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Lumbosacral transitional vertebra in 14 dog breeds in Norway: Occurrence, risk factors and association with hip dysplasia

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ABSTRACT

A lumbosacral transitional vertebra (LTV) is a congenital anomaly of the spine and has been suggested to predispose to canine hip dysplasia (CHD). This retrospective, cross-sectional study investigated the prevalence of LTV and CHD among 14 dog breeds in Norway, the possible associations with risk factors, and whether LTV was a risk factor for the development of hip dysplasia. The results were based on evaluation of ventrodorsal radiographs from the CHD screening program from the Norwegian Kennel Club from February 2014 to January 2022. A total of 13,950 dogs were included in the study. For statistical analysis, CHD grades were reclassified from the official Federation Cynologique Internationale (FCI) grades into three grades: CHD free (CHD=A, B), CHD mild (CHD=C), and CHD severe (CHD=D, E). In the study sample, the overall occurrence of LTV was 18.5%, of which 32.9% were type 1, 45.7% type 2% and 21.4% type 3. The occurrence of LTV varied significantly among the included breeds, ranging from 9.5% to 46.2%. There was no association between sex and LTV. The frequencies of CHD grades were A: 43.1%; B: 31.4%; C: 18.4%; D: 6.0%; E: 1.1%. There was a statistically significant association with mild and severe CHD in dogs with LTV type 2 and LTV type 3 ($P < 0.001$). In the population studied, the prevalence of LTV was different among breeds. This supports initial data on the heredity of LTV and the diverse occurrence of LTV among breeds. Our results indicate that LTV type 2 and type 3 are associated with mild and severe CHD development. Therefore, this study has potentially identified an additional risk factor for the development of hip dysplasia.

Introduction

Congenital pathologies of the vertebral column are common in certain dog breeds (Morgan, 1968). The appropriate terminology and classification of vertebral malformations is not without controversy. However, congenital spinal anomalies are typically grouped based on either their original developmental stage or the anatomical region/structure involved. Nonetheless, due to the complexity of many malformations, assigning a single category can often be challenging (Westworth and Sturges, 2010). One of the most frequent congenital anomalies of the vertebral column is transitional vertebrae (Morgan, 1968). The cause of a transitional vertebra is unknown, but the anomaly can occur during both embryogenesis and the foetal period, depending on the actual anomaly (Westworth and Sturges, 2010).

A lumbosacral transitional vertebra (LTV) can be described as an abnormal vertebra between the last normal lumbar vertebra and the first normal sacral vertebra and is often separated with a disc space (Morgan, 1968; Morgan, 1999). Morphologically, LTV can vary widely and may have characteristics of both lumbar and sacral vertebrae (Morgan, 1968; Larsen, 1977; Winkler and Loeffler, 1986; Damur-Djuric et al., 2006).

The occurrence of LTV in dogs varies and is reported to be as high as 67% depending on breed, classification system, diagnostic modality, and geographical area. Most studies do not report any sex predisposition (Larsen, 1977; Winkler and Loeffler, 1986; Morgan, 1999; Damur-Djuric et al., 2006; Ledecký et al., 2007; Wigger et al., 2009; Lappalainen et al., 2012; Fialová et al., 2014; Kuricová et al., 2018; Gong et al., 2020), although two papers report a higher prevalence in females (Winkler and Loeffler, 1986; Gluding et al., 2021).

The clinical implication of LTV in dogs was initially thought to be negliable (Morgan, 1968), although an association with hip dysplasia

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has been suspected (Larsen, 1977). Hip dysplasia is an inherited developmental orthopaