LAMENESS IN THE BORDER COLLIE:
A RETROSPECTIVE STUDY OF 200 DOGS

by

Valentine VERPAALEN
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Valentine VERPAALEN

Promotors:
Prof. Dr. Bernadette Van Ryssen
Dr. Delphine Van Vynckt

Research Report
as part of the Master’s Dissertation
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PREFACE

As a student in my final year of veterinary medicine at the University of Ghent, my foremost goal is to become an outstanding small animal orthopedic surgeon. Working on this research project has provided me with the opportunity to immerse myself in a wide range of musculoskeletal disorders. This experience has been of great value in preparing myself for a future career in veterinary orthopedics. I would like to extend my deepest gratitude to my promotors, Prof. Dr. Van Ryssen and Dr. Van Vynckt, for granting me this unique opportunity, for their enthusiasm and excellent guidance, and for being a source of inspiration to me. It was a privilege to work with such exceptional orthopedic surgeons and I hope to have the honor of continuing to do so in the future. I would also like to thank my family and friends for all of their love and support. I could not have done it without you!
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ABSTRACT

Border Collies, due to their speed, stamina, and willingness to please, are one of the most popular breeds used in agility competitions, currently one of the fastest-growing canine sports. Despite this, only a handful of studies describe the occurrence of certain musculoskeletal disorders within this breed. Border Collies have been reported to be predisposed for humeral head osteochondrosis and hip dysplasia, while having a decreased risk of developing cranial cruciate ligament disease. One study evaluating the prevalence of injuries during agility training and competitions discovered that Border Collies have a higher risk of contracting traumatic injuries than other breeds, and that this was unrelated to their popularity within the sport. As part of this dissertation, a retrospective study including 200 Border Collies was performed in order to evaluate the importance of different musculoskeletal disorders within the Border Collie breed, to compare the prevalence of these disorders in Border Collies with other large-breed dogs, and to evaluate the importance of different musculoskeletal disorders within the Border Collie athlete. The most common causes of lameness in the Border Collie consisted of traumatic injuries, humeral head osteochondrosis, cranial cruciate ligament disease, hip dysplasia, medial coronoid disease, and coxofemoral luxations. Compared to other large-breed dogs, Border Collies had a significantly higher risk of developing humeral head osteochondrosis and contracting traumatic injuries, more specifically muscle, tendon, and ligament injuries. Border Collies had a lower risk of cranial cruciate ligament disease and medial coronoid disease compared to other large-breed dogs. This study also included several musculoskeletal disorders, which, to the author’s knowledge, have not been described in Border Collies in prior literature. These disorders include osteochondrosis of the elbow joint, elbow joint incongruity, and meniscal injury subsequent to cranial cruciate ligament rupture. As such, this study has provided valuable insights into the importance and prevalence of musculoskeletal disorders within the Border Collie breed.

Key Words: Agility - Border Collie – Injury – Lameness - Orthopedic
SAMENVATTING

Hondensporten, en dan voornamelijk agility, zijn de laatste jaren erg in populariteit aan het toenemen. Sedert 2003 is er een jaarlijkse stijging van 10% waarnembaar in de deelnamen aan agility wedstrijden van de American Kennel Club, met een totaal van 1,242,159 deelnamen in het jaar 2013. Border Collies vertegenwoordigen, vanwege hun snelheid, uithoudingsvermogen, en hun extreme bereidwilligheid om te werken, één van de populairste rassen om te gebruiken in de agility. Een aantal studies hebben de aard van letsels onderzocht die opgelopen werden tijdens agility wedstrijden. Deze studies hebben aangetoond dat Border Collies een vergroot risico hebben op het oplopen van letsels in vergelijking met andere hondenrassen. Dit vergroot risico zou te wijten kunnen zijn aan het feit dat alle gewrichten van Border Collies een verhoogde beweeglijkheid vertonen in vergelijking met de Labrador Retriever, en vermoedelijk ook andere rassen. Tevens zou het mogelijk kunnen zijn dat Border Collies, wegens hun werkwilling, onvoldoende aangeven als een training hun te veel wordt en daardoor meer overbelast worden. ‘Warming-up’ en ‘cooling-down’ sessies zouden het risico op traumatische letsels tijdens trainingen en wedstrijden verminderen. De letsels gerelateerd aan agility zijn voornamelijk gelokaliseerd ter hoogte van de heup- en carpaal-gewrichten. Border Collies staan verder bekend om hun predispositie tot het ontwikkelen van zowel osteochondrose van het schoudergewricht als heupdysplasie. Ook zouden zij een lager risico lopen op het ontwikkelen van een voorste kruisband ruptuur. Voor zover bekend, zijn er meerdere orthopedische aandoeningen regelmatig beschreven bij Border Collies, maar nog niet specifiek onderzocht in dit ras, terwijl andere aandoeningen nog geneens beschreven zijn bij de Border Collie. De bestaande informatie omtrent deze orthopedische aandoeningen wordt samengevat in deze literatuurstudie. Aangezien een onderzoek die het voorkomen van verschillende orthopedische aandoeningen binnen de Border Collie ras evalueren momenteel nog ontbreekt, is er vervolgens besloten om een retrospectieve studie uit te voeren op 200 Border Collies en 200 andere grote honden (>15kg) die zich hebben gemeld aan de Faculteit Diergeneeskunde te Merelbeke met klachten van manken. Ten eerste werd er onderzocht welke orthopedische aandoeningen van belang zijn bij het Border Collie ras. De meest voorkomende aandoeningen waren traumatische letsels, osteochondrose van het schoudergewricht, voorste kruisband ruptuur, heup dysplasie, pathologien van het mediaal coronoïd, en coxofemorale luxaties. Hierbij is er tevens per aandoening de gemiddelde leeftijd waarop de diagnose is gesteld vermeld, en zijn eventuele geslachtsoorkeuren onderzocht. Hoewel er wel aanwijzingen zijn dat geslachtsoorkeuren optreden bij verschillende aandoeningen, is er maar één statistisch kunnen bevestigd worden, namelijk: een predispositie voor osteochondrose van het schoudergewricht in mannelijke Border Collies. Na deze initiële analyse zijn de verschillende gediagnosticeerde orthopedische aandoeningen vergeleken met de controle-groep bestaande uit 200 grote honden. Statistische analyses hebben bevestigd dat Border Collies een significant groter risico lopen dan andere grote honden op osteochondrose van het schoudergewricht en traumatische letsels, en dan voornamelijk letsels van spieren, pezen, en gewrichtsbanden. De traumatische letsels waren het meest gelokaliseerd ter hoogte van de schouder- en tarsaalgewrichten. Hoewel Border Collies geen significant verhoogd risico lopen tot heupdysplasie, blijft dit een
belangrijke aandoening binnen dit ras. Het zou aangewezen kunnen zijn om een verbeterde screening protocol op te stellen voor heupdysplasie bij de Border Collie. Om de traumatische letsels te voorkomen, is het aangewezen voor de eigenaren om vóór en na hun trainingen een ‘warming-up’ en ‘cooling-down’ sessie in te lassen.

Verder vertoonden Border Collies een verlaagd risico op het ontwikkelen van voorste kruisband rupturen en pathologïën van het mediaal coronoid. Voor zover bekend, zijn er in dit onderzoek verschillende orthopedische aandoeningen voor het eerst officieel beschreven bij de Border Collie, zoals osteochondrose van het ellebooggewricht, elleboog incongruentie, en beschadiging van de mediale meniscus in combinatie met een voorste kruisband ruptuur.

De bevinden van dit onderzoek hebben waardevolle inzichten aan te bieden met betrekking tot het voorkomen en de uiting van verschillende orthopedische aandoeningen bij het Border Collie ras, zowel voor de eigenaar als de behandelende dierenarts.
1. INTRODUCTION

Canine sports are rapidly growing in popularity, and entries for agility competitions from the American Kennel Club have been expanding annually by approximately 10% since 2003, giving a total of 1,242,159 entries in the year 2013 (American Kennel Club, 2015). Border Collies, due to their speed, stamina, and willingness to please, are a popular breed within agility competitions. Several studies evaluating injuries obtained during agility training and competition have noted a predisposition for traumatic injuries in the Border Collie, unrelated to their popularity within the sport (Cullen et al., 2013a, Cullen et al., 2013b, Levy et al., 2009). Traumatic injuries contracted during agility training have been noted to most frequently affect the hips and carpal joints (Levy et al., 2009). Besides these traumatic injuries, Border Collies are well known for developing osteochondrosis of the humeral head, and this has been statistically confirmed in a prior study (LaFond et al., 2002). Border Collies have also been noted to be predisposed to developing hip dysplasia, and to have a lower risk for cranial cruciate ligament disease (Dorn, 2002, LaFond et al., 2002). Even though several other musculoskeletal disorders have been reported to occur in the Border Collie, these reports are often limited to mere descriptions. Other musculoskeletal disorders have, to the author’s knowledge, not yet been described to occur in the Border Collie breed in current literature. To the author’s knowledge, no previous studies have been performed to evaluate the incidence of different musculoskeletal disorders within the Border Collie breed. In this literature study, current publications concerning the epidemiology and pathogenesis of a variety of musculoskeletal disorders have been summarized, including the occurrence of these disorders in Border Collie dogs. Subsequently, a retrospective study was performed including 200 Border Collies and 200 large-breed dogs that all had presented at the veterinary faculty of Ghent University for lameness. This retrospective study was performed in order to evaluate the importance of different musculoskeletal disorders within the Border Collie breed. The incidences, as well as age and gender predispositions were described. In order to evaluate the relative risk of attenuating each musculoskeletal disorder, the results were compared with a control group, comprised of 200 large-breed dogs. Finally, the incidences of musculoskeletal disorders in Border Collie athletes were examined separately and compared to the more sedentary Border Collies. It was hypothesized that high incidences of osteochondrosis of the shoulder joint, hip dysplasia, and traumatic injuries are seen within the Border Collie breed, and that Border Collies are at a higher risk of developing these disorders compared to the control group. It was also hypothesized that Border Collie athletes are predisposed to contracting traumatic injuries, especially involving the hips, back, and carpal joints. This study is suggested to provide valuable insights into the importance and prevalence of different musculoskeletal disorders within the Border Collie breed.
2. LITERATURE STUDY

2.1. MUSCULOSKELETAL DISORDERS AND THEIR IMPORTANCE IN THE BORDER COLLIE BREED

2.1.1. Developmental Disorders

2.1.1.a. Osteochondrosis

Osteochondrosis is a developmental disorder of the immature skeleton in which there is a focal disturbance of endochondral ossification in the growth cartilage of epiphyses and growth plates. This results in the retention of cartilage, which may lead to the formation of a cartilaginous flap, which is subsequently referred to as osteochondritis dissecans (OCD). In a large retrospective study osteochondrosis accounted for 5% of appendicular joint disorders and an incidence of 5.2 in 1000 patients was found. Typical locations for osteochondrosis in the dog are the caudal aspect of the humeral head, the medial aspect of the humeral condyle, the lateral or medial femoral condyle, and the medial or lateral trochlear ridge of the talus. The shoulder joint is most commonly affected, followed by the elbow, tarsus and, least of all, the stifle joint (Johnson et al., 1994). Osteochondrosis generally develops between 4 and 8 months of age, though differences between joint locations have been described (see later) (Johnston, 1998, Slater et al., 1991). Though males are clearly more frequently affected by OCD in the shoulder joint than female dogs (see later), gender differences remain debatable in the elbow and stifle joints and seem absent in OCD of the tarsocrural joint.

Osteochondrosis is generally considered a multifactorial disorder with polygenic heritability. It is often associated with large and giant breeds, with specific breed dispositions varying per anatomical location. Slater et al. and LaFond et al. were able to demonstrate statistically significant odds ratios (OR) in a variety of breeds for each type of osteochondrosis (Table 1).

A positive correlation has been found between rapid growth and skeletal disorders such as osteochondrosis, and the predisposition of large and giant breeds for a more rapid rate of skeletal growth could help to explain why they are at a higher risk of developing this disease than smaller breeds (Breur and Lambrechts, 2012, LaFond et al., 2002, Meyer and Zentek, 1991). Nutritional factors may lead to rapid growth and disturbances in endochondral ossification and have been suggested to predispose for osteochondrosis. These factors include high levels of energy, calcium, and vitamin D (Dämmrich, 1991, Richardson and Zentek, 1998, Slater et al., 1992). Most nutritional studies concerning osteochondrosis, however, have only looked at the effects of nutrition on skeletal development in the Great Dane, and are yet to be confirmed in other breeds. Furthermore, though nutrition has been related to disturbances in endochondral ossification, direct correlations between these dietary factors and the actual development of osteochondrosis are yet to be found. Besides these hereditary, growth and nutritional factors, increased biomechanical stress and trauma related to exercise might play additional roles in the development of OCD (Skelley et al., 1997, Slater et al., 1992). Rapid growth or hormonal dysregulations of physeal bone growth can lead to increased
biomechanical stress. It is unsure, however, if these increases in biomechanical loads can initiate osteochondrosis or if they merely enhance the progression of these lesions. In humans, macro-trauma caused by increased levels of exercise has been shown to enhance the progression of osteochondrosis to OCD, thus resulting in a higher prevalence and severity of OCD lesions (Bohndorf, 1998).

Table 1: Breeds at Risk for Developing Osteochondrosis. Statistically significant odds ratios determined by Slater et al., 1991 and LaFond et al., 2001 per breed and anatomical location.

<table>
<thead>
<tr>
<th>Breed</th>
<th>Shoulder Slater</th>
<th>Elbow Slater</th>
<th>Stifle Slater</th>
<th>Tarsus Slater</th>
<th>Shoulder LaFond</th>
<th>Elbow LaFond</th>
<th>Stifle LaFond</th>
<th>Tarsus LaFond</th>
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</table>

Osteochondrosis of the Shoulder Joint

In the shoulder joint, OCD lesions are most frequently located at the caudocentral or caudomedial aspect of the humeral head, opposite to the caudoventral rim of the glenoid (Figure 1). The loads are primarily transferred across the joint at this exact location, suggesting trauma may play a specific role in the development of humeral head osteochondrosis (Rochat, 2012).

In accordance with general findings on osteochondrosis, the age of onset of clinical signs for humeral head OCD peaks between 4 and 8 months of age (Lande et al., 2014, Maddox et al., 2013).
Slater et al. confirmed this with statistically significant odds ratios, and, furthermore, found a prolonged period of age of onset in comparison to other forms of OCD, extending up to 12 months of age (Slater et al., 1991). A possible explanation for this would be the fact that the proximal humeral growth plate only closes at an age of 10-13 months, while the distal humeral growth plate, for example, closes at an age of 6-8 months (Breur and Lambrechts, 2012). Slater et al. went on to make a clear distinction between age of onset and age of diagnosis, which amounted to 6 to 18 months of age. This gap between the onset and actual diagnosis can be explained by a delayed response on either the part of the owner or the referring veterinarian (Slater et al., 1991). Gender differences in OCD are unique to the shoulder joint, with similar documented male:female ratios of 2:1, 2.24:1 and 2.27:1 (Biezynski et al., 2012, Rudd et al., 1990, Slater et al., 1991). Osteochondrosis often develops bilaterally, though dogs usually present with unilateral lameness and the lesions may not necessarily progress to OCD in the clinically sound limb (Kippenes and Johnston, 1998). When looking at a variety of studies, a bilateral distribution of lesions was found in 42-68% of dogs with shoulder OCD (Lande et al., 2014, Maddox et al., 2013, Olivieri et al., 2007, Olsson, 1987, Person, 1989, Ryssen et al., 1993, Slater et al., 1991). Van Bree was able to measure the size of osteochondritic lesions as a percentage of humeral head width and found a positive correlation with the extent of pain and lameness experienced by the patient (Van Bree, 1994).

