Investigation of possible causes of early development of osteoarthritis in Boxer stifles using computed tomography

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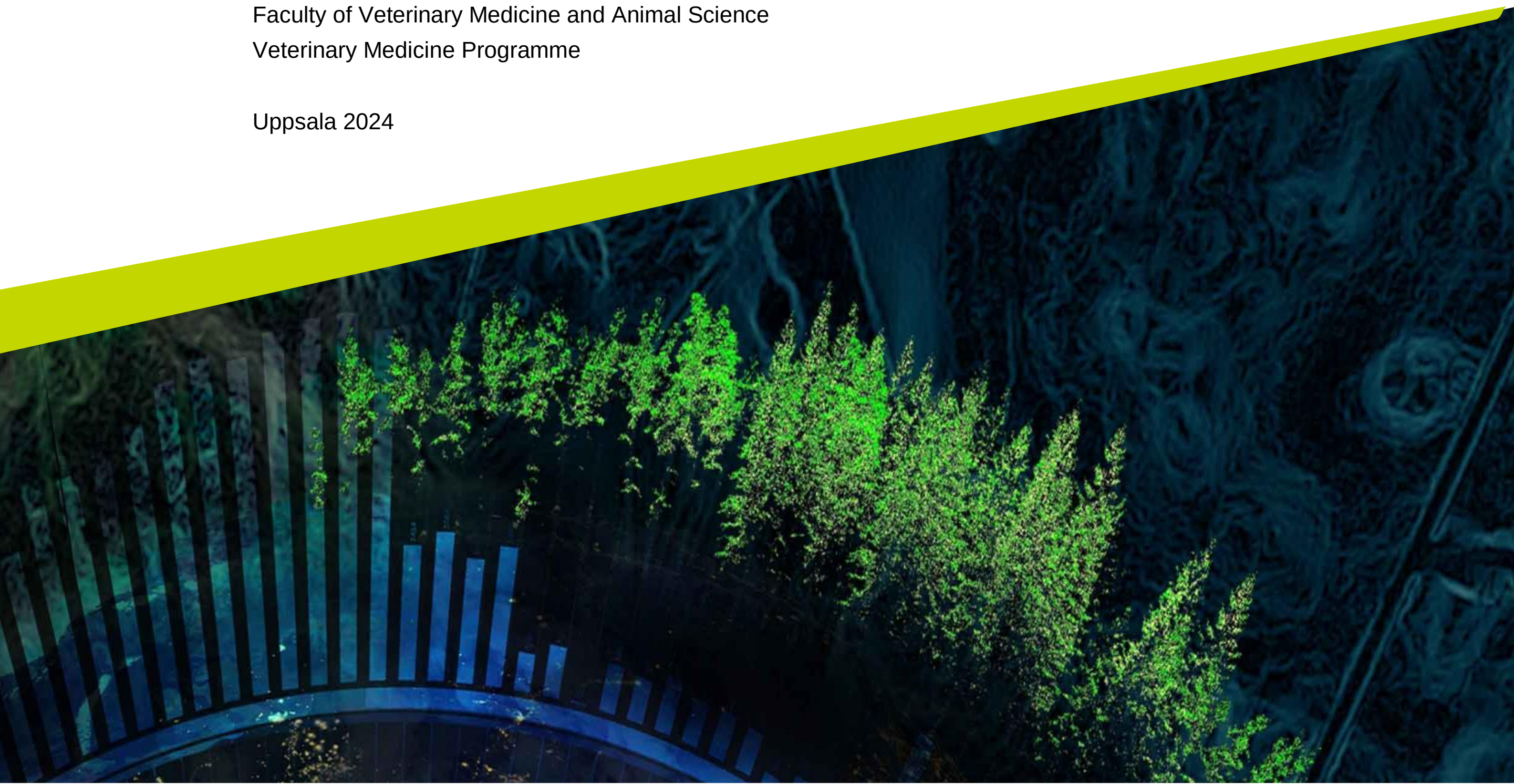

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Abstract

Boxer dogs are reported to suffer from an increased risk of orthopedic disease affecting the stifle such as osteochondrosis, cruciate ligament disease, patellar luxation and these diseases often lead to osteoarthritis, a disease affecting Boxers even at a young age.

This study aims to investigate possible causes of early development of osteoarthritis in Boxer stifles using computed tomography (CT). Other aims are to investigate whether the observed CT changes can be observed in radiographs as well as investigating the outcome in Boxers that participated in an official Swedish Kennel Club radiographic screening of Boxer stifles.

In the study, patient medical journals, CT images, and radiographs were collected from Evidensia Strömsholm Referral Small Animal Hospital. The CT images of 20 Boxers were assessed for presence of any abnormalities within the joint. Seventeen (85%) of the Boxers evaluated had presence of focal, well defined, hypoattenuating, round or branching tubular structures in one or both stifles in the intercondylar area of the femur and/or the axial aspect of the lateral condyle of the femur. Twelve (60%) Boxers had presence of osteophytes on the medial or lateral condyle of the femur. Twelve (60%) Boxers had presence of osteophytes and/or sclerosis on the proximal aspect of the tibia. Twelve (60%) Boxers had similar hypoattenuating structures to the ones found on the intercondylar surface of the femur but located on the tibia medial to the attachment of the cranial cruciate ligament. All stifles with a hypoattenuating structure located on the tibia had one located on the intercondylar and/or the axial aspect of the lateral condyle. In six stifles (15%) in five dogs, hypoattenuating structures in the stifle (found on the tibia or femur or both) were present without any presence of osteophytes.

In order to assess the presence of these CT hypoattenuating structures in radiographs and investigate if they were present in dogs with radiographically detectable osteophytes, radiographs from the Swedish Kennel Clubs (SKK) public database were used for seven dogs. Additional radiographs were collected for four dogs from Evidensia Strömsholm Referral Small Animal Hospital. In total, eleven dogs that had CT images also had radiographs that could be assessed. Nine (82%) had identifiable changes (osteophytes, increased volume of the soft tissue opacity or enthesophytes) in their radiographs. In five stifles of three individuals, the hypoattenuating structures seen on CT in the intercondylar and lateral condyle axial areas could be seen in the radiographs.

The outcome of dogs participating in the official Boxer stifle health program was assessed using a survey that current and past owners of Boxers could answer. Information was gathered regarding the participation in the health program, grade received, development of stifle problems and the diagnoses set by a veterinarian of any stifle problems. The survey generated 296 answers regarding the outcome of Boxers, 160 about Boxers that did participate in the official program and 136 that did not. Problems with one or both stifles developed in 46 (16%) of Boxers and 41 of these had diagnoses set by veterinarians. Thirty-eight dogs had problems with their left stifle and eleven had problems with their right stifle. Ten dogs were reported to have problems with both their stifles.

The results of this study cannot provide definitive conclusions regarding the underlying cause of early development of stifle osteoarthritis in Boxers, but it did identify new areas of interest such as the presence of hypoattenuating structures in the intercondylar and axial lateral condyle regions of the femur and their possible significance to lameness and development of osteoarthritis. To increase the understanding of the causes of stifle joint problems, future studies could investigate the microscopic morphology of hypoattenuating areas commonly seen in this study on the axial aspect of the lateral femoral condyle and in the intercondyloid region of the femur, and studies of CT images from stifles of other dog breeds can further investigate if these hypoattenuating areas are related to specific dog breeds.

Keywords: Boxer, CT, osteochondrosis, OCD, cranial cruciate ligament, hind limb lameness, CCLD, patellar luxation

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Abbreviations

BSI	Breed specific instructions
CCLD	Cranial cruciate ligament disease
CT	Computed tomography
ESRSAH	Evidensia Strömsholm Referral Small Animal Hospital
FCI	Fédération Cynologique Internationale
HD	Hip dysplasia
OA	Osteoarthritis
OC	Osteochondrosis
OCD	Osteochondrosis dissecans
OCM	Osteochondrosis manifesta
RAS	Breed specific breeding strategy
SLU	Swedish University of Agricultural Sciences
SKK	Swedish Kennel Club
TPA	Tibial plateau angle
TPLO	Tibial plateau leveling osteotomy

1. Introduction

The Boxer breed was developed during the 19th century in Germany but was not recognized as a breed by the Fédération Cynologique Internationale (FCI) until 1955 (Fédération Cynologique Internationale, n.d.). It is a molosser breed of mastiff type and is classified as a working breed within FCI's classification of breeds. The peak of its popularity in Sweden was during the 60s and 70s (Svenska Boxer-klubben, 2018b).

Orthopedic problems affecting the stifle have frequently been reported within Boxers (O'Neill et al., 2023). Development of lameness from the stifle can be caused by multiple diseases, such as, but not limited to osteochondrosis, cruciate ligament disease, patellar luxation, trauma, septic arthritis or due to underlying biomechanics and conformation of the stifle. In many cases this progresses to osteoarthritis (OA), the end stage of joint disease with osteophyte formation.

Because of this, in 1995 the Swedish Boxer Club applied to the Swedish Kennel Club (SKK) to start a health program for Boxer stifles using radiographs. The health program was launched January the 1st 1996 and as time went on, the requirements of the health program became stricter demanding both the dam and the sire to have a result without any signs of OA while initially mild OA was allowed (Svenska Boxerklubben, 2018a). The efficacy of the health program was questioned by the veterinary scrutinizers at the SKK and on July 1st 2019, the official health program was ended (Svenska Boxerklubben, 2018a; Svenska Kennelklubben, 2019).

Health programs of joints in dog breeds aim to identify hereditary defects that cause suffering and traditionally this has been done using radiographs. Computed tomography (CT) enables much higher detail of the joint compared to radiography since it overcomes the problem of summation (Soler et al., 2007; Marino and Loughin, 2010).

The primary aim of the study is to investigate possible causes of the early development of OA in Boxer stifles using CT. A secondary aim is to investigate if CT changes that are suspected to be the underlying causes of OA can be detected in radiographs acquired prior to the CT. A tertiary aim is a survey to investigate the outcome in Boxers that have had an official screening of their stifles.

2. Literature overview

2.1 The Boxer

2.1.1 Breed standard and conformation comparison

The Boxer is a medium sized, sturdy dog, characterized by its athletic, compact, square build and distinctive brachycephalic head (Fédération Cynologique Internationale, 2008). The breed standard puts great emphasis on the Boxer being a moderate breed – neither too heavy nor light. Important proportions include the squareness of the build, depth of chest as well as length of nose bridge.

According to the breed standard, the general appearance of the hindquarters should be very muscular, with the hindlegs being straight as seen from the rear (Fédération Cynologique Internationale, 2008). The thigh should be long and broad with the angle of hip and knee open. The stifle would ideally touch a vertical line from point of hip to ground. The hock should be well defined with an angle of approximately 140 degrees. The rear pasterns (metatarsus) ought to have slight inclination with 95–100-degree angle to the ground.

The build of the Belgian shepherd has been previously used as a control meant to represent a wolf-like build (Fischer et al., 2018). In comparison to the Boxer, the Belgian shepherd breed standard calls for perfectly parallel hindquarters as seen from behind, the thigh being medium long and just like the Boxer, the stifle should be on the vertical line from the hip. The lower thigh is of medium length, the hocks having moderate angulation (Fédération Cynologique Internationale, 2002). This would mean that the main differences in the conformation of hind quarters between a Boxer and a wolf is the length of the upper and lower thigh as well as the angle of stifle and hocks.

