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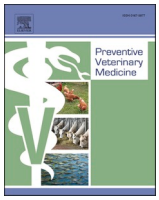

The epidemiology of patellar luxation in an insured Swedish dog population

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ABSTRACT

Patellar luxation (PL) is a common orthopaedic condition in dogs. This study aimed to evaluate the incidence and cause-specific mortality rate, age at diagnosis, and risk factors for medial PL (MPL), lateral PL (LPL), and bidirectional PL (BPL). Other diagnoses in dogs with PL were also explored. The study population included just over 600,000 dogs insured by Agria Pet Insurance in Sweden (2011–2016). There were 2726 dogs with PL. Medial patellar luxation affected 90 % of the dogs with PL, followed by LPL (5.9 %), BPL (2.4 %), and unspecified PL (1.6 %). The median age at first diagnosis during the study period was 2.8 years for MPL, 2.7 years for LPL, and 1.5 years for BPL. In total, 168 (6.2 %) of the dogs with PL had cruciate ligament rupture. There were substantial breed-specific differences in the risk of PL: almost all breeds at increased risk of MPL were small-sized, while several of the breeds at increased risk of LPL were large-sized. The breeds at high risk of BPL varied in size. Females had an increased risk of MPL (RR 1.2, 95 % CI: 1.1–1.3, $p < 0.001$) and a decreased risk of LPL (RR 0.72, 95 % CI: 0.51–1.0, $p = 0.042$) compared to males. In total, 116 dogs were euthanised due to PL and the breeds with the highest risk of PL-related euthanasia were the Pyrenean mountain dog, Dogue de Bordeaux, and German pinscher. The median age for PL-related euthanasia was 2.2 years.

1. Introduction

The patella is a sesamoid bone located in the trochlear groove of the femur and is crucial for the stifle joint's extensor mechanism (McKee and Cook, 2006). Patellar luxation (PL) is one of the most common orthopaedic conditions in dogs and involves a medial or lateral dislocation of the patella (Johnson et al., 1994). The condition can be either congenital, developmental, or traumatic, although most cases are considered developmental with anatomical deviations that start to develop after birth (Perry and Dejardin, 2021). Patellar luxation is generally graded from 1 to 4, where a grade 1 patella can be manually luxated but repositions when released, while a grade 4 patella is permanently luxated (Putnam, 1968; Singleton, 1969; L'Eplattenier and Montavon, 2002). There are also alternative grading systems available and used by kennel clubs and breed associations, such as the 0 to 3 grading used by the Swedish Kennel Club. Anatomical deviations associated with medial patellar luxation (MPL) are medial displacement of the quadriceps muscle, excessive distal femoral varus, hypoplasia of the medial femoral condyle, internal proximal tibial torsion, and medial displacement of the tibial tuberosity (as summarised by Perry and Dejardin, 2021 and Schulz, 2013). Lateral patellar luxation (LPL) is associated with a lateral shift of the force of the quadriceps muscle, resulting in anatomical deviations that mirror the deviations seen in MPL (Schulz, 2013). The aetiopathogenesis of the disease is not fully understood, and the impact of each anatomical deviation on the pathogenesis is unclear (Perry and Dejardin, 2021). Patellar luxation predisposes to stifle joint osteoarthritis associated with chronic pain and thereby impacts the welfare of affected dogs (Alam et al., 2011; Summers et al., 2019; Anderson et al., 2020; Perry and Dejardin, 2021). Cranial cruciate ligament disease, another common stifle joint disorder in dogs, has been described to co-occur with PL, but studies describing their co-occurrence are sparse (Gibbons et al., 2006; Campbell et al., 2010; Candela Andrade et al., 2022).

The prevalence of PL has been estimated to be 1.3 % in dogs attending primary-care veterinary clinics but varies up to 12–75 % in specific breeds (Lavrijsen et al., 2013; Soontornvipart et al., 2013; Wangdee et al., 2014; O'Neill et al., 2016; Nilsson et al., 2018). A 12 times higher risk of PL has been described in small-sized compared to large-sized breeds and the risk is higher in females than males (Priester, 1972; O'Neill et al., 2016). Further, higher odds of PL have been

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reported in neutered dogs (Vidoni et al., 2006). Medial patellar luxation is the most common type of luxation regardless of breed size, but an increasing proportion of lateral patellar luxation has been observed as the size of the dog increases (Hayes et al., 1994; Alam et al., 2007; Bound et al., 2009). Breeds described to be at high risk of PL include the Bichon frise, Boston terrier, Cavalier King Charles spaniel, Chihuahua, English bulldog, Flat coated retriever, French bulldog, Miniature and Toy poodle, Miniature pinscher, Pomeranian, Pug, Pyrenean mountain dog, Silky terrier, Toy fox terrier, West Highland white terrier, and Yorkshire terrier (Priester, 1972; LaFond et al., 2002; Vidoni et al., 2006; O'Neill et al., 2016), and breeds reported to be at low risk include the Beagle, Collie, Dachshund, Jack Russell terrier, Golden retriever, Labrador retriever, and the mixed breed (Priester, 1972; Vidoni et al., 2006; Wiles et al., 2017).

Epidemiologic data on the incidence and risk factors for disease development are necessary to evaluate the impact of PL at a population level. Previous studies have used data from veterinary teaching hospitals, primary care veterinary practices, and kennel clubs to evaluate the epidemiology of PL (Priester, 1972; LaFond et al., 2002; O'Neill et al., 2016; Wiles et al., 2017). Insurance data is also a potential data source for epidemiologic studies of PL. The data include information about disease cases and healthy dogs, which enables the calculation of disease incidence. Sweden has the highest coverage of the dog population worldwide; around 90 % of the dog population was insured in 2017 (Agria Pet Insurance Sweden, 2017). Agria Pet Insurance Sweden is the leading animal insurance company and insured approximately 38 % of the Swedish dog population in 2016. Data from Agria Pet Insurance Sweden have been used in studies on canine adrenocortical insufficiency, atopic dermatitis, and dystocia (Bergström et al., 2006; Nødtvedt et al., 2007; Hanson et al., 2016).

This study aimed to explore the incidence and cause-specific mortality rate of PL and risk factors for disease development in a population of insured dogs in Sweden. An additional aim was to describe the occurrence of other diagnoses in dogs with PL, with a focus on stifle joint disorders.

