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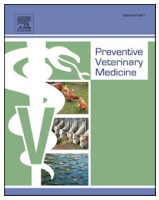

The epidemiology of osteochondrosis in an insured Swedish dog population

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ABSTRACT

Osteochondrosis (OC) is a focal disturbance of endochondral ossification due to a failure of blood supply to the epiphyseal growth cartilage. In dogs, OC most commonly affects the shoulder joint, followed by the elbow, tarsal, and stifle joints. The condition is associated with clinical signs such as lameness and pain and the prognosis varies depending on the affected joint. Most epidemiologic studies of OC in dogs were performed over 20 years ago, and updated estimates of disease incidence are lacking. Therefore, the objectives of this study were to provide population-based estimates of the incidence rate, cause-specific mortality rate, and age at diagnosis of appendicular OC (AOC, including OC of the shoulder, elbow, stifle, and tarsal joints) and stifle and tarsal OC separately, using data from Agria Djurförsäkring in Sweden (2011–2016). Further, the study aimed to evaluate the risk of OC in subgroups divided by breed and sex and describe previous, concurrent, and subsequent diagnoses of the affected joint in dogs with stifle or tarsal joint OC. The study population included just over 600,000 dogs, of which 685 were affected by AOC. Stifle joint OC (n = 113) was more common than tarsal joint OC (n = 80). The incidence rate of AOC was 3.77 (95% confidence interval (CI): 3.49–4.07) cases per 10,000 dog-years at risk, while the incidence rate of stifle and joint tarsal OC was 0.64 (95% CI: 0.53–0.77) and 0.43 (95% CI: 0.34–0.54) cases per 10,000 dog-years at risk, respectively. All breeds at increased risk of AOC were large or giant, and male dogs had an increased risk of AOC compared to female dogs (RR 1.76, 95% CI: 1.50–2.07, $p < 0.001$). The median age at first diagnosis during the study period was 0.74 (0.32–11.5) years for AOC, 2.62 (0.45–8.82) years for stifle joint OC, and 0.73 (0.35–7.35) years for tarsal joint OC. Of the dogs with stifle or tarsal joint OC, 30.2% and 15.0% had a previous diagnosis of stifle/tarsal joint pain or other unspecific clinical signs, respectively, and 13.8% of the dogs with stifle joint OC suffered subsequent cruciate ligament rupture. Osteochondrosis was the most common reason for euthanasia in the affected dogs. In total, 77 dogs were euthanised due to AOC during the study period.

1. Introduction

Osteochondrosis (OC) is defined as a focal disturbance of endochondral ossification, which may develop into osteochondrosis dissecans (OCD) if the cartilage over the lesion area fractures (Olstad et al., 2015). The cause of OC in pigs and horses is a failure of the blood supply to the epiphyseal growth cartilage and associated ischemic chondronecrosis (Carlson et al., 1991; Ytrehus et al., 2007). The cause is likely the same in dogs, although further studies are needed to confirm this (Ekman and Carlson, 1998; Ytrehus et al., 2007; Olstad et al., 2015). The shoulder joint has been reported as most commonly affected contributing 60% of the OC cases in dogs, followed by the elbow joint, tarsal joint, and stifle joint (Johnson et al., 1994). Osteochondrosis may also affect the sacrum and vertebrae (Hanna, 2001). Multiple joint involvement is common both in dogs and other domesticated fast-growing animals (Reiland, 1978; Slater et al., 1991; McIlwraith, 1993).

Estimates of the incidence of OC in dogs in the literature are few. Osteochondrosis comprised 5% of all appendicular joint diagnoses in the Veterinary Medical Database 1980–1989, and the incidence was reported as 5.2 cases per 1000 patients (Johnson et al., 1994). Further, the prevalence of OC in Kennel Club registered dogs in the UK has been estimated to be 0.22% (Wiles et al., 2017). It should be noted that these estimates are based on OC causing clinical or radiographic signs, which represent chronic stages of the disease rather than the primary process. These stages include OC dissecans and the pre-stage OC manifesta, where the OC lesion is macroscopically and radiographically visible (Ytrehus et al., 2007). However, dogs affected by OC latens, the first

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subclinical stage of OC characterised histologically by a focal area of necrosis in the growth cartilage are not included in these studies (Ytrehus et al., 2007). Thus, the true prevalence and incidence of all stages of OC is likely higher than previously reported.

Clinical signs of OC mainly affect large-sized dogs and include lameness, joint pain, and joint effusion, which are generally recognised before the age of one year (Slater et al., 1991; van der Peijl et al., 2012; Wall et al., 2015). Reported high-risk breeds vary depending on the affected joint: the breeds at highest risk of shoulder joint OC include the Bernese mountain dog, Irish wolfhound, Münsterländer, and Pyrenean mountain dog, and the breeds at highest risk of elbow joint OC include the Newfoundland, Rottweiler and Labrador retriever (LaFond et al., 2002). The breeds at the highest risk of stifle joint OC include the Mastiff, Irish Wolfhound, and Great Dane, while the breeds at highest risk of tarsal joint OC include the Rottweiler, Bullmastiff and Labrador retriever (LaFond et al., 2002). If the actual prevalence of all stages of OC is higher in large-sized, heavy breeds compared to small-sized, lightweight breeds or if these larger breeds are more prone to develop clinical signs of OC due to their size, body weight or some other confounding factor such as activity pattern is unknown.