Several studies have been performed in order to determine breed predispositions for humeral head osteochondrosis. LaFond et al. and Slater et al. performed epidemiological studies including 1,242 and 141 cases of humeral head osteochondrosis, respectively. Odds ratios were statistically significant in several different breeds, such as the Great Dane, Bernese Mountain Dog, English Setter, German Short-Haired Pointer, Golden Retriever, among others (LaFond et al., 2002, Slater et al., 2001). Though LaFond et al. also found an increased risk of humeral head osteochondrosis in the Border Collie Slater et al. did not. Maddox et al. used CT to detect shoulder lesions in 89 dogs presenting with thoracic limb lameness. In this study, Border Collies were found to be the breed most commonly affected by osteochondrosis, with a calculated odds ratio of 9.3. However, this study included a mere total of 8 Border Collies with OCD, and the reliability of these findings therefore remains questionable (Maddox et al., 2013). Biezynski et al. did not calculate odds ratios but did describe a high prevalence of OCD in Labrador Retrievers (28%), Golden Retrievers (25%) and Border Collies (14%) (Biezynski et al., 2012). A fourth study was performed by Coopman et al., determining the prevalence of hip dysplasia, elbow dysplasia and humeral head...
osteoarthritis in dogs in Belgium. Of the 267 dogs examined for humeral head osteochondrosis, merely 6% were affected. No Bernese Mountain Dogs were affected, and only a low prevalence were detected in the Labrador Retriever (5%), Golden Retriever (9%) and Greater Swiss Mountain Dog (10%) (Coopman et al., 2008). Though Border Collies are generally considered at a higher risk for developing humeral head osteochondrosis, the lack of epidemiological studies including substantial numbers of Border Collies not only make it difficult to confirm this belief objectively, but to quantify it as well.

Osteochondrosis of the Elbow Joint

Osteochondrosis of the canine elbow joint is typically situated at the medial aspect of the humeral condyle, and is one of the main components contributing to elbow dysplasia (see later). Typically, OCD of the medial aspect of the humeral condyle presents at 4 to 8 months of age (Cook, 2001, Fitzpatrick et al., 2009b, Slater et al., 1991). Several studies suggest a predilection in male dogs, and male to female ratios of up to 12.5:1 have been reported. However, no statistical analyses were performed in these studies in order to confirm these findings. Slater et al., on the other hand, did calculate odds ratios and found no significant gender preference (Bennett et al., 1981, Fitzpatrick et al., 2009b, Slater et al., 1991). In a wide range of approximately 10-62% of cases of elbow OCD, lesions have shown a bilateral distribution (Bennett et al., 1981, Cook, 2001, Fitzpatrick et al., 2009b, Slater et al. 1991, Van Ryssen and Van Bree, 1997).

Significant odds ratios were recognized for the Newfoundland, Rottweiler, Labrador Retriever, Chow Chow, Golden Retriever, Great Dane and German Shepherd. These results support more subjective findings described by other studies (Fitzpatrick et al., 2009b, Janutta et al., 2006, LaFond et al., 2002, Slater et al., 1991, Van Ryssen and Van Bree, 1997). In current literature, no case of osteochondrosis of the medial aspect of the humeral condyle has yet been described in the Border Collie.

Osteochondrosis of the Stifle Joint

Of the four different joints affected by osteochondrosis, the stifle joint is least frequently affected (Johnson et al., 1994). 96% of osteochondritis lesions in the stifle joint are located at the medial aspect of the lateral femoral condyle. The remaining 4% affect the lateral aspect of the medial femoral condyle, and may be found in combination with lesions of the lateral condyle (Kowaleski et al., 2012, Olsson, 1987). Concurrent with OCD in the other joints, age of onset is typically between 4 and 8 months of age. However, a diagnosis is often made as late as 18 months of age (Slater et al., 1991). Slater et al. suggested that concurrent hip dysplasia might result in the veterinarian overlooking stifle pathology until degenerative changes become evident. It is unsure whether or not males are at a higher risk for developing stifle OCD (Kowaleski et al., 2012, Slater et al., 1991). Bilateral distributions have been reported in 50-63% of cases (Olsson, 1987, Slater et al., 1991). Breed predispositions, on the other hand, have been recognized, and are represented by the Mastiff, Irish Wolfhound, Great Dane, Rottweiler, Boxer, Bulldog, Labrador Retriever, German Shepherd, and Golden Retriever (LaFond et al., 2002, Slater et al., 1991). Osteochondrosis of the stifle has been described in Border Collies as well (Knecht et al., 1977).
Osteochondrosis of the Tarsocrural Joint

Osteochondrosis in the tarsocrural joint typically presents at the medial (79%) and lateral (21%) trochlear ridges (Fitch and Beale, 1998). The majority (80%) of medial trochlear lesions are located on the plantar aspect of the ridge, while lateral trochlear lesions usually (70%) present on the dorsal aspect of the ridge. Concurrent with the other forms of OCD, onset of disease occurs between 4 and 8 months of age. Similar to the stifle joint, OCD of the tarsocrural joint is often diagnosed up to an age of 18 months. This may be due to the gradual onset of clinical signs or due to overshadowing by concurrent diseases such as hip dysplasia. To the author's knowledge, no gender differences have been reported for osteochondrosis in the tarsocrural joint. Bilateral involvement has been recorded in a wide range of 12-63% of affected individuals (Fitch and Beale, 1998, Slater et al., 1991). Rottweiler and Labrador Retriever dogs are the most commonly affected breeds, accounting for more than 70% of cases. Furthermore, the Rottweiler has been noted to represent no less than 80% of dogs with osteochondrosis of the lateral trochlear ridge (Fitch and Beale, 1998). Besides these two breeds, Bullmastiff's, Bull Terriers, and Australian Cattle Dogs are also predisposed to developing tarsal OCD (Fitch and Beale, 1998, LaFond et al., 2002). Osteochondrosis of the medial trochlear ridge has been described in the Border Collie breed (Dingemanse et al., 2013).

2.1.1.b Elbow Dysplasia

Elbow dysplasia is a general term used to describe the presence of one or more specific pathologies of the elbow joint which are often seen in conjunction with each other, namely elbow OCD, medial coronoid disease (MCD), ununited anconeal process (UAP), and joint incongruity (Bennett et al., 1981, Griffon, 2012, International Elbow Working Group, Remy et al., 2004, Slater et al., 1991). Within this group of disorders, a differentiation is made between UAP on the one hand, which is located caudally in the joint, and MCD, OCD, and joint incongruity on the other hand, more commonly referred to as medial compartment disease (Griffon, 2012). Elbow dysplasia is recognized as a multifactorial disorder, where genetics, hormones, nutrition, growth rate, and trauma may each play a role in its development. Elbow dysplasia can be noticed as young as 4 to 7 months of age, though it is often diagnosed at a later stage. Clinical symptoms may only first present at a much older age due to the progression of degenerative joint disease. Male dogs have been reported to be affected twice as much as females, though the pathology remains equally severe in both genders. Etiological factors may vary between the different components of elbow dysplasia (Beuing et al., 2000, Boulay, 1998, Lavrijsen et al., 2012, Mäki et al., 2000, Meyer-Lindenberg et al., 2006, Proks et al., 2011). As in osteochondrosis, nutritional factors may influence growth rate, hereby exacerbating many developmental skeletal disorders, including elbow dysplasia (Dämmrich, 1991).

Large and giant dogs are typically affected, though elbow dysplasia has been described in chondrodysplastic dogs as well (Narojek et al., 2008, Sjöström, 1998). The heritability of elbow dysplasia has been quantified for the Labrador Retriever, Golden Retriever and Bernese Mountain Dog (Lavrijsen et al., 2012). Even though the different components of elbow dysplasia often occur
simultaneously, they are inherited independently as polygenic traits (Guthrie and Pidduck, 1990, Mäki et al., 2004). Lavrijsen et al., for example, reported a higher incidence (50%) of elbow incongruity in the Bernese Mountain Dog in comparison to the Labrador and Golden Retriever (6%). The elbow incongruity observed in the Bernese Mountain Dogs was almost always seen in combination with MCD. On the other hand, a high incidence of elbow OCD was detected in the Labrador and Golden Retriever (13% and 25%, respectively), comparing to a mere 3% in the Bernese Mountain Dog. As OCD of the elbow has been discussed earlier, we refer to section 1.1.1.b for further information concerning this disorder. Based on current literature, elbow dysplasia in the Border Collie breed seems to manifest primarily as medial coronoid disease, as, to the author’s knowledge, no cases of OCD, incongruity or UAP have yet been described.

Medial Coronoid Disease

Until recently, MCD was more commonly referred to as fragmentation of the medial coronoid process (FCP) and is the most frequently perceived component of elbow dysplasia (Johnson et al., 1994, Lavrijsen et al., 2012). The use of this more general term has been justified by the wide variety of lesions that have been described to affect the medial coronoid process (MCP), ranging from sclerosis, fissures and microfractures to fragmentation (Fitzpatrick and Yeadon, 2009). MCD has previously been suggested to reflect a specific form of osteochondrosis (Olsson, 1987), however, no histomorphometric evidence of osteochondrosis has been detected. Instead, osteocyte loss is recognized with microcracks either along the craniodistal tip of the coronoid process (the typical location for fragmentation) or along the radial incisure of the medial portion of the coronoid process, where fissures are frequently detected (Danielson et al., 2006). These findings suggest that microtrauma due to excessive loading, such as with repetitive or high impact exercise, or radioulnar and radiohumeral incongruity (see later), may play a significant role in the development of these lesions. According to Temwichitr et al., the fragmented medial coronoid is often still attached to the annular ligament, suggesting that fragmentation results from an avulsion fracture induced by tension forces, which derive from the annular ligament (Temwichitr et al., 2010). This was supported by the findings of Wolschrijn and Weijs, who noted that, at 4 months of age, the trabeculae in the medial coronoid possess the same orientation as the annular ligament (Wolschrijn and Weijs, 2004).

Epidemiological factors tend to be analogous amongst the different studies concerning MCD. MCD may present from an age of 4-7 months, but is often diagnosed at an older age (averaging at 13 months). A higher risk in male dogs is generally accepted and a bilateral distribution was found in approximately 25-50% of cases (Boulay, 1998, Cook et al., 2001, Meyer-Lindenberg, 2002, Morgan et al., 1999, Remy et al., 2004, Van Ryssen and Van Bree, 1997). Genetic predispositions for MCD have been detected in a wide variety of breeds, with Bernese Mountain Dogs, Labrador Retrievers, Golden Retrievers, Newfoundlanders, German Shepherds, Boxers and American Staffordshire Terriers most frequently affected. MCD, unlike the other components of elbow dysplasia, has been described in the Border Collie breed on several occasions (Burton et al., 2010, Cook et al., 2001, Fitzpatrick et al., 2009a, Gemmill et al., 2005, LaFond et al., 2002, Meyer-Lindenberg, 2002, Temwichitr et al., 2009, Van Ryssen and Van Bree, 1997).
Elbow Joint Incongruity

Various types of elbow joint incongruity have been described, including radioulnar length disparity, radioulnar incisure incongruity, and humeroulnar incongruity (Figure 2). A rotational incongruity resulting from a mismatch between the brachialis and biceps muscles has recently been proposed as an additional type of elbow joint incongruity (Fitzpatrick and Yeadon, 2009, Michelson, 2013).

A static radioulnar incongruity, in which the radial head is located more distally in relation to the ulna, will result in a transfer of loads from the radial head towards the medial part of the coronoid process. These excessive forces on the medial coronoid process have been proposed to contribute to the development of MCD (Griffon, 2012, Meyer-Lindenberg et al., 2006, Preston et al., 2000, Samoy et al., 2006). On the other hand, a radioulnar incongruity in which the radial head is located more proximally in relation to the ulna is suggested to result in an abnormal load distribution towards the anconeal process, leading to fragmentation or non-union of this process (Sjostrom et al., 1995).

Humeroulnar incongruity coincides either with an elliptically shaped ulnar trochlear notch, in which the radius of the curvature of the ulnar notch is smaller than the curvature of the humeral trochlea, or a proximally located radial head which displaces (subluxates) the humeral head cranially from the ulnar notch (Michelson, 2013, Proks et al., 2011). This subluxation is thus primarily due to a radioulnar incongruity, which is more frequently associated with elbow dysplasia than an abnormally shaped ulnar notch. An elliptical ulnar trochlear notch is suggested to result in an abnormal load distribution towards both the medial coronoid process as well as the anconeal process. The low incidence of simultaneous MCD and UAP suggests this type of incongruity may not play as an important role as was primarily suggested, though it may be argued that incongruity under 20 weeks of age will primarily lead to UAP and incongruity after 20 weeks of age will solely result in MCD (Kirberger and Fourie, 1998). Proks et al. quantified humeroulnar incongruity in 26 Labrador Retrievers with MCD and determined significantly greater incongruity in the affected elbows compared to the unaffected elbows (Proks et al., 2011).

![Figure 2: Different forms of elbow joint incongruity. A) Congruent joint with parallel joint space with 1. humerus, 2. ulna, 3. radius, 4. Trochlear notch of the ulna. B) Incongruent joint with elliptical shape of the trochlear notch instead of round. C) Incongruent joint with short radius. There is a step in the joint, due to the more distal joint surface of the radius. D) Incongruent joint with short ulna. There is a step in the joint, due to the more distal joint surface of the ulna. (Samoy et al., 2006)](image-url)
Theoretically, rotational incongruity has been suggested to occur (Figure 3), in which shear forces act on the lateral aspect of the medial coronoid process, compressing the process against the radius and causing crushing injuries along the radial incisure of the coronoid process. This rotational instability could result from ligamentous insufficiency, from a discrepancy between the radial incisure of the medial coronoid process and the radial head, or from a mismatch between the biceps brachii/brachialis muscles in relation to their bony insertion point at the medial coronoid process (Fitzpatrick and Yeadon, 2009).

Evidence of such injuries is, however, limited to three cases only (Fitzpatrick et al., 2009a, Samoy et al., 2012, Van Ryssen and Van Bree, 1997).

Temporary, dynamic and localized forms of incongruity could play an important role in elbow dysplasia and may be missed on radiographic and computed tomography (CT) images (Griffon, J. D., 2012). On the other hand, a mild degree of radioulnar incongruity has been detected in normal joints (Kramer et al., 2006, Preston et al., 2000). These factors make it difficult to evaluate the severity of elbow joint incongruity and its relative importance to the pathogenesis of elbow dysplasia. Radiographic evaluation of elbow joint incongruity is acknowledged as an insensitive technique, requiring at least a 2mm-step in order to obtain a sensitivity level of 90 to 100% (Blond et al., 2005). Though arthroscopy is considered the most sensitive technique for detecting elbow incongruity, it may be advised to perform both CT and arthroscopy when evaluating elbow dysplasia as a whole, as they have been shown to detect different types of MCP lesions (Böttcher et al., 2009, Moores et al., 2008, Wagner et al., 2007).

Both the pathogenesis of elbow joint incongruity and its role in elbow dysplasia remain ill defined, and the simultaneous presence of other abnormalities such as MCD may make it difficult to differentiate epidemiological factors specific to its occurrence. In a study evaluating the four different components of elbow dysplasia (OCD, MCD, UAP and joint incongruity) in 154 dysplastic elbows in German Shepherd dogs, joint incongruity was the most common disorder, affecting 16.3% of the population. Furthermore, all of the dogs that were diagnosed with multiple dysplastic disorders had incongruent elbows (Remy et al., 2004). Elbow joint incongruity has been detected between 6 and 18 months of age and, to date, no gender differences specific to joint incongruity have been defined. Bilateral involvement occurs in 35.5% of patients (Puccio et al., 2003). Elbow joint incongruity is most frequently seen in large-breed dogs such as Labrador Retrievers, Golden Retrievers, German Shepherds, Rottweilers and Bernese Mountain Dogs (Gemmill et al., 2005), though chondrodystrophic
dogs may present with joint incongruity as well. To the author’s knowledge, elbow joint incongruity is yet to be described in the Border Collie breed.