2.1.2 General health status of Boxers

Similar to other breeds, the limited genetic pool and conformation of the Boxer breed predisposes Boxers to several diseases. A retrospective study done in the UK showed that the most prevalent disorder group was skin disorders (17.74%) followed by neoplasia (14.20%), ear disorders (10.41%), mass lesions (10.10%) and ophthalmological disorder (9.94%) (O'Neill et al., 2023). In the same study, 8.88% Boxers suffered from various orthopedic issues. In a study of insured Swedish dogs, Boxers had the highest relative risk of stifle joint disease (RR 3.56) (Engdahl et al., 2021a). In a different study of the same population, Boxer dogs had an increased risk ratio of cruciate ligament rupture (RR 2.71) (Engdahl et al., 2021b).

According to the Breed specific breeding strategy (RAS) for Boxers made jointly by the SKK and Swedish Boxer club, the health areas to be prioritized in breeding Boxers in Sweden from 2017 are hip dysplasia (HD), stifle joint disease, spondylosis, and cardiac disorders (Svenska Boxerklubben 2017). The Breed Specific Instructions (BSI) from the Nordic Kennel Clubs list both breathing problems due to brachycephaly and skin irritation and discolorations as risk areas that dog show judges should pay extra attention to (The Nordic Kennel Clubs, 2018).

2.2 Anatomy of the canine stifle

The canine stifle is a condylar join composed of the femorotibial, femoropatellar, and proximal tibiofibular joint. The primary motion of the stifle is flexion and extension; however, the stifle also has range of motion in other planes (Carpenter Jr and Cooper, 2008). The mean angle of the stifle in dogs is 145° at extension (Giansetto et al., 2022; Decamp et al., 1993).

The bones of the stifle joint include the distal femur, proximal tibia, proximal fibula as well as four sesamoid bones, the patella being the largest of them. Three surfaces on the femur are included in the stifle – the femoral trochlea as well as the medial and lateral femoral condyles. The trochlea is located on the cranial surface of the femur and is continuous with the condyles (Carpenter Jr and Cooper, 2008).

The patella is held in the femoral trochlea by the lateral and medial femoral fascia as well as the femoropatellar ligaments. The patellar tendon is a part of the insertion of the quadriceps femoris muscle group (Carpenter Jr and Cooper, 2008). The medial and lateral collaterals as well as the cranial and caudal cruciate ligaments are the ones primarily responsible for stability of the stifle. Rupture of the cranial crucial ligament is a common musculoskeletal disease with high incidence (Johnson et al., 1994).

The proximal end of the tibia, often referred to as the tibial plateau, is divided into medial and lateral condyles. The condyles vary in shape with the medial one being more oval while the lateral is more rounded. Caudally the condyles have a small indentation called the popliteal notch. Cranioproximal on the tibia is a ridge called the tibial tuberosity where the patellar ligament inserts. The fibulas' primary function is to serve as a site for muscle and ligament attachments (Carpenter Jr and Cooper, 2008).

The menisci are fibrocartilaginous cushions positioned between the surface of the joint of the femur and tibia. There is a medial and a lateral one. The menisci absorb energy, stabilize the joint and transfer stress across the stifle joint (Canapp Jr, 2007).

2.3 Diseases affecting the stifle joint

The stifle is a complex structure and a frequently injured joint in dogs. This section of the literature study will primarily focus on stifle joint diseases that affect young dogs including OA, which is the end stage of many of these diseases.

2.3.1 Osteoarthritis

Osteoarthritis is the end stage of joint disease with degeneration of the joint and osteophyte formation caused by long term micro- and macro-injury (Osteoarthritis Cartilage, 2015). Underlying disease within synovial joints such as damage to the surface of the joint; instability within the joint; and/or mechanical injury, can over time lead to OA (Meeson et al., 2019). This process is initiated by biochemical changes within the joint and can be differentiated into two categories; the slowly progressing spontaneous one where age, obesity and repeated strain on the joint increases the risk of developing OA, and the rapidly advancing one that has been observed experimentally after introducing trauma to the joint (McDevitt and Muir, 1976; Liu et al., 2003; Meeson et al., 2019). Studies show that the changes in proteoglycans levels in the cartilage of dogs with spontaneous vs experimentally traumatically induced OA vary significantly, suggesting that the mechanism that causes OA in these two instances differ from each other (McDevitt and Muir, 1976; Liu et al., 2003).

The clinical prevalence of OA in dogs varies in reports from 2.5% in annual period prevalence (Anderson et al., 2018) to over 20% in dogs over 1 year old (Johnston, 1997). There are several influencing factors, such as breed, body size, obesity, feeding schedule, sex, neuter status and age (Smith et al., 2006; Runge et al., 2008; Huck et al., 2009; Yusuf et al., 2009; Anderson et al., 2018). Boxers and dogs weighing more than 35kg have been shown to have more severe OA in the stifle when diagnosed with cranial cruciate ligament injury, suggesting a larger body mass contributes to an increase in OA formation when a ligament is injured (Gilbert et al, 2019). The pathogenesis of obesity related OA has been suggested to be caused both by the biomechanical effects of increased weight on the joints as well as adipose tissue promoting systemic low-grade inflammation (Yusuf et al., 2009; Francisco et al., 2017). Canine adipocytes have been shown to express adipokines that promote inflammation, thus supporting the idea that obesity can drive metabolic factors that promote OA (Ryan et al., 2010).

2.3.2 Osteochondrosis

Osteochondrosis (OC) is caused by a failure of endochondral ossification. Cartilage canals supply cartilage in the epiphysis with blood and nutriments, and during growth, these canals regress as the cartilage chondrifies and ossifies (van Weeren and Olstad, 2016). As the ossification center advances to surround the cartilage canal, the vessels become reliant on supply from an artery that needs to cross the ossification center before it can enter the cartilage canals (van Wereen and Olstad, 2015). It has been suggested that supplying arteries may be particularly prone to damage where they traverse the ossification center due to the sharp stiffness gradient of the ossifying bone (Olstad et al., 2008). Lack of oxygenated blood leads to ischemic necrosis of the ossifying cartilage, also known as osteochondrosis latens (Olstad et al., 2015). This causes failure of endochondral ossification and over time becomes clinically apparent as osteochondrosis manifesta (OCM). Traumatic forces, even very mild ones, can cause a cartilaginous flap to form or dislodge from the bone, known as osteochondrosis dissecans (OCD).

There are several predilection sites for OC in dogs. The primary sites of occurrence are the shoulder, elbow, stifle, and hock (Novotny and Runyon, 1986) however it can occur in other joints as well (Thibault et al., 2023). In the stifle, the most common site of occurrence is the femoral condyles, the lesions being more common on the lateral condyle where the distal articular surface is flattened and irregularity of the condyle can be seen as well as possible free fragments within the joint if the cartilaginous flap have dislodged (Bradley, 2011). Osteochondrosis dissecans of the stifle usually affects dogs between three and nine months of age (Novotny and Runyon, 1986) but can also be diagnosed much later (Necas et al., 1999).

2.3.3 Diseases in the stifle joint related to biomechanics

The biomechanics of the stifle includes its structure and motion. The cranial tibial thrust is a force produced by the tibia compressing during movement that results in cranial translation of the tibia. This is a force that the cranial cruciate ligament is directly responsible for counteracting. The tibial plateau angle is important for the distribution of force during canine movement as it’s related directly to the amount of cranial tibial thrust (Fujita et al., 2006).

Caudal angulation of the proximal tibia results in an abnormally high tibial plateau angle and is associated with rupture of the cranial cruciate ligament (Read and Robins, 1982). The tibial plateau angle and shape varies by breed due to skeletal conformation (Seo et al., 2020). Normal tibial plateau angle (TPA) has been reported to vary between 18.1-25.0° in large breed dogs, while dogs suffering from rupture of the cranial cruciate ligament having significantly higher tibial plateau angles (Seo et al., 2020). In one study, a tibial plateau angle of 22.6° or greater was associated with an increased risk of rupture of the cranial cruciate ligament (Slocum and Devine, 1983). Labrador retrievers have been reported to have a very high (27.97°) angle and to be at higher risk for rupture of the cranial cruciate ligament (Engdahl et al., 2021a; Todorovic et al., 2022). It has been suggested that high TPA can be considered a good predictive factor for rupture of the cranial cruciate ligament (Seo et al., 2020). Reif and Probst (2003) reported however that TPA in Labrador retrievers with or without cranial cruciate deficient stifles were not statistically significant.

In a 2013 study of tibial plateau geometry, it was seen that Boxers had a larger lateral condyle area than terrier and mixed breeds (Ocal et al., 2013). The study suggested that this would give a greater tibial rotation followed by cranial cruciate ligament injury. In the same study, Boxers had a relatively small tibial tuberosity compared to other breeds, suggested to cause greater strain on the patellar ligament from the quadriceps muscle. The straight legged conformation of the Boxer has been suggested in another study to play a role in the pathophysiology and clinical expression of cranial crucial ligament disease (Gilbert et al., 2019).

Other biomechanical aspects that should be considered in stifle joint disease are instability of various types; muscle weakness; malalignment; conformational changes; and distorted joint contact areas (Cook, 2010).

2.3.4 Cruciate ligament disease

Caudal cruciate ligament rupture occurs infrequently in dogs and is most commonly associated with trauma (Johnson and Olmstead, 1987; Harari, 1993), while cranial cruciate ligament disease (CCLD) is more commonly seen and more frequently not associated with trauma. As CCLD includes progressive degeneration of the joint with the presence of osteophytes, synovial hyperplasia, cartilage degeneration and subchondral bone sclerosis, it is considered a disease of the whole joint rather than just of the ligament (Cook, 2010).

Disease affecting the cranial cruciate ligament is the most frequently diagnosed condition of the stifle and one of the main causes for hindlimb lameness in dogs (de Rooster et al., 2006). Rupture of the cranial crucial ligament in dogs is most often a result of a degenerative process over time that leads to progressive lameness and OA (Cook, 2010). A conclusive cause for CCLD is unknown at this point but has been presumed to be an amalgamation of dysfunction in the biology and biomechanics of the stifle. Rupture of the cranial cruciate ligament has also been reported to occur from a single traumatic event (Cook, 2010).

There are many predisposing factors for developing CCLD. The most studied factors have been breed, sex, age and conformation of the stifle. Several breeds (including the Boxer) have been listed multiple times as having a higher risk for developing CCLD (Baker and Muir, 2018; Engdahl et al, 2021b, Spinella et al., 2021). Dogs with hyperextended position of the hindlimbs with highly open joint angles (such as seen in the Boxer breed [Fédération Cynologique Internationale, 2008]) have been observed to have a higher risk for CCLD (Zink and Carr, 2018).