Radiography, computer tomography, ultrasound, magnetic resonance imaging, or arthroscopy can be used to confirm the diagnosis (Demko and McLaughlin, 2005; van der Peijl et al., 2012). The recommended treatment varies depending on factors such as the affected joint, the severity of the clinical signs, and the owner's financial resources, and can be either conservative or surgical (Demko and McLaughlin, 2005). Surgical treatment of OCD has traditionally involved removing the cartilage flap and stimulating defect healing by curetting the cartilage defect (Demko and McLaughlin, 2005). The prognosis has been reported as good for shoulder joint OC, but guarded for OC in the stifle, elbow, and tarsal joints (Demko and McLaughlin, 2005; van der Peijl et al., 2012), although newer treatment methods with autografts or allografts to resurface the joint contour or fill the defect have shown more promising results (McCarty et al., 2016; Egan et al., 2018; Boyer et al., 2020; Franklin et al., 2021; Cinti et al., 2022).

Estimates of disease occurrence are necessary to evaluate the welfare impact of a disease in a population (Summers et al., 2019), and such estimates require primary or secondary data gathered at a population level. Most of the previous epidemiologic studies on OC in dogs were performed over 20 years ago (Slater et al., 1991; Johnson et al., 1994; Nečas et al., 1999; LaFond et al., 2002), and current estimates of the incidence of and breed predisposition to OC are lacking. Insurance data can be used to evaluate disease occurrence, and the results can be generalised to the reference population if a sufficient proportion of the dog population is insured. Sweden has the highest percentage of dogs covered by insurance worldwide, with 90% of the dogs in the country being insured (Agria Djurförsäkring, 2017). Agria Djurförsäkring (Agria Djurförsäkring, Stockholm, Sweden) is a leading pet insurance company based in Sweden with operations in nine markets across Europe. In 2016, Agria Djurförsäkring insured approximately 38% of the Swedish dog population (Engdahl et al., 2021). Data from Agria Djurförsäkring have been used in research projects on diseases such as adrenocortical insufficiency, atopy, cruciate ligament rupture, dystocia, mammary tumours, and kidney disease (Egenvall et al., 2005; Bergström et al., 2006; Nødtvedt et al., 2006; Pelander et al., 2015; Hanson et al., 2016; Engdahl et al., 2021).

The objectives of this study were to provide population-based estimates of the incidence rate, cause-specific mortality rate, and age at diagnosis of appendicular OC (AOC) in total, and stifle OC and tarsal OC separately, and to evaluate the risk of OC by breed and sex using data from Agria Djurförsäkring. Further, the study aimed at describing previous, concurrent, and subsequent diagnoses of the affected joint in dogs with stifle or tarsal joint OC.

2. Materials and methods

Study population

The study population included dogs insured by Agria Djurförsäkring in Sweden between 1 January 2011 and 31 December 2016. There were two types of insurance policies: veterinary care and life. The data included information about breed, age, sex (not neuter status), duration of the insurance period, and diagnostic codes attached to the veterinary care claims or life insurance settlements during the study period (if any). The breeds were classified according to the Swedish Kennel Club and the Federation Cynologique Internationale. The age at diagnosis was based on the first veterinary care claim for OC during the study period, and the age at euthanasia was based on the date of the life insurance settlement.

The diagnostic codes attached to the insurance claims were chosen by the examining veterinarians from a hierarchical diagnostic registry (Svenska Djursjukhusföreningen, 1993). The diagnostic codes for OC in the registry are grouped based on the affected bone: humerus, femur, and talus, and there are four codes for each localisation: osteochondrosis, osteochondrosis with joint mice, osteochondrosis without joint mice, and subchondral bone cyst of osteochondrosis type. It was not possible to differentiate shoulder and elbow joint osteochondrosis as both were coded as humeral osteochondrosis. Osteochondrosis affecting other sites than humerus, femur, and talus was excluded. A category for cases of AOC was generated, including humeral OC (i.e. shoulder and elbow joint OC), femoral OC (i.e. stifle joint OC), and OC of the talus (i.e. tarsal joint OC). Further, subcategories for stifle and tarsal joint OC were generated. Information on other stifle and tarsal joint diagnoses and unspecified lameness in dogs with stifle or tarsal joint OC was gathered. There was no information on diagnoses before the study period, or diseases present before insurance enrolment.

The owner chose the deductible of insurance at insurance enrolment and the associated cost of all veterinary care events during rolling 125-day periods needed to exceed the deductible limit for the veterinary care events to be registered in the insurance database. Insurance claims for OC were only covered in dogs enrolled in veterinary care insurance before the age of four months. Insurance claims for OC-related clinical signs in dogs enrolled in insurance after the age of four months were covered with a maximum of 3000 SEK until OC was diagnosed. The life insurance terminated at 8, 10, or 12 years of age, depending on breed (Supplementary Table 1). Euthanasia and natural death were not distinguishable. The dogs could be enrolled in life insurance before the age of four years (for breeds with life insurance termination at eight years of age) or six years (all other breeds), and in veterinary care insurance at any age.

Exclusion criteria included missing information about sex, age, breed, or date of insurance enrolment.

2.1. Data analysis

The data analysis was performed in R version 4.2.1 (R Core Team, 2021). Categorical variables were presented as numbers and percentages per category, and continuous variables as median (range). The Shapiro-Wilk test was used to evaluate the normal distribution of continuous variables. The Wilcoxon rank sum test was used to compare age at diagnosis and age at OC-related euthanasia. The dog-years at risk (DYAR) for incidence rate calculation were based on the duration of the insurance period during 2011–2016, and in dogs with claims for OC, the DYAR were based on the time to the first OC claim. The incidence and cause-specific mortality rates were expressed as the number of OC cases per 10,000 DYAR, and the relative risks for breed and sex were calculated by dividing the incidence rate of the group of interest by the incidence rate of the rest of the population. Forest plots generated with the R package "forestplot" were used to visualise breed risks (Gordon and Lumley, 2019). Poisson confidence intervals (CI) were generated with the R package "exactci" (Fay, 2010). Bonferroni correction based on the number of comparisons was performed. P values < 0.05, after

correction, were considered to indicate statistical significance.