Ununited Anconeal Process

In normal elbows, the center(s) of ossification appear in the anconeal process around 11 to 12 weeks of age. The time at which fusion occurs varies slightly between breeds, with 14 to 15 weeks described for Greyhounds, and 16 to 20 weeks for German Shepherds (Sjöstrom, 1998). Similar to MCD, different theories have been put forward in an attempt to explain the pathogenesis of UAP. It has been suggested to exist as a manifestation of osteochondrosis (Sjöstrom, 1998). Others insinuate that a disruption of the microcirculation during ossification prevents union of the anconeal process (Olsson, 1993). As has been discussed earlier, a static joint incongruity in which the ulna is positioned more distally in relation the radius has been proposed to result in excessive forces originating from the humeral condyle and directing towards the anconeal process, hereby preventing its fusion (Griffon, 2012). An ununited anconeal process can therefore not be correctly diagnosed before 5 months of age, which is the age at which fusion should normally occur. It often takes up to 1 year to be recognized and bilateral involvement occurs in 20-35% of cases. In several studies, male dogs have been shown to have twice as much risk of developing UAP compared to females. In one major study, no less than 13% and 50% of dogs with UAP had concurrent MCD and elbow incongruity, respectively, and 72% of affected individuals belonged to the German Shepherd breed (Meyer-Lindenberg et al., 2006). UAP is also overrepresented in Bernese Mountain Dogs and Mastiffs. It is recognized in a large number of breeds typically affected by other forms of elbow dysplasia, including the Golden Retriever, Labrador Retriever, Great Dane, Newfoundlander, Rottweiler and Saint Bernard (LaFond et al., 2002). Some breeds are less commonly affected by elbow dysplasia but were still associated with UAP, including the Bloodhound, Weimaraner and smaller dogs such as the Basset Hound, French Bulldog and Dachshund (Sjöstrom, 1998). To the author’s knowledge, UAP has not yet been described in the Border Collie breed.

2.1.1.c Hip Dysplasia

Hip dysplasia (HD) is a complex multifactorial disorder controlled by numerous genes which are under influence of a variety of environmental factors, and is the most common joint disease in dogs (Johnson et al., 1994). A distinction is made between a juvenile and a chronic form of HD. The juvenile form has a sudden onset at 5-12 months of age and is associated with extreme joint laxity. At a later stage, periarticular fibrosis may partially stabilize the joint, but progressive worsening of the hip laxity may also occur. In the chronic form of HD, the onset is variable and shows a gradual deterioration. In these cases, pain usually results from the progression of degenerative joint disease rather than the luxation itself (Smith et al., 2012). One study evaluating hips of 46 Labrador Retrievers during their entire lifespan noted that the onset of HD always occurred before 2 years of age (Smith et al., 2009). Though susceptible loci have been mapped to several chromosomes, and that quantitative trait loci for acetabular osteophyte formation have been revealed in different breeds, the underlying genetics of HD is a complex matter and has only been slightly unraveled (Chase et al., 2004, Chase et
Joint laxity, measured via the distraction index, is recognized as the primary risk factor for development of HD (Runge et al., 2010, Smith et al., 2001). At approximately one month of age, the femoral head ligament is the main component insuring hip joint stability and excessive lengthening of this ligament will permit a lateral coxofemoral subluxation (Burton-Wurster et al., 1999, Smith et al., 2012). In order to compensate for this laterization of the joint’s center of rotation, the surrounding muscles are required to exert increased forces across the coxofemoral joint. The femoral head is thought to subluxate during the swing phase, and, subsequently, a traumatic reduction occurs during the weight bearing phase. The area over which the forces are exerted is decreased in a subluxated hip, resulting in cartilage stress, and, ultimately, cartilage damage, joint inflammation, and osteoarthritis (Smith et al., 2012). Other factors associated with HD include an increased synovial fluid volume, increased body weight, rapid growth rate, and low muscle mass (Comhaire and Snaps, 2008, Kealy et al., 2002, Smith et al., 2001, Smith et al., 2006, Smith et al., 2012). Hormonal and nutritional risk factors have also been described, such as high levels of relaxin, a high dietary anion gap and excesses in calcium and vitamin D (Nap et al., 1991, Nap et al., 1993, Nap and Hazewinkel, 1994, Steinetz et al., 1987).

Hip dysplasia is typically seen in large and giant breed dogs, such as the Newfoundland, German Shepherd, Golden Retriever, Rottweiler, Labrador Retriever, and Saint Bernard (Comhaire and Snaps, 2008, Coopman et al., 2008, Genevois et al., 2008, Witsberger et al., 2008). Small dogs and sight hounds such as the Miniature Schnauzer, Chihuahua, Maltese, Greyhound, and Barzoi have a low risk of developing HD (Kapatkin et al., 2004, Witsberger et al., 2008). Witsberger et al. performed a large-scale study evaluating the prevalence and risk factors for HD. Their study revealed that castrated males have a higher risk of developing HD, while both intact and spayed females have a significantly lower risk. Diagnosis of HD generally occurred between 2 months and 4 years of age (Witsberger et al., 2008).

Hip dysplasia has been detected in Border Collies (Figure 4), making up 4% to 57% of the affected population (Friedenberg et al., 2011, Lafond et al., 2002, Stanin et al., 2011, Witsberger et al., 2008). Statistical analysis has been performed in merely two of these studies, of which one showed a significantly higher risk of HD in the Border Collie breed (LaFond et al., 2002). Fibrillin 2 deletion haplotypes, which are

![Figure 4: Severe hip dysplasia in an 8-year-old male Border Collie.](image)
associated with HD and subsequent osteoarthritis, have been detected in a variety of breeds, including the Border Collie (Friedenberg et al., 2011).

2.1.2.d Patellar Luxation

Patellar luxation can occur either in relation to a traumatic event, or, in most cases, as part of a developmental disorder originating from certain congenital conformational abnormalities. The patella can luxate medially, laterally, or in both directions. Current literature suggests a predisposition for patellar luxation in small-breed females and large-breed males and a mean age of diagnosis ranging from approximately 1 to 3 years of age (Alam et al., 2007, Arthurs and Hobbs, 2007, Bound et al., 2009, Gibbons et al., 2006, Hayes et al., 1992, Priester, 1972, Remedios et al., 1992).

A medial patellar luxation (MPL) occurs more frequently than a lateral patellar luxation (LPL), with a prevalence of approximately 95% to 98% in small-sized dogs and 67% to 81% in medium- to giant-sized dogs (Hayes et al., 1992). A congenital coxa vara and relative retroversion of the femur have been suggested to result in a medial malalignment of the quadriceps muscles. Subsequently, the quadriceps muscles will exert increased forces on the medial aspect of the distal femoral physis. This will lead to a delayed growth of the medial side of the stifle joint, which can be expressed as a wide variety of deformities, such as: femoral varus, hypoplasia of the medial femoral condyle, proximal tibial varus, internal rotation of the proximal tibia, external rotation of the distal tibia, medial displacement of the tibial tuberosity and internal rotation of the foot (Kowaleski et al., 2012). The primary role of a coxa vara conformation has been disputed by Bound et al., however, who reported a high incidence of coxa valga in dogs with MPL (Bound et al., 2009). During a normal anatomical development, the pressure exerted by the patella will lead to a deepening of the trochlear groove. Inadequate pressure may occur in the case of quadriceps malalignment, most often characterized by a poor development of the medial ridge and resulting in what is known as trochlear hypoplasia. A shallow trochlear groove may also appear at a later stage, when intermittent luxation and reduction of the patella leads to a progressive wearing of the medial ridge. In some cases, a tibial valgus might be recognized (as opposed to a tibial varus), presumably arising as a compensatory change to the distal femoral varus (Kowaleski et al., 2012). A relationship has been suggested between cranial cruciate ligament disease (CCLD) and MPL in several studies (Arthurs and Hobbs 2006, Arthurs et al., 2006, Gibbons et al., 2006, Persuki et al., 2006, Piermattei et al., 2006). The exact nature of this relationship, as to which disorder precedes the other, remains unknown. In large-breed dogs a correlation has been found between MPL and a patella alta, as well as a lengthened patellar ligament (Johnson et al., 2002, Johnson et al., 2006, Mostafa et al., 2008). MPL is most frequently recognized in small-breed dogs, and a higher risk of MPL has been detected in the Chihuahua, Poodle, Yorkshire Terrier, Pomeranian, and Boston Terrier, among others (Bound et al., 2009, Priester, 1972). The incidence of MPL seems to be increasing in large-breed dogs, however (Gibbons et al., 2006, Priester, 1972). Especially Labrador Retrievers seem to be predisposed to developing MPL, though it has also been reported on several occasions in Rottweilers, American Staffordshire Terriers, Australian Cattle Dogs, and Newfoundlanders. Labrador Retrievers, Rottweilers, and Newfoundlanders are also predisposed to CCLD, and the simultaneous occurrence of these two disorders is more common in these breeds (Arthurs et al., 2006, Arthurs and Hobbs, 2007,
Bound et al., 2009, Gibbons et al., 2006, Johnson et al., 2006). MPL has been reported in Border Collies, representing 1.5% to 8.6% of the affected population (Bound et al., 2009, Gibbons et al., 2006).

The congenital skeletal deformities that lead to a LPL occur in an opposite direction than for a MPL and consist of a coxa valga and a relative anteversion of the femur. Through the same quadriceps mechanism, forces are distributed unequally to the femoral physis and developmental conformational abnormalities may follow. These deformities include a femoral valgus, hypoplasia of the lateral femoral condyle, proximal tibial valgus, and external rotation of the tibia (Kowaleski et al., 2012). In contrary to MPL, a long proximal tibia and patella baja are often recognized in lateral patellar luxations (Mostafa et al., 2008). LPL has been reported in dogs of all sizes, though large-breed dogs are more commonly affected than smaller breeds. Having said this, LPL was diagnosed most frequently in the Cocker Spaniel in one study (Alam et al., 2007, Arthurs et al., 2006, Bound et al., 2009, Mostafa et al., 2008).

2.1.2. Degenerative Disorders

2.1.2.a Cranial Cruciate Ligament Disease

CCLD is the second most frequently occurring joint disease in dogs, affecting 15.5 in 1000 dogs (Johnson et al., 1994). Partial or complete rupture of the cranial cruciate ligament (CCL) may result from either an acute trauma or, in most cases, a progressive degenerative process within the ligament itself. Traumatic ruptures are a rarity and are generally associated with immoderate loading, internal rotation of the tibia, or hyperextension of the stifle, in which the forces acting on the ligament exceed its respective strength.

Progressive degeneration of the cranial cruciate ligament has been confirmed both biomechanically (decreased elasticity, maximal stress and strain energy) and histologically (loss and metaplasia of fibroblasts) (Hayashi et al., 2003, Vasseur et al., 1985). Degenerative CCLD results in a weakened ligament, incapable of withstanding repetitive physiological forces, and ultimately leading to a partial or complete rupture of the CCL. Complete CCL ruptures are seen more frequently than partial ruptures, and have been reported to make up 53% to 86% of all CCL ruptures (Casale and McCarthy, 2009, Corr and Brown, 2007, Ertelt and Fehr, 2002, Metelmann et al., 1995, Ralphs and Whitney, 2002). The exact etiology of degenerative CCLD is difficult to discern, as multiple risk factors contribute to the development of this disease. The risk of CCLD is significant greater from an age of 4 years old onwards, peaking between 4 and 7 years of age. Though no significant gender differences have been discovered, both castrated males and spayed females seem predisposed to developing CCLD (Fitzpatrick and Solano, 2010, Guastella et al., 2007, Witsberger et al., 2012). In different studies, 37% to 48% of dogs were affected in the contralateral limb within 5.5 to 17 months after the first CCL rupture. Age, tibial plateau angle (TPA), gender and weight were not recognized as risk factor for the development of CCLD in the contralateral limb (Buote et al., 2009, Cabrera et al., 2008, Doverspike et al., 1993).

Conformational abnormalities associated with CCLD are numerous, and include: an increased TPA, a caudal insertion patellar ligament, a deviant femoral condyle diameter, a femoral anteversion.
angle, and a decreased intercondylar notch width. Though an increase in TPA is generally associated with CCLD, Brown et al. recently demonstrated higher loading of the CCL in stifles with a decrease in TPA as well (Aiken et al., 1995, Brown et al., 2013, Morris and Lipowitz, 2001). An increased TPA may contribute to the progression of CCLD; however, it is a common finding in unaffected individuals as well, suggesting that a direct causal relationship is unlikely (Reif and Probst, 2003, Wilke et al., 2002). The TPA is therefore not considered as a valuable predictor for the development of CCLD. Obesity and a poor athletic condition have been associated with a higher risk of developing CCLD (Lampman and Lipowitz, 2003), supposedly by modifying the protective mechanisms of the CCL, hereby predisposing to repetitive strain injury and concurrent mechanical failure (Kowaleski et al., 2012, Miyatsu et al., 1993).

A genetic component may also be involved, as CCLD is frequently seen in certain large and giant breed dogs such as the Newfoundland, Rottweiler, Labrador Retriever, Bulldog, and Boxer, among others (Witsberger et al., 2008). Dogs weighing 15 kilograms or more have been shown to develop a more severe CCLD at an earlier age than smaller dogs (Vasseur et al., 1985). When evaluating the biomechanical properties of the CCL in Greyhounds and Rottweilers, the CCL’s of Rottweilers ruptured at half of the load per unit of body weight needed to rupture the CCL in Greyhounds, suggesting an inherent vulnerability in the Rottweiler’s CCL (Wingfield et al., 2000). Witsberger et al. also evaluated the risk of developing both HD and CCLD simultaneously, and discovered an elevated risk in several breeds, including the Newfoundland, Rottweiler, Saint Bernard and Bulldog (Witsberger et al., 2008). Though CCLD has been described in Border Collies, no significant predisposition has been detected (Witsberger et al., 2008), and one study even reported a significantly lower risk of developing CCLD in the Border Collie breed (Dorn, 2002).

2.1.2.b. Meniscal Injury

Meniscal injuries are almost always associated with the instability and concomitant abnormal loading seen in CCL-deficient stifle joints. Meniscal injury has been reported in 37.5% to 77% of dogs first presenting with CCLD, and as a cause of residual post-surgical lameness in 13.8% to 21.7% of CCLD cases. Some studies report post-surgical meniscal injury incidences as low as 2.8%, however, these studies do not account for the number of meniscectomies and/or meniscal releases performed. Late meniscal injuries are diagnosed as either postliminary tears (occurring due to residual stifle joint instability) or latent tears (overlooked at the time of surgery) and usually occur within 4 to 6 months of surgery (Casale and McCarthy, 2009, Corr and Brown, 2007, Ertelt and Fehr, 2009, Fitzpatrick and Solano, 2010, Lafaver et al., 2007, Metelman et al., 1995, Ralphs and Whitney, 2002, Stein and Schmoekel, 2008). Though a meniscal release procedure may prevent issues associated with late meniscal injury and concomitant degenerative joint disease, the menisci possess valuable stabilizing and lubricating functions, and its removal may promote degenerative joint disease just the same (Luther et al., 2009). Furthermore, Thieman et al. reported that meniscal release does not reduce the risk of subsequent meniscal injury and had no affects on client-assessed outcome (Thieman et al., 2006). Meniscal release therefore remains a controversial procedure. In the medial meniscus, the caudal and cranial poles are maximally loaded in joint flexion and joint extension, respectively. In a
CCL-deficient stifle joint, excessive loading of the caudal and cranial poles during weight bearing predisposes to meniscal injury. Furthermore, the medial meniscus is forced to take over the CCL’s primary role of limiting cranial tibial translation, and thereby becomes an important stabilizer of the stifle joint (Pozzi et al., 2006). As the medial meniscus is firmly attached to the tibia, cranial translation of the tibia will lead to crushing of the medial meniscus between the femoral and tibial condyle. This will produce circumferential tensile stress often resulting in longitudinal or ‘bucket tears. Meniscal tears have been classified arthroscopically into five different types, namely: vertical longitudinal tears, radial tears, complex tears, flap tears, or horizontal tears (Figure 5). Vertical longitudinal tears may either be nondisplaced (incomplete tears) or displaced (bucket-handle tears). Each of these tears may be accompanied by degeneration of the meniscus, macroscopically recognized as a pale yellow, fibrillated structure with a soft texture (Thieman et al., 2009, Kowaleski et al., 2012). Thieman et al. went on to evaluate the contact mechanics of these different types of tears, concluding that all except

Figure 5: Classification of meniscal tears.