2. Materials and methods

2.1. Data

A cohort study including dogs insured by Agria Pet Insurance Sweden between January 2011 and 31 December 2016 was performed. The dogs had either veterinary care insurance, life insurance, or both. The data included information about the breed, sex (female/male, not neuter status), age, type of insurance, date of insurance enrolment and termination, and dates and diagnostic codes for veterinary care claims and life insurance settlement during the study period (if any). Access to the medical records of the included dogs was not possible, for GDPR reasons. Therefore, more detailed clinical information about the grade of PL, the presence of lameness, and treatment was unavailable. The breeds and breed groups were classified according to the Federation Cynologique Internationale and the Swedish Kennel Club. The date of and age at first PL diagnosis was based on the date of the first registered claim for PL during the study period. Age at first PL diagnosis was also evaluated in a subpopulation of dogs insured during the study period before the age of six months, in case some dogs in the study population had their first PL diagnosis before the study period, which would bias the age at first PL diagnosis.

The owner could choose between the available deductible limits at insurance enrolment. The total veterinary cost over rolling 125-day periods had to exceed the insurance deductible for an insurance claim to be reimbursed. If receipts from several veterinary appointments were submitted together, these were usually recorded as separate claims but on the same date. Each insurance claim had one or several diagnostic codes attached, chosen by the examining veterinarian from a national hierarchical diagnostic registry (Svenska Djursjukhusföreningen, 1993). Six diagnostic codes were available for PL; unilateral/bilateral MPL, unilateral/bilateral LPL, and unilateral/bilateral unspecified PL. Claims for PL were only reimbursed in dogs insured before the age of four months. Veterinary examination due to suspected PL in dogs enroled in insurance after four months of age was covered with a maximum of 3000 Swedish kronor until PL was confirmed.

The life insurance terminated at eight, ten, or twelve years of age, depending on the breed (see Supplementary Table 1 for more information). The dogs could be enroled in veterinary care insurance at any age but in life insurance only before four years of age (for breeds with insurance termination at eight years of age) or six years (for all other breeds). Settlement of the life insurance required a certificate from a veterinarian, sometimes in combination with an autopsy. It was not possible to differentiate between natural death and euthanasia.

Dogs were excluded in case of uncertain information about the breed, sex, age, or date of insurance enrolment.

2.2. Statistical analysis

The data analysis was performed in R version 1.3.959 (R Core Team, 2022). Categorical variables are presented as numbers and percentages per category, and continuous variables as median (min–max). The Shapiro-Wilk test was used to test the normal distribution of continuous variables. The total dog-years at risk (DYAR) were calculated by summing the insurance duration for each dog during the study period. Age differences were evaluated with the Wilcoxon rank sum test.

One group with all dogs with PL and subgroups of dogs with MPL, LPL, and bidirectional PL (BPL) were generated. Dogs with claims for both MPL and LPL were considered to have BPL, even though it could not be confirmed that these affected the same hindlimb. The first PL claim was used for incidence calculation, and the DYAR were based on the time to the first claim for PL. The incidence rate and cause-specific mortality rate were expressed as the number of PL cases per 10,000 DYAR. The relative risks (RR) for breeds and sex were calculated by dividing the incidence rate of the subgroup of interest by the incidence rate of all other dogs. The R package "exactci" version 1.3.3 was used to generate confidence intervals based on the Poisson distribution, and the package "forestplot" version 1.10.1 to generate forest plots of breed risks (Fay, 2010; Gordon and Lumley, 2019). Bonferroni (BF) correction, based on the number of comparisons, was used to correct for multiple comparisons and p-values < 0.05 after correction were considered to indicate statistical significance.

A control group consisting of dogs without PL claims was generated to assess predisposition to other disorders in dogs with PL. Each dog with PL was matched to five controls based on age, insurance duration, and breed with the R function matchit() from the package "MatchIt" using nearest neighbour matching on propensity scores (Ho et al., 2011). All veterinary care claims were extracted for cases and controls, and the disorders were grouped based on the organ system according to the diagnostic registry (Svenska Djursjukhusföreningen, 1993). Prior and subsequent diagnoses (compared to the first PL claim and the date of matching in the controls) were compared using conditional logistic regression with the clogit() function from the "survival" package (Therneau, 2021). The PL diagnosis was set as the main exposure variable and the comorbidity as the outcome. In addition, other stifle joint disorders were divided into categories based on the diagnostic codes: CLR (information about cranial/caudal ligament rupture was unavailable), pain and/or clinical signs from the stifle joint or patella/fabellae without confirmed cause, degenerative changes, traumatic, arthritis, meniscal injury, fracture, osteochondrosis, inflammation in the patella/fabellae, and malformation/growth disorders (Engdahl et al., 2021). The occurrence of other stifle joint disorders was compared in cases and controls using conditional logistic regression as previously described.

3. Results

3.1. Study population

The study population included just over 600,000 dogs. Of these, 61.8 % had both veterinary care and life insurance, 35.4 % had only veterinary care insurance, and 2.7 % had only life insurance. The median age at enrolment in veterinary care insurance during the study period was 15.7 weeks (3.4 weeks–17.5 years). Additional descriptive features of the study population are presented in Table 1. In total, 649 dogs were excluded based on the exclusion criteria.

3.2. Patellar luxation

There were 2726 dogs with claims for PL and the incidence rate was 15.6 (95 % CI: 15.0–16.2) cases per 10,000 DYAR. The median number of veterinary care claims for PL in affected dogs was 2 (1−13), which approximately corresponds to the number of veterinary appointments related to the diagnosis. Medial patellar luxation was most common, affecting 2456 (90.1 %) of the dogs with PL, followed by LPL (162 dogs, 5.9 %), and BPL (65 dogs, 2.4 %). The direction of the luxation was unspecified in 43 (1.6 %) dogs. Females had an increased risk of PL compared to males (RR 1.2, 95 % CI: 1.1–1.3, $p < 0.001$).