3. Results

3.1. Study population

The study population included just over 600,000 dogs, after exclusion of 649 dogs based on the exclusion criteria. Of the included dogs, 61.8% had both veterinary care and life insurance, 35.4% had only veterinary care insurance, and 2.72% had only life insurance. The total duration of the veterinary care and life insurance in the population was > 1.75 million years and > 1.10 million years, respectively. The median insurance duration per dog was 2.67 years (9.15 weeks–6.00 years) for the veterinary care insurance and 2.51 years (9.15 weeks–6.00 years) for the life insurance during the study period. The median age at enrolment in veterinary care insurance during the study period was 15.7 weeks (3.43 weeks–17.5 years). The sex distribution was relatively even, with 49.1% females and 50.9% males in the veterinary care-insured population, and 49.5% females and 50.5% males in the life-insured population.

3.2. The incidence rate of OC

In total, 685 dogs were affected by AOC, including 493 dogs with humeral OC, 116 dogs with stifle joint OC, and 80 with tarsal joint OC. Of these, 662 had veterinary care claims for AOC, 113 for stifle joint OC, and 76 for tarsal joint OC. The incidence rate of AOC was 3.77 (95% CI: 3.49–4.07) cases per 10,000 DYAR, while the incidence rates of stifle and tarsal joint OC were 0.64 (95% CI: 0.53–0.77) and 0.43 (95% CI: 0.34–0.54) cases per 10,000 DYAR, respectively. One dog had both humeral and stifle joint OC, and three dogs had humeral and tarsal joint OC. There were no dogs with both stifle and tarsal joint OC.

3.3. The risk of OC by breed

The number of breeds with veterinary care claims for AOC, stifle, and tarsal joint OC were 80, 31, and 21, respectively. The breeds with an increased or decreased risk of OC are presented in Fig. 1. For AOC, only breeds with a relative risk significantly different from one after Bonferroni correction are presented (the full list of high-risk and low-risk breeds, without Bonferroni correction, can be found in Fig. S1).

3.4. The risk of OC in female and male dogs

Male dogs had a significantly increased risk of AOC compared to female dogs (RR 1.76, 95% CI: 1.50–2.07, $p < 0.001$). The risk of stifle or tarsal joint OC was not significantly different between male and female dogs (RR 1.35, 95% CI: 0.91–2.01, $p = 0.137$ and RR 0.70, 95% CI: 0.43–1.13, $p = 0.151$, respectively).

3.5. Age at diagnosis

The median age at first diagnosis during the study period was 0.74 (0.32–11.5) years for AOC, 2.62

(0.45–8.82) years for stifle joint OC, and 0.73 (0.35–7.35) years for tarsal joint OC. The age at first diagnosis of OC did not differ between male and female dogs for the different OC sites. The median age at first diagnosis of AOC was 0.73 (0.32–9.48) years in male dogs and 0.75 (0.35–11.5) years in female dogs; the median age at first diagnosis of stifle joint OC was 3.08 (0.45–8.82) in male dogs and 2.03 years (0.47–8.39) in female dogs; and the median age at first diagnosis of tarsal joint OC was 0.74 (0.39–4.53) in male dogs and 0.73 (0.35–7.35) years in female dogs (Wilcoxon rank sum test, $p > 0.05$ for all comparisons). Breeds with an age at first diagnosis that differed significantly from all other breeds are presented in Table 1.

3.6. Other joint disorders

Of the 116 dogs with stifle joint OC, 76 (65.5%) had other stifle joint diagnoses. Pain and other unspecific signs were the most common stifle joint diagnoses before OC was diagnosed (35 dogs, 30.2%) while cruciate ligament rupture was the most common subsequent diagnosis (16 dogs, 13.8%). A summary of the other stifle joint diagnoses can be found in Table 2. In addition, 48 (41.4%) of the dogs had an insurance claim for unspecified lameness before the diagnosis of stifle joint OC.

Of the 80 dogs with tarsal joint OC, 30 (37.5%) had other tarsal joint diagnoses. Pain and other unspecific signs were the most common diagnoses both before (12 dogs, 15.0%) and after (7 dogs, 8.75%) the OC diagnosis. In addition, 21 (26.3%) of the dogs had an insurance claim for unspecified lameness before the diagnosis of tarsal OC.

3.7. OC-related mortality

In total, 77 dogs were euthanised due to AOC, of which 20 dogs were euthanised due to stifle joint OC, and 14 dogs due to tarsal joint OC. Life insurance settlements in dogs with veterinary care claims for OC are presented in Fig. 2. Approximately 50% of these life insurance settlements were due to OC (51.4% in the dogs with AOC, 46.0% in the dogs with stifle joint OC, and 50.0% in the dogs with tarsal joint OC). The median time from first OC diagnosis during the study period to OC-related euthanasia was 0 days (i.e., the dog was euthanised when OC was diagnosed), and ranged up to 2.13 years for AOC, 96 days for stifle joint OC, and 74 days for tarsal joint OC.

The cause-specific mortality rate was 0.70 (95% CI: 0.55–0.87) cases per 10,000 DYAR for AOC, 0.18 (95% CI: 0.11–0.28) cases per 10,000 DYAR for stifle joint OC, and 0.13 (95% CI: 0.07–0.21) cases per 10,000 DYAR for tarsal joint OC, respectively. The breeds with an increased or decreased risk of OC-related euthanasia are presented in Fig. 3.

Male dogs had a higher risk of AOC-related euthanasia than female dogs (RR 2.14, 95% CI: 1.30–3.63, $p = 0.002$), but the risk of stifle or tarsal OC-related euthanasia was not significantly different in male and female dogs (RR 1.46, 95% CI: 0.55–4.11, $p = 0.547$, and RR 0.73, 95% CI: 0.21–2.39, $p = 0.747$, respectively).