A) Intact meniscus.
B) Vertical longitudinal (nondisplaced) tear – Occurs within the body of the meniscus, parallel to the collagen fibers. Precursor to the bucket-handle tear.
C) Bucket-handle (displaced) tear: The most common type of tear.
D) Oblique/flap tear: Usually start as vertical tears, progressing to bucket-handle tears and then tearing completely at one end. The flap may become macerated.
E) Radial tears: Vertical tears from the inner edge of the meniscus towards the periphery. Most often seen axially in the lateral meniscus as ‘axial fringe tears’.
F) Horizontal tear: Occur in the transverse plane and are frequently associated with complex/degenerative tears.
G) Complex tear: A combination of multiple tears, usually seen in very chronic cases.
H) Degeneration of the meniscus: Most commonly found with complex tears, recognized by its pale yellow color, fibrillated surface, and softer texture.

(Kowaleski et al., 2012).
radial and vertical nondisplaced tears change the contact mechanics of the stifle and therefore require debridement. Though meniscal injuries are suggested to predominate in the medial meniscus, one study evaluating 100 cases of CCLD arthroscopically reports an incidence of 77% for radial tears of the lateral meniscus. Rotational and translational motion has been proposed to result in pinching of the free axial edge of the lateral meniscus between the lateral intercondylar tubercle and the lateral femoral condyle. (Ralphs and Whitney, 2002). It was suggested that these lateral meniscal lesions were missed in previous studies, either due to the fact that the stifle joints were inspected using arthrotomy as opposed to arthroscopy, or because surgeons simply did not include standard inspection of the lateral meniscus during their arthroscopic evaluation. The clinical importance of these radial tears is, however, unidentified.

Contrary to CCLD, no correlation was found between TPA or gender and meniscal injury. Obesity proved to be a risk factor for developing meniscal injury, as well as chronic or complete CCLD. Fitzpatrick and Solano performed a large-scale study and noted no significant breed predispositions for meniscal injury. Having said this, Hayes et al. did find a higher risk of meniscal injury in Rottweilers and Golden Retrievers compared to Labrador Retrievers, while West Highland White Terriers had a reduced risk. These findings suggest, contrary to previous belief, breed predispositions do occur. The risk factors for meniscal injury are, however, difficult to determine due to the low incidence of independent meniscal injuries (Fitzpatrick and Solano, 2010, Hayes et al., 2010, Metelman et al., 1995, Ralphs and Whitney, 2002). Though meniscal injury subsequent to CCLD is suspected to occur in Border Collies, this has not yet been specified in current literature. One case of an isolated meniscal injury, seemingly unrelated to a traumatic event, has been described in an active Border Collie participating in Agility competitions (Ridge, 2006).

2.1.2.c. Flexor Enthesopathy

Flexor enthesopathy is a term used to describe the pathological changes that are frequently recognized in the flexor muscles at their point of origin on the medial humeral epicondyle. Typically, these pathological changes involve calcified bodies near or within the flexor muscles or bony spur formation at the caudal edge of the medial epicondyle (Figure 6) (Grondalen and Braut, 1976, de Bakker et al., 2013b, Zontine et al., 1989). A variety of forms and etiologies of flexor enthesopathy have been suggested to occur, and the true pathogenesis of these lesions remains unclear. Lesions at the medial humeral epicondyle were first described as an ununited medial epicondyle (Ljunggren et al., 1966, Paster et al., 2009). However, no radiographic evidence of non-union was found, and the occurrence of a pre-formed ossification center was suggested instead (Grondalen and Braut, 1976). Avulsions of the medial humeral epicondyle have also been reported as a possibility, which may or may not be associated with a recent traumatic event. Acute traumatic avulsions are generally associated with bilateral lesions and a recent trauma, while chronic traumatic avulsions mainly occur unilaterally and have no history of a recent traumatic event. Avulsion of the medial humeral condyle can occur in both mature and immature dogs, the latter presumably occurring before 10 weeks of age, when fusion of the center of ossification takes place (Culvenor and Howlett, 1982, Hare, 1961, Zontine et al., 1989). Finally, dystrophic calcification of the flexor tendon origin has also been implied as a
possible etiology for flexor enthesopathy (Grondalen and Braut, 1976, Zontine et al., 1989). In this case, an ossifying tendinitis is suggested to occur.

Flexor enthesopathy has been described to be either primary or secondary (concomitant) in nature (de Bakker et al., 2013). In primary flexor enthesopathy, no other simultaneous orthopedic elbow disorders can be detected. On the contrary, concurrent elbow disorders such as medial coronoid disease, elbow osteochondrosis, arthrosis, microtrauma or stress injuries could result in secondary (or concomitant) flexor enthesopathy (de Bakker et al., 2011, Zontine et al., 1989). The clinical significance of flexor enthesopathy is debatable, as subclinical forms of flexor enthesopathy have also been described (de Bakker et al., 2013a, Zontine et al., 1989). Concomitant flexor enthesopathy is much more common than primary flexor enthesopathy, with incidences of 34% and 6%, respectively (de Bakker et al., 2013a).

Lesions of the flexor tendons most often present as a central core of either calcified material or bony fragments, surrounded by (fibro-) cartilaginous tissue (de Bakker et al., 2011). On the other hand, a recent study performed histopathologic analysis of primary lesions in eight dogs and noted degenerative and metaplastic changes without the presence of an ossified fragment (Van Ryssen et al., 2012).

Flexor enthesopathy generally affects adult dogs, with a reported mean age of 5 years of age. However, dogs as young as 7 months and as old as 9 years may be affected (de Bakker et al., 2013a, Grondalen and Braut, 1976, Ljunggren et al., 1966, Zontine et al., 1989). A predisposition for male dogs seems to exist, and an incidence of 65% has been reported. Medium- and large-breed dogs seem to be overrepresented when examining flexor enthesopathy. In one study, the Great Swiss Mountain Dog was affected most frequently when compared with other breeds. Labrador Retrievers were found to have the highest incidence of concomitant flexor enthesopathy, possibly due to their popularity and the high prevalence of medial coronoid disease in this specific breed. Flexor enthesopathy has been described in the Border Collie breed (de Bakker et al., 2013a).

Figure 6: Spur formation at the caudodistal aspect of the medial humeral epicondyle in a 4-year-old female Border Collie with flexor enthesopathy.
2.1.2.d Biceps Brachii Tendinopathy

Biceps brachii tendinopathy is a common cause of shoulder lameness in the dog and encompasses a wide variety of pathologies, which may occur simultaneously, and are all located at the tendon of origin of the m. biceps brachii (Cook and Cook, 2009). These pathologies include complete and partial tearing at the supraglenoid tubercle, midsubstance tearing, tendinitis and tenosynovitis, bipartition, and luxation. Even though biceps tendinopathy is generally recognized as a common musculoskeletal disorder, the exact prevalence, etiology, and pathogenesis remain unclear. In 33% and 76% of patients diagnosed with a bicipital tendon rupture, concomitant tendinitis and subluxation was reported, respectively (Bardet, 1999). Biceps brachii tendinopathy is a difficult disorder to diagnose, as both clinical and radiographic signs are insensitive techniques and often lead to false-positive diagnoses. Synovial fluid, contrast arthrography and especially sonography are helpful tools in evaluating biceps brachii tendinopathy. In current literature, a distinction is often made between primary and secondary tendinopathy (Bruce et al., 2000). Primary biceps brachii tendinopathy is thought to result from an inflammation caused by chronic repetitive injury (microtrauma) or overloading of the biceps tendon. Avulsion fractures and ruptures located at the muscle-tendon junction are generally more likely to occur than tendon ruptures, due to the high tensile strength of healthy tendons (Bardet, 1999). Factors predisposing to tendinopathy that weaken the tendon, such as overloading and chronic repetitive injuries, therefore suggestively occur (Rochat, 2012). A relative hypovascularity of the tendon at its origin may predispose the bicipital tendon for injury (Piermattei et al., 2006). Bardet suggested that the biomechanical properties of tendons deteriorate with age, and may contribute to susceptibility to injury. He also noted a higher risk of biceps tendinopathy in French Poodles and Labrador Retrievers, though breed predispositions have not properly evaluated in current literature (Bardet, 1999).

Secondary tendinopathy may result from a variety of primary factors, such as an acute trauma, intra-articular disease, localized joint mice and mineralizations, sepsis, or neoplasia (Bruce et al., 2000). Evidently, the amount of research done regarding bicipital tendinopathy is limited, and contradicting results concerning its etiological factors have been reported. A wide variety of pathophysiological mechanisms are suggested to occur, which may reflect the diversity of lesions described.

2.1.3. Traumatic Disorders
2.1.3.a. Muscle Injuries

Muscle injuries can vary from contusions, lacerations, strains, ruptures, to contractures, and usually result from either overstretching of the muscle or a direct trauma (Carmichael and Marshall, 2012a). Muscle injuries suggestively vastly underdiagnosed in dogs, with one large-scale study noting an incidence of less than 5%, and only 0.1% with strains and myositis (Johnson et al., 1994). In human athletes, on the other hand, 30% of all injuries are stretch-induced muscular injuries (Zachaweski, 1996). Dogs with muscle pain may present with only subtle clinical signs of a transient nature and, due to their specific localization and the often stoic nature of canine athletes, are often
difficult to diagnose (Steiss, 2002). Soft tissue changes cannot be properly assessed using radiography, though it is often the first imaging technique used when evaluating lameness. Imaging techniques that are more appropriate at visualizing muscle injuries, such as ultrasound, scintigraphy, and magnetic resonance imaging (MRI), are seldom used.

Contusions and lacerations are a result of direct blunt and sharp injuries, respectively, and are perhaps of less importance when evaluating the role of breed and activity level in muscle injuries. Muscle strains and ruptures, on the other hand, result from indirect injuries such as overuse or overstretching of the muscle-tendon unit. Strain injuries mostly occur at the musculotendinous junction and are often caused by a powerful active contraction simultaneous with a passive extension and are of particular importance in canine athletes. Muscles that cross more than one joint are at a higher risk of injury (Anderson, 2006, Carmichael and Marshall, 2012a, Steiss, 2002). The severity of the strain depends on the degree of force generated during injury, and three stages have been defined. Stage I, or mild, strains are characterized by a mild myositis and contusion with minimal changes to the architecture of the tissues, muscle strength, joint range of motion (ROM), or gait. In stage II or moderate strains, myositis is seen in conjunction with mild tearing of the fascial sheath and decreased muscle strength and ROM. In stage III or severe strains, both the fascial sheath and muscle fibers are torn and muscle function is significantly compromised (Carmichael and Marshall, 2012a, Steiss, 2002). Even more severe injuries result in partial or complete muscle ruptures. Stage I and II are typically seen in the group of ‘power’ muscles, such as the m. triceps brachii, m. biceps femoris, m. quadriceps femoris, m. tensor fascia lata, m. semitendinosus and the m. semimembranosus. Stage III strains commonly affect the long heads of the m. triceps brachii, m. gracilis, m. gastrocnemius, and the m. tensor fascia lata (Steiss, 2002). Strains have also been reported in the m. rhomboideus, m. serratus ventralis, m. extensor carpi radialis, m. flexor carpi radialis, m. flexor carpi ulnaris, m. iliopsoas, m. pectineus, and the deep pectoral muscles (Carmichael and Marshall, 2012a). Iliopsoas and pectineus strains are the most common strain injuries occurring in pet dogs (Nielsen and Pluhar, 2005). Injuries to the m. tensor fascia latae, m. gracilis and the long head of the m. triceps brachii are common injuries in racing Greyhounds, and gracilis ruptures have also been reported in German Shepherds and Foxhounds (Leighton, 1981).

Repetitive strain injuries, among others, can eventually lead to muscle contractures, also known as fibrotic myopathies. After muscle injury, healing can occur through direct regeneration (if the sarcolemmal nuclei are still intact) or via fibrous scar tissue formation. Direct regeneration will allow full regain of function, whereas profuse scar tissue generation will cause a significant impairment of the capacity to produce tension (Carmichael and Marshall, 2012a, Garrett et al., 1984, Nikollau et al., 1987). Such is the case with muscle contractures, in which excessive scar tissue formation causes a shortening of the muscle and subsequent resistance to stretching. Besides repetitive strain injuries, a wide variety of pathologies may result in muscle contracture, such as compartment syndrome, infection, prolonged immobilization, primary muscle disease, and traumatic events such as fractures (Carmichael and Marshall, 2012a). In an acute phase, the affected muscles may be swollen and painful and the dog may show a reluctance to bear weight. In the chronic phase, a characteristic gait can be seen which reflects a functional problem rather than a painful one (Steiss, 2002).
Common muscle contractures in the dog involve the m. infraspinatus, m. quadriceps femoris, m. gracilis and the m. semitendinosus. A contracture of the infraspinatus mainly affects medium- to large-breed sporting and working dogs and has been reported in the Pointer, Labrador Retriever, Brittany Spaniel, and the Border Collie, among others (Bennett, 1986, Dillon et al., 1989, Vaughan, 1979). Infraspinatus contracture typically presents unilaterally as shoulder abduction, elbow adduction and both carpal and pedal abduction in rest, with external rotation of the foot and carpus during flexion (Steiss, 2002). Gracilis and semitendinosus contractures often develop bilaterally and are most frequently diagnosed in German Shepherd dogs, though it has been noted in Doberman Pinschers and Rottweilers, among others. The gait abnormality is characterized by a shortened stride with external rotation of the hock and internal rotation of foot during flexion of the limb. It has been suggested that repetitive strain injuries resulting from sprinting and jumping activities may predispose to gracilis and semitendinosus contractures (Carmichael and Marshall, 2012a, Steiss, 2002). Contractures of the m. quadriceps femoris are mostly associated with an acute trauma, such as femoral fractures or excessive immobilization of the stifle in an extended position. Congenital and infectious forms of quadriceps contracture also occur (Anderson, 2006, Stead et al., 1977). Typically, the stifle cannot be flexed and the hind limb is held in full extension. As a result, the paw may be dragged across the floor, causing excoriations (Carmichael and Marshall, 2012a). The consequences of quadriceps contracture are generally more severe than other forms of fibrotic myopathy, with possible patellar luxation and hip subluxation (Anderson, 2006). Congenital contractures may lead to growth disorders within the affected limb (Carmichael and Marshall, 2012a).