In humans, it has been observed that caudal cruciate ligament injuries lead to early onset of OA due to cartilage breakdown progressing to OA, however the mechanism is not fully understood (Friel and Chu, 2019). Additionally, the lack of a fully functional cruciate ligament leads to chronic changes in the stress put upon the stifle, causing increased forces on the stifle cartilage and meniscus which potentially leads to OA (Andriacchi et al., 2004).

2.3.5 Patellar luxation

Patellar luxation is a very common orthopedic condition in dogs, where the patella luxates from its normal position in medial or lateral direction, or both. In the vast majority of cases (75-80%) the patella luxates medially (Harasen, 2006) and this is typical for smaller breeds. In larger breeds, the luxation is also most commonly medial but the frequency of lateral luxation is much higher than in smaller breeds (Harasen, 2006). However, Boxer is a larger breed where the number of young dogs shown to suffer from medial patellar luxation has increased over time (Harasen, 2006; Alam et al., 2007; Bosio et al., 2017).

Common causes for patellar luxation include deviations in the conformation of the tibial crest, tightness of the quadriceps muscle, patella alta and shallow trochlear groove (Alam et al., 2007). It is common for OA to develop as a result of patellar luxation because of the increased stress on other structures in the stifle during luxation, such as the CCL (Alam et al., 2007). Medial patellar luxation has been reported to increase the stress on the CCL, predisposing it to degeneration and rupture (DeAngelis et al, 1970). While patellar luxation can be traumatic, most cases are considered developmental as they occur during adolescence and anatomical deformities causing the luxation can be identified as early as puppyhood (Bosio et al., 2017).

2.3.6 Septic arthritis

Septic arthritis is not as common among dogs as in other species; however it is likely to be underdiagnosed as it can be mild and manifest as a mild chronic lameness (Marchevsky and Read, 2008). In a retrospective study of 31 dogs with bacterial septic arthritis, the stifle was the joint most commonly affected (Clements et al., 2005).

The source of the infection can arise from direct penetration into the joint due to trauma or surgery or through hematogenous spread. Cases of spontaneous septic arthritis have also been reported (Mielke et al., 2018). While a study showed a 94% success in clearing the infection, they also reported that normal joint function can seldom be restored (Clements et al., 2005). Resolving the septic arthritis without developing long-term OA has been reported to be challenging (Hewes and Macintire, 2011). A case study showed that OA can develop rapidly in a joint after being treated for septic arthritis despite the joint being normal at the start of injury (Hewes and Macintire, 2011).

2.3.7 Traumatic injuries to the stifle

Traumatic injuries to the stifle can cause several of the diseases mentioned above such as rupture of the cruciate ligaments, patellar luxation, septic arthritis, as well as changes in the biomechanics.

2.4 Diagnostic imaging

2.4.1 Computed tomography

Computed tomography allows for an image of a single slice of body to be produced (Marino and Loughin, 2010). It is a noninvasive technique that allows the images to be reconstructed in any plane or as 3D images. A CT system consists of a source of x-rays, a table, an x-ray detector and a data processing unit for computation of the data (NIBIB, 2022).

A narrow beam of x-rays is aimed at the structure of interest and quickly rotated around the body. Computed tomography scanners use digital x-ray detectors located directly opposite to the x-ray source to receive the x-rays leaving the structure. The signals received by this is processed by the machine which allows it to generate cross-section images of the structure, also known as “slices”. These slices can give more detailed information than conventional radiology and be digitally processed to give a three-dimensional image of the structure of interest (National institute of Biomedical Imaging and Bioengineering, 2022).

In order to enhance osseous structures, a wide window width can be used, while a narrow one provides better definition of soft tissues (Soler et al., 2007). Measurements in CT studies are also more reproducible than those performed on radiographs (Todorovic et al., 2022).

2.4.2 Computed tomography of the stifle

Computed tomography enables better definition of the different components of the joint compared to radiography due to an improved resolution of anatomic structures and lack of superimposition of tissues (Soler et al., 2007; Marino and Loughin, 2010). Sammi and Dyce (2004) showed that it was possible to identify cranial and caudal cruciate ligaments, medial and lateral meniscus, patellar tendon and the medial and lateral collateral ligaments in transverse CT images without arthrography and that multiplanar reconstruction allowed some limited evaluation of the continuity of the cruciate ligaments and menisci.

Computed tomography is also superior to radiography when it comes to imaging osseous structures. As an example, imaging of the intercondylar notch using CT is more reliable compared to radiographs (Marino and Loughin, 2010). Radiography imaging of the width of the intercondylar notch is more inconsistent compared to CT and tends to underestimate its size when compared to gross measurements (Fitch et al., 1996).

In pigs conventional CT has been successfully used to assess and longitudinally follow osteochondrosis dissecans and manifesta lesions (Olstad et al., 2014). Detection of osteochondrosis latens is reported in an ex vivo contrast-enhanced micro-CT study of foals (Olstad et al., 2008) but osteochondrosis latens is not detectable in vivo without contrast using conventional CT.

Computed tomography is also superior to conventional radiology in assessing the tibial plateau angle of the stifle. The margin of error of the angle decreases to less than 3 degrees with CT compared to up to 14 degrees with conventional radiology (Todorovic et al., 2022).

2.4.3 Diagnostic imagine as a tool for health screening

All health programs of joints in dog breeds aim to address hereditary defects that cause suffering and traditionally this has been done using radiographs. The first ever health screening procedure using diagnostic imaging originated in Sweden during the 1950's. The screening was used to screen German shepherds belonging to the breeding colony of the Swedish Armed Forces for HD (Hedhammar, 2020). Since then, many radiological screening programs for dogs have developed using radiography to screen primarily for hip and elbow dysplasia. Screening methods for other non-joint related diseases such as genetic testing, are widely available today and many private laboratories offer breed specific genetic tests. Future studies aim to be able to identify genetic features of HD thanks to genome wide association studies which would allow for genomic selection of less dysplastic hips (Hedhammar, 2020).

To the best of the author's knowledge, there are no current CT screening programs aimed at selecting or removing dogs from pedigree breeding populations. However, CT scans are today used in the Norwegian pig industry to select against OC by screening the breeding population for the presence of OCM lesions (Olstad et al., 2022). Historically the breeding value for boars was based on pedigree and macroscopic scoring of osteochondral lesions in the slaughterhouse. This changed in the late 00s, when a breeding company started using whole-body CTs of boars to quantify the percentage of lean meat and fat (Gjerlaug-Enger et al., 2012). This allowed scoring of osteochondral lesions using the same images and with that, CT became a tool for screening boar candidates in the breeding program (Aasnunstad et al., 2013). In order to standardize the screening, a whole-body scan is carried out at 120kg live body weight and the scoring of osteochondral lesions is performed in the elbow and stifle. While this is today done manually, the aspiration is to develop an algorithm that will perform this, thus making the screening more cost effective (Olstad et al., 2022).

2.5 Stifle joint health program in Swedish Boxers

During the 80's, stifle disease in Boxers started to gain attention. Veterinarian Lars Audell radiographed multiple puppies and young dogs in order to try to find a screening method to decrease the prevalence of stifle disease within the Boxer breed (Svenska Boxerklubben, 2018a). In 1987 he initiated a trial screening of Boxer stifles and in 1995 the Swedish Boxer Club applied to the SKK to start a health program for Boxer stifles following the original evaluation made by Lars Audell (Svenska Boxerklubben, 2018a). The health program was initiated in July 1996 and initially the program just required that both the dam and sire had been screened for the puppies to be able to be registered within the SKK. The requirements became stricter in January 2006, demanding both the dam and the sire to have a result without any signs of OA (Svenska Boxerklubben, 2018a).

The screening included sending a single medio-lateral projection of each stifle joint to the official SKK veterinary radiologists who graded the stifles. The grading ranged from 0-3, where grade 0, or "without remark", meant that no osteophytes could be seen, grad 1 representing mild presence of osteophytes, grade 2 representing moderate presence of osteophytes while grade 3 represented severe osteophyte formation in the stifle joint (Svenska Boxerklubben, n.d.). The screening focused solely on the formation of osteophytes in the joint and other identifiable pathologies such as soft tissue swelling, subchondral defects, subchondral cyst-like lesions, and sclerosis, were not considered (Bradley, 2011; Innes et al., 2004; Svenska Kennel Klubben, 2016). The minimum age for a Boxer to be screened was 12 months, with the average age between the years 2004-2010 being 16-18 months (Svenska Boxerklubben, n.d.)

In 2016, the SKK veterinary radiologists announced that they considered the current health program not optimal due to it not detecting the underlying cause of the Boxer stifle problems (Svenska Kennel Klubben, 2016). They reported that the health program did not give information that is reliable in helping breeders reduce the incidence of stifle joint disease. It was decided by the SKK Breeding Committee that, starting on July 1st, 2019, the official health program would end and as such, the dam and sire no longer needed to have the stifles screened prior to breeding (Svenska Boxerklubben, 2018a; Svenska Kennelklubben, 2019). This decision was opposed to by the Swedish Boxer club as they considered the health program a success due to the decreasing number of Boxers graded 1 and higher since the screening was initiated (Svenska Boxerklubben, 2018a).

The Swedish Boxer Club continued the stifle screening unofficially starting fall/winter 2020. This stifle screening consists of 3-4 radiographs; a medio-lateral projection with the joint lightly flexed and a caudocranial/craniocaudal per stifle. If the images are taken at the same time as HD screening, then it is acceptable to just send in the ventro-dorsal projection taken of the hips, as long as both stifle joints are completely included in the image and the dog is not planned to be bred in the future. If the purpose of the screening is to use the individual in breeding, separate caudocranial/craniocaudal projections of each stifle joint are required. The radiographs are sent to a veterinarian who grades the stifles. The grading goes from "without remark" to "severe OA", with no numerical grading. The grading is sent to the Swedish Boxer club that publish the result on their website and notifies the dog owner.

A previous study on Boxer stifles observed that majority of owners of Swedish Boxers did not consider stifle problems were an issue within Boxers compared to other breeds (Rebhan, 2022). An earlier study (Wistedt, 2006) pointed out that the decreasing trend of the official grading of Boxer stifles was likely due to the initial sampling of older affected dogs vs more random sampling of a larger portion of the population and decreased age when graded which would result in an apparent downward trend in OA rather than an actual improvement in the stifle status of Boxers.

3. Materials and methods

This study was done at the Department of Clinical Sciences at the Swedish University of Agricultural Sciences (SLU) and at Evidensia Strömsholm Referral Small Animal Hospital (ESRSAH). The study was done in two parts.

- A survey directed at past and present Boxer owners in Sweden
- Collecting CT cases of Boxer stifles from ESRSAH

Apart from providing voluntary contact and dog identification information in the survey, the data collected is presented so that no connection can be made to a specific case, dog, or owner.

3.1 The survey

The survey was a multiple-choice questionnaire with free text section for the pedigree name/number and owner email address, created using Netigate and the link for it was distributed by email to breeders associated with the Swedish Boxer Club and through social media (Facebook groups aimed at Boxer aficionados). The survey questions were created by the student responsible for the study with help from the supervisors. Before the survey was distributed, a test version was approved by the supervisors and the board of the Swedish Boxer club.

