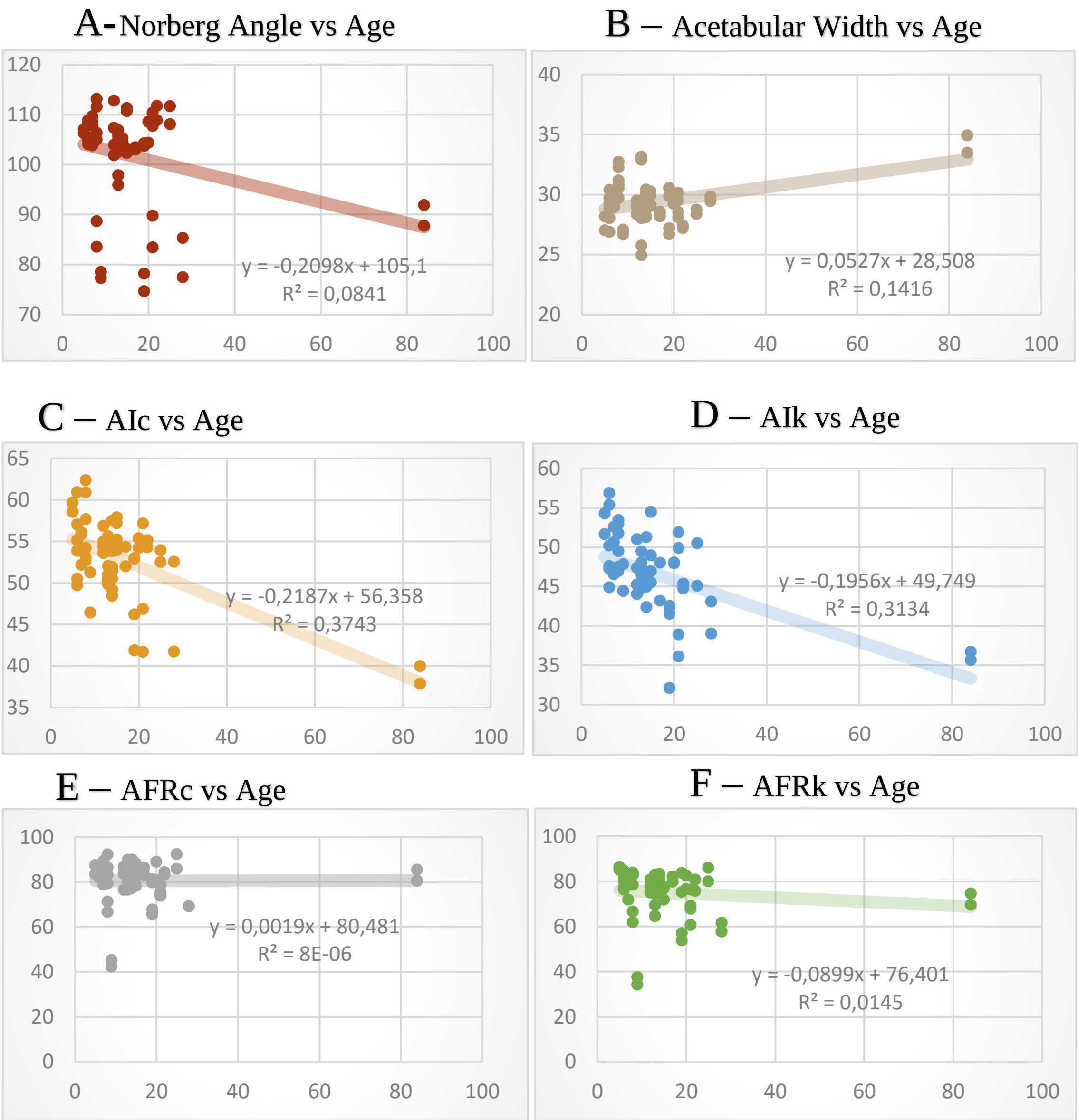

Figure 22 - Correlation between Age and six other parameters

A – Norberg Angle vs Age; **B** – Acetabular Width vs Age; **C** – AIc vs Age;