2.1.3.b. Tendon Injuries

As with muscular injuries, tendon injuries can occur as a result from both direct trauma (contusion, laceration) and indirect trauma (acute or chronic overload). Tendon injuries, however, are often more debilitating than muscle injuries and generally require surgical intervention (Carmichael and Marshall, 2012a). This is especially the case in injuries to sheathed (avascular) tendons, such as the digital flexor tendons. Sheathed tendons rely purely on intrinsic blood supply for healing and tendon distraction within the sheath results in increased fibrous scar tissue formation. Paratenon-covered (vascular) tendons, on the other hand, have access to an extrinsic blood supply derived from the surrounding soft tissue structures, causing them to heal more rapidly (Anderson, 2006, Carmichael and Marshall, 2012a). Avulsion fractures and ruptures at the musculotendinous junction are more commonly recognized than mid-substance tears, due to the tendon’s high tensile strength. Though adhesion formation may limit recovery, restoration of tensile strength is far more important within small animals (Anderson, 2006). Recovery of tensile strength, however, is a time-consuming process, taking up to 6 weeks after reconstruction before limited exercise can be tolerated and amounting to merely 79% of its original value after one year (Dueland and Quenin, 1980).

As has been discussed earlier, bicipital tendon ruptures may be traumatic in nature, though underlying degenerative process is suggested in most cases. Medial displacement of the bicipital tendon of origin and injury to the bicipital tendon insertion have also been described and suggested to be more traumatic in nature (Carmichael and Marshall, 2012a). Displacement occurs due to rupture of
the transverse humeral ligament, and is most commonly recognized in Greyhounds (Boemo and Eaton-Wells, 1995). Medial luxation has been occasionally described in other breeds as well, including the Poodle, German Shepherd, and Border Collie (Bennett and Campbell 1979, Vaughan, 1979).

Injuries to the common calcaneal tendon are one of the most common tendon injuries in dogs and consist of traumatic rupture or atraumatic avulsion injuries. The common calcaneal tendon is composed of tendons from several muscles, namely: the m. gastrocnemius, m. gracilis, m. semitendinosus, m. biceps femoris, and the m. flexor digitalis superficialis. Traumatic ruptures are typically complete, involving all of the different components of the common calcaneal tendon, while atraumatic ruptures often present as an avulsion of the m. gastrocnemius from the calcaneus. A complete traumatic rupture usually occurs in the mid-substance of the tendon. Typically, hyperflexion of the tarsocrural joint can be appreciated during weight bearing, combined with hyperextension of the stifle and a plantigrade stance. The atraumatic avulsion of the tendon of insertion of the gastrocnemius muscle is most commonly seen in medium- to large-sized breeds, especially the Labrador Retriever, Dobermann Pinscher and Border Collie (Corr et al., 2010).

Though gastrocnemius tendon avulsion generally presents without a history of acute trauma, it has been suggested that repetitive micro-trauma such as repetitive strain injuries may predispose to this specific injury. Clinical symptoms consist of a swelling at the tendon of insertion on the calcaneus, hyperflexion of the tarsocrural joint, and digital knuckling due to the intact superficial digital flexor muscle (Figure 7) (Carmichael and Marshall, 2012b).

A luxation of the superficial digital flexor muscle tendon has occasionally been recognized, mostly affecting Sheepdogs, Collies and racing Greyhounds. Displacement of the long digital extensor tendon has been described in active large-breed dogs (Carmichael and Marshall, 2012a, Carmichael and Marshall, 2012b, Vaughan, 1979).

2.1.3.c. Ligament Injuries and Luxations

Carpal injuries

Carpal instability and luxation may occur either due to an acute trauma or a chronic weakening of the supporting structures of the carpal joints. Acute trauma may consist of an accident or a fall, as well as a high performance activity. Chronic weakening may occur due to degenerative or inflammatory processes (Gibson et al., 1999). Ligament sprain injuries generally do not cause a carpal instability initially, but may progress in severity and therefore lead to carpal (sub)luxation. Carpal
injuries are a common finding in the Border Collie breed (Gibson et al., 1999, Lotsikas and Radasch, 2006).

Carpal ligament sprain injuries are a common finding in racing Greyhounds and, though they can often be treated conservatively, the prognosis for full recovery is guarded due to their high recurrence rate. These strain injuries may be accompanied by horizontal or vertical tearing of the superficial palmar fascia (Guilliard, 2006, Guilliard and Mayo, 2000a). The most common injury to the carpus consists of rupture of the palmar ligaments and fibrocartilage (Denny and Barr, 1991). This results in a hyperextension of the carpus, and the luxation can be localized at three different levels, namely: the antebrachiocarpal joint, the intercarpal joint, or the carpometacarpal joint. Conflicting reports have been made concerning the distribution of these injuries, and it is unclear whether specific joint predilection sites occur (Parker et al., 1981, Piermattei et al., 2006). Injury usually occurs due to falls or jumps, though they may be immune-mediated (and therefore atraumatic) in origin. This atraumatic inflammatory polyarthropathy has specifically been noted in Rough Collies (Guilliard, 2006). Complete luxation or lateral subluxation of the accessory carpal bone may be associated with hyperextension injuries (Guilliard, 2001).

Sprains and ruptures of the radial and ulnar collateral ligaments, as well as the dorsal radiocarpal ligament, have been reported and may be of particular importance in the canine athlete. Traumatic sprains have been noted in racing Greyhounds, and often involve the short radial collateral ligament (Guilliard and Mayo, 2000b). Avulsion fractures of the origin of the dorsal radiocarpal ligament may be recognized in racing Greyhounds as well, and must be differentiated from sprain injuries (Guilliard, 1997). Chronic lateral collateral ligament sprains have been reported in Doberman Pinschers and Border Collies (Gemmill et al., 2006, Langley-Hobbs et al., 2007). Repetitive trauma or underlying conformational abnormalities have been suggested as causal factors for the chronic sprains (Kapatkin et al., 2012). Complete carpal luxation is rare and usually occurs during high-performance activities. The carpus luxates caudally and can be seen in combination with a distal ulnar fracture. The ligaments, however, are usually still intact (Guilliard, 2006).

Tarsal Injuries

Tarsal luxations can be subdivided into tarsocrural, intertarsal, and tarsometatarsal luxations. Tarsocrural luxations are often associated with collateral ligament ruptures, malleolar fractures, and/or shearing injuries, often resulting from an acute trauma (Carmichael and Marshall, 2012b). Due to the mild valgus conformation of the tarsus, the medial collateral ligament is under more stress than the lateral collateral ligament, and is therefore predisposed to injury (Diamond et al., 1999, Sumner-Smith and Kuzma, 1989). Simultaneous injuries of lateral and medial structures, however, often occur and may result in joint luxation. Collateral ligament ruptures usually result from stage III sprains in the mid-substance of the ligament or present as avulsion fractures. These ligament avulsions mostly occur at their attachment to the tibia or fibula. Unilateral collateral ligament injury will lead to a subluxation, while bilateral involvement will lead to a complete luxation of the joint (Carmichael and Marshall, 2012b).
Plantar intertarsal luxations occur as a result of injuries to the plantar ligaments of the tarsus, and lead to a plantar instability with hyperextension of the calcanoquartal and talocalcaneocentral joints (Allen et al., 1993). These injuries often have a bilateral distribution and are mostly seen in obese Shetland Sheepdogs and other collie breeds (Campbell et al., 1976). This strong breed predisposition suggests that an intrinsic weakening of the plantar ligaments may be apparent (Carmichael and Marshall, 2012b). Injury to the short dorsal ligaments of the tarsus, on the other hand, will lead to a dorsal instability located at the proximal intertarsal joint. These injuries usually occur after a fall, though they may be atraumatic in nature as well (Guilliard, 2003). Intertarsal collateral ligament injuries may be seen in isolation or in concurrence with other soft tissue injuries (Guilliard, 2006).

Tarsometatarsal luxations usually occur due to a severe trauma and are often seen in combination with fractures of the fourth tarsal bone, the second metatarsal bone and/or the fifth metatarsal bone. These injuries may include injuries to the tarsometatarsal collateral ligaments and often lead to a plantar instability, though dorsal and dorsomedial instabilities may also be appreciated (Carmichael and Marshall, 2012b).

**Digital Injuries**

Digital luxations may include the metacarpophalangeal, proximal interphalangeal and distal interphalangeal joints. Multiple structures are generally involved and it is often difficult to evaluate the exact extent of injury. Metacarpopharyngeal luxations may be acute or chronic in nature. Chronic luxations are often a result of osteoarthritis. Proximal interphalangeal luxations often include a dorsal sesamoid luxation with disruption of the joint capsule. This may lead to failure of the collateral ligament. Distinct pain on palpation usually suggests the presence of an avulsion fracture. Distal interphalangeal luxations are often associated with a small laceration, where the distal end of the second phalanx has protruded through the skin during the traumatic event (Eaton-Wells, 2006).

**Coxofemoral Luxations**

Coxofemoral luxations make up the majority of all luxations in dogs and, of these, 6% occur bilaterally (Johnson et al., 1994). Most coxofemoral luxations result from hit-by-car accidents, and the remaining can be due to falls, spontaneous luxations, severe HD, or an unknown trauma. As a traumatic event is the cause in most cases of coxofemoral luxations, it is important to note that 55% of patients with coxofemoral luxations have concurrent injuries to other body systems (Basher et al., 1986, Bone et al., 1984, Trostel et al., 2000, Wardlaw and McLaughlin, 2012). Most coxofemoral luxations are orientated craniodorsally, and there are two scenarios in which such a luxations typically occur. First of all, a fall with the hind limb in adduction will cause distraction of the femoral head ligament and stretching of the joint capsule. As the greater trochanter hits the ground, the femoral head is forced over the dorsal rim of the acetabulum, causing tearing or avulsion of the joint capsule. Secondly, a dorsally directed force to the limb or a ventrally directed force to the pelvis combined with an adducted limb may also lead to a craniodorsal luxation. Once the femoral head is luxated, the gluteal muscles will pull it in a craniodorsal direction (Piermattei et al., 2006, Wardlaw and McLaughlin,
A ventrocaudal luxation usually occurs when the limb is forced into abduction and is often seen in combination with an avulsion fracture of the greater trochanter (Harari et al., 1984). When the hip is rotating internally during luxation, the femoral head will often luxate into the obturator foramen. On the other hand, an external rotation will displace the femoral head to a position next to the pubis (Wardlaw and McLaughlin, 2012).

2.2. MUSCULOSKELETAL DISORDERS AND THEIR IMPORTANCE IN THE AGILITY DOG

Agility is one of the most popular and rapidly growing canine sports. Entries for agility competitions from the American Kennel Club have been expanding annually by approximately 10% since 2003, giving a total of 1,242,159 entries in the year 2013 (American Kennel Club, 2015). Border Collies, due to their speed, stamina, and willingness to please, are overrepresented in agility competitions. Only a few studies have been designed in an attempt to evaluate injury patterns and their risk factors in agility dogs. Although more research has previously been conducted on greyhounds and gundogs, extrapolating data from research relating to injuries sustained in these activities may not be reliable due to the marked differences in the types of movements involved in agility training compared to hunting and racing. Results from research on horses are even less reliable due to the additional significant differences in size and anatomical structure. Though more research on agility injuries is necessary, studies so far have been able to elucidate interesting information concerning these injuries, possible risk factors involved, and the specific involvement of the Border Collie breed.

Levy et al. studied injuries occurring in dogs participating in canine agility by means of a retrospective survey of 1627 agility dogs in total, including 239 Border Collies (Levy et al., 2009). Soft tissue injuries such as sprains, strains and contusions were the most predominant type of injury and of the 33% of injured agility dogs, 58% were injured during competition. 35% of these injuries were due to direct contact with an obstacle, most commonly A-frames, dogwalks and bar jumps. Border Collies took up 25% of the injured population and were injured more frequently than would have been predicted by their exposure. Of all of the injuries sustained by Border Collies in this survey, 15% were located in the shoulder, 13% in the back, 10% in the hips and 9% in the carpus. A lower percentage of shoulder and back injuries were sustained in Border Collies than in Australian Shepherds, Shetland Sheepdogs and the total population of agility dogs. On the other side, a higher percentage of Border Collies was affected by hip and carpal injuries than in the total population (both at 6%). This could suggest that hip and carpal injuries could play a relatively more important role in the Border Collie in comparison to other breeds.

A second retrospective survey study concerning injuries in agility dogs was executed by Cullen et al., including 3801 dogs in total, including 639 Border Collies (Cullen et al., 2013a). Cullen et al. also looked at the frequency of participation in training and competition. Yet again, Border Collies appeared to sustain a significantly higher number of injuries than the other breeds. Consistent with Levy et al.’s findings, bar jumps, A-frames and dogwalks were most commonly associated with predominantly soft tissue type injuries and most frequently located in the shoulder (22.9%) and the
back (18.5%). These injury sites were closely followed by the phalanges (13.3%) and neck (12.4%). Cullen et al.’s study went further into detail by showing that the A-frame obstacle was more commonly associated with injuries in the shoulders and phalanges, while the bar jump more frequently resulted in shoulder, antebrachium, stifle and carpal joint injuries and accidents involving the dogwalk often resulted in ribcage and head injuries. Cullen et al. performed a follow-up study in an attempt to identify specific risk factors for injuries in agility dogs (Cullen et al. 2013b). The Border Collie breed, previous agility-related injury, use of alternative therapeutic treatments (acupuncture, massage, chiropraxy) and less experience all proved to be significant risk factors. They found that, after controlling several variables (such as amount of practice and number of events per month) Border Collies had 1.7 times more chance of sustaining an injury than other breeds. It was suggested that the Border Collie’s speed, agility and drive might put it at a higher risk for injury.

This higher expected risk of injury may be related to actual kinetic parameters of jump landing. Pfau et al., decided to quantify these parameters in 11 Border Collies participating in agility (Pfau et al., 2011). Kinetic (force, impulse) and kinematic (landing angle, speed) data were measured while running and while clearing bar jumps and long jumps with configurations commonly used in agility competitions. Results showed that higher obstacles were associated with both a lower approach speed as well as a more acute landing angle. A more acute landing angle in turn resulted in increased peak vertical force, vertical impulse and accelerative impulse. Per degree of landing angle, higher changes in kinetic parameters were found in the forelimbs compared to the hind limbs. An average shift of weight distribution to the forelimbs was found with increasing jump height, reaching 60%/40% in bar jumps. Bar jumps also resulted in both increased vertical loads as well as increased accelerative horizontal impulses. In the hind limbs, a significant correlation was found between decelerative impulse and stance time. In order to relate these findings to the increased risk of injuries, further evaluation of internal loads in specific joints need to be determined.

Birch and Lesniak added to these findings, suggesting that not only increased loading may predispose to injuries, but excessive joint movement as well. Their study involved measuring joint angles in agility dogs jumping over fences of different heights. (Birch and Lesniak, 2013). The joint angles were determined during the five different phases of jumping (approach, takeoff, aerial, landing, and departure). During the takeoff phase, an increase in height resulted in significant increases in flexion of the scapulohumeral, radioulnar as well as the base of the neck. A significant extension of the sacroiliacal joint was also noted during this phase. During the aerial phase, flexion of the scapulohumeral and radioulnar joints persisted. Though Pfau et al., found significant differences in landing angles between different types of jumps, Birch and Lesniak interestingly did not find any significant differences in joint angles during the landing phase. The increased joint angles in the scapulohumeral and sacroiliacal joints coincide with the high frequency of shoulder and back injuries in Levy et al.’s study. A recent study evaluating range of motion via goniometry has demonstrated that Border Collies possess a greater range of motion in all of the thoracic and pelvic limb joints when compared to Labrador Retrievers. Female dogs also had a greater range of motion than males (Hady et al., 2015).
3. RESEARCH REPORT

3.1. MATERIALS AND METHODS

3.1.1 Data Collection

All of the dogs included in this study were presented at the orthopedic service of Ghent University’s Faculty of Veterinary Medicine. The population under examination included 200 Border Collies received during the period of June 2005 until July 2014. A control group of 200 dogs was assembled based on an ideal weight of 15 kilograms or more, and all of these dogs were seen between March and July 2014. Starting from the 31st of July, 2014 and looking retrospectively, all dogs that met the specific criteria were included in the study until a total of 200 dogs were assembled.