The age at OC-related euthanasia was 0.72 (0.36–9.60) years for AOC, 0.80 (0.48–7.53) years for stifle joint OC, and 0.54 (0.36–9.60) years for tarsal joint OC. One breed, the German shepherd dog, had a median age at AOC-euthanasia that differed significantly from all other breeds (3.70 (0.69–7.53) years, Wilcoxon rank sum test, $p = 0.006$).

4. Discussion

This study reports the incidence and cause-specific mortality rates of canine AOC (including shoulder, elbow, stifle, and tarsal joint OC), and stifle and tarsal joint OC separately, based on insurance claims in dogs insured by Agria Djurförsäkringar, Sweden (2011–2016). Stifle joint OC was more common than tarsal joint OC, and was generally diagnosed at an older age (median age 2.62 years) than AOC in general (median age 0.74 years) and tarsal OC (median age 0.73 years). All breeds with high risk of OC were large or giant. Male dogs had a higher risk of AOC than female dogs, while the risk of stifle and tarsal joint OC did not differ between sexes. Osteochondrosis was a common cause of euthanasia in the affected dogs: around 50% of the dogs with OC and life insurance settlement during the study period were euthanised due to OC. These dogs were often euthanised in close association to the first diagnosis of OC.

The incidence rate of AOC was 3.77 (95% CI: 3.49–4.07) cases per 10,000 DYAR, while the incidence rates of stifle and tarsal joint OC were 0.64 (0.53–0.77) and 0.43 (0.34–0.54), respectively. These incidence rates were lower than the incidence rates of cruciate ligament rupture (23.8 cases per 10,000 DYAR) and patellar luxation (15.6 cases per 10,000 DYAR) in the same study population during the same period (Engdahl et al., 2021, 2023). The shoulder joint has been reported as the

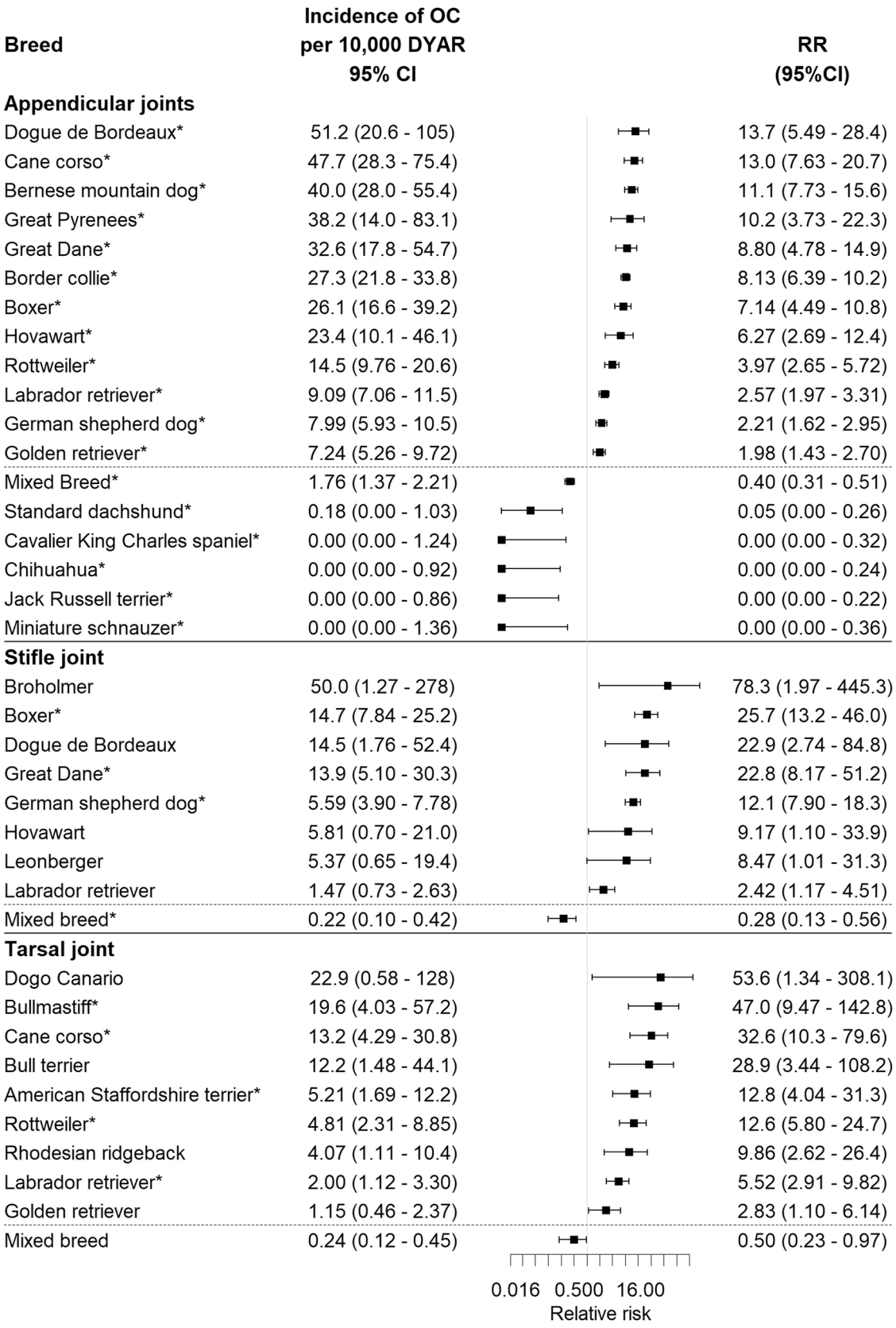

Fig. 1. Breeds with an increased or decreased relative risk (RR) of a veterinary care claim for osteochondrosis (OC) (relative to the rest of the population with the breed excluded) in a cohort of dogs insured by Agria Djurförsäkring in Sweden (2011–2016). Appendicular osteochondrosis includes cases of osteochondrosis in the shoulder, elbow, stifle, and tarsal joints. A fudge factor of 0.05 was added to the relative risk and its lower confidence interval boundary in case these were zero, to present these on a log scale (x-axis). *These breeds had a relative risk significantly different from one after the Bonferroni correction (number of comparisons = 339). *CI* confidence interval, *DYAR* dog-years at risk.