D – AIk vs Age; **E** – AFRc vs Age; **F** – AFRk vs Age

5. Discussion

The overall percentage of dysplastic dogs in this study was 27,3%, while the non-dysplastic was 72,7%. These numbers correspond to a higher percentage than the one OFA describes in their database, where the overall percentage of dysplastic German Shepherds Dogs is 20,6%, and the percentage of dysplastic dogs born since 2018 is 21,3% [207]. Moreover, the breed-specific summary report indicates a 19,32 percentage of dysplastic German Shepherd and a 1,75 percentage of equivocal hips (all data as of 31/12/2020) [208]. The 6,7% difference can be related to the number of animals evaluated. One significant difference is that the OFA database is composed of over 130 000 German Shepherd (GS) hips evaluation while this study only evaluates 33 animals. Moreover, the minimum age for a dog to be screened and graded by the OFA scheme is 24 months. Preliminary evaluation is available from 4 to 23 months of age, this study had animals as young as 5 months being screened and an average of 15,79 months of age [208]. The explanation for this age difference resides in the reason why the animals were submitted to screening, as in the clinical settings, more concerned owners seek radiographic screening earlier so they can have a wider range of possible treatments. However, the prevalence of CHD increases in older animals even after 24 months of age, meaning some dogs that are classified as non-dysplastic can later in life be classified as dysplastic, whereas the opposite does not happen [209]. Thus, the fact that younger overall dogs had a higher percentage of hip dysplasia can mean that the percentage of dysplasia in the group in a few years is even higher than 27,3%. The higher percentage of dysplastic dogs may also be related to different populations of dogs evaluated, for the OFA organization evaluates dogs in North America, hence analysis a different population from the one present in Europe and more specifically in Portugal. The fact that dysplastic dogs are not reported to the official grading systems may also have an influence on the lower percentage of dysplastic displayed by the OFA stats. This happens because there is a fee associated with the submission, whether it is to OFA or other grading systems, and when the veterinary surgeon that performs the exam clearly notices dysplasia, the owners often opt not to send it to an official grading system.

The Norberg angle intraobserver-reliability coefficient 0,981which is slightly higher than one presented in a study from 2020 that reported an intraobserver reliability of 0,975, both with a 95% confidence interval [210]. However, the study from 2020 had some differences from the one presented here. The radiographs were taken more than once, which didn’t happen in this study, where each animal had one radiograph, that the same experienced veterinarian took, and that radiograph was evaluated three times by the same not so experienced observer. These facts alone can explain the marginally higher value obtained when evaluating the intra-rater agreement.

As discussed in the previous paragraph, the study's overall setting can slightly increase the overall intra-rater agreement observed. However, as the values obtained ranged from 0,955 to 0,985, the measures obtained in this study seem to be reliable and reproducible, at least in what the intraobserver reliability is concerned.

The correlation coefficients grading was done according to Schober *et al*. (2018) cut-off points and interpretation [211].

The age variable had medium to weak correlation coefficients with almost all the other measurements when all data was being used. It only showed a moderate correlation with both the acetabular indices. This parameter has a particularity, an outlier that is a male dog of 84 months of age. This is reflected in the 4 months difference in the average age between both genders and in the increased SD and SEM. Thus, the correlation coefficient between age and the Norberg angle, the acetabular depths (both), and the ratios between acetabular depths and femoral head portions increased when only Female data was being studied, with a negative value meaning an increase in age leads to those parameters decrease. However, the coefficient between age and the acetabular indices was higher when only male data was analyzed. This might have some relation to the lower number of data available for male radiographic measurements. Once again, the coefficient was negative, thus suggesting that an increase in age leads to a decrease in the acetabular indices’ values. Overall, even when all data is being analyzed, the acetabular indices seem to have a moderate negative correlation to the age of the German shepherd dogs.

The Norberg angle is used in the FCI grading scheme as an objective measurement of joint laxity [210]. The value of the different correlation coefficients reveals that the NA seems to have moderate to strong correlations with every parameter except age and acetabular width. Those two factors only seemed to correlate weakly with the NA. Again, apart from those two variables, it also establishes positive correlations with all the other parameters, meaning a change in magnitude in the NA will lead to a change in magnitude in the same direction of these other variables. The femoral head portion is a measure similar to the femoral head coverage percentage, and this perhaps is why a higher Norberg angle is strongly correlated to a higher femoral head portion distance because this means the femur is probably seated deeply into the acetabular socket. This is reinforced by the fact that both ratios between the femoral head portion and the acetabular depth are also strongly correlated with the Norberg angle. The ratio corresponds to the percentage of acetabular depth filled with femoral bone, thus providing an idea of how deeply the femoral head is seated in the acetabular socket. The differences between the Norberg angle correlation with the acetabular depths and femoral head portions in males and females were less than 0,1, and with the latter, NA established strong correlations, whereas with the ADc and ADk, it established moderate correlations. One of the challenges with the obtention of an exact NA occurred in dysplastic patients. Where perfect positioning sometimes was not possible due to the advanced OA present, or in order to protect the dogs and the operators from radiation when a diagnostic was available the perfect positioning was not sought in more radiographs. The same, however, did not happen with the non-dysplastic, where the radiographs had, most of the times, to be submitted at the German Shepherd Association. Thus, a nearly perfect positioning was sought. According to a study, the defects in positioning affect the NA values [59].