During the selection process, several inclusion criteria were employed. Only dogs presenting with clinical symptoms at the time of evaluation were included in this study. All dogs included in the study had not been previously diagnosed or treated for the specific presenting complaint at Ghent University. Independent orthopedic issues occurring in the same dog were considered as separate cases (for example: A Rottweiler presenting for forelimb lameness in June and hind limb lameness in July). As an exception, (sub-)clinical HD was also recorded. Clinical symptoms that allowed for inclusion in the study consisted of lameness, stiffness, hopping, and swaying. On the other hand, dogs presenting with clear neurological symptoms such as ataxia and paresis were excluded from the study. Follow-up consultations, be it post-operatively or for recurring issues, were also excluded. All cases for which an iatrogenic cause was detected, such as surgical complications, tight bandaging, or drug reaction, were excluded from this study. Finally, patients were not included if information from more than one of the data categories (such as breed, age, gender) was missing.

Data collected for both groups included breed, age, gender, weight, function, and diagnosis. Due to different limiting circumstances, such as financial or motivational issues on the part of the owner or unremarkable diagnostic findings, it was not always possible to find the exact underlying pathology causing lameness. In these cases, location and pathology were defined as concise as possible (for example: painful digits). Still, 4.5% of all diagnoses remained unclear. If multiple

Figure 7: Measurement of the radiographic appearance of an osteochondritic lesion of the humeral head on a lateral projection of the shoulder joint in an 8-month old male Border Collie.
musculoskeletal disorders were diagnosed in the same dog, such as MCD and elbow OCD, these were noted separately, leading to a total number of diagnoses exceeding the number of dogs in each group.

For all cases of osteochondrosis and elbow dysplasia, the distribution (unilateral vs. bilateral) of lesions was reported. For humeral head osteochondrosis, the extent of osteochondritic lesions was determined. Several radiographic and arthroscopic reports obtained qualitative and quantitative descriptions pertaining to the size of the lesions. These descriptions are, however, very sensitive to inter-observer variability, as several clinicians were involved in evaluating these patients. Moreover, qualitative descriptions were not considered to be specific enough. Subsequently, it was decided to measure the radiographic appearance of osteochondritic lesions using the lateral projections provided. In order to do this as objectively as possible, an oval template was created that followed the contours of the intact humeral head and this was used to measure both length and width of the cartilage defect (Figure 7). This means that, in general, an overestimation of the defect size was made. All of these measurements, however, were made by the same individual in order to maintain consistency. The lesions were categorized into five different groups according to their size.

In CCLD, a distinction was made between complete and partial ruptures, and the prevalence of meniscal injury was recorded. Meniscal involvement was thus noted as a component of CCLD, rather than as a separate diagnosis. The data concerning the extent of intra-articular injury was only included from those cases which were evaluated via arthrotomy.

### 3.1.2. Data Analysis

Univariable statistical analysis methods were chosen to process the collected data, using a 95% confidence interval. Results were significant if they had a p-value <0.05 and a confidence interval excluding 1. For each musculoskeletal disorder occurring at a frequency greater than three (n>3) in either of the two study groups, a chi-square test was performed. Within the Border Collie group, the chi-square test was also used to compare the frequency of affected males with affected females for each disorder (with n>3). Also, this test was used to compare active with sedentary dogs within the Border Collie group.

A binary logistic regression was used to evaluate age predispositions for the different musculoskeletal disorders. The regression analyses were based on the patterns observed during classification of patients into different groups and based on findings in current literature. This was especially important for developmental disorders, since we expect a low incidence at younger and older ages, and a peak incidence during development. For example, in the case of humeral head osteochondrosis, separate analyses were made for 0-8 months of age, 0-12 months of age, and for dogs 8 months and older.

### 3.2. RESULTS

#### 3.2.1 Population Structure

The Border Collie group was composed of 107 males and 91 females (the gender was not recorded for two of the subjects) ranging from approximately 3 months to 13 years of age. The age
was not recorded for one Border Collie belonging to both groups. Mean and median age of amounted to 2.6 and 3.1 years, respectively. The mean average weight of Border Collies selected in this study was 20.2 kilograms. Thirty-one (15.5%) of the Border Collies were active working dogs, participating in agility (48.4%), flyball (19.4%), sheep herding (16.1%), obedience (16.1%), frisbee (6.5%), and policework (3.2%). Some dogs participated in a combination of these activities. The type of activity was not defined in two dogs. The active Border Collie group was composed of 14 males and 17 females ranging from 6 months to 10 years of age, with a mean and median age of 4.5 years.

The control group was selected *ad random* and comprised of 110 males and 90 females from 3 months up to 13 years of age, with a mean and median age of 4 years and 2.6 years, respectively. The mean average weight amounted to 37 kilograms.

Six percent of dogs were of mixed origin and the remaining 94% belonging to a variety of 54 different breeds, predominantly Labrador Retrievers (16.0%), Golden Retrievers (10.0%), German Shepherds (7.5%), American Staffordshire Terriers (5.5%) and Rottweilers (4.5%) (*Table 2*). The vast majority of dogs in the control group were held as companions, and merely 6 working dogs were noted in total. These consisted of 4 hunting dogs, 1 police dog and 1 agility competitor.

### Table 2: The prevalence of different breeds within the control group.
*Only breeds with a frequency n>1 are included in this table.*

<table>
<thead>
<tr>
<th>Breed*</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labrador Retriever</td>
<td>32</td>
</tr>
<tr>
<td>Golden Retriever</td>
<td>20</td>
</tr>
<tr>
<td>German Shepherd</td>
<td>15</td>
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<tr>
<td>Mix</td>
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</tr>
<tr>
<td>American Staffordshire Terrier</td>
<td>11</td>
</tr>
<tr>
<td>Rottweiler</td>
<td>9</td>
</tr>
<tr>
<td>Malinois</td>
<td>8</td>
</tr>
<tr>
<td>Bernese Mountain Dog</td>
<td>8</td>
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<td>7</td>
</tr>
<tr>
<td>White Shepherd</td>
<td>6</td>
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<tr>
<td>Bouvier des Flandres</td>
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</tr>
<tr>
<td>English Bulldog</td>
<td>4</td>
</tr>
<tr>
<td>Rhodesian Ridgeback</td>
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</tr>
<tr>
<td>Great Dane</td>
<td>3</td>
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<tr>
<td>St. Bernard</td>
<td>3</td>
</tr>
<tr>
<td>Newfoundland</td>
<td>3</td>
</tr>
<tr>
<td>Galgo Espanol</td>
<td>3</td>
</tr>
<tr>
<td>Chow Chow</td>
<td>2</td>
</tr>
<tr>
<td>Doberman</td>
<td>2</td>
</tr>
<tr>
<td>Anatolian Shepherd</td>
<td>2</td>
</tr>
<tr>
<td>Dalmatian</td>
<td>2</td>
</tr>
<tr>
<td>English Cocker Spaniel</td>
<td>2</td>
</tr>
<tr>
<td>Weimaraner</td>
<td>2</td>
</tr>
<tr>
<td>Boerboel</td>
<td>2</td>
</tr>
<tr>
<td>Leonberger</td>
<td>2</td>
</tr>
</tbody>
</table>

### 3.2.2. Musculoskeletal Disorders in the Border Collie

Within the Border Collie group, a total of 219 diagnoses were made, with 101 cases of forelimb lameness and 93 cases of hind limb lameness. Six Border Collies showed both fore- and hind limb lameness. Border Collies were most frequently affected in the shoulder (25.5%), followed by the hip (16%), elbow (15%), stifle (12%), tarsus (7%), digits (6.5%) and least in the carpus (3.5%). The majority of musculoskeletal disorders were developmental conditions (39.5%), followed by traumatic (33.5%), and degenerative (23%) disorders. The most common causes of lameness were shoulder OCD (17.5%), CCLD (10.5%), HD (10%), MCD (5.5%), coxofemoral luxation (5.5%), biceps...
tendinopathy (4.5%), and flexor enthesopathy (3.5%). In a significant number of Border Collies (4.5%), no definitive diagnosis was made.

This compared to a total number of diagnoses of 229 in the control group, with 138 and 89 cases of fore- and hind limb lameness, respectively, and 2 cases of both fore- and hind limb lameness. Large-breed dogs were most frequently affected in the elbow (47.5%), followed by the stifle (28%), hip (5.5%), tarsus (3.5%), digits (3.5%), and least in the carpus (2%). The majority of musculoskeletal disorders were once again developmental conditions (54.5%), followed by degenerative (29.5%) and traumatic disorders (12.5%). The most common causes of lameness in large-breed dogs were MCD (29%), CCLD (22.5%), fracture (6.5%), elbow incongruity (5.5%), HD (5%), patellar luxation (3.5%), and flexor enthesopathy (3.5%). In no less than 5%, no definitive diagnosis was made.

Statistical analysis showed that Border Collies have a significantly higher risk of developing humeral head osteochondrosis (OR=8.27) compared to the control group. According to the results, Border Collies were also at a higher risk of contracting traumatic injuries (OR=3.29), including muscle, tendon, and ligament injuries (OR=4.04). On the other hand, Border Collies had significantly lower risks of developing MCD (OR=0.14) and CCLD (OR=0.40).

3.2.2.a Developmental Disorders

Shoulder OCD was the most common musculoskeletal disorder recognized in the Border Collie, affecting 17.5% of the population presented for lameness. According to these results, Border Collies are 8 times more at risk for developing shoulder OCD than other dogs. Of the 35 Border Collies affected by humeral head OCD, bilateral osteochondritic lesions were found in 17 (48.57%) of dogs, making up a total of 52 affected shoulder joints. Other forms of OCD were far less prevalent within the Border Collie breed. OCD of the tarsocrural affected 2.5% of Border Collies and compared to an incidence of 1% in the control group, while elbow OCD affected 1.5% of the Border Collie population, and twice as many dogs in the control group (3%).

Border Collies diagnosed with humeral head OCD ranged from 5 months to 6 years of age. The mean and median ages at which Border Collies were diagnosed with shoulder OCD averaged to 1.1 years and 8 months, respectively. Male dogs were at a significantly higher risk for developing humeral head OCD (OR=3.20) than female dogs. The osteochondritic lesions could be measured for 37 (71.15%) of the affected shoulders. One of the radiographs showed no abnormalities, though a large lesion was noted during arthroscopy. For the remaining OCD’s, no radiographic images were available. The mean size was 0.13cm², which falls into the range of category 3/5. Furthermore, the majority of lesions (32.43%) fell into this category (Table 3). In the control group, shoulder OCD was merely detected in 5 dogs, with 7 shoulders affected in total. Large lesions were common in this group, with 42.86% of lesions being categorized into group 5 (Table 4). A mean size of 0.198cm² was determined, only just falling into category 4/5. Males were at a significantly higher risk of developing shoulder OCD than females, with a male:female ratio of 2.8:1.
Elbow dysplasia was not a common finding within the Border Collie group, affecting 11 (5.5%) of Border Collies in total. In comparison, no less than 63% of the control group was affected by elbow dysplasia. MCD was detected in all cases of elbow dysplasia in the Border Collie, and, on statistical analysis, Border Collies were found to have a significantly lower risk of developing MCD than other large-breed dogs (OR= 0.14). MCD showed a bilateral distribution in 45% of affected Border Collies. CT and/or arthroscopy was performed in 7 (64%) dogs, and these techniques showed concurrent elbow pathologies in 50% of elbows with MCD. 25% of elbows with MCD had signs of incongruity and 25% had OCD lesions. Joint incongruity and OCD were only seen in combination with MCD. 6.3% of elbows with MCD also had simultaneous flexor enthesopathy. While the mean age of diagnosis amounted to 2.9 years, median age of diagnosis was 10.5 months. The male:female ratio for MCD was 2.7:1.

Table 3: The size and classification of osteochondritic lesions of the shoulder joint in the control group, and their respective frequencies and incidences.

<table>
<thead>
<tr>
<th>Group</th>
<th>1 (&lt;0.05cm²)</th>
<th>2 (0.05-0.100cm²)</th>
<th>3 (0.101-0.15cm²)</th>
<th>4 (0.151-0.2cm²)</th>
<th>5 (&gt;0.20cm²)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>0.048</td>
<td>0.053</td>
<td>0.144</td>
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<td>0.180</td>
<td>0.210</td>
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<tr>
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<td>0.063</td>
<td>0.108</td>
<td>0.200</td>
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<tr>
<td></td>
<td>0.047</td>
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<table>
<thead>
<tr>
<th>Frequency</th>
<th>Incidence (%)</th>
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<td>4</td>
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<tr>
<td>9</td>
<td>24.32</td>
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<tr>
<td>12</td>
<td>32.43</td>
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<tr>
<td>6</td>
<td>16.22</td>
</tr>
<tr>
<td>6</td>
<td>16.22</td>
</tr>
</tbody>
</table>

Table 4: The size and classification of osteochondritic lesions of the shoulder joint in the control group, and their respective frequencies and incidences.

<table>
<thead>
<tr>
<th>Group</th>
<th>1 (&lt;0.05cm²)</th>
<th>2 (0.05-0.100cm²)</th>
<th>3 (0.101-0.15cm²)</th>
<th>4 (0.151-0.2cm²)</th>
<th>5 (&gt;0.20cm²)</th>
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<tr>
<td></td>
<td>0.055</td>
<td>0.138</td>
<td>0.165</td>
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<td></td>
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<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Incidence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
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<tr>
<td>2</td>
<td>28.57</td>
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<tr>
<td>1</td>
<td>14.29</td>
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<tr>
<td>1</td>
<td>14.29</td>
</tr>
<tr>
<td>3</td>
<td>42.86</td>
</tr>
</tbody>
</table>

Elbow dysplasia was not a common finding within the Border Collie group, affecting 11 (5.5%) of Border Collies in total. In comparison, no less than 63% of the control group was affected by elbow dysplasia. MCD was detected in all cases of elbow dysplasia in the Border Collie, and, on statistical analysis, Border Collies were found to have a significantly lower risk of developing MCD than other large-breed dogs (OR= 0.14). MCD showed a bilateral distribution in 45% of affected Border Collies. CT and/or arthroscopy was performed in 7 (64%) dogs, and these techniques showed concurrent elbow pathologies in 50% of elbows with MCD. 25% of elbows with MCD had signs of incongruity and 25% had OCD lesions. Joint incongruity and OCD were only seen in combination with MCD. 6.3% of elbows with MCD also had simultaneous flexor enthesopathy. While the mean age of diagnosis amounted to 2.9 years, median age of diagnosis was 10.5 months. The male:female ratio for MCD was 2.7:1.
Hip dysplasia was diagnosed as the cause of lameness in 10% of Border Collies, with 25% of these cases classified as the juvenile form (diagnosed before 12 months of age) and the remaining 75% as the chronic form (occurring at >12 months of age). The youngest age at which HD was diagnosed was 6 months of age. The mean and median ages for diagnosis were 4.7 years and 4.6 years, respectively. Three percent of Border Collies in our study population was diagnosed with subclinical HD, bringing the total incidence of HD up to 13%. This compared to an incidence of merely 5% for clinical HD and no less than 13% for subclinical HD in the control group. Statistical analysis, however, showed no significant differences between the two groups. In 19% of Border Collies diagnosed with CCLD simultaneous HD was also detected.