The study was aimed at both current and previous owners of Boxer dogs registered in SKK, regardless of whether their dog had been part of the official health program for Boxer stifles or not. The study required one answer per dog and as such, an owner could fill out the survey multiple times if they had had several Boxers. Boxers who were no longer alive at the time of the survey were included and no specific time period was targeted. Apart from respondents having the option of providing voluntary contact and dog identification information, the survey responses were anonymous. The voluntary contact information was included for owners who were interested in participating in future studies and the dog's registration number was used to check the results of the health program for Boxer stifles in cases where the owners didn't remember the grading.

The multiple-choice questions and options (possible answers) are presented in Appendix 1. The survey included so called “logic” which meant that depending on the answer given, different question followed.

3.2 Computed tomography cases from Evidensia Strömsholm Referral Small Animal Hospital

3.2.1 Selection of cases

When visiting ESRSAH, animal owners gave consent for the use of their animal’s medical journals and images for research. The student gained permission from the hospital to use images and medical journals at the beginning of the study. The selection of cases was done by manually checking the CT logs from the radiology department at ESRSAH between 2002-2022, looking for Boxers whose examination included at least one stifle. Journal records and CT images were copied into a database.

In cases where a SKK registration number was available (or accessible through the dog’s microchip number), the SKK public database was used to determine if any of the dogs had been a part of the official health program for Boxer stifles. After the dogs with official screening results had been identified, one of the supervisors obtained official permission from SKK to access and retrieve their archived radiographs for those individuals. No personal information regarding the owners was collected. As the journal number of the dog could be connected to a specific owner, the data was coded in Microsoft Excel 365.

3.2.2 Information regarding the cases

The following data was collected for the CT image cohort

- Case record number (not presented in the study)
- Name of the dog (not presented in the study)
- Sex of the dog
- Year of birth
- Age at which the Boxer had its CT examination
- The radiographic evaluation of the stifles from ESRSAH
- Whether the dog had a history of hindleg lameness
- Whether the dog had any stifle surgery and if so, the surgery report if available
- Whether any histology was performed on the lesions in the stifle (if applicable)

- Whether the Boxer had any other performed on their stifles
- Whether the Boxer was a part of the official SKK health program for Boxer stifles
- The grade the Boxer received in the official SKK health program for Boxer stifles (if applicable)

3.2.3 Evaluation of the radiographic and computed tomography images

One of the supervisors assessed the radiographs of the dogs that had been included in the official SKK health program, and that were still available in the SKK archives. The radiographs were evaluated by the supervisor for the presence of any identifiable stifle lesions. The images available consisted of a mediolateral project-tion of each stifle joint. In cases where hip screening images were available with the stifle joints partly or completely included, those images were also evaluated, thus providing a craniocaudal projection of the stifles. In cases where radiographs of the stifles were available from ESRSAH, these were evaluated by the student and supervisors together with the CT images.

The supervisor group and the student together evaluated and discussed the CT images for stifle abnormalities. At the time of evaluation, the supervisors were not aware of any information from the patient journal except the age of the dog. The entire joint was evaluated in both bone and soft tissue windows and algorithms using three-dimension multiplanar reconstruction. The assessment included evaluation for the presence of periarticular osteophytes, subchondral bone hyper/hypo-attenuation, focal subchondral hypoattenuation considered to be cyst-like lesions, increased volume of soft tissue attenuation within the joint space, and separate mineral attenuations within the joint space. Lesions that had a typical appearance for OC were recorded. Osteophytes were graded as non-present, mild, moderate or severe. Changes seen on radiographs or CT images were compared to the other modality to see whether the abnormalities could be detected there. The grading of the images was recorded by the student in Microsoft Word 365 during the grading process and screenshot images recorded as examples of the detected lesions.

3.3 Analysis of data

All data from both the survey and the cases from ESRSAH were transferred to Microsoft Excel 365 where it was processed. All the tables and figures in this study were made in Excel. The results of the survey and evaluation of the images are presented as descriptions of frequencies of changes including tables and figures.

4. Results

4.1 Survey

The survey was open for 14 days between 17-30th October 2023 and generated 302 responses. Not all questionnaires were correctly and/or completely answered and as such the total number of answers per question varied. Only 150 out of the 302 questionnaires had complete answers to all questions. Incomplete surveys were, when possible, included in the results. Two of the Boxers that participated in the survey had done a CT study of the stifle joints at ESRSAH.

4.1.1 The number and participation in the official health program

Of the 302 questionnaires, 300 had an answer to the question regarding participation in the official health screening program for Boxer stifles. Participation was stated by the owner in 162 (54%) cases; of these cases 150 (94%) received grade 0, four (3%) received grade 1, two (1%) received grade 2 and none received grade 3. Three owners did not remember what grade their dog had been given and an additional three owners did not continue with the survey past the question regarding participation in the health program.

For these six dogs the grading results were searched for in the SKK's public database (Hunddata) using the pedigree name and/or number that the owner had given in the questionnaire. Three of these Boxers received grade 0, one received grade 1 and one did not have a published result and therefore couldn't have been part of the official health program. The sixth couldn't be found in the database due to incorrect pedigree name/number. Adding this information to the previously stated numbers gives a total of 160 dogs in the survey with an official screening result, either confirmed or stated by the owner (Table 1). Of these, 153 (96%) dogs were given grade 0, five (3%) were given grade 1, two (1%) were given grade 2 and none grade 3.

__Table 1:__ Number of Boxers in the survey and whether they were screened in the Swedish Kennel Clubs official stifle health program.

Participation in the official health program	Number of dogs that participated in the survey
Participated	160
Did not participate	139
Unknown participation	1
Total number of Boxers	300

The survey answers were evaluated for the participation and grading, or lack thereof, in the official Boxer stifle health program and whether they had developed problems with one or both stifles at the time of the survey. Of the 302 questionaries, 296 answered whether the dog had developed stifle problems with one or both stifles. As seen in Table 2, 46 (16%) dogs had developed problems with one or both stifles.

__Table 2:__ Number of Boxers in the survey, their participation in the official health program, their grading and subsequent development of problems with one or both stifles. The percentage of dogs developing problems with one or both stifles represents the percentage within that grading.

Grading in the health program	Developed problems with one or both stifles		Did not develop problems with one or both stifles	
	Number of cases	%	Number of cases	%
Grade 0 (n=154)	23	15	131	85
Grade 1 (n=4)	2	50	2	50
Grade 2 (n=2)	2	100	0	0
Grade 3 (n=0)	0	-	0	-
Did not participate (n=136)	19	14	117	86
Total number	46		250	

4.1.2 Diagnoses of stifle diseases of Boxers participating in the study

Of the 46 Boxers that developed problems with one or both stifles, one didn't have a confirmed diagnosis and two owners did not remember their dog's diagnosis at the time of the survey. Two owners did not visit a veterinarian regarding the problems in the stifles of their dog. All the diagnoses reported by the owner were specified to have been determined by a veterinarian and the most common diagnoses were arthritis/OA (50%) and cruciate ligament disease (45%) as seen in Table 3. Five dogs were reported to have both arthritis/OA and cruciate ligament disease, where one dog had both bilaterally. None of the dogs in the survey were reported to suffer from tumor diseases in the stifle. The only case where the owner of a dog answered that the dog received diagnosis of "other" was one of the dogs that did not have a diagnosis.

Table 3: *Number and percentage of Boxers in the survey that developed problems with one or both stifles and the diagnosis set by a veterinarian. If a Boxer had multiple diagnoses, it appears in several columns. A total of 41 dogs had diagnoses set by veterinarians.*

Grading in the health program	Osteochondrosis/ developmental disorders of the stifle	Arthritis/ Osteoarthritis	Cruciate ligament disease	Patellar luxation
	Number of cases (%)	Number of cases (%)	Number of cases (%)	Number of cases (%)
Grade 0 (n=19)	3 (16)	10 (53)	12 (63)	0
Grade 1 (n=2)	0	2 (100)	0	1 (50)
Grade 2 (n=2)	0	2 (100)	1 (50)	0
Grade 3 (n=0)	0	0	0	0
Did not participate (n=18)	3 (17)	9 (50)	8 (44)	2 (11)
Total number	6	23	21	3

Bilateral stifle problems were reported in 10 dogs, while 38 dogs reported had problems with their left stifle vs 11 having had problems with their right stifle (Table 4). Osteochondrosis/OCD/developmental disorders in the stifle was reported to occur in six (15%) of Boxers that developed problems, and in all those cases the diagnosis was given to the left stifle joint.

Table 4: *The occurrence of diagnoses in Boxers included in the survey suffering from problems with their right and/or left stifle. If a Boxer had several diagnoses, it could appear in several rows. A total of 41 dogs had diagnoses set by veterinarians. 10 Boxers had diagnoses set bilaterally.*

Diagnosis set by veterinarian	Left	Right
Osteochondrosis/OCD/developmental disorders in the stifle	6	0
Arthritis/Osteoarthritis	22	4
Crucial ligament disease	21	6
Patellar luxation	2	1
Tumor	0	0
Other	0	1
Do not know	1	2
Diagnosis could not be set	0	1
Total number of diagnoses	52	15
Total number of dogs	38	11

4.2 Cases from Evidensia Strömsholm Referral Small Animal Hospital

4.2.1 Total number, diagnoses, and participation in the official health program

Twenty-four Boxers had a CT examination of their stifles performed at ESRSAH between 2004-2022. The majority of them (n =20) were adults (2 years or older), four individuals were over 8 years of age, and four individuals were under 2 years of age (2-23 months). Twenty (83%) of the dogs presented with a history of lameness. One dog had a history of trauma, another of ataxia and a third of neoplastic changes. The records of one dog were corrupted and could not be accessed. All dogs with a history of lameness except for one were diagnosed with stifle disease according to the patient journal. The most common radiological diagnosis from the patients' journal was OA (60%).

Of the 24 Boxers, 16 dogs had their microchip number in the hospital journals. Three of these did not have their identification number registered in SKK's public database (Hunddata). Eight were identified to have been a part of the official health program for Boxer stifles. The dogs that had participated in the official health program had all received grade 0, meaning no visible periarticular osteophytes. Five of the dogs had digital radiographs and three had analog radiographs. For one dog with analog radiographs, the images had been discarded by the SKK because they were over 10 years old.

Of the 24 cases identified above, 20 had CTs that could be evaluated in accordance with the areas described under methods. Of the four cases that could not be evaluated, two suffered from stair-step artifact and two could not be evaluated due to the young age of the dog and ossification stage of the stifle.