In total, 1303 of the 2726 dogs (47.8%) with PL had prior veterinary claims for other diagnoses, and 1562 of the 2726 dogs (55.6 %) with PL had subsequent veterinary care claims for other diagnoses. The corresponding numbers in the control group were 3510/13,630 (25.8 %) and 4710/13,630 (34.6 %) (Table 2). Gastrointestinal and musculoskeletal disorders were the most common disorders in dogs with PL, while gastrointestinal and dermatologic disorders were the most common in the control dogs. Dogs with PL had higher odds of prior and subsequent diagnoses in all organ systems except for the endocrine and hematopoietic, compared to the controls ($p < 0.05$ after Bonferroni correction).

Of the dogs with PL, 332 (12.2 %) had veterinary care claims for other stifle joint diagnoses, of which the most common diagnosis was CLR, affecting 168 (6.2 %) dogs (Table 3). For comparison, 165 (1.2 %) dogs in the control group had veterinary care claims for stifle joint diagnoses, of which CLR was the most common affecting 91 dogs (0.67 %). In dogs with PL and CLR, 52 (31.0 %) had their first claim for CLR before their first claim for PL, with a median time between the claims of 0.3 years (6 days–3.8 years), 89 (53.0 %) dogs had their first claim for CLR after their first claim for PL, with a median time between the claims of 0.45 years (2 days–5.8 years), and 27 (16.1 %) dogs had their first claims for CLR and PL on the same date.

Table 1
Descriptive features of dogs insured in Agria Pet Insurance Sweden during 2011–2016.

	Veterinary care insurance	Life insurance
The total duration of insurance (years)	> 1.7 million	> 1.1 million
Insurance duration, median (range)*	2.7 y (9.2 w–6.0 y)	2.51 y (9.2 w–6.0 y)
Sex (%)		
Female	49.1 %	49.5 %
Male	50.9 %	50.5 %
Number of dogs with claims for PL	2726	116
Medial	2456 (90.1 %)	95 (81.9 %)
Lateral	162 (5.9 %)	17 (14.7 %)
Bidirectional	65 (2.4 %)	-
Unspecified	43 (1.6 %)	4 (3.5 %)
Age at PL claim, median (range)**	2.8 y (8.7 w–16.2 y)	2.2 y (11.9 w–11.7 y)

PL: patellar luxation, *w:* weeks, *y:* years.
* Per dog, during 2011–2016
** Age at first PL claim during the study period, for the veterinary care claims

3.3. Medial patellar luxation

There were 2456 dogs from 134 breeds with veterinary care claims for MPL, and the incidence rate was 14.0 (95 % CI: 13.5–14.6) cases per 10,000 DYAR. Eighteen breeds had an increased risk of MPL and 21 breeds had a decreased risk, after BF correction (Fig. 1). The risk of MLP was higher in females than in males (RR 1.2, 95 % CI: 1.1–1.3, $p < 0.001$).

The median age at MPL diagnosis during the study period was 2.8 years (8.7 weeks–16.2 years) and did not vary in females and males (median 2.9 and 2.8 years, respectively, $p = 0.915$). The breeds that were younger or older than all other breeds at MPL diagnosis are presented in Table 4. In the subpopulation of dogs with MPL enroled in insurance during the study period before six months of age ($n = 1124$), the age at MPL diagnosis was 1.7 years (8.7 weeks–5.9 years).

3.4. Lateral patellar luxation

There were 162 dogs from 55 breeds with veterinary care claims for LPL, and the incidence rate was 0.92 (95 % CI: 0.79–1.1) cases per 10,000 DYAR. Fourteen breeds had an increased risk of LPL and two breeds had a decreased risk (Fig. 2). Females had a decreased risk of LPL compared to males (RR 0.72, 95 % CI: 0.51–1.0, $p = 0.042$).

The median age at LPL diagnosis during the study period was 2.7 years (13.3 weeks–14.0 years) and did not vary in females and males (median 2.2 and 3.2 years, respectively, $p = 0.186$). The breeds that were younger or older than all other breeds at LPL diagnosis are presented in Table 4. In the subpopulation of dogs with LPL enroled in insurance during the study period before six months of age ($n = 75$), the age at LPL diagnosis was 1.2 years (13.3 weeks–5.6 years).

3.5. Bidirectional patellar luxation

There were 65 dogs from 37 breeds that had claims for both medial and lateral PL (BPL) and the incidence rate was 0.37 (95 % CI: 0.29–0.47) cases per 10,000 DYAR. Seven breeds had a significantly increased risk of BPL, and the mixed breed had a decreased risk (Fig. 3). There was no difference in the risk of BPL in females compared to males ($p = 0.359$).

The median age at first PL diagnosis in dogs with BPL was 1.5 years (14.4 weeks–10.0 years) and did not vary significantly in females and males (median 1.8 and 1.2 years, respectively, $p = 0.238$) or in different breeds ($p > 0.05$). In the subpopulation of dogs with BPL enroled in insurance during the study period before six months of age ($n = 39$), the median age at first PL diagnosis was 1.0 years (13.3 weeks–4.9 years).

3.6. Euthanasia due to patellar luxation

There were 116 dogs of 53 breeds with life insurance settlement due to PL and the cause-specific mortality rate was 1.0 (95 % CI: 0.87–1.3) cases per 10,000 DYAR. Of the 2726 dogs with veterinary care claims for PL, 2001 (73.4 %) had life insurance, and 187 (9.4 %) of these dogs had life insurance settlements during the study period of which 61 (32.6 %) were due to PL. Thus, 61/116 (52.6 %) of the dogs euthanised because of PL had prior veterinary care claims for PL. The median time from the first PL claim to PL-related euthanasia was 6.1 weeks (0 days–4.1 years). There was no significant difference in the risk of PL-related euthanasia in females and males ($p = 0.171$). Twelve breeds had an increased risk of PL-related euthanasia, while the mixed breed and Labrador retriever had a decreased risk (Fig. 4).

The median age at PL-related euthanasia was 2.2 years (11.9 weeks–11.7 years), and dogs euthanised due to PL were significantly younger than dogs euthanised for other reasons (median age 7.5 years, $p < 0.001$). The Pyrenean mountain dog and mixed breeds were younger at PL-related euthanasia than all other breeds, with a median age of 0.40 (0.40–0.40) and 0.85 (0.23–3.77) years, respectively. The

Table 2
Prior and subsequent veterinary care claims* by organ system in dogs with patellar luxation (n = 2726) and control dogs without veterinary care claims for patellar luxation (n = 13,630) matched on age, breed, and duration of the veterinary care insurance in a cohort of dogs insured by Agria Pet Insurance Sweden (2011–2016).