Table 1
Breeds with an age-at-first osteochondrosis (OC) diagnosis during the study period (2011–2016) that differed significantly from all other breeds, in dogs insured by Agria Djurförsäkring in Sweden.

	Younger at diagnosis		Older at diagnosis	
	Breed	Age	Breed	Age
Appendicular OC	Chow chow	0.45 (0.45–0.45)	German shepherd dog*	2.04 (0.36–8.47)
	Dalmatian	0.50 (0.44–0.79)	Boxer*	2.85 (0.49–8.00)
	Cane corso	0.61 (0.36–1.16)		
	Border collie	0.67 (0.39–7.54)		
Stifle joint OC	Labrador retriever	0.84 (0.54–6.74)	Mixed breed	4.02 (2.62–8.79)
	Great Dane	1.17 (0.50–1.74)	Boxer	4.85 (2.19–8.00)
Tarsal joint OC	-		Labrador retriever	1.04 (0.37–7.35)

Age is presented in years (min-max)
*Age at diagnosis is significantly different from all other breeds, after Bonferroni correction based on the number of comparisons (n = 80)

Table 2
Other stifle joint diagnoses in 116 dogs with stifle joint osteochondrosis (OC), in a population of dogs insured by Agria Djurförsäkring in Sweden (2011–2016).

	Before OC*	Same date as OC*	After OC*
Arthritis	7 (6.03%)	-	2 (1.72%)
Cruciate ligament rupture	10 (8.62%)	5 (4.31%)	16 (13.8%)
Degenerative changes	17 (14.7%)	1 (0.86%)	10 (8.62%)
Immune-mediated	1 (0.86%)	-	-
Malformation/growth disorder	1 (0.86%)	-	-
Meniscal injury	1 (0.86%)	-	4 (3.45%)
Pain/signs SJ	35 (30.2%)	2 (1.72%)	6 (5.17%)
Patellar luxation	-	-	1 (0.86%)
Traumatic injuries	1 (0.86%)	-	-
Tumour	-	-	1 (0.86%)

Each dog could be included once in each before category and once in each after category. Pain/signs SJ pain and/or clinical signs from the stifle joint without confirmed cause
* Compared to the first insurance claim for stifle joint OC in each dog, during the study period.

most common site for AOC (Johnson et al., 1994; Nečas et al., 1999; LaFond et al., 2002), which was likely the case in the current study too, even though shoulder and elbow joint OC could not be differentiated. Tarsal joint OC has been reported as more common than stifle joint OC in some studies (Johnson et al., 1994; LaFond et al., 2002), but not in all (Nečas et al., 1999). In the current study, the incidence of stifle joint OC was higher than for tarsal joint OC.

Previous research in pigs and horses suggested that OC is a multifocal disease (Reiland, 1978; McIlwraith, 1993) and that OC in the contralateral joint is much more common than in other joints (McIlwraith, 1993). Bilateral occurrence of OC has also been described as common in dogs (Olsson, 1987; Slater et al., 1991; Nečas et al., 1999). For example, 20–85% of dogs with shoulder joint OC have been reported to be bilaterally affected, of which only 21% showed bilateral lameness (as summarised by Johnston 1998). The occurrence of bilateral disease could not be assessed in the current study, as the diagnostic codes did not reveal if the condition was unilateral or bilateral. However, multiple joint involvement of other joints than the contralateral was uncommon: one dog had humeral and stifle joint OC, and three dogs had humeral and tarsal joint OC. There were no dogs with both stifle and tarsal joint OC. Unfortunately, it was not possible to determine the risk for simultaneously occurring elbow and shoulder OC. Our results were in line with a study that evaluated OC in dogs using hospital records, which reported that only a few of the 208 included dogs were affected in two or more different joints (Slater et al., 1991). However, it contrasted a study that evaluated OC at necropsy, which described that 25/89 of the examined dogs had more than one affected joint (Olsson, 1987). Thus, the occurrence of multifocal OC might be underestimated in studies using clinical data as these data only include cases with clinical signs of OC, compared to the study by Olsson (1987) which included cases of both OC manifesta and dissecans. However, the results of the current study indicated that overt clinical signs related to OC in joints other than the contralateral were uncommon, as such clinical signs likely would have been recognised when OC was diagnosed.

Several breeds at high or low risk of AOC, stifle and tarsal joint OC were identified. All high-risk breeds were large or giant, in concordance with previous studies (Nečas et al., 1999; LaFond et al., 2002; Wiles et al., 2017), while all low-risk breeds were small-sized. Breed-related differences in the risk of OC suggest a genetic component to the disease aetiology, which has been described previously (Ubbink et al., 1992; Ekman and Carlson, 1998; LaFond et al., 2002; Ytrehus et al., 2007). For example, anatomic conformation of the joint has been suggested an important heritable risk factor for OC development in pigs (Grondalen, 1974; Ytrehus et al., 2007), and anatomy-related features causing repeated microtrauma due to impingement of the humeral head has been associated with OC in the shoulder joint of dogs (Olsson, 1987).