4.2.2 Computed tomography image evaluation

Table 5: *Evaluation of 20 Boxers' right (R) and left (L) stifles using computed tomography images for presence and location of the findings: osteophyte (o), hypoattenuating structure (h), sclerosis (s), luxation (l), subluxation (j); and presence (x)/absence (blank) of increased soft tissue attenuation volume in the stifle joint; and presence (x)/absence (blank) of osteophyte/s anywhere in the joint.*

Case number	Medial condyle and lateral part of the lateral condyle of the femur		Intercondylar surface or/and axial surface of the lateral condyle of the femur		Proximal surface of the tibia		Femoral trochlea		Patella		Increased volume of soft tissue attenuation in the stifle joint		Osteophyte anywhere in the joint	
	R	L	R	L	R	L	R	L	R	L	R	L	R	L
1	o	s	s		o		o				x		x	
2														
3														
5	o, s	o	h	s, h		o	o	o	o		x	x	x	x
7	o	o	s, h	s, h	s, h	s, h	o	o	o	o	x	x	x	x
8			s, h		h			o		l		x		x
9			h	h	h	h	o				x		x	
10	o	o	s, h	s, h	h	o, h	o	o					x	x
12	o	o	s, h	s, h	o	o, h	o				x		x	x
13			h	s, h	h		o	o			x	x	x	x
14	o		s, h	s, h	o, h	h	o	o			x	x	x	x
15			h	s, h			o				x		x	
16		o	h	s, h	o, h	o	o	o	o			x	x	x
17		o, s	s, h	s, h			o						x	x
18		o	h	s, h	s	s, o	o	o					x	x
19	j	j	h	h	h, j	h, j			l	l	x	x		
20	o	o	h	h	o, h	o, h	o	o			x	x	x	x
22	o	o	h	s, h	o		o				x	x	x	x
23	o	o	s, h	s, h	o, h	o, h	o	o	o	o	x	x	x	x
24			h	h	o, h	h							x	
Total number of joints with findings / structures	10	12	18	16	15	12	15	10	5	4	12	10	16	13

4.2.2.1 Medial and lateral condyle of the femur

Nine (45%) right and ten (50%) left stifles in a total of 12 dogs (7 bilaterally), had presence of osteophytes on the medial and/or lateral condyle of the femur (Table 5). This varied from very mild (nine medial respectively seven lateral condyles) to very severe (four medial respectively four lateral condyles).

Figure 1: *Computed tomography image of the stifle joint of a middle aged (6 years) Boxer demonstrating focal sclerosis in the axial aspect of the lateral condyle.*

4.2.2.2 Intercondylar surface of the femur

Seventeen (85%) right and 16 (80%) left stifles in a total of 17 dogs had identifiable hypoattenuating structures in the intercondylar area of the femur and/or the axial aspect of the lateral condyle of the femur (Table 5). The majority of Boxers (16 out of 20; 80%) had these structures bilaterally. In six (15%) stifles in five dogs, hypoattenuating structures in the intercondylar area of the femur and/or the axial aspect of the lateral condyle of the femur were present without any presence of osteophytes.

The hypoattenuating structures (Figure 2) were focal, well defined, and varied greatly in size. The structures varied from 0.8 mm to 5 mm in width. Some were round while others appeared tubular or branching tubular. Some were surrounded by a thin zone of sclerosis while others were not. In 11 (28%) stifles where the hypoattenuating structures were primarily focused to the intercondylar surface of the femur, a sclerotic area was concurrently present on the axial surface of the lateral condyle. The opposite was also seen in three stifles (8%), with a sclerotic intercondylar area when the hypoattenuating structures were limited to the axial surface of the lateral femoral condyle.

In six (15%) stifles, the hypoattenuating structures were large enough to encompass both the axial aspect of the lateral condyle and the intercondylar area. The majority of the hypoattenuating structures on the axial surface of the lateral femoral condyle were localized to the center of the axial surface but in two Boxers, the structures were seen more distal than central. In one of these cases, this was bilateral. In six (15%) stifles, the hypoattenuating structures were located solely to the axial surface of the lateral condyle.

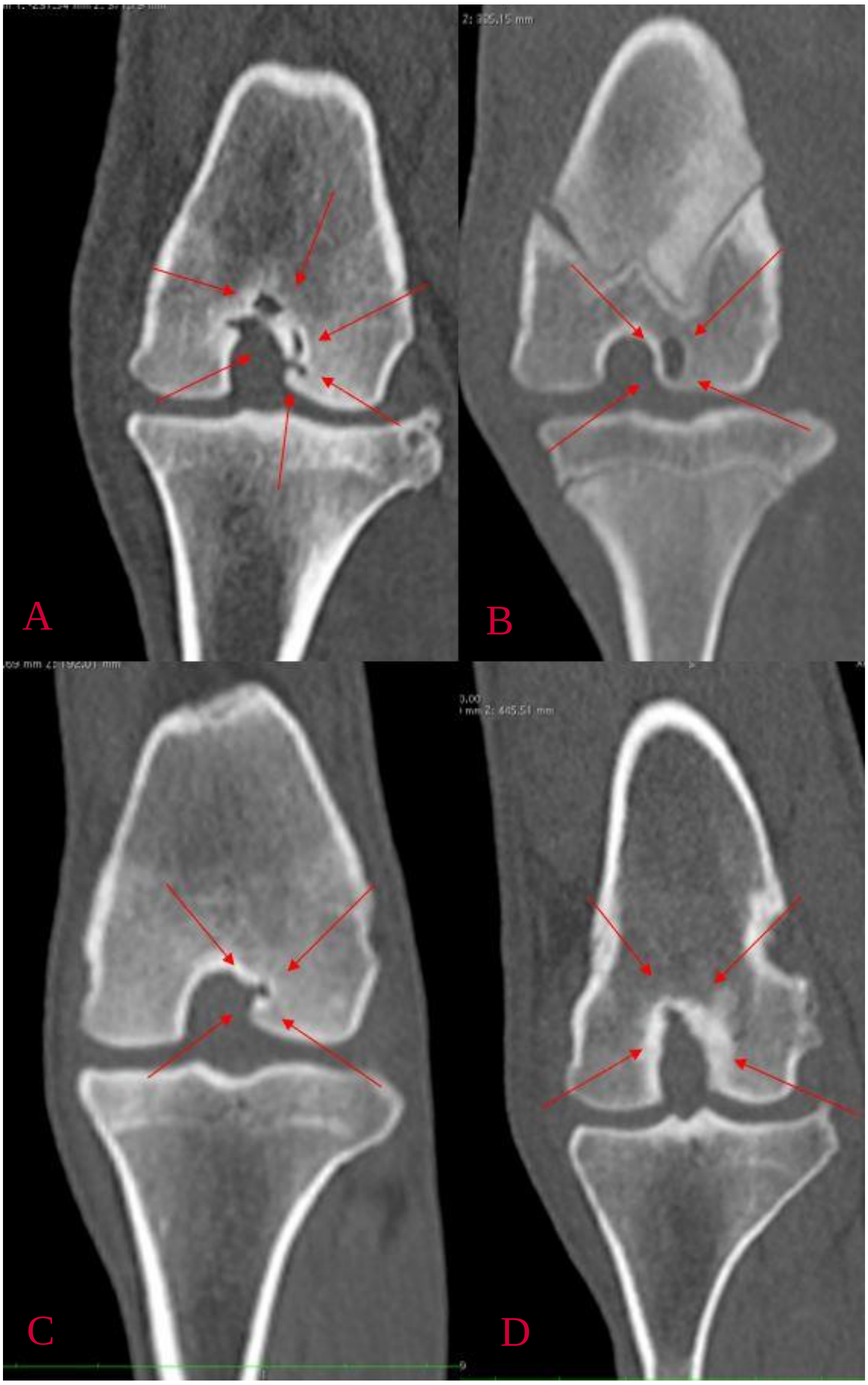

Figure 2: *Computed tomography images of the intercondylar area of the femur and the axial aspect of the lateral condyle of the femur displayed in bone window. A: rounded hypoattenuating structures in the intercondylar area and branching tubular hypoattenuating structures in the axial surface of the lateral condyle in a three-year-old Boxer. The tubular structures in the axial aspect of the lateral condyle reach the surface of the bone. B: Large round hypoattenuating structure in the axial surface of the lateral condyle in a seven-month-old Boxer. C: Small rounded hypoattenuating structure in the axial surface of the lateral condyle that reaches the bone surface in a six-year-old Boxer. D: Small concave defect in the intercondylar surface isolated to the intercondylar surface of the femur surrounded by sclerosis in a six-year-old Boxer.*

4.2.2.3 Surface of the tibia

Out of the 20 evaluated Boxers, 10 (50%) right respectively 8 (40%) left stifles in 12 dogs (6 bilaterally) had presence of osteophytes and/or sclerosis on proximal tibia (Table 5). This varied from mild to severe (Figure 3). Twenty (50%) stifles (12 dogs) had similar hypoattenuating structures to the ones found on the intercondylar surface of the femur (Table 5), where majority of the hypoattenuating structures were very small. The hypoattenuating structures were located medial to the attachment of the cranial cruciate ligament and were surrounded by a thin zone of sclerosis (Figure 3). In cases of focal sclerosis and no hypoattenuating structure in the tibia, there was always a hypoattenuating structure on the intercondylar surface or axial surface of the lateral condyle of the femur.

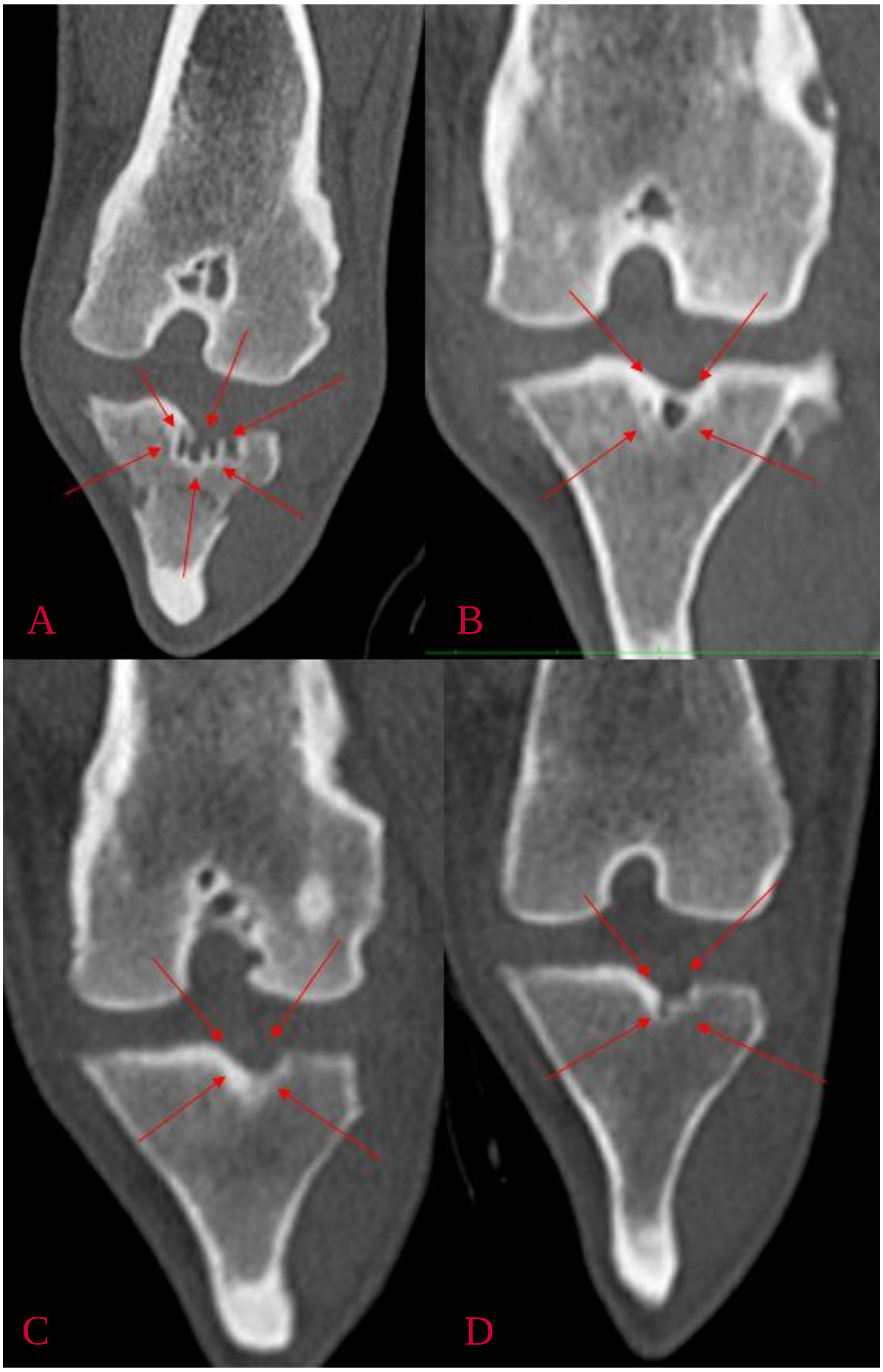

Figure 3: *Computed tomography images of the stifle joint displayed in bone window. A: Multiple round and tubular hypoattenuating structures in proximal tibia in a two-year-old Boxer. B: Large round hypoattenuating subchondral structure in proximal tibia in a six-year-old Boxer. C: Focal sclerosis in the same location as the hypoattenuating structures in other tibias in a six-year-old Boxer. Note the hypoattenuating structure in the intercondylar area and axial aspect of the lateral condyle of the femur. D: Small tubular hypoattenuating structures in proximal tibia in a six-year-old Boxer.*

4.2.2.4 Femoral trochlea

Out of the 20 evaluated Boxers, 15 (75%) right respectively 10 (50%) left stifles in 16 dogs (9 bilaterally) had presence of osteophytes on their femoral trochlea, varying from mild to severe (Table 5). Four (10%) stifles were observed to have a depression on the proximal end of the femoral trochlea.

4.2.2.5 Patella

Out of the 20 evaluated Boxers, five (25%) right respectively four (20%) left stifles in six dogs had presence of findings associated to the patella (3 dogs bilaterally) (Table 5, Figure 4). Osteophytes were found in four (20%) right respectively two (10%) left stifles. Osteophytes were primarily located at the proximal end of the patella but were observed on both the proximal and distal end. Four (10%) of the stifles were observed to have a poorly defined distal contour of the patella, which was considered within normal variation for the Boxer breed. Both stifles in one dog had severe lateral luxation of the patella (Figure 4) and patellar luxation of the left stifle was seen in one other dog.

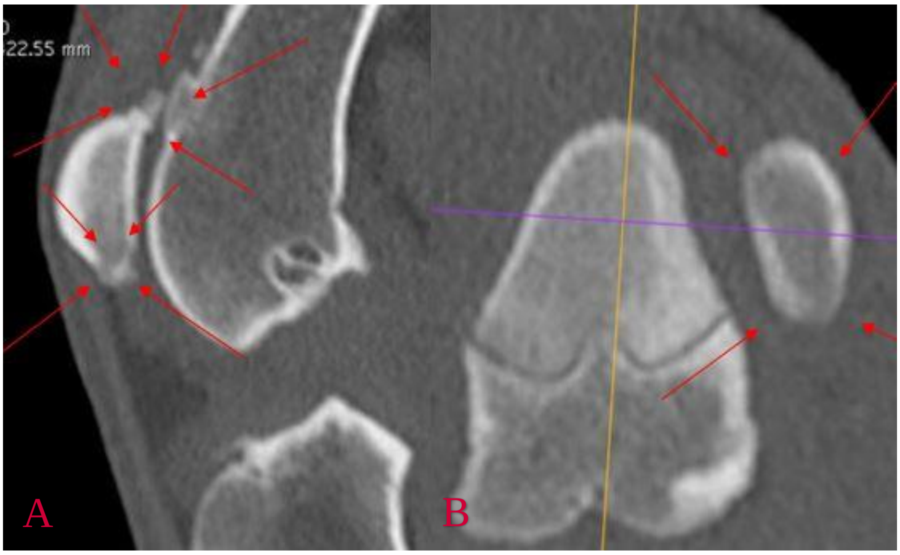

Figure 4: *Bone window of computed tomography images of abnormalities found associated with the patella. A: Severe osteophyte formation on both the proximal and distal end of the patella in a 6-year-old Boxer. B: Severe lateral luxation of the patella found in a seven-month-old Boxer.*

4.2.2.6 Increased volume of soft tissue attenuation in the stifle joint

Out of the 20 evaluated Boxers, 12 (60%) right respectively 10 (50%) left stifles of 14 dogs had increased volume of the soft tissues in the stifle joint, eight dogs having this bilaterally. This varied from mild to severe.

4.2.2.7 Presence of osteophytes

Out of the 20 evaluated Boxers, 17 dogs had presence of osteophytes. Twelve (60%) dogs had bilateral osteophytes. Twelve (55%) right respectively seven (35%) left stifles had having mild osteophytes. One (5%) right respectively three (15%) left stifles had moderate osteophytes. Three (15%) right respectively three (15%) left stifles had severe osteophytes.

4.2.3 Findings on radiographs

Out of the initial 24 Boxer cases, eight (33%) dogs had participated in SKKs official health program for stifle joints and radiographs of seven (29%) of them could be evaluated (Table 6). Additional radiographs of five dogs were accessed via ESRSAH. One of them had a tibial plateau leveling osteotomy (TPLO) done before the radiographs were taken which prevented them from be evaluated.

Table 6: *Evaluation of 11 Boxers' stifles using radiography images from Swedish Kennel Club database (green) and Evidensia Strömsholm Referral Small Animal Hospital (purple). Presence of a lesion is indicated with x, its absence by a blank square and not available images by na.*

Case number	Increased volume of soft tissue opacity		Osteophytes on the proximal trochlea		Osteophytes on the distal patella		Osteophytes on proximal tibia		Osteophytes on condyles of the femur		Enthesophytes on the attachment of the gastrocnemius muscle		Hypoattenuating structures seen on computed tomography images are also seen in radiographs		Hypoattenuating structures seen on computed tomography images	
	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L
1	x	x			x											
2		x														
3																
4											x					
5															x	x
6	x		x				x									
7			x	x			x	x							x	x
8	x	x		x		x		x							x	
15	x	na	x	na	x	na		na		na		na	x	na	x	x
22	x	x	x	x	x		x	x	x	x			x	x	x	x
23	x	x	x	x	x	x	x	x	x	x			x	x	x	x
Number of lesions/ structures	6	5	5	4	4	2	4	3	2	2	1	0	3	2	6	5

Out of the total 11 dogs with radiographs included in this study, nine (82%) had identifiable changes in their radiographs.

As seen in Table 6, the most common change was increased volume of soft tissue opacity in the stifle joint (11 stifles). Other findings included osteophytes on the proximal trochlea; distal patella; and proximal tibia. One individual had enthesophytes on the attachment of the gastrocnemius muscle. In five stifles of three individuals, the hypoattenuating structures seen on CT in the intercondylar and lateral condyle axial areas could be seen in the radiographs as seen in Figure 5.

All of the seven Boxers with results from the official health program received grade 0, “without remarks”. Increased volume of soft tissue opacity in the stifle could be seen in three individuals, bilaterally for one of them. The proximal trochlea was pointed/irregular in two dogs, bilaterally for one of them, which was interpreted as most likely a very mild amount of osteophyte formation. Osteophytes could be seen on the distal patella in one stifle.

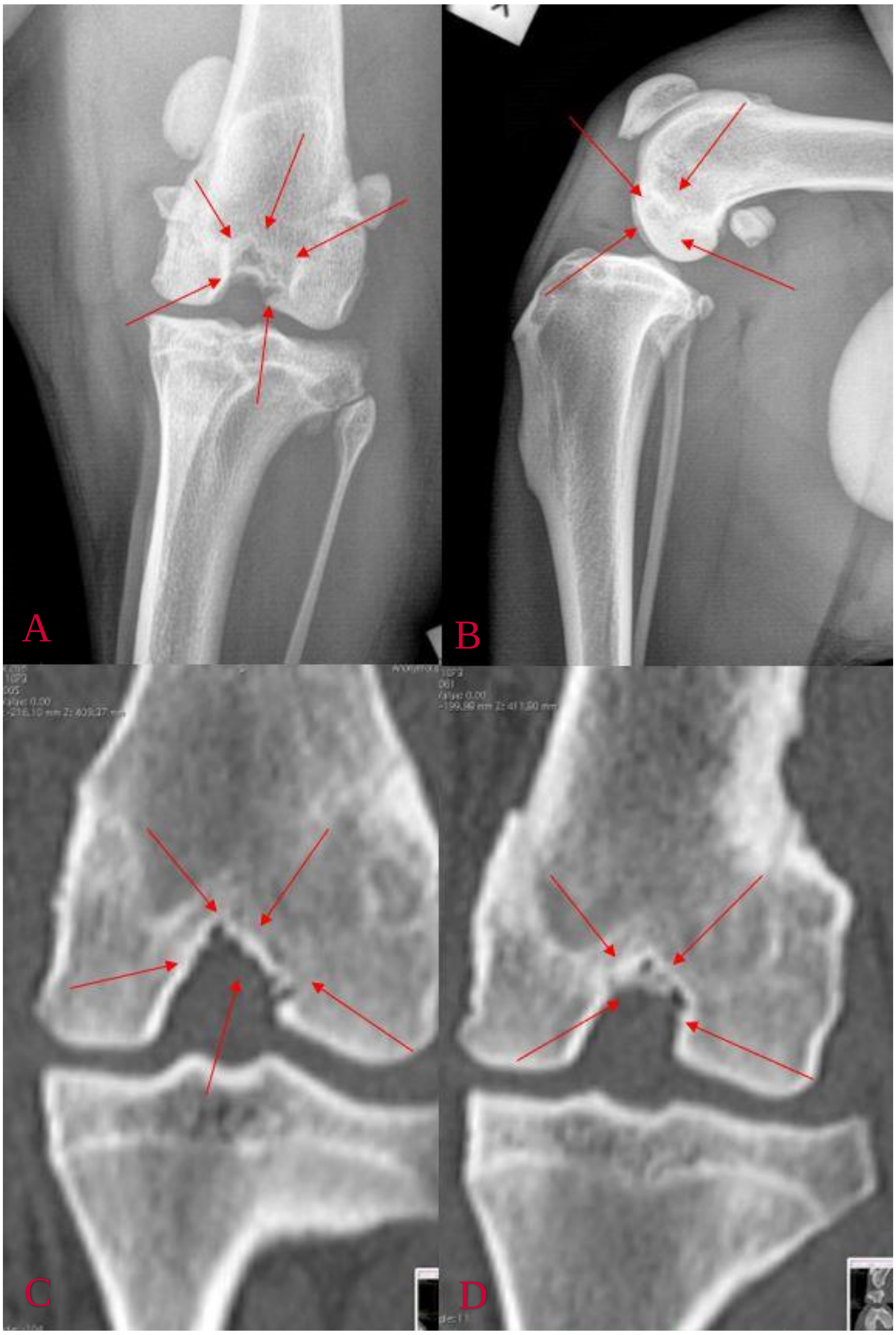

Figure 5: *Computed tomography (CT) and radiographic images of the right stifle joint of Boxer with medial patella luxation. The Boxer was nine months old at the time of the CT study and eleven months old when the radiographs were taken. A: Craniocaudal radiographic projection of the stifle, shows lucent regions corresponding to the hypoattenuating structures seen in the CT images (arrows) in the intercondylar area of the femur and axial aspect of the lateral femoral condyle. B: Mediolateral radiographic projection of the stifle where the hypoattenuating areas cannot be defined C: CT image displaying round/tubular hypoattenuating structures in the intercondylar area and axial surface of the lateral condyle. D: CT image displaying multiple round tubular hypoattenuating structures found in the intercondylar area and axial surface of the lateral condyle.*