	Prior diagnoses				Subsequent diagnoses			
Organ system	Cases (%)	Controls (%)	Odds ratio	p-value**	Cases (%)	Controls (%)	Odds ratio	p-value**
Cardiovascular	38 (1.4)	66 (0.5)	2.9 (2.0–4.4)	< 0.001	78 (2.9)	202 (1.5)	2.0 (1.5–2.6)	< 0.001
Endocrine	10 (0.4)	37 (0.3)	1.4 (0.7–2.7)	0.396	28 (1.3)	85 (0.6)	1.7 (1.1–2.5)	0.022
Gastrointestinal	559 (20.5)	1341 (9.8)	2.4 (2.2–2.7)	< 0.001	566 (20.8)	1863 (13.7)	1.7 (1.5–1.9)	< 0.001
Hematopoietic	15 (0.6)	37 (0.3)	2.0 (1.1–3.7)	0.021	30 (1.1)	102 (0.7)	1.5 (1.0–2.2)	0.062
Hepatic	39 (1.4)	58 (0.4)	3.4 (2.3–5.1)	< 0.001	72 (2.6)	165 (1.2)	2.2 (1.7–2.9)	< 0.001
Integumentary	399 (14.6)	1157 (8.5)	1.9 (1.7–2.1)	< 0.001	504 (18.5)	1608 (11.8)	1.7 (1.5–1.9)	< 0.001
Musculoskeletal	493 (18.1)	667 (4.9)	4.3 (3.8–4.8)	< 0.001	602 (22.1)	950 (7.0)	3.8 (3.4–4.2)	< 0.001
Neurologic	54 (2.0)	127 (0.9)	2.2 (1.6–3.0)	< 0.001	96 (3.5)	286 (2.1)	1.7 (1.4–2.2)	< 0.001
Ophthalmic	173 (6.3)	480 (3.5)	1.9 (1.6–2.2)	< 0.001	183 (6.7)	564 (4.1)	1.7 (1.4–2.0)	< 0.001
Other (general/unspecific)	289 (10.6)	687 (5.0)	2.2 (1.9–2.6)	< 0.001	418 (15.3)	1121 (8.2)	2.0 (1.8–2.3)	< 0.001
Respiratory	138 (5.1)	265 (1.9)	2.7 (2.2–3.3)	< 0.001	161 (5.9)	433 (3.2)	1.9 (1.6–2.3)	< 0.001
Urogenital	193 (7.1)	540 (4.0)	1.8 (1.6–2.2)	< 0.001	273 (10.0)	914 (6.7)	1.6 (1.4–1.8)	< 0.001
All diagnoses combined	1303 (47.8)	3510 (25.8)	2.7 (2.5–2.9)	< 0.001	1562 (55.6)	4710 (34.6)	2.4 (2.2–2.7)	< 0.001

* Relative to the first veterinary care claim for PL during the study period, or the date of matching for the controls.
** Significance level 0.05/13 (number of comparisons of prior and subsequent diagnoses) = 0.004

Table 3
Insurance claims for stifle joint disorders (SJD) in 2726 dogs with patellar luxation (PL) and 13,630 control dogs matched on breed, age, and insurance duration, in a population of dogs insured by Agria Pet Insurance Sweden (2011–2016).

	SJD claims before PL* (%)	SJD claims after PL* (%)	All SJD claims in cases** (%)	All SJD claims in controls (%)	Odds ratio	p-value ***
Arthritis	< 5 (< 0.18)	22 (0.81)	27 (0.99)	15 (0.11)	9.0 (4.8–16.9)	< 0.001
CLR	52 (1.9)	110 (4.04)	168 (6.2)	91 (0.67)	9.8 (7.5–12.7)	< 0.001
Degenerative	7 (0.26)	26 (10.95)	37 (1.4)	18 (0.13)	10.3 (5.9–10.1)	< 0.001
Fracture	< 5 (< 0.18)	5 (0.18)	5 (0.18)	< 5 (< 0.04)	25.0 (2.9–214.0)	0.003
Inflammation PF	-	< 5 (< 0.18)	< 5 (< 0.18)	-	-	-
Malformation or growth disorder	-	< 5 (< 0.18)	< 5 (< 0.18)	-	-	-
Meniscal injury	< 5 (< 0.18)	< 5 (< 0.18)	6 (0.22)	6 (0.04)	5.0 (1.6–15.5)	0.005
OC	< 5 (< 0.18)	-	< 5 (< 0.18)	-	-	-
Pain/signs PF	8 (0.29)	< 5 (< 0.18)	13 (0.48)	< 5 (< 0.04)	21.7 (6.2–76.0)	< 0.001
Pain/signs SJ	43 (1.6)	50 (1.83)	106 (3.9)	49 (0.36)	10.8 (7.7–15.2)	< 0.001
Traumatic	16 (0.59)	12 (0.44)	35 (1.3)	7 (0.05)	25.0 (11.1–56.3)	< 0.001

CLR: cruciate ligament rupture, *Degenerative:* degenerative changes, *OC:* osteochondrosis, *PF:* patella/fabellae, *Pain/signs, PF:* pain and/or clinical signs from patella or the fabellae without confirmed cause, *Pain/signs SJ:* pain and/or clinical signs from the stifle joint without confirmed cause
* Diagnoses before and after the first claim for patellar luxation.
** Diagnoses before, after, and on the same date as the first claim for PL combined
*** Significance level 0.05/8 (number of comparisons) = 0.0063

Yorkshire terrier and the Bichon Havanais were older than other breeds at PL-related euthanasia, with a median age of 8.1 (6.5–9.3) and 10.4 (10.0–11.4) years, respectively. However, none of the breeds had an age at PL-related euthanasia that differed from all other breeds after BF correction based on the number of comparisons (n = 53).