Patellar luxation affected merely three (1.5%) of Border Collies. This is low compared to an incidence of 3.5% in the control group. All patellar luxations in the control group were developmental in nature, while one of the patellar luxations reported in Border Collies was due to a traumatic event. The Border Collies with developmental patellar luxation were both female dogs, and diagnosed at 1.8 years and 7.3 years of age. The latter presented with severe osteoarthritis due to chronic patellar luxation.

3.2.2.b. Degenerative Disorders

Border Collies were at a significantly lower risk of developing cranial cruciate ligament disease than other dogs (OR=0.40). Having said this, CCLD still affected 10.5% of Border Collies. In 15 out of the 21 (71%) Border Collies diagnosed with CCLD, direct visualization of the stifle via arthrotomy was performed. In 87% of these cases evaluated via arthrotomy a complete rupture was diagnosed, leaving an incidence of 13% of partial ruptures. The meniscus was injured in 53% of cases, and 88% of these meniscal injuries occurred in combination with a complete rupture. Two of the meniscal injuries occurred as a post-surgical complication, though standard meniscal release was performed in all dogs. The mean and median ages at which dogs were diagnosed with CCLD were 6.9 years and 7.3 years, respectively.

Biceps brachii tendinopathy affected 4.5% of Border Collies, and, of these, 11% consisted of complete ruptures of the bicipital tendon of origin. The remaining 89% had partial ruptures, and, in one case, partial rupture was secondary to a luxation of the tendon. One clear case of a traumatic rupture of the bicipital tendon of origin was reported. Mean and median ages amounted to 4.6 and 4.4 years, respectively, and a male:female ratio of 1:2 was detected.

Flexor enthesopathy was diagnosed in 3.5% of both Border Collies and other large-breed dogs. In 71% of cases of flexor enthesopathy in Border Collies, no underlying pathology was found. The remaining 29% had simultaneous medial coronoid disease. Mean age of diagnosis was 3.9 years and a male:female ratio of 1:2.5 was found.
3.2.2.c. Traumatic Disorders

Border Collies had three times the risk of acquiring traumatic injuries than other large-breed dogs. A total of 64 traumatic injuries were recorded, hereby affecting 32% of the study population. Of these traumatic injuries, 42% consisted of fractures and 50% concerned muscle, tendon, and ligament injuries. These muscle, tendon, and ligament injuries were 4 times more prevalent within the Border Collie breed and ranged from strain injuries to ruptures, avulsions and luxations. Ligament injuries and luxations were most prevalent, affecting 10.5% of the total Border Collie population. Coxofemoral luxations were diagnosed in no less than 5.5% of Border Collies, of which two had a history of HD.

Muscle and tendon injuries were diagnosed in 2.5% and 3% of Border Collies, respectively, and included one case of a traumatic rupture of the biceps tendon of insertion and one case of a traumatic patellar luxation. The variety of traumatic injuries is listed in Table 5. More females were affected by traumatic injuries than males, with a male:female ratio of 1:1.3. Mean and median age amounted to 3.4 and 2.8 years, respectively.

<table>
<thead>
<tr>
<th>Traumatic Disorders in Border Collies</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture</td>
<td>27</td>
</tr>
<tr>
<td>Coxofemoral Luxation</td>
<td>11</td>
</tr>
<tr>
<td>Ligament Injury</td>
<td>7</td>
</tr>
<tr>
<td>Achilles Tendon Rupture</td>
<td>2</td>
</tr>
<tr>
<td>Tarsal Sprain</td>
<td>2</td>
</tr>
<tr>
<td>Musculature Trauma to the Shoulder</td>
<td>2</td>
</tr>
<tr>
<td>Tendinitis Digit</td>
<td>2</td>
</tr>
<tr>
<td>Arthritis digit</td>
<td>1</td>
</tr>
<tr>
<td>Rupture m. Triceps Brachii</td>
<td>1</td>
</tr>
<tr>
<td>Avulsion m. Gastrocnemius</td>
<td>1</td>
</tr>
<tr>
<td>Atypical Cartilage Injury Elbow</td>
<td>1</td>
</tr>
<tr>
<td>Patellar Luxation</td>
<td>1</td>
</tr>
<tr>
<td>Carpal Instability</td>
<td>1</td>
</tr>
<tr>
<td>Rupture m. Flexor Carpi Ulnaris</td>
<td>1</td>
</tr>
<tr>
<td>Carpal Overload</td>
<td>1</td>
</tr>
<tr>
<td>IS Luxation</td>
<td>1</td>
</tr>
<tr>
<td>Shearing Injury</td>
<td>1</td>
</tr>
<tr>
<td>Biceps Tendon Rupture</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5: A list of the traumatic injuries diagnosed in Border Collies and their respective frequencies.

<table>
<thead>
<tr>
<th>Musculoskeletal Disorders in Border Collie Athletes</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder OCD</td>
<td>6</td>
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<tr>
<td>Ligament Injury</td>
<td>3</td>
</tr>
<tr>
<td>No Definitive Diagnosis</td>
<td>3</td>
</tr>
<tr>
<td>Tarsocural OCD</td>
<td>1</td>
</tr>
<tr>
<td>MCD</td>
<td>1</td>
</tr>
<tr>
<td>Traumatic Arthritis Digit</td>
<td>1</td>
</tr>
<tr>
<td>Achilles Tendon Rupture</td>
<td>1</td>
</tr>
<tr>
<td>Flexor Enthesopathy</td>
<td>1</td>
</tr>
<tr>
<td>OA Digits</td>
<td>1</td>
</tr>
<tr>
<td>OA Carpus</td>
<td>1</td>
</tr>
<tr>
<td>Tarsal Pain (microtrauma)</td>
<td>1</td>
</tr>
<tr>
<td>Gastrocnemius Avulsion</td>
<td>1</td>
</tr>
<tr>
<td>OA Elbow</td>
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</tr>
<tr>
<td>Neoplasia</td>
<td>1</td>
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<td>Biceps Tendon Rupture</td>
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</tr>
<tr>
<td>CCL Disease</td>
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<tr>
<td>OA Tarsus</td>
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<tr>
<td>Patellar Luxation (possibly traumatic)</td>
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</tr>
<tr>
<td>Carpal Instability</td>
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</tr>
<tr>
<td>Tendinitis Digit</td>
<td>1</td>
</tr>
<tr>
<td>Carpal Overload</td>
<td>1</td>
</tr>
<tr>
<td>Fracture</td>
<td>1</td>
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</table>

Table 6: A list of the musculoskeletal disorders diagnosed in the Border Collie athletes and their respective frequencies.
3.2.3. Musculoskeletal Disorders in the Border Collie Athlete

Of the 31 Border Collie athletes, 61.2% were affected in the forelimbs and 38.7% in the hind limb. The shoulder and tarsal joints were most commonly affected (22.5% each), followed by elbow and digits (12.9%), carpus (9.7%), and stifle (6.5%). Traumatic injuries were most frequently diagnosed, affecting 38.7% of Border Collie athletes. The majority of traumatic injuries involved muscles, tendons, or ligaments (75%) and, furthermore, no less than 31% of muscle, tendon, or ligament injuries in the total Border Collie population occurred in athletic dogs. The remaining three cases of traumatic injuries were diagnosed with traumatic arthritis, carpal overload, and fractures of the radius and ulna (Table 6). As in all Border Collies, humeral head OCD was an important disorder amongst athletic dogs, affecting 19.4% of the population. No definitive diagnosis could be made in 9.7% of these Border Collies, making up one third of all undefined diagnoses in Border Collie dogs. On statistical comparison of athletic and sedentary Border Collies, however, no significant differences were found.

3.3. DISCUSSION

3.3.1. Musculoskeletal Disorders in the Border Collie

3.3.1.a. Developmental disorders

Osteochondrosis was the most prevalent musculoskeletal disorder within the Border Collie breed, affecting 21.5% of the population, with the shoulder joint as the most common localization. Furthermore, Border Collies were at a significantly higher risk of developing shoulder OCD compared to the control group of large breed dogs (OR=8.27). This confirms LaFond et al.’s findings, which noted an OR of no less than 15.0 for shoulder OCD within the Border Collie breed (LaFond et al., 2002). At least 51% of the control group in this study, however, consisted of breeds with a predisposition to developing humeral head osteochondrosis. This could explain why the OR calculated in this study is lower than expected. Mean (1.1 years) and median (8 months) age of diagnosis corresponded with literature findings, which stated an age of onset between 4 and 8 to 12 months of age and an age of diagnosis between 6 and 18 months of age (Lande et al., 2014, Maddox et al., 2013, Slater et al., 1991). The male:female ratio (2.8:1) was higher than those reported in current literature (2:1 to 2.27:1) (Biezynski et al. 2012, Rudd et al., 1990, Slater et al., 1991). The size of osteochondritic lesions in Border Collies tended to be medium-sized (3/5), which was smaller than the average size (4/5) in the control group. The mean size of osteochondritic lesions in Border Collies was 0.130cm², comparing to an average of 0.198cm² in the control group. An important limitation of this measuring technique is that it does not give a reliable representation of the actual size of each lesion. First of all, the area was calculated by multiplying the maximum length and depth of the lesion, not accounting for the actual shape, and thus area, of the lesion. In retrospect, it may have been more accurate to estimate size using the diameter of the lesion. Furthermore, radiographic positioning will influence the degree of lesion exposure, hereby risking under- or over-estimation of lesion size. Additionally, small lesions could have been missed on radiography. Arthroscopic measurements made by the same individual may be a much more accurate way of estimating the true size of OCD lesions.
Though it seems Border Collies tend to develop smaller lesions than other dogs, these results may not be reliable due to the small sample size (n=7) of OCD lesions in the control group. More research is needed to accurately evaluate the actual size of OCD lesions, as well as possible variability between different breeds.

A large-scale study evaluating the incidence of musculoskeletal disorders in dogs noted a highest incidence of OCD in the shoulder, followed by the elbow, tarsus, and stifle (Johnson et al., 1994). In this study, however, osteochondrosis of the tarsocrural joint was the second most common localization for osteochondrosis (affecting 2.5% of the population), closely followed by the elbow joint (1.5%). None of the Border Collies included in this study were affected by osteochondrosis of the stifle joint. To the author’s knowledge, osteochondrosis of the medial aspect of the humeral condyle has not yet specifically been reported in the Border Collie breed. In this study, all three of elbow OCD cases were seen in combination with medial coronoid disease. Border Collies had a significantly lower risk of developing MCD than the control group, and this could explain why the incidence of elbow OCD was so low in comparison to the tarsocrural joint.

Elbow dysplasia was not a common finding within the Border Collie breed (5.5%), and, even though all cases of elbow dysplasia involved MCD, Border Collies had a significantly lower risk of developing MCD than the control group. The majority of the control group however, consisted of breeds that have been shown in several studies to have a predisposition for elbow dysplasia. It is therefore unsure if Border Collies are truly at a lower risk of developing elbow dysplasia, or if this is falsely indicated due to the high prevalence of elbow dysplasia in the control group. Elbow joint incongruity and OCD were equally represented, and no Border Collies were affected by UAP.

Danielson et al. suggested that MCD could result from repetitive or high impact exercise (Danielson et al., 2006). If this were the case, we would expect the incidence of MCD to be higher in more active Border Collies. Only one case of MCD was reported within the athletic Border Collie group, however. Even though MCD may present from an age of 4-7 months, it is often diagnosed at an older age. This is confirmed by our findings, as the mean and median age of diagnosis amounted to 2.9 years and 10.5 months, respectively. The onset of lameness is often intermittent and insidious, which may result in a more expectant approach on part of the owner or the referring veterinarian. Several studies have suggested a predisposition in male dogs, and this has been confirmed in this study, with a male:female ratio of 2.7:1. The percentage of bilateral cases (45%) of MCD in this study falls within the range reported in literature so far (25-50%) (Boulay, 1998, Cook et al., 2001, Meyer-Lindenberg, 2002, Morgan et al., 1999, Remy et al., 2004, Van Ryssen and Van Bree, 1997). To the author’s knowledge, this is the first study to describe elbow OCD and elbow joint incongruity specifically in the Border Collie breed, though, unfortunately, the type of incongruity was not specified. It is possible that certain types of incongruity, such as a radioulnar mismatch, predispose to MCD within the Border Collie breed. More research is needed in order to evaluate what types of incongruity occur within the Border Collie breed.

Hip dysplasia clinically affected a larger proportion of Border Collies (10%) than other large-breed dogs (5%), and hereby proves to be an important musculoskeletal disorder within this breed.
The majority of cases of HD (75%) belonged to the adult form of HD, occurring later than 12 months of age. Even though the incidence of subclinical HD was a lot lower in Border Collies (3%) compared to the control group (13.5%), we suspect this value to be an underestimation of subclinical HD in Border Collies. The subclinical forms of HD discovered in this study were, after all, incidental findings when evaluating other musculoskeletal disorders (most frequently CCLD). Border Collies are not well known for developing HD or CCLD, while the control group consisted of a substantial amount of breeds in which HD and/or CCLD are more frequently reported. Screening for HD, therefore, is not a common practice within the Border Collie breed. On the other hand, it is possible that, due to their lean build, clinical symptoms of HD are seen in an earlier stage than in other large breed dogs. The mean age of diagnosis was 4.7 years, however, which is higher than what has been reported in current literature (Witsberger et al. 2008). More research is needed in order to evaluate the importance and clinical presentation of HD within the Border Collie breed. No statistically significant gender predispositions were found, though a male:female ratio of 1.5:1 was noted. A higher risk of HD has been described in castrated males (Witsberger et al., 2008). Unfortunately, since the neuter status of patients was often ill defined, the effects of castration on the development of HD within Border Collies could not be evaluated in this study.

Developmental medial patellar luxation seldom occurs within the Border Collie breed, affecting merely two dogs (1%) in this study. This compared to an incidence of 3.5% in other large-breed dogs. One additional case of (traumatic) lateral patellar luxation was also diagnosed. Literature findings report a typical presentation of MPL between 1 and 3 years of age. One of the Border Collies fell within this range (22 months of age), the other, however, was diagnosed at more than 7 years of age. In this case, severe stifle osteoarthritis was detected on radiography, from a chronic MPL, suggesting that the disorder developed at a much younger age. Previous studies have shown small-breed females and large-breed male dogs to be predisposed to MPL, and both dogs affected in this study were females (Alam et al., 2007, Arthurs and Hobbs, 2007, Bound et al., 2009, Gibbons et al., 2006, Hayes et al., 1992, Priester, 1972, Remedios et al., 1992). Due to the low incidence of patellar luxation, no definitive conclusions can be made concerning the epidemiological factors of patellar luxation within the Border Collie breed. Research involving a larger amount of Border Collies with patellar luxation is needed to evaluate at what age Border Collies are most likely to develop this disorder, and whether a predisposition for female dogs occurs in this breed.