A recent study implied that acetabular width could be used to estimate the acetabular depth and found strong correlations between AW and acetabular depth ($r = 0,876$) [204]. However, this study evaluated small breed dogs and dogs not affected by hip dysplasia. In the present study, only a weak correlation could be found when all data was being analyzed, whether relative to the ADc or the ADk. This, however, changed when only the non-dysplastic were being evaluated. It almost doubled the correlation coefficient value, ADc had an $r = 0,652$ while ADk had an $r = 0,620$ in this scenario. This disparity in the correlation coefficient value can possibly be explained by the altered anatomy of the acetabulum of dogs with canine hip dysplasia. The acetabular depths mean values in this scenario also changed, with the non-dysplastic displaying a deeper acetabulum. When ADc was used, a 1,76mm changed was verified, meaning an increase of 12,38% when non-dysplastic joints were measured. The ADk had a 1,35mm difference meaning an increase of 10,64%. This data reinforces the change in acetabular depths when a dog suffers from hip dysplasia regardless of the method chosen to evaluate that depth. When the data were grouped by gender, there seemed to be no significant differences between acetabular depths. The Independent Samples t-Test confirmed this.

The acetabular depths revealed a very strong correlation to one another (r =,899), which was to be expected. Somehow these two measures correlated slightly higher (r =,901) when only dysplastic joints were evaluated. Perhaps due to the lower number of cases in this data group. The ADk also showed a slightly higher intra-observer agreement, but the difference was not significant. This being said, in the present study, it is not possible to infer which acetabular depth measurement method is best, but because they correlate so strongly to one another, it can be said that both can be used, although defining one method only could help compare data between breeds. In humans, acetabular depth is important in determining hip dysplasia, and in some populations, an acetabular depth below 9,00 mm can mean hip dysplasia [212]. Nowadays, this parameter is evaluated in humans using a CT scan, and although there are differences in the acetabular configuration of people and dogs. Thus, the method to measure the parameters are slightly different.

As expected, because they are part of the formula used to obtain such parameters and because they are so strongly correlated to one another, the acetabular depths had strong correlations to the acetabular indices. However, the same didn’t happen in the ratios between the femoral head portion and the acetabular depth. This might be due to the fact that, in this case, the femoral head portion is the most influential variable in the ratio formula. This is supported by the strong correlation FHPc and FHPk had to the AFRc and AFRk, respectively. Both acetabular depths correlated strongly with their respective femoral head portion when non-dysplastic data was analyzed. Moreover, a strong correlation to the same variables turned into moderate when only dysplastic data was included. This could be due to the larger variance observed in these parameters when only dysplastic joints are considered, supported by an increase of the standard error of the mean and the standard deviation. A study in humans reported an intraobserver reliability of 0,8. The ones reported in this study are higher at 0,954 and 0,96 [213]. That study, however, had more than one observer thus, more than one value of intraobserver reliability, concretely one observer seemed to lower the average intraobserver reliability. That study was conducted in 2014 since then, radiographic hardware and software have been upgraded. Thus, higher resolution is possible when obtaining radiographs, and this can lead to easier identification of anatomic regions and landmarks, possibly justifying the increase in the intraobserver reliability observed in this study.

The femoral head portion/acetabular depth ratio is similar to the femoral head extrusion index used in human medicine. However, the focus is on estimating how much depth of the acetabulum is occupied by femoral head bone rather than estimating acetabular coverage [214]. The objective of using this measure was to understand whether, because of joint laxity, the femoral head was seated less deeply into the acetabulum even when the acetabular depth was not as much affected, which would happen in the earlier stages of the disease. There were significant differences between the values of this parameter in dysplastic and non-dysplastic dogs. As anticipated, both ratios correlated very strongly to each other (r = 0,911), curiously having a greater correlation when the dysplastic group was being evaluated, and only a moderate correlation in the non-dysplastic group. The same happened to the correlation between these ratios and the NA. When comparison was made according to gender correlation between the AFRc and AFRk to the acetabular indices significant correlations existed just in females (males had *p*-values > 0,05), even though it only was moderate. Overall, females exhibited slightly higher values of AFRc and AFRk, and the differences were considered statistically significant by an Independent Samples t-Test.