4. Discussion

The current study is an epidemiologic overview of PL in insured dogs in Sweden and reports substantial breed-specific differences in the risk of PL. The risk of PL in breeds was evaluated for MPL, LPL, and BPL separately, which differentiates from most of the earlier epidemiologic studies that do not provide separate analyses for MPL/LPL/BPL (Priester, 1972; LaFond et al., 2002; O'Neill et al., 2016; Wiles et al., 2017). The breeds at highest risk of MPL were the Pomeranian, Prazsky krysarik, and Boston terrier, the breeds at highest risk of LPL were the Clumber spaniel, Irish wolfhound, and Coton de Tulear, and the breeds at highest risk of BPL were the Miniature bull terrier, Finnish Lapponian dog, and Coton de Tulear. Cruciate ligament rupture was the most common stifle joint comorbidity in dogs with PL, affecting 6.2 %. The median age for PL-related euthanasia was 2.2 years, and the Pyrenean mountain dog had the highest risk of PL-related euthanasia.

A size difference in breeds at high risk of MPL and LPL was observed. Almost all breeds with an increased risk of MPL were of small or medium size; the expected bodyweight of 13/18 (72.2 %) high-risk breeds was under 10 kg and ranged over 15 kg only in 2/18 (11.1 %) breeds (American Kennel Club, 2022; Swedish Kennel Club, 2022). Several high-risk breeds, such as the Pomeranian, Boston terrier, Chihuahua, and Yorkshire terrier, are reported as high-risk breeds in previous studies (LaFond et al., 2002; O'Neill et al., 2016), and vice versa for some of the low-risk breeds, such as the Dachshund, Rough collie, Golden retriever, Rottweiler, German pointing dog, and Labrador retriever (Priester, 1972; Hayes et al., 1994; Wiles et al., 2017). A clear majority (13/18, 72.2 %) of the high-risk breeds belonged to breed group nine (companion and toy dogs).

The size of the breeds at high risk of LPL differed, as the expected bodyweight was under 10 kg only for 4/16 (25.0 %) breeds and ≥ 15 kg in 7/16 (43.8 %) breeds (American Kennel Club, 2022; Swedish Kennel Club, 2022). This supports the theory that the risk of LPL increases with breed size (Hayes et al., 1994; Alam et al., 2007; Bound et al., 2009). Breed group nine was the most common breed group among the high-risk breeds, followed by breed group eight (retrievers – flushing dogs – water dogs). The French bulldog, Bichon frise, and the Miniature and Toy poodles had increased risk of both MPL and LPL.

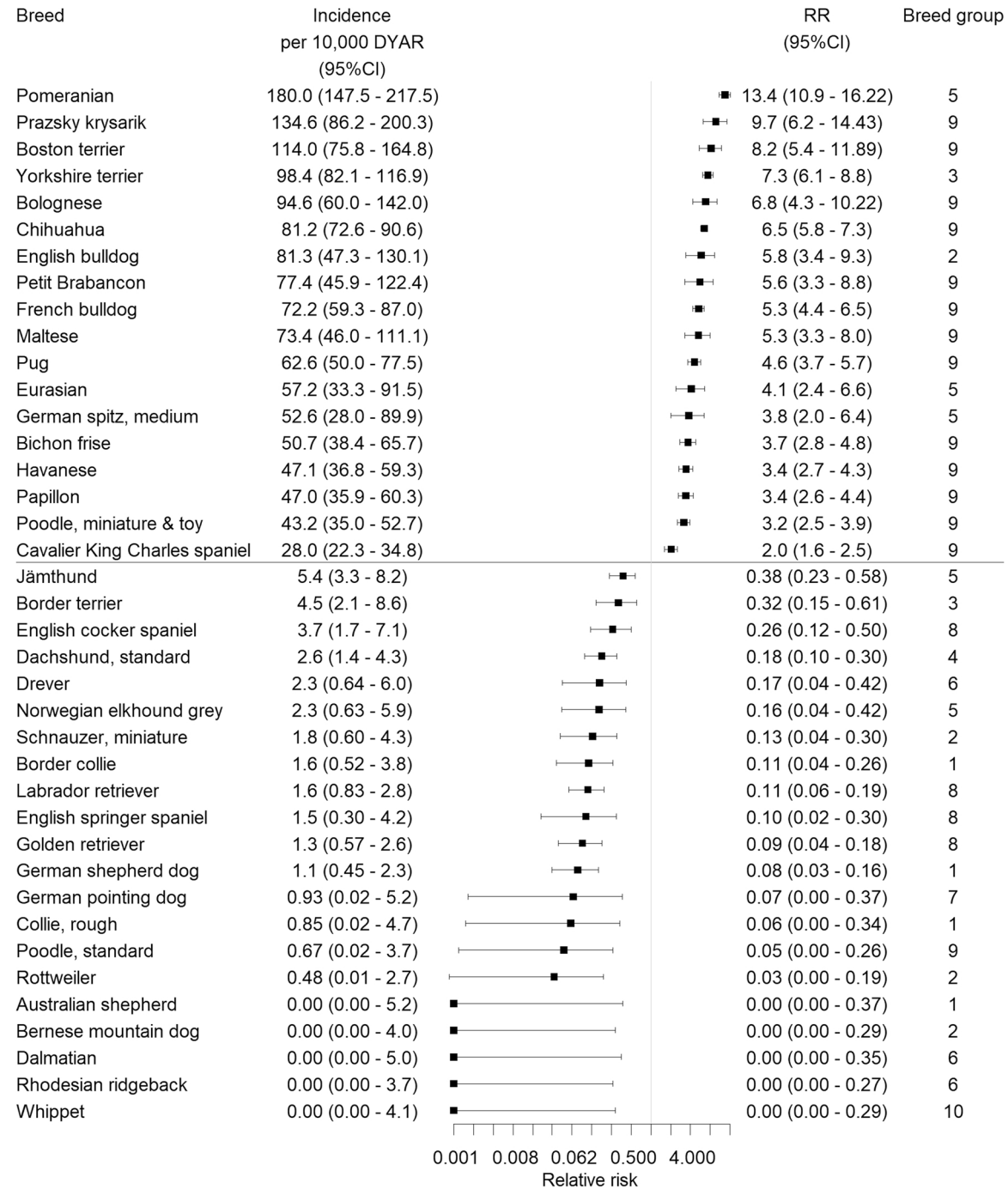

Fig. 1. Breeds with significantly increased and decreased risk of medial patellar luxation after Bonferroni correction based on the number of comparisons (n = 339), in dogs insured by Agria Pet Insurance Sweden (2011–2016). A fudge factor of 0.01 was added to the RR of the breeds with a RR of zero, to present the RRs on a log scale. Breed groups: 1. Sheepdogs and cattledogs (except Swiss cattledogs) 2. Pinscher and Schnauzer – molossoid and Swiss mountain and cattledogs 3. Terriers 4. Dachshunds 5. Spitz and primitive types 6. Scent hounds and related breeds 7. Pointing dogs 8. Retrievers – flushing dogs – water dogs 9. Companion and toy dogs 10. Sighthounds. *CI:* confidence interval, *DYAR:* dog-years at risk, *RR:* relative risk.

Several breeds, such as the Miniature bull terrier, Finnish Lapponian dog, and Coton de Tulear, had an increased risk of BPL. This could either mean that they were affected by unilateral/bilateral BPL, or that they were affected by MPL on one hindlimb and LPL on the other. Patella alta (or high-riding patella) has been described as a risk factor for BPL (affecting one stifle), as the decreased support from the lateral and medial trochlear ridges could predispose to luxation (Wangdee et al., 2015). An increased ratio between the length of the patellar ligament and the patellar bone length indicates patella alta. However, the ratio did not differ significantly in Pomeranians with and without BPL in a previous study (Wangdee et al., 2015). Instead, a functional patella alta caused by stifle hyperextension was suggested to cause BPL. If functional patella alta explains why some breeds only develop MPL or LPL while others develop BPL is not known, and further studies are warranted.

The risk of MPL and LPL varied with sex. The pathogenesis for this association is unknown, although it has been proposed that hormones may impact the growth rate and musculoskeletal development (O'Neill et al., 2016). Females had an increased risk of PL overall compared to males, which concords with previous research (Priester, 1972; Hayes et al., 1994; O'Neill et al., 2016). A similar result was seen for MPL (RR

Table 4
Age at diagnosis of medial or lateral patellar luxation during the study period in breeds with an age at diagnosis that differed significantly from all other breeds*, in dogs insured by Agria Pet Insurance Sweden (2011–2016).

	Medial patellar luxation		Lateral patellar luxation	
	Breed	Age at diagnosis (years)	Breed	Age at diagnosis (years)
Breeds younger at diagnosis	Eurasian dog	0.90 (0.59–4.64)	Irish wolfhound	0.3 (0.25–0.57)
	French bulldog	2.1 (0.40–7.1)	Labrador retriever	0.4 (0.32–0.46)
			Newfoundland	0.4 (0.41–0.43)
			Flat coated retriever	1.3 (0.35–3.7)
Breeds older at diagnosis	Bichon frise	4.7 (0.36–15.3)	Miniature & Toy poodle	8.4 (1.5–11.2)
	Jack Russell terrier	4.7 (0.80–14.4)	Chihuahua	9.4 (4.2–10.7)
	Yorkshire terrier	5.3 (0.57–13.4)		
	Cairn terrier	7.6 (0.78–12.8)		

* after Bonferroni correction based on the number of comparisons (n = 134) for medial patellar luxation, but not for lateral patellar luxation as there were no breeds with age that differed significantly from all other breeds after Bonferroni correction based on the number of comparisons (n = 55).

1.20, $p < 0.001$). However, females had a decreased risk of LPL compared to males (RR 0.72, $p < 0.042$). Gibbons et al. (2006) suggested that patellar luxation might be more common in male large-breed dogs and female small-breed dogs. This theory could explain our findings, as a higher proportion of the breeds with increased risk of LPL were large and vice versa. However, it should be noted that the suggestion from Gibbons et al. (2006) was based on the sex distribution (male:female ratio of 1.8:1) in large dogs with PL compared to the sex distribution in studies of small dogs with PL, without comparison to a control group (Gibbons et al., 2006).

The median age at diagnosis of MPL (2.8 years) and LPL (2.7 years) during the study period was relatively high, given that the disease often develops during the growth period. It might be that subtle clinical signs of PL debuted earlier and that PL was diagnosed later when the hindlimb lameness had become more prominent. However, the median age at MPL and LPL diagnosis in dogs first insured at under 6 months of age during the study period was 1.4 and 1.2 years, respectively. Thus, the median age at diagnosis of MPL and LPL is likely between 1.4–2.8 and 1.2–2.7 years. The median age at first PL diagnosis in dogs with BPL (1.51 years for all dogs, 1.0 years for dogs in the subgroup) was lower. The grade of luxation (and the associated clinical signs) is a potential confounder for the observed low age at diagnosis in dogs with BPL, as an association between younger age at presentation and higher grade of luxation has been shown in a previous study of LPL (Kalff et al., 2014). The age at first MPL/LPL diagnosis varied with the breed; all breeds diagnosed at a younger age were large-sized (except for the French bulldog), while all breeds diagnosed at a higher age were small, in concordance with an earlier study (Hayes et al., 1994). Larger breeds might develop more pronounced clinical signs at an early age e.g., due to a more severe grade of PL or weight-related stress and rapid disease progression resulting in an earlier diagnosis, while smaller breeds might be diagnosed later e.g., due to less severe grades, slower disease-progression, or being less affected overall by the PL that only is registered as a clinical finding when the dog is brought to the veterinarian for another reason. It might also be easier for the owners to detect lameness in large breeds compared to small breeds. The degree of PL is thus a potential confounder for the association between breed and age at diagnosis, which could not be evaluated since there was no information about luxation grade in the available database.

Dogs with PL had significantly higher odds of prior and subsequent cardiovascular, gastrointestinal, hepatic, integumentary, musculoskeletal, neurologic, ophthalmic, respiratory, urogenital, and other/unspecific diagnoses, with highest odds for other musculoskeletal diagnoses, compared to the control group. It could be that dogs with PL were affected by higher morbidity in general, that PL may be noted at clinical examination and registered as an incidental finding in dogs that are evaluated for another disease, or that some owners are more likely to