3.3.1.b. Degenerative disorders

Cranial cruciate ligament disease is another important musculoskeletal disorder within the Border Collie breed, affecting 10.5% of the population. Having said this, Border Collies were shown to have a lower risk of developing CCLD than other large-breed dogs (OR=0.40), confirming current literature findings (Dorn, 2002, Witsberger et al., 2008). In this study, 87% of dogs diagnosed with CCLD had a complete rupture of the cranial cruciate ligament, which is slightly higher than what has been reported so far (53% to 86%) (Casale and McCarthy, 2009, Corr and Brown, 2007, Ertelt and Fehr, 2002, Metelmann et al., 1995, Ralphe and Whitney, 2002). A differentiation between complete and partial ruptures was, however, only concerned reliable if direct visualization of the ligament via
arthrotomy had been performed. Differentiation between complete and partial ruptures using findings on clinical and orthopedic examination is difficult, and may lead to false diagnoses. Complete ruptures are generally associated with a severe or non-weight bearing lameness and a more obvious cranial drawer motion, for example (Kowaleski et al., 2012). In chronic cases, however, periarticular fibrosis partially stabilizes the stifle joint, hereby potentially masking these ‘typical’ signs. Partial ruptures may show a variable degree of cranial drawer motion, depending on the exact localization of the lesion. If, for example, the craniomedial band is ruptured, cranial drawer motion will only be evident in a flexed position. Furthermore, concurrent meniscal injury may exacerbate clinical symptoms, often causing a non-weight bearing lameness (Kowaleski et al., 2012). All of these factors, along with the fact that the dogs included in this study were examined by a variety of clinicians, greatly reduce the reliability of making an accurate differentiation between complete and partial ruptures via external examination. It is unclear, however, whether the ratio of complete:partial CCL ruptures presented in this study forms an accurate representation of the reality. Due to the fact that partial ruptures are often accompanied with more subtle clinical signs, it is possible that less of these cases are referred to the veterinary faculty, or that a more conservative medical management (excluding direct evaluation of the CCL) was chosen.

Previous studies have shown that the risk for developing CCLD significantly increases after 4 years of age (and peaks between 4 and 7 years of age) (Fitzpatrick and Solano, 2010, Guastella et al., 2007, Witsberger et al., 2012). In this study, the majority (85.7%) of CCLD cases were diagnosed after 4 years of age, though only 33% of these fell into the range of 4 to 7 years of age and the remaining 67% was diagnosed at an age older than 7 years. Though a statistical analysis was not performed, the observed trend contradicts previous findings. The fact that Border Collies are not well known for developing CCLD, could cause a delay in referral and/or diagnosis of the disease. Vasseur et al. showed that dogs weighing more than 15 kilograms develop CCLD at an earlier age than smaller dogs (Vasseur et al., 1985). The leaner build of Border Collies compared to other breeds susceptible to developing CCLD may help to explain why a large proportion of Border Collies was diagnosed at an older age. Even though the average weight of Border Collies in this study amounted to 20.2 kilograms, no body and/or muscle conditioning scores were reported, and young dogs that had not yet reached their adult body weight were also included in this calculation. More research is needed to determine whether the observed trend is specific to the Border Collie breed or applies to the pathogenesis of CCLD in general.

Though no significant gender differences have been described for CCLD, castrated males and spayed females have been shown to have a higher risk of developing CCLD (Fitzpatrick and Solano, 2010, Guastella et al., 2007, Witsberger et al., 2012). Male and female Border Collies were equally affected by CCLD in this study. Unfortunately, since the neuter status of patients was often ill defined, the effects of castration and sterilization on the development of CCLD within Border Collies could not be evaluated.

Witsberger et al. noted a higher risk of developing simultaneous HD with CCLD in certain breeds (Witsberger et al., 2012). HD was detected in no less than 19.04% of Border Collies diagnosed
with CCLD, suggesting that it may be valuable to screen hips for dysplastic changes in all Border Collies with CCLD.

Meniscal injury subsequent to CCLD has, to the author’s knowledge, not yet specifically been reported in the Border Collie breed. In this study, meniscal injury was found in 53% of stifles with CCLD, and this incidence falls into the range reported by previous studies (37.5 to 77%). The majority (87%) of these meniscal injuries concerned dogs with complete ruptures of the CCL. Thieman et al. showed that meniscal release does not reduce the risk of subsequent meniscal injury (Thieman et al., 2006). As meniscal release is standard procedure at the veterinary faculty of Ghent, it was not possible to evaluate the risk of subsequent meniscal injuries in dogs that did not undergo a meniscal release. In the group of Border Collies included in this study, two of the meniscal injuries occurred as a post-surgical complication, despite meniscal release during the initial surgery. No differentiation could be made between the different types of meniscal injury in this study. Further research is needed to determine whether specific types of meniscal injury are more commonly associated with certain breeds or activity types (such as agility, for example).

Flexor enthesopathy was diagnosed in 3.5% of both Border Collies and other large-breed dogs. Only 29% of Border Collies diagnosed with flexor enthesopathy had simultaneous elbow pathology (namely MCD). This is contrary to literature findings, which describe concomitant flexor enthesopathy as a more common pathology than primary flexor enthesopathy (de Bakker et al., 2013). A mean age of diagnosis of 3.9 years was found, which is only slightly lower than what was expected based on current literature (de Bakker et al., 2013a, Grondalen and Braut, 1976, Ljunggren et al., 1966, Zontine et al., 1989). In this study, more females than males were affected by flexor enthesopathy, with a female: male ratio of 2.5:1. Previous literature findings, however, suggest that males are predisposed to developing flexor enthesopathy (de Bakker et al., 2013a). No statistically significant gender predisposition was found, however, and this is most likely due to the low prevalence of this disorder.

Biceps brachii tendinopathy affected more Border Collies (4.5%) than other large-breed dogs (1.5%). Eleven percent of cases of biceps brachii tendinopathy in Border Collies were complete ruptures and the remaining 89% consisted of partial ruptures. The majority of cases consisted of primary tendinopathies, as only one clear case of secondary tendinopathy (due to an acute trauma) was reported. In merely one dog (11.11%) a partial rupture was noted to occur secondary to a luxation of the tendon. This is less than what is expected based on current literature findings, where simultaneous tendinitis and subluxation has been reported in 33% to 76% of bicipital tendon ruptures (Bardet, 1999). Biceps brachii tendinopathy has been suggested to occur more frequently in middle-aged and older dogs, due to mechanical deterioration of tendons with age (Bardet, 1999). To the author’s knowledge, no specific gender predispositions have been reported so far. In this study, middle-aged dogs were most commonly affected by biceps brachii tendinopathy, and female dogs were affected twice as much as males. Due to the relatively low incidence of this disorder, however, it is unsure whether these results are reliable. More research is needed in order to elucidate the exact etiology and pathogenesis of biceps brachii tendinopathy, both in general, and specific to the Border Collie breed. Primary biceps tendinopathy has been suggested to occur as a result from chronic
repetitive injuries or overloading, and this would suggest a higher incidence in more active dogs (Rochat, 2012). On the other hand, exercise increases tendon strength and may thus protect tendons from injury. These findings suggest that both too little as well as too much exercise could lead to biceps tendinopathy. In this study, none of the active Border Collies were affected by degenerative biceps tendinopathy (one case of traumatic biceps rupture), confirming that regular exercise may prove a valuable protecting factor for biceps tendinopathy. The reliability of these results, however, is questionable, due to the small sample size of affected individuals. Furthermore, statistical analysis showed no differences between active and sedentary dogs.

3.3.1.c. Traumatic Disorders

A predisposition for traumatic injuries in the Border Collie breed has been described in recent literature and was confirmed in the current study. Cullen et al. evaluated traumatic injuries in agility dogs and discovered that Border Collies had nearly twice the risk of contracting injuries compared to other breeds (Cullen et al., 2013a, Cullen et al., 2013b). In this study, Border Collies were shown to have an even higher risk of developing traumatic injuries, with a calculated odds ratio of 3.29 and, more specifically, an odds ratio of 4.04 for muscle, tendon, and ligament injuries. In comparison to Cullen et al.’s findings, the traumatic disorders in this study included a wider range of injuries and etiologies (such as fractures and certain traumatic luxations due to high-impact traumas, including traffic road accidents), which could explain the higher risk of traumatic injuries compared to previous reports.

Muscle, tendon, and ligament injuries made up the majority (50%) of traumatic disorders and affected 32 dogs in total. Of these different types of injuries, ligament injuries and luxations were most prevalent, affecting 10.5% of the total Border Collie population. Muscle and tendon injuries were diagnosed in 2.5% and 3% of Border Collies, respectively. Muscle injuries involved the m. gastrocnemius, m. triceps brachii, and m. flexor carpi ulnaris. The two remaining muscle injuries could not be localized specifically to one muscle. According to Steiss, the m. gastrocnemius and m. biceps brachii are indeed predisposed to stage III strain injuries, in which muscle tears are prominent (Steiss, 2002). Strain injuries have been reported in the m. flexor carpi ulnaris as well (Carmichael and Marshall, 2012a). Injuries to the common calcaneal tendon and the biceps brachii tendon are well described in current literature, and made up no less than 50% of tendon injuries in this study.

Presumably, these results are an underestimation of the true incidence of traumatic injuries, especially certain muscle injuries such as strains. Strain injuries often give mild or transient clinical symptoms, and, because of this, it is likely that a substantial amount of these cases recover without the need of veterinary care, or, when seen by the primary veterinarian, are not referred to the veterinary faculty. This could explain why the majority of these patients were diagnosed with ligament injuries and luxations, which generally require surgical intervention. Similarly, the muscle and tendon injuries included in this study were mostly quite severe, consisting of ruptures and avulsions. The use of clinical metrology instruments, as well as research including patients seen in primary practices would help to evaluate the true incidence of these types of injuries. Excessive joint movement may
predispose to injuries, and could be of significant importance within the Border Collie breed. After all, Border Collies have been noted to possess a greater range of motion in all thoracic and pelvic limb joints compared to Labrador Retrievers (Hady et al., 2015). More research is needed in order to determine whether Border Collies also have a greater ROM compared to other breeds, and if an increased ROM truly predisposes to such injuries. On the other hand, it is possible that the Border Collies included in this study participated in more strenuous exercise than the dogs included in the control group. A substantial amount of the Border Collies included in this study were participating in sporting competitions, after all.

3.3.2. Musculoskeletal Disorders in the Border Collie Athlete

The athletic Border Collies included in this study participated in sporting competitions such as agility, flyball, sheep herding, obedience, and frisbee. The most important musculoskeletal disorders in this study were traumatic injuries, with a reported incidence of 38.7%. The majority of these disorders consisted of muscle, tendon, and ligament injuries. Levy et al. suggested that hip and carpal injuries contracted during agility work are of more importance in Border Collies compared to other breeds (Levy et al., 2009). In this study, the shoulder and tarsal joints were most commonly affected, followed by the elbow and digits. This could be due to the fact that a variety of activities were included in this study, while Levy et al. looked at agility dogs only. Secondly, Levy et al. were also able to include more minor injuries in their study. These types of injuries may resolve spontaneously or via conservative treatment by the primary clinician, and, as a result, are not seen at referral practices such as the veterinary faculty. When comparing the prevalence of the different orthopedic conditions between athletic and sedentary Border Collies, no significant differences were found. This may be due to an inaccurate classification of Border Collies as ‘active’ and ‘sedentary’. Patient histories provided only limited information concerning activity level, and it is possible that several dogs held as companion animals had an activity level similar to some of the Border Collie athletes.

3.3.3. Limitations

Besides the limitations that have already been mentioned for specific musculoskeletal disorders, other important limitations were also recognized, mostly due to the retrospective nature of this study. First of all, selection and information bias may have had an important influence on the results obtained. Though the dogs were chosen ad random, no standardization algorithm was used to select the patients. The Border Collie cases that were included extended much farther back in time (up to June, 2005) than the control group, which were all seen within a period of 4 months time (March to July, 2014). It is possible that different types of musculoskeletal disorders were of importance in 2005 compared to 2014. This depends on several factors, such as the evolution of veterinary orthopedics over time, as well as changes in owner/breeder motivation and knowledge.

In this retrospective study, the outcome assessment could not be controlled and we had to rely on the variety of clinicians involved for accurate recordkeeping. Some of the diagnoses included in this study were not 100% conclusive, such as some of the cases of medial coronoid disease, in which the diagnosis was made on suggestive findings on clinical examination and radiography and were not
confirmed via CT or arthroscopy. When evaluating HD in dogs with multiple orthopedic issues, it was sometimes difficult to determine whether the HD was causing clinical symptoms or not.

As this was a retrospective study including a wide variety of musculoskeletal disorders, the incidence of some of these disorders was too low to perform statistical analyses. Though certain trends were recognized, further research is needed in order to statistically confirm these findings.

As has been mentioned earlier, an important limitation to this study is the fact that the musculoskeletal disorders seen at the veterinary faculty represent merely a fraction of the orthopedic conditions in dogs. Many causes of lameness, especially muscle disorders such as strains, are more transient in nature, and can resolve spontaneously or are treated conservatively at primary practices. These cases will be missed at referral centers such as the veterinary faculty. More research is needed in order to determine the true incidence of certain musculoskeletal disorders within the Border Collie breed.

Another important limitation in this study is the univariable statistical methods used to analyze the data. Univariate analysis is the simplest method of processing data, and is suitable for making preliminary descriptions. Complementary bi- or multivariate analysis should be performed in order to account for possible bias and to establish relationships between different variables.

### 4. CONCLUSION

This study was able to confirm several previous findings on the prevalence of musculoskeletal disorders in the Border Collie breed. First of all, the hypothesis that humeral head osteochondrosis remains an important disorder in Border Collies was confirmed. A substantial amount of Border Collies in this study was affected by humeral head osteochondrosis. Furthermore, a significantly higher risk of developing shoulder osteochondrosis was detected in Border Collies compared to other dogs. Secondly, the importance of hip dysplasia in the Border Collie breed was also confirmed. It was hypothesized that Border Collies have a significantly higher risk of developing hip dysplasia compared to other dogs, and, although this hypothesis had to be rejected, hip dysplasia still affected a substantial amount of the study population and its importance within this breed must not be underestimated. It seems that the control group used in this study may not have been appropriate in determining this risk, as it contained a substantial amount of dog breeds known to have a high risk of developing hip dysplasia. The low number of subclinical forms of hip dysplasia detected in Border Collies could suggest inadequate screening of this breed, possibly due to the fact that they are not commonly associated with this disorder. The findings in this study suggest that more diligent screening of Border Collies for hip dysplasia may be appropriate. Third of all, the hypothesis that Border Collies have a lower risk of developing cranial cruciate ligament disease than other dogs was also confirmed. Lastly, as predicted, Border Collies are at a significantly higher risk of developing traumatic injuries than other dogs. Traumatic injuries also made up the majority of musculoskeletal disorders affecting the Border Collie athletes included in this study. Our hypothesis that traumatic injuries would most frequently affect the hips and carpal joints was rejected. The majority of traumatic injuries in this study involved ligament injuries and was located at the shoulder and tarsal joints. The localization of these
injuries could be explained by the unique composition of cases seen at a referral center. Several theories have been put forward to explain why Border Collies are more prone to injuries than other breeds, such as an increased range of motion and specific behavioral traits. More research is needed in order to determine if the increased range of motion discovered in Border Collies predisposed them to injury. One of the theories suggests that, due to their extreme willingness to please, Border Collies are worked harder and longer during training sessions than other dogs (Cullen et al., 2013b). It is important for trainers of Border Collies to be aware of their predisposition to injury, as well as the ways in which these injuries might be prevented. Warming-up and cooling-down sessions before and after trainings and competitions have been proven to protect against injuries and even increase the level of performance, and is therefore recommended in all sporting dogs.

The results of this study also show several findings, which, to the author's knowledge, have not yet been described in Border Collies. This includes the occurrence of elbow joint incongruity, osteochondrosis of the elbow joint, and meniscal injury. This study also shows that Border Collies have a lower risk of developing medial coronoid disease compared to other large-breed dogs. Yet again, this could be due to an inappropriate composition of the control group, which was composed of a substantial amount of dog breeds predisposed to medial coronoid disease. Nonetheless, medial coronoid disease was not a frequent finding within the Border Collie, diagnosed in merely 5.5% of cases.

The findings of this study have provided new insights into the different causes of lameness in the Border Collie breed and form a valuable asset to both the owner as well as the veterinarian in assessing musculoskeletal disorders in Border Collies.

REFERENCE LIST