5. Discussion

5.1 Survey

This study examined the outcome of Boxers graded in the official health program and those not included in the health program. All dogs that received grade 1-2 were reported by their owners to have clinical signs of stifle disease at some point in their life. This is consistent with the expected progression of OA as presence of osteophytes in relatively young dogs such as those that participated in the health program are likely to worsen with age. It is however unknown whether Boxers with grade 1-2 had any clinical signs of stifle disease at the time they were entered into the official health program.

The percentage of Boxers graded 0 (without remark) and those not participating in the official health program that developed problems with one or both stifles was very similar (15% respectively 14%). The number of Boxers in the survey is however very low. A larger sample pool as well as statistical support regarding evaluation of the association between health program results and clinical signs would be needed in order to provide more definite conclusions.

The survey in this study also examined the frequency of stifle problems in Boxer dogs and the different diagnoses set by veterinarians. The most common diagnoses were arthritis/OA and cruciate ligament disease. This is in agreement with other studies that show that Boxers have a high risk of being affected by CCL rupture in comparison to other breeds (Baker and Muir, 2018; Engdahl et al., 2021b; Spinella et al., 2021). It should however be noted that no comparison was made to other breeds in this study. It could suggest that out of diseases that affect the stifle, Boxers are most prone to OA and cruciate ligament disease. It is known that damage to the cruciate ligament causes OA to develop within the stifle joint (McDevitt and Muir, 1976; Liu et al., 2003), however it is yet not known whether the opposite holds true and whether underlying OA can cause degeneration and eventual rupture of the CCL. As Boxers have several factors that predispose them to OA, such as large body mass and energetic character that can be a reason for increased loading and strain on their joints, underlying OA leading to rupture of the CCL could provide an explanation for the high prevalence of CCL rupture in the breed.

Another factor to consider is the biomechanics of the Boxer conformation and whether their breed standard might be a predisposing factor to develop stifle problems. The tibial plateau angle is a good predictive factor when it comes to cranial cruciate ligament rupture (Seo et al., 2020), a value unknown for Boxers. It is however known that Boxers have a larger lateral condyle area than terrier and mixed breeds, which has been suggested result in cranial cruciate ligament injury due to greater tibial rotation (Ocal et al., 2013). Boxers' straight hindlimbs have previously been suggested to play a role in the pathophysiology of CCL rupture (Gilbert et al., 2019). A difference to a wolf-like build is the length of the upper and lower thigh which are both increased as well as the angle of stifle and hocks in Boxers which becomes very straight. This may be considered a malalignment of the joint and thus contribute to stifle disease via a change in biomechanics of the joint (Cook, 2010). Dogs with hyperextended position of the hindlimbs with highly open joint angles have been observed to have a higher risk for CCLD (Zink and Carr, 2018), supporting this theory.

In the survey, osteochondrosis/OCD/developmental disorders were only reported to have been diagnosed on the left stifles, however this is most likely due to chance, small number of entries, inaccurate survey responses as well as the multiple-choice questions asking about the diagnosis of the left stifle before asking about the right one rather than a significant finding. It is however worth noting that more than triple the number of dogs developed clinical signs of stifle disease in their left vs right stifle. While this could also be due to pure chance or inaccurate survey responses, it may be that there are underlying factors that affect the left stifle more than the right one. As the Boxer is a working dog subject to working trials and is classified as such in Sweden, many Boxers go through training preparing them for such trials. The focal position of the dog during such trials is heeling at the left side of the handler, with the focus of the dog on the handler (Fédération Cynologique Internationale, 2020). Ideally the motion is done with the head stretched upwards to look at the handler; the body slightly twisted towards the handler; with high drive; and a prancing motion is often encouraged. This could mean increased weight placed on especially the hind limbs and an over-extension of the left hind limb, however the only study found examining a similar subject focused only on the pressure on the individual paws (Charalambous et al., 2023). Regardless, the exercise often starts at a very young age and will have been repeated a large number of times before the dog is ready to compete. This could mean that together with the Boxers' conformation, the activity and specific motions of the dog could be an underlying factor in developing stifle disease.

Possible future research could examine the kinetics of heeling and whether an additional strain is put on the hind limbs in general and stifles more specifically. Additional surveys could focus on starting age and frequency of heeling exercises.

5.2 Radiological findings

In the CT cases included in this study, the vast majority of stifles (85% of right ones, 80% of left ones) had identifiable hypoattenuating structures on the inter-condylar surface of the femur and/or the axial aspect of the lateral condyle of the femur. Majority (n = 20) of the stifles also had corresponding lesions on the surface of the tibia. Similar structures have been previously reported in the same area of the femur in a lame seven-month-old Boxer female (Cavanaugh et al., 2007) and in one eight-months-old respectively one five months old Labrador female (Earley et al., 2017). In the previous reports of similar structures, the radiological diagnosis set in all three cases was OC and arthroscopy was performed. In the case of the Boxer, an OCD lesion was confirmed while the report of the other two do not mention whether the arthroscopy findings were concurrent with an OCD lesion.

A different study reported a similar subchondral bone lesion but bilaterally in the glenoid cavity of the scapulohumeral joint of a 6-month-old Labrador Retriever (Lande et al., 2014). The appearance of the lesions resembled the osseous cyst-like lesions seen in horses. The same study examined CT lesions in scapulohumeral joints of 32 immature dogs with thoracic limb lameness and identified very small, focal, round or linear defects that the authors thought to represent vascular channels seen in all 32 dogs and all 64 joints. In 19 scapulohumeral joints they found other lesions such as OC. Olstad et al. (2014) examined the formation of pseudocysts and true cysts in horses. Their findings suggested that OC can lead to formation of pseudocysts or a dilatation of blood vessels followed by formation of true cysts.

While OC is an obvious differential for the structures found on the femur and tibia in this study, in the cases of multiple smaller structures, these had the appearance of vascular channels as described by Olstad et al. (2014). The tubular and branching appearance is also suggestive of vascular structures. These do however not preclude the other, and the different appearances of the structures could be considered a gradient in the structures with the large vascular structures possibly developing into large cyst-like lesions that are more suggestive of OCD due to their large size, contour abnormalities and surrounding sclerosis. In order to have a definite classification for the structures observed, histology would need to be performed, which was beyond the scope of this study.

An aspect to consider is that not all of the Boxers that had the hypoattenuating structures in femur/tibia had any observable presence of osteophytes. This suggests that the structures do not necessarily result in OA, and that they are not secondary to OA in all cases. However, it is unknown whether OA could have a contributing factor in their formation. When examining bones from real stifles, the intercondylar area is heavily vascularized, meaning smaller structures without surrounding sclerosis could be part of natural variation rather than pathological lesions. Whether there is any connection to cruciate ligament disease is also unknown. In a case study by Earley et al. (2017), the authors observed that fragments from the lesion in the intercondylar fossa migrated and during arthrotomy a partial cranial cruciate ligament tear was found. Similarly, Cavanaugh et al. (2007) found that a small portion of the cranial cruciate ligament was frayed and suspected that the cause was disruption of the ligament's origin by the OCD lesion.

Classically, radiographs are used to assess presence of OC in the stifle. The hypoattenuating structures observed in this study were however not always visible on radiographs. This could be due to them developing over time and the radiographs been taken earlier. To the author's best knowledge, it is at this point not defined how large a vessel can be identified and still be considered being within normal variation. A large, dilated vessel could however in theory look like a cyst-like lesion.

Computed tomography has been successfully used in the detection of cranial and caudal ligament and meniscal tears in dogs. A study from 2009 regarding the use of CT arthrography in diagnosing cranial cruciate ligament rupture reported a sensitivity and specificity between 96-100% respectively 75-100% using CT arthrography when reviewed by three board-certified radiologists inexperienced at interpreting CT stifle studies (Samii et al., 2009). While CT was able to visualize bony structures very well, even the soft tissue algorithm failed to visualize the cartilage of the joint which is a vital part of every joint. The CT studies were thus limited to subjectively evaluating the volume of soft tissue in the joint, which is also possible to do with radiographs. In order to visualize the soft tissue structures better, one would need to perform CT arthrography, which is a much more invasive and expensive technique, making it not suitable for a health screening program.

This study failed to definitively identify a lesion that explain Boxers' predisposition for lameness originating from the stifle joint and conclusively identify potential causes for development of OA. It did however identify that majority of the CT cases had hypoattenuating structures on the intercondylar surface and the axial aspect of the lateral condyle of the femur. While these structures could be a possible cause of the early development of OA in Boxer stifles, more information is needed.

5.3 Improvements to method

The setting of the survey meant that all the questions were not mandatory to answer, which resulted in the frequency of answers between individual questions to vary greatly. This has meant that the results for multiple questions have fewer answers than for others and that few conclusions can be drawn from them. This has also meant that a large amount of time was spent to manually analyzing the questionnaire answers as survey analyzing tools could not be fully utilized. The survey could also have been timed to coincide with the quarterly newsletter published by the Swedish Boxer club to get a larger outreach.

This study focused solely on CT images of Boxer stifles from ESRSAH and the number of cases was limited by the cohort of dogs that had done their imaging studies there. A larger case number could have been obtained by gaining access to cases from more small animal hospitals. A larger number of matched CT and radiography cases could potentially also shed more light on the presence of the hypoattenuating structures on radiographs. More CT scans from non-lame dogs could also help to clarify whether there is a connection between the presence of the hypoattenuating structures and lameness.

5.4 Limitations

5.4.1 Survey

The results of the survey have several limitations. The main one is dependent on the questionnaire respondent's accuracy, ability to recollect and interest in answering the survey. The diagnoses set by a veterinarian on an individual can't be verified without gaining access to the hospital records of each individual which is far past the scope of this study. As the questionnaire was also open to deceased dogs, the owner's ability to recollect specifics of the dogs may vary. Many respondents chose to end the survey in the middle of it, meaning that the number of answers for the last questions was very low.