Rapid weight gain and/or accelerated growth rate due to increased feeding and/or heritable traits has been suggested to increase the risk of OC both in dogs and swine (Hedhammar et al., 1974; Dämmrich, 1991; Ekman and Carlson, 1998; Richardson and Zentek, 1998; Ytrehus et al., 2007), although studies in swine have failed to demonstrate a direct impact of growth rate on OC occurrence (as reviewed by Ytrehus et al. 2007). Differences in performed activities and activity levels between breeds might also impact the risk of development of OC. Research in pigs has shown that fattening pigs in free-range housing have a higher prevalence and severity of OC compared to pigs housed in confined indoor pens, which according to the authors might have been due to increased biomechanical stress on joint structures (Etterlin et al., 2014, 2015). Despite this, no significant difference in lameness was found between the groups of pigs, suggesting that free-range pigs might be less clinically affected than confined pigs, potentially due to strengthening of joint supportive tissues and improved joint support and biomechanics (Etterlin et al., 2015). If the same associations between OC, lameness and activity level exist in dogs is not yet known, but if so is the case, differences in activity levels between breeds might impact their risk of developing clinical signs due to OC. It should also, as previously mentioned, be emphasised that the increased risk of OC in many large-sized breeds might be related to an actual higher incidence of OC, or a higher risk of developing clinical signs due to OC compared to small-sized breeds.

In the current study, 12/19 (63.2%) of the high-risk breeds presented in Fig. 1 belonged to breed group two, Pinscher and Schnauzer – Molossoid and Swiss Mountain and Cattledogs (Federation Cynologique Internationale, 2023). Of these, 11/12 (91.7%) were of the Molossian type, of which 8/11 (72.7%) were of the mastiff type. Molosser breeds have an increased risk of CLR and are overrepresented among breeds with elbow dysplasia and CLR and concurrent hip dysplasia (Witsberger et al., 2008; Oberbauer et al., 2017; Engdahl et al., 2021). The reason for this likely varies with the condition but could be linked to factors such as joint conformation, body constitution, performed activities, or rate of growth.

The risk of AOC and AOC-related euthanasia was higher in male than female dogs, although no sex-related difference in the risk of stifle and tarsal joint OC-related euthanasia was found. An increased risk of OC in male dogs, potentially linked to growth rate, has been reported previously (Slater et al., 1991; Ekman and Carlson, 1998; Nečas et al., 1999), although the exact cause is unknown.

The median age at diagnosis of stifle joint OC (2.62 years) was higher than for AOC (0.74 years) and tarsal joint OC (0.73 years), in agreement

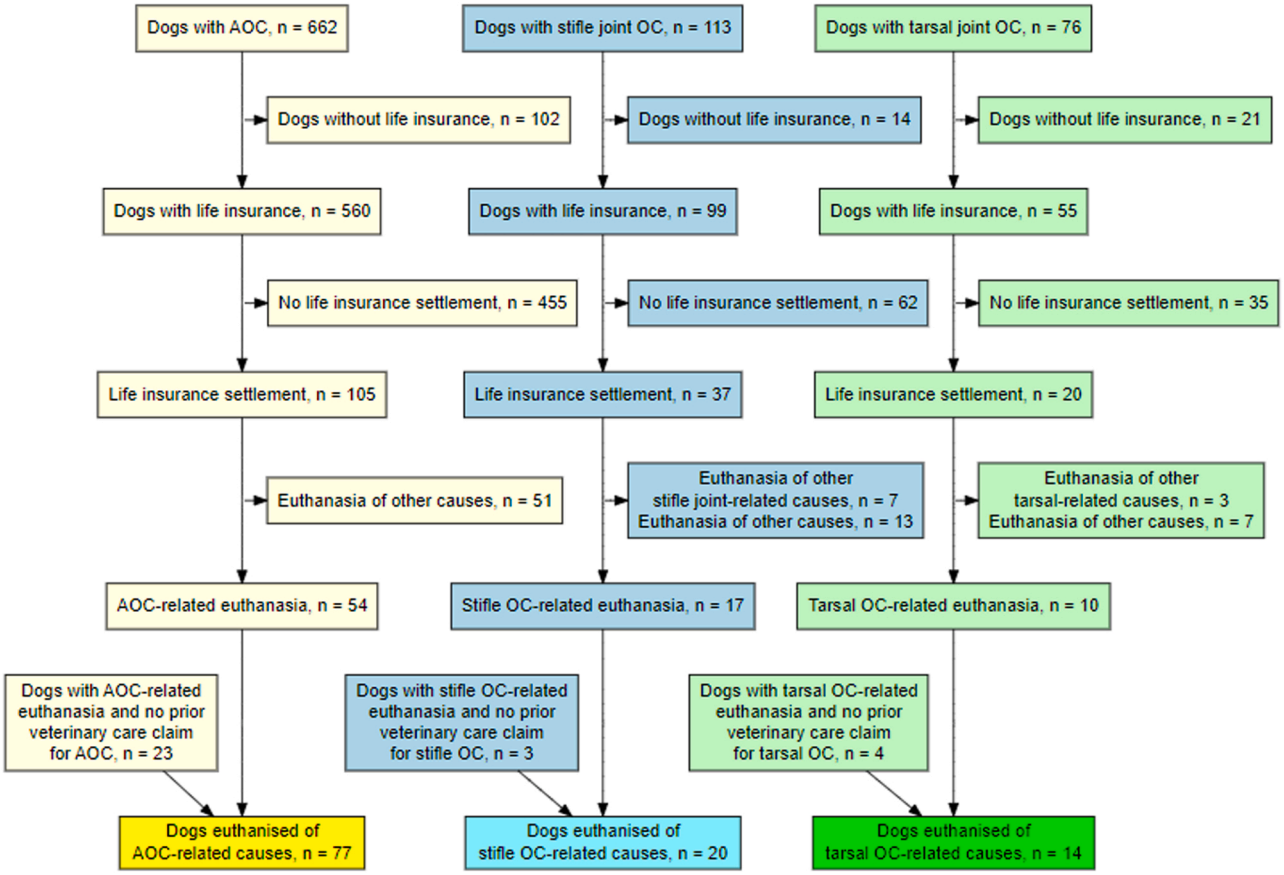

Fig. 2. Life insurance settlements in dogs with veterinary care insurance claims for appendicular osteochondrosis (OC), stifle joint OC, and tarsal joint OC, and the total number of dogs that were euthanised due to these conditions in a cohort of dogs insured by Agria Djurförsäkring in Sweden (2011–2016).