The acetabular width only had moderate to weak correlations with some variables, but in most cases, it was neglectable or even not statistically confirmed with *p*-values > 0,05. The measurement also didn't confirm statistically that the dysplasia status provoked changes in the values measured. This might mean that the acetabular width is not affected significantly by a dog having dysplasia. Furthermore, a study found a correlation between AW and body weight, but not with age [204]. The same is observed related to age in this study. As previously mentioned, that same study found a strong correlation between AW and acetabular depth. Again, it was only composed of non-dysplastic and small breed dogs. Since a positive correlation was found between body weight and AW, it is not surprising that in this study, the mean AW was 29,34, and in that study performed in Maltese and Shih Tzu dogs, it was about 10mm and 14mm, respectively [204]. Gender did seem to have statistical relevance in influencing the acetabular width, with males displaying a generally wider acetabulum.

The acetabular index calculated in a study with *Estrela Mountain* dogs reported an average value of 55 [205]. That study measured the acetabular depth using the acetabular circle, thus the comparable parameter in this study is the AIc with an average value of 52,90, which is similar to the Estrela Mountain dog, that is not unexpected as both breeds (GS and Estrela Mountain dog) are considered to be large. German Shepherd dogs have been associated with having a deeper and less open acetabulum than, for instance, Labrador Retrievers, Boxers, and Saint Bernhards [215]. Therefore, it was also expected that the GS would have higher values of acetabular indices than those dogs.

Both indices correlated strongly to each other, just like the femoral head portion/acetabular depth ratios and the acetabular depths, which was expected given the very strong correlation between depths. The gender influence was not the same for both acetabular indices. The AIc had different average values for females and males that were found to be statistically significant p-value < 0,023. The same was not true for the AIk that displayed a p-value > 0,245. However, the dysplasia status had a statistically significant influence on the values of the AIc and AIk. The average values between dysplastic and non-dysplastic joints differ in around 12% in the AIk and 13% in the AIc. However, the results do not agree with the findings in *Estrela Mountain* dogs, where no statistically relevant difference was found between acetabular indices of dysplastic and non-dysplastic dogs [205].

In the AIc case, the non-dysplastic minimum value (48,43) was marginally more elevated than the dysplastic average (48,40). However, in the AIk, the non-dysplastic minimum (41,53) was relatively less elevated than the dysplastic average (43,21). This gives the information that using the indices alone to determine if a GS dog has is dysplastic or non-dysplastic may not be indicated.

Overall, gender seemed to influence the possibility of the GS dog being dysplastic or not in this group. More females were present in this study which might have influenced the previously stated fact. In addition, the average age of the males was higher, and as previous studies have stated, CHD prevalence increases in older animals [209]. This might help explain the higher prevalence registered in males, but also does the smaller number of males evaluated might have also had an impact.

6. Conclusion

The femoral and acetabular congruency is important in the coxofemoral joint, and it is one of the parameters evaluated in the grading of CHD. Thus, making those parameters more objective might help inexperienced raters and also help in borderline cases. In addition, having reference intervals or established correlations between some acetabular measurements might help to choose the acetabular cup when performing total hip replacements. These measurements might be more relevant when both joints are affected, and a total hip replacement is considered.

Nowadays, radiographs allow for better visualization of the anatomic landmarks because of the hardware and software evolution. Moreover, an x-ray machine is currently available in almost all clinics, and it is still the standard method to diagnose canine hip dysplasia. On the other hand, although CT scanners are becoming more popular, they are still not a primary diagnosis machine available in most clinics.

The acetabular index is a measure used in human medicine (in that case, it is named acetabular depth ratio or approximate acetabular quotient), and it has reference values in order to help in the diagnosing developmental dysplasia of the hip, which is the correspondent to CHD [25,216]. The author believes that building reference intervals for the acetabular index for the most common breeds that are greatly affected by CHD can be of help to anticipate the diagnosis or even improve the breeding selection process. Further investigation is warranted to define criteria and evaluate if the acetabular index can be a reliable measurement even when not performed by CT.

This study suggested statistically relevant differences between dysplastic and non-dysplastic dogs, particularly in the following parameters: Norberg angle, acetabular depth measured using the acetabular circle, acetabular depth measured as when obtained by computed tomography, the ratio between the acetabular depth and femoral head portion calculated by dividing the FHPc by the ADc, the ratio between the FHPk by the ADk, acetabular index using the ADc, and acetabular index using the ADk.

It also suggested statistically relevant differences between male and female German Shepherds, in the Norberg angle, the acetabular width, the FHPc, FHPk, and the AIc parameters specifically. Also, being male seemed to statistically influence the existence of dysplasia.

More studies on this topic should be encouraged to evaluate these and other parameters that might help narrow and increase the criteria's objectiveness to decide if a dog has or has not canine hip dysplasia and better chose potential breeders without limiting the gene pool too an extremely limitative point.

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