This survey was distributed via social media groups aimed at Boxer enthusiasts and by email to breeders associated with the Swedish Boxer club. This means that Boxer owners not using social media were much less likely to see and answer the study. Owners with Boxers that had stifle issues could have also been overrepresented in their keenness to answer the survey. Some breeders chose to share the survey, which could cause bias for certain Boxer families. Equally so, breeders that didn't renew their membership with the Swedish Boxer club within the last 12 months did not receive the email, and dogs from their breeding were as such less likely to be entered. It is likely that previous Boxer were less likely to be targeted by the survey as many stop renewing their membership of the breed club when no longer in ownership of a dog of that breed.

Another limitation of the study is caused by the fact that the question regarding problem with the left stifle was before the one asking about problems with the right one. This could have skewed the answers if owners chose to leave the survey at that point and could be the underlying reason for many more dogs suffering from problems of the left than the right stifle.

5.4.2 Cases from Evidensia Strömsholm Referral Small Animal Hospital

The study was limited to the hospital journal entries made by clinicians at ESRSAH. This means that the study was limited to the information provided by them, and that some information of interest to this study (such as the dog's microchip number) was not able to be obtained in all cases. Equally so, four dogs had microchip number but weren't registered in Hunddata.

This study is also limited by the diagnostic method used. As cartilage is a vital part of every joint, it would ideally be visualized which it is not when using CT. As such, this study cannot answer whether the hypoattenuating structures reach the surface of the joint. Another limit of this study is being unable to say whether the hypoattenuating structures are part of the normal variation of Boxer (or even all dogs) or whether they are in fact lesions. In order to do so, histology data would be needed to determine the character of the hypoattenuating structures which was beyond the scope of this study.

5.5 Further studies

This study should be seen as a pilot study for future investigations. Suggestions on areas for future studies include examination of CT images of other breeds and dogs of different ages to determine whether the hypoattenuating structures primarily affect Boxers and other breeds predisposed for stifle problems or whether they are equally present in breeds without such problems.

Progression of the structures is also of great interest and studies could focus on following dogs with repeated CTs and post-mortem assessment of the character of the hypoattenuating structures. Another factor to look at is to define the normal variation of large vessels seen on radiographs.

Other studies could look at cohorts of Boxers with different stifle angles and whether any group developed problems earlier or more severely. In such a cohort, the activity levels and familial ties could also be examined. Gait assessment of Boxers could also be of great value to assess the effects of the structures and whether any exhibited movement disorders can be tied to the appearance of the structures.

Another area of focus is the much higher number of Boxers that developed problems with their left vs right stifle. As such, studies could examine the load on individual joints during dog sport specific movements such as heeling.

5.6 Conclusions

The aim of this study was to investigate possible cause of early OA development in Boxer stifles using CT, investigate if the changes seen that were suspected to be the underlying causes of OA can be detected in radiographs and to investigate the outcome in Boxers that have had an official screening of their stifles.

This study failed to definitively identify a lesion that explain Boxers' predisposition for lameness originating from the stifle joint. It did however identify that majority of CT cases had hypoattenuating structures on the intercondylar surface and the axial aspect of the lateral condyle of the femur that are similar to other reports in the literature of stifle lesions in lame young dogs. While these structures could be a possible cause of the early development of OA in Boxer stifles, more information is needed about the character of these structures. In a few isolated cases, the hypoattenuating structures seen on the CT could be visualized in radiographs. As such, the study was able to partially answer its primary and secondary aims.

The investigation of the outcome of Boxers that have had an official screening of their stifles suggests that more Swedish Boxers suffer from stifle disease from their left stifle joint compared to the right one. While this could be due to the methodology of the study, it raises interesting queries regarding the impact of canine sports on the joints.

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Popular science summary

The Boxer is a dog breed developed during the 19th century in Germany. In the present, the breed suffers from several health issues, lameness and other orthopedic issues being one of them. Unlike many other breeds suffering from similar issues, Boxers are more frequently affected by lameness from the stifle and at a younger age than other breeds. As such, the Swedish Boxer Club and the Swedish Kennel Club initiated a health program involving screening with x-rays of Boxer stifles. This program lasted from 1989 until 2019.

Computed tomography (CT) is a technique that uses multiple x-rays to make slice-like images of a patient and can be made into 3D images. This allows for much higher detail of a joint as the structures in the joint don't overlap over each other.

There are multiple diseases that can affect the stifle and cause lameness. One of the most common causes for lameness originating from the stifle is osteoarthritis (OA). OA is the end stage of joint disease where the joint is degenerated, and new bone spurs develop on the margins of the joint due to the joint damage and inflammation. Another very common cause for lameness from the stifle is disease of the cranial cruciate ligament, a ligament that stabilizes the stifle. Over time, the ligament can deteriorate, causing it to fully or partially rupture. Another cause for lameness can be due to a development disorder of the skeleton, where bone is unable to form correctly. This is also known as osteochondrosis. The structure and motion of the stifle plays a big role in how well the joint can handle the repeated forces it is exposed to and a mismatch or defect in the joint can predispose it for lameness due to the dysfunction in the build of the stifle and the forces applied to it. Other causes for stifle lameness include traumatic injuries and infections of the joint.

The main aim of this study was to investigate possible causes of early development of OA in Boxers originating from the stifle using CT. A second aim was to investigate whether the changes seen in CT images could be seen in radiographs. A third aim was to investigate the outcome in Boxers that had an official x-ray screening of their stifles.

In order to investigate the aims of this study, a survey and a case study were performed. The survey questions were created by the student responsible for the study with help from the supervisors. Before the survey was sent out, a test version was approved by the supervisors and the board of the Swedish Boxer club. Apart from respondents having the option of providing voluntary contact and dog identification information, the survey responses were anonymous. The survey was distributed via social media.

The case study was performed with the help of Evidensia Strömsholm Referral Small Animal Hospital (ESRSAH). Cases of Boxers with a CT of their stifles were identified by the student and together with medical records used for evaluating the stifle joints for any abnormalities. The evaluation focused on looking at five areas of the thigh bone (femur), shin bone (tibia) and kneecap (patella) as well as presence of increased joint fluid (a common sign of inflammation in the joint) and presence of bone spurs (osteophytes).

The survey generated a total of 302 answers. The percentage of Boxers graded 0 (without remark) and those not participating in the official health program that developed problems with one or both stifles was very similar (15% respectively 14%). The search in ESRSAH records generated 25 cases where 20 had CTs that could be evaluated.

Evaluation of the CT images showed that the vast majority of stifles (85% of right ones, 80% of left ones) had identifiable changes that appeared as small defects in the bone on the deep notch between the rounded areas at the end of the femur and/or on the inside surface of one of the rounded areas at the end of the femur (the rounded area on the outside). The majority of the stifles also had similar small bone defect changes on the surface of the tibia where it meets the femur. While the majority of cases where these small bone defect structures were present had presence of new bone spurs, all did not. The smaller bone defect structures had the appearance of blood vessels while larger ones looked like osteochondrosis. As such, the different appearances of the structures could possibly be a gradient in the structures with the smaller vessels developing into osteochondrosis lesions, or a mixture of blood vessels and osteochondrosis lesions. In order to be able to define the changes observed, one would need to microscopically examine the tissue with the changes which was not possible in this study. As such, it is unknown what the small bone defect changes that were seen are and whether they have any relevance to the development of lameness.

This study should be seen as a pilot study for future investigations. Suggestions on areas for future studies include examination of CT images of the stifle joints of other breeds and dogs of different ages to determine whether the small bone defect changes seen primarily affect Boxers and other breeds predisposed for stifle problems or whether they are equally present in breeds without such problems.

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I would like to express my deepest thanks to my supervisors for their time and guidance in writing this thesis. This study would have not been possible without Evidensia Strömsholm Referral Small Animal Hospital and a very special thanks goes out to the radiology department in ESRSAH for their kindness and help in accessing the materials needed for this study.

Appendix 1

1. Boxerknän

Denna enkät är del av ett examensarbete inom veterinärmedicin vid Sveriges Lantbruksuniversitet. Syftet är att få mer insikt i knäproblematiken hos boxer. Enkäten vänder sig till både privatpersoner och uppfödare. Enbart SKK-registrerade boxrar inkluderas i enkäten. Svaren är helt anonyma och kommer redovisas i ett examensarbete.

Enkäten beräknas ta 5-10 min.
Enkäten kommer finnas att tillgänglig fram till 29/10-2023.

En boxer per enkätsvar – har du haft flera vänligen fyll i enkäten flera gånger, en gång per hund.
Enkäten kan fyllas i för avlidna hundar.

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Tack så mycket för din hjälp!

Veterinärstudent: Martyna Zelek
Kontakt: mazk0001@stud.slu.se
Handledare: Charles Ley, Institutionen för kliniska vetenskaper

Vad är din boxers stamtavlenamn eller registreringsnummer?

Skriv ditt svar här...

Har din boxer varit del av SKK:s officiella hälsoprogram för knäleder? (Det officiella screeningprogrammet varade från 1989 till 2019)

- Ja
- Nej

Vilken gradering fick din boxer i SKK:s hälsoprogram för knäleder?

- 0 (utan anmarkning)
- 1
- 2
- 3
- Minns inte

Har din boxer utvecklat knäledsproblem på ett eller båda ben?

- Ja
- Nej

Om din boxer utvecklade knäledsproblem på ett eller båda ben, uppsöktes veterinär för konsultation angående detta?

- Ja
- Nej

SLU

Vilken/vilka diagnoser sattes av veterinär på din boxers vänstra knä?

- [ ] Osteokondros/OCD/utvecklingsrubbning i skelettet
- [ ] Artros/Osteoartrit
- [ ] Korsbandsskada
- [ ] Patellaluxation
- [ ] Tumör
- [ ] Annan
- [ ] Vet ej
- [ ] Diagnos kunde inte fastställas
- [ ] Min boxers vänstra knä var friskt

Vilken/vilka diagnoser sattes av veterinär på din boxers högra knä?

- [ ] Osteokondros/OCD/utvecklingsrubbning i skelettet

Survey powered by Netigate

SLU

- [ ] Min boxers vänstra knä var friskt

Vilken/vilka diagnoser sattes av veterinär på din boxers högra knä?

- [ ] Osteokondros/OCD/utvecklingsrubbning i skelettet
- [ ] Artros/Osteoartrit
- [ ] Korsbandsskada
- [ ] Patellaluxation
- [ ] Tumör
- [ ] Annan
- [ ] Vet ej
- [ ] Diagnos kunde inte fastställas
- [ ] Min boxers högra knä var friskt

Survey powered by Netigate

Gjordes någon ytterligare diagnostik utöver veterinärundersökning?

- [ ] Röntgen
- [ ] CT/Datortomografi
- [ ] Ultraljud
- [ ] Titthålskirurgi/kirurgi
- [ ] Ja, men kommer inte ihåg vad
- [ ] Nej
- [ ] Annat

Är du villig att bli kontaktad av oss via mejl för att eventuellt besvara några fler frågor?

- ( ) Ja
- ( ) Nej


Var vänlig fyll i din mejladress här:
Skriv ditt svar här...


Tack för din hjälp!

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