with previous publications (Slater et al., 1991; Nečas et al., 1999). Attribution of the early clinical signs of OC to other causes of hindlimb lameness in young dogs has been suggested as the reason for this late diagnosis (Slater et al., 1991). For example, several of the breeds at high risk of stifle joint OC have an increased risk of hip dysplasia and panosteitis (LaFond et al., 2002; Witsberger et al., 2008). It could also be that some dogs with stifle joint OC lacked clinical signs and that the OC was an incidental finding during radiography or arthroscopy due to CLR. Other stifle joint diagnoses were common in the dogs with stifle joint OC, affecting 65.5%. Stifle joint pain and/or clinical signs of unknown origin were the most common diagnoses before the OC diagnosis (30.2%), and CLR was the most common subsequent diagnosis (13.8%). Osteochondrosis has been suggested to cause CLR and vice versa (Macpherson and Allan, 1993), although the causal relationship of the conditions should be explored in future research. Other tarsal joint diagnoses in dogs with tarsal OC were less common, affecting 37.5% of the dogs, and were mainly related to pain and other unspecific clinical signs.

Age at diagnosis also varied with breed; some breeds were diagnosed at a younger age (Chow chow, Dalmatian, Cane corso, Border collie, Labrador retriever (stifle OC)), while some breeds were diagnosed at an older age (German shepherd dog, Boxer, Mixed breed, Labrador retriever (tarsal OC)). Diagnosis at a younger age could be attributed to more severe or an earlier onset of clinical signs, even though this could not be investigated as information regarding the severity and onset of the clinical signs was unavailable.

The cause-specific mortality of AOC, stifle, and tarsal joint OC was 0.70, 0.18, and 0.13 cases per 10,000 DYAR, respectively, which is similar to the cause-specific mortality of patellar luxation (1.0 cases per 10,000 DYAR, (Engdahl et al., 2023) but lower than for CLR (4.04 cases per 10,000 DYAR) (Engdahl et al., 2021) in the same study population. These low numbers indicate that OC is a relatively uncommon cause of euthanasia, although no previous estimates of OC-related mortality are available in the literature. However, in dogs with OC and life insurance settlement during the study period, around 50% were euthanised due to OC, the majority on the day of diagnosis. Therefore, OC was an important life-limiting condition of the affected dogs. The age at OC-related euthanasia was low; 0.72 years for AOC, 0.80 years for stifle joint OC, and 0.54 years for tarsal joint OC. This was lower than the general age at OC diagnosis, especially for stifle joint OC, and indicates that OC diagnosed at a younger age is associated with a higher rate of euthanasia. All breeds with an increased risk of OC-related euthanasia were large or giant. The exact reason for euthanasia in these dogs, e.g., severe clinical signs, diagnosis of bilateral OC, or guarded prognosis, could not be investigated.

Some limitations should be mentioned. The hierarchical diagnostic registry classified OC by the affected bone, not the affected joint. Therefore, differentiation between shoulder and elbow OC was impossible, which would have been optimal to describe the epidemiology of AOC in dogs. Further, osteochondrosis affecting other sites than humerus, femur, and talus was excluded. Although the dataset was large (over 600,000 individuals), yielding high statistical power, the power might be low in some analyses due to the few included individuals, increasing the risk of type II errors. This could for example be the case when sex was evaluated as a risk factor for stifle or tarsal OC-related euthanasia. This also highlights the importance of taking the width of the confidence intervals into account when the results are interpreted, as these show the precision of the point estimates. The incidence and cause-specific mortality of OC were likely underestimated, for several reasons. The percentage of all OC cases that were diagnosed likely varied with the affected joint, depending on factors such as the severity of the