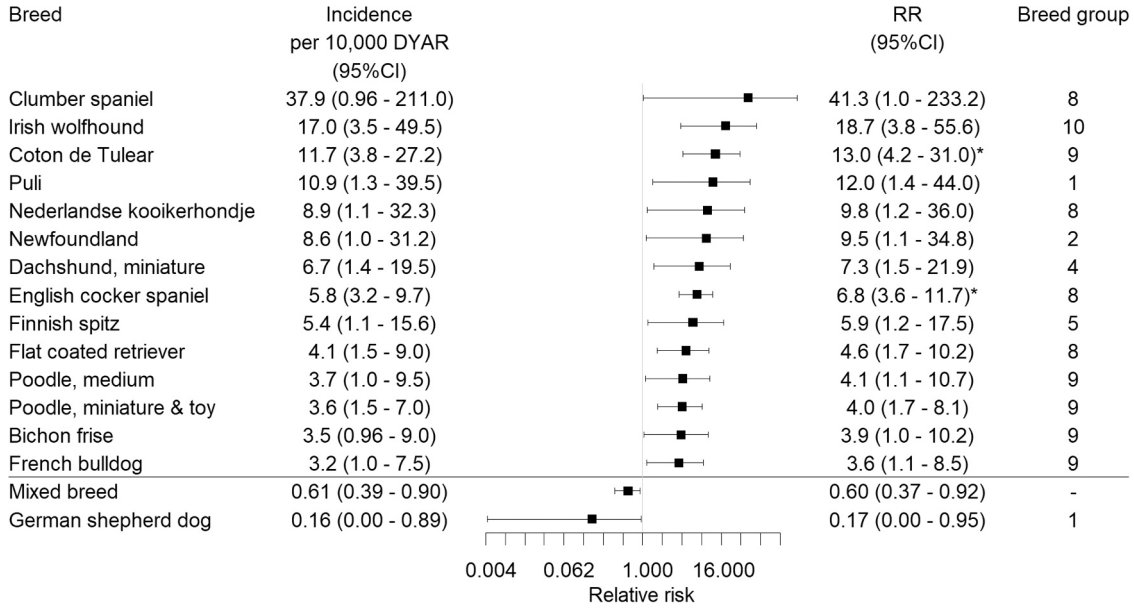

Fig. 2. Breeds with significantly increased and decreased risk of lateral patellar luxation, in dogs insured by Agria Pet Insurance Sweden (2011–2016). *The English cocker spaniel and the Coton de Tulear were the only breeds with significantly increased risk after Bonferroni correction based on the number of comparisons (n = 339). Breed groups: 1. Sheepdogs and cattledogs (except Swiss cattledogs) 2. Pinscher and Schnauzer – molossoid and Swiss mountain and cattledogs 4. Dachshunds 5. Spitz and primitive types 8. Retrievers – flushing dogs – water dogs 9. Companion and toy dogs. CI: confidence interval, DYAR: dog-years at risk, RR: relative risk.

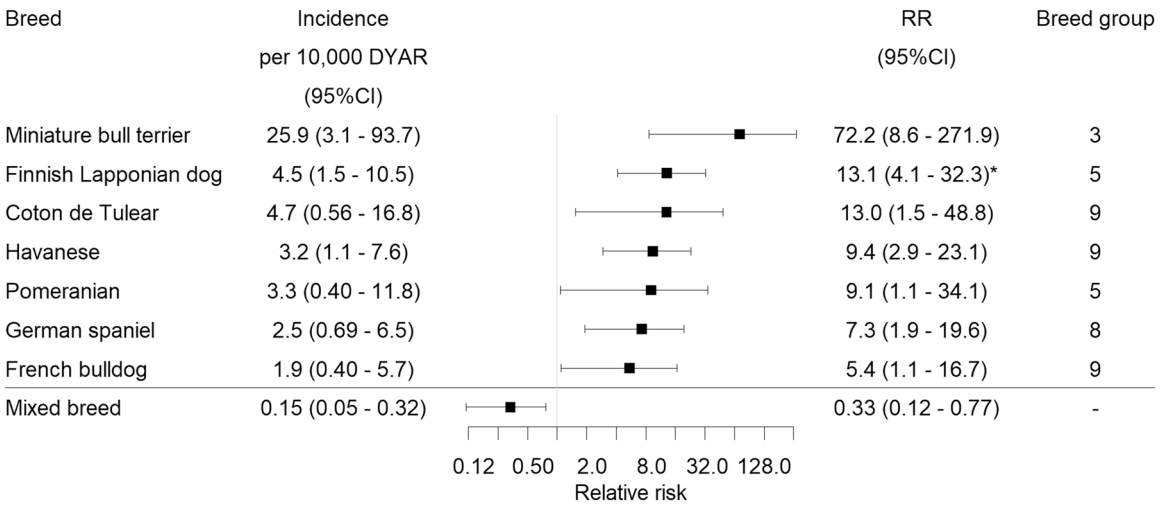

Fig. 3. Breeds with significantly increased and decreased risk of bidirectional patellar luxation, in dogs insured by Agria Pet Insurance Sweden (2011–2016). *The Finnish Lapponian dog was the only breed with significantly increased risk after the Bonferroni correction based on the number of comparisons (n = 339). Breed groups: 3. Terriers 5. Spitz and primitive types 8. Retrievers – flushing dogs – water dogs 9. Companion and toy dogs. CI: confidence interval, DYAR: dog-years at risk, RR: relative risk.

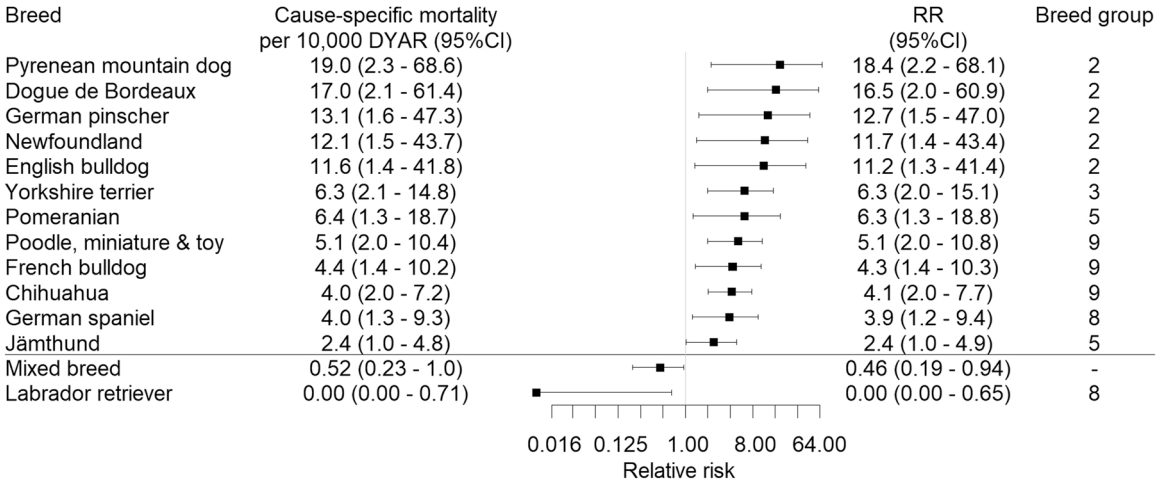

Fig. 4. Breeds with significantly increased and decreased risk of euthanasia due to patellar luxation, in dogs insured by Agria Pet Insurance Sweden (2011–2016). No breed had a relative risk significantly different from one after the Bonferroni correction based on the number of comparisons (n = 335). *DYAR:* dog-years at risk, *CI:* confidence interval, *RR:* relative risk. Breed groups: 2. Pinscher and Schnauzer – molossoid and Swiss mountain and cattledogs 3. Terriers 5. Spitz and primitive types 8. Retrievers – flushing dogs – water dogs 9. Companion and toy dogs.

bring their dogs to a veterinarian than others are. Follow-up re-checks after PL diagnosis may also have increased the probability of registration of subsequent diagnoses in dogs with PL.

Cruciate ligament rupture was the most common stifle joint comorbidity in dogs with PL, affecting just over 6 %. The two conditions have been described to co-occur, and the reported prevalence of CLR in dogs with PL varies between 13.3 % and 41.5 % (Gibbons et al., 2006; Campbell et al., 2010; Brower et al., 2017; Candela Andrade et al., 2020). Referral bias with more complicated cases likely contributed to the higher prevalence in some of these studies. Further, the study by Gibbons et al. (2006) only included large-breed dogs, and it might be that the prevalence of CLR in dogs with PL is higher in larger dogs. In the study by Candela Andrade et al. (2020), concurrent CLR was evaluated during surgical treatment of PL, which also might have contributed to the higher prevalence than in the current study. In the current study, 1.91 % of the dogs with PL had a CLR claim before the first PL claim, while 3.26 % had a CLR claim after the first PL claim. This correlates with the general observation that dogs are older when they are diagnosed with CLR than with PL (Remedios et al., 1992; Whitehair et al., 1993; Hayes et al., 1994; Necas et al., 2000; Gibbons et al., 2006; Adams et al., 2011; Kalff et al., 2014; Taylor-Brown et al., 2015; O'Neill et al., 2016). It has been suggested that stifle joint instability caused by cranial CLR could result in PL and that PL could increase the risk of cranial CLR by causing stifle joint instability and abnormal stress on the cranial cruciate ligament (Candela Andrade et al., 2022). Additionally, PL is a potential complication after CLR surgery (Arthurs and Langley-Hobbs, 2007). The causal association between PL and CLR should be evaluated in prospective studies.

The top five breeds with the highest risk of PL-related euthanasia (Pyrenean mountain dog, Dogue de Bordeaux, Pinscher, Newfoundland, and English bulldog) were all large- or medium-sized, which indicated that the severity of the clinical signs increased with increasing size of the dog. However, there are other possible reasons for PL-related euthanasia, such as restricted economy precluding surgical intervention, postoperative complications after PL surgery, laborious postoperative rehabilitation period in a heavy dog with difficulties walking, or a perceived guarded prognosis for a working dog. The last alternative might have been the case for the Jämthund, a breed commonly used for

hunting in Sweden, which had a decreased risk of MPL but an increased risk of PL-related euthanasia.

Some limitations should be mentioned. The incidence of PL was based on diagnoses recorded by clinicians, and the insurance claims were registered if their associated costs exceeded the insurance deductible. The accuracy of the diagnostic codes relied on the examining veterinarians, and some cases of PL might have been reported under less specific diagnostic codes such as "Lameness without further specification". Thus, the true incidence of PL is likely higher. The reported incidence probably reflects PL causing clinical signs, which is acknowledged as a limitation, even though we believe these cases of PL are most relevant from a clinical perspective. Further, insurance claims for PL were only reimbursed in dogs enroled in insurance before four months of age, so there is a risk that PL in dogs insured at a higher age was missed. However, claims for stifle joint problems in these dogs were reimbursed with a maximum of 3000 Swedish kronor until PL was confirmed, which increases the chance that these cases also were included.

It should also be noted that the data used in this study were from 2011 to 2016. There might be time trends in the incidence of PL related to factors such as breed popularity, which were not captured in this study. Further, a screening programme for PL is available at the Swedish Kennel Club, and for some breeds screening for PL in breeding animals is required in order to register the puppies in the kennel club (Swedish Kennel Club, 2023). The screening program might have affected the incidence of PL in some breeds, both during and after the study period.

The morbidity and mortality of insured dogs cannot be assumed to reflect the morbidity and mortality of uninsured dogs (Egenvall et al., 2009). For example, increased odds of PL have been reported in insured dogs in the UK (O'Neill et al., 2016). However, around 90 % of Swedish dogs are insured (Agria Pet Insurance Sweden, 2017), so the results should be generalisable to the Swedish dog population and insured dog populations in other countries. The data lacked information about unilateral/bilateral disease, body weight, and neuter status. Increased odds of PL have been reported in dogs with a bodyweight lower than the mean bodyweight of the breed and in neutered dogs, but these associations could not be evaluated in the current study (O'Neill et al., 2016). Finally, dogs were classified as euthanised of PL-related causes if a PL diagnosis was assigned to the life insurance claim, even though comorbidities might have contributed to the decision of euthanasia.

5. Conclusion

Patellar luxation affected 2726 of the dogs in the study population, and MPL was most common (90.1 %), followed by LPL (5.9 %), BPL (2.4 %), and unspecified luxation (1.6 %). Females had an increased risk of MPL (RR 1.2) and a decreased risk of LPL (RR 0.72) compared to males. Medial patellar luxation mainly affected small-sized breeds, while LPL affected medium- and large-sized breeds to a greater extent. Several breeds had an increased risk of PL-related euthanasia, of which the top five breeds were medium- or large-sized. Demographic factors associated with PL can guide veterinarians in their clinical work, inform breeders and dog owners about breeds at increased risk of disease, and highlight important risk factors for disease development that can guide future studies on the aetiopathogenesis of PL.

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.2023.106034.

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