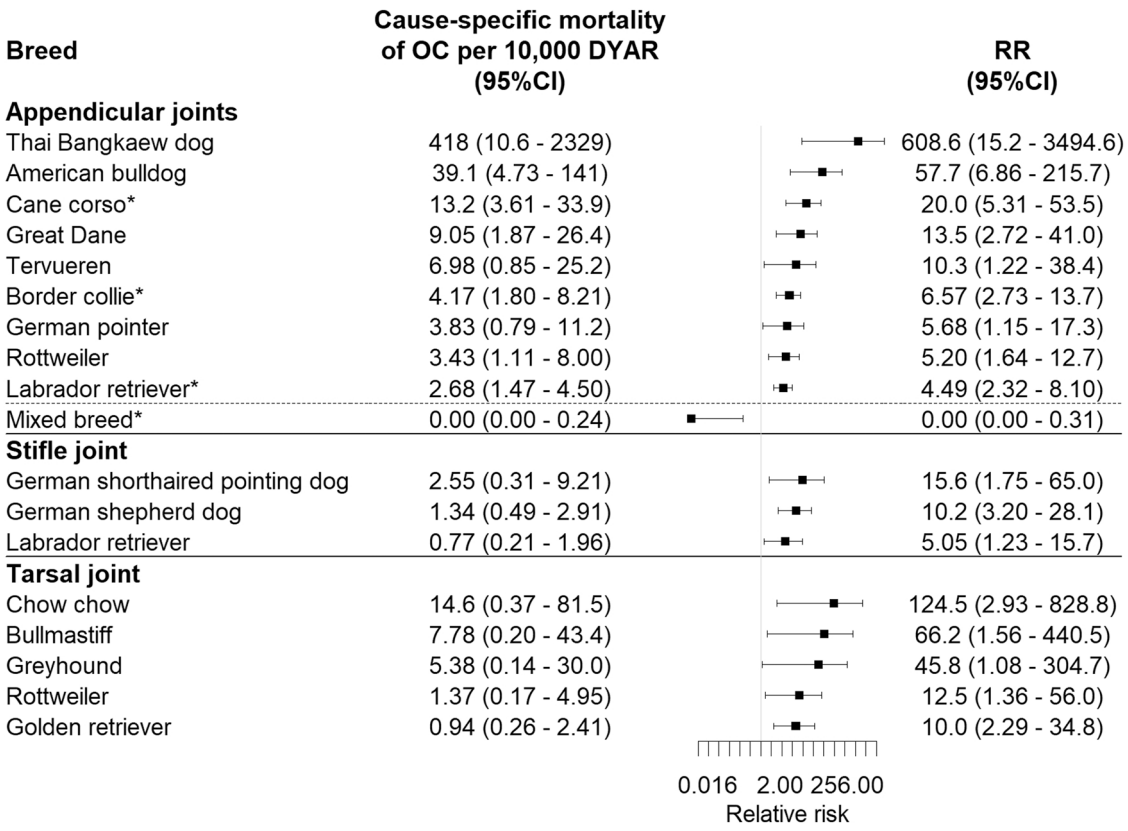

Fig. 3. The breeds with an increased or decreased relative risk (RR) of euthanasia due to osteochondrosis (OC) (relative to the rest of the population with the breed excluded) in a cohort of dogs insured by Agria Djurförsäkring in Sweden during 2011–2016. A fudge factor of 0.01 was added to the RR of the mixed breed to present the RR on the log-scaled x-axis. *These breeds had a relative risk of OC-related euthanasia that was significantly different from 1, after Bonferroni correction based on the number of breeds included in the comparison, n = 335. *DYAR* dog-years at risk, *CI* confidence interval.

clinical signs and comorbidities of the joint. Diagnostic imaging, sometimes in combination with arthroscopy, is necessary to diagnose OC manifesta and/or dissecans, which might have been declined by some owners for reasons such as financial constraints. Cases of OC latens need to be diagnosed histologically, and thus such cases were likely not included in the current study. The insurance coverage of OC in dogs insured after 12 months of age was limited. However, OC diagnoses in these dogs were likely registered in the insurance database, as the dog owners were reimbursed for a maximum of 3000 SEK until OC was confirmed. In addition, only veterinary appointments with costs exceeding the deductible limit were registered. Even so, this should not impact the incidence to a large extent, as the techniques used to diagnose OC generally yield costs exceeding the deductible limit.

Evaluation of other potential risk factors of OC, such as diet, exercise or activities, growth rate, and body weight (Hedhammar et al., 1974; Dämmrich, 1991; Slater et al., 1992; Ekman and Carlson, 1998; Richardson and Zentek, 1998; Ytrehus et al., 2007) would have been desirable, but was impossible due to a lack of information.

The Agria Djurförsäkring database was validated against practice records > 20 years ago and revealed excellent agreement for demographic data such as sex and breed and fair agreement for diagnostic information (Egenvall et al., 1998). An updated validation of OC diagnoses against practice records would have been optimal, but GDPR precluded access to the medical records. Morbidity and mortality rates in insured dogs do not necessarily reflect those of uninsured dogs (Egenvall et al., 2009). However, since over 90% of the Swedish dog population is insured (approximately 38% in Agria Djurförsäkring in 2016 (Olsson, 2020)), it is reasonable to assume that the results can be generalised to the entire dog population in Sweden and possibly also to insured dog populations in other countries (Agria Djurförsäkring, 2017). The cause-specific mortality due to OC likely reflected the rate of OC-related euthanasia in the Swedish dog population. However, decisions on when to euthanise an animal and the rate of euthanasia (vs unassisted death) in dogs registered at veterinary practices vary between countries, from 22% in Taiwan (Huang et al., 2017) to 91% in New Zealand (Gates et al., 2017) (summarised by Pepper et al. 2023). Thus, the results related to mortality might have limited generalisability to international dog populations.

5. Conclusions

Appendicular OC affected 685 dogs in the study population, and stifle joint OC (n = 113) was more common than tarsal joint OC (n = 76). Males had an increased risk of AOC compared to females (RR = 1.76), while the risk of stifle and tarsal joint OC did not differ between sexes. All breeds at increased risk of OC were large or giant. The median age at first diagnosis of AOC during the study period was 0.74 years and was higher for stifle joint OC (2.62 years) than for tarsal joint OC (0.73 years). Osteochondrosis was a common cause of euthanasia in the affected dogs: around 50% of the dogs with OC and life insurance settlement during the study period were euthanised due to OC. Demographic factors associated with OC can guide veterinarians in their daily clinical work, and provide information to dog owners and breeders regarding breeds at risk of OC.

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CRediT authorship contribution statement

Annika Bergström: Writing – review & editing, Supervision, Methodology, Conceptualization. **Jeanette Hanson:** Writing – review & editing, Methodology, Conceptualization. **Åke Hedhammar:** Writing – review & editing, Methodology, Conceptualization. **Odd Höglund:** Writing – review & editing, Methodology, Conceptualization. **Karolina Engdahl:** Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of Competing Interest

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2024.106229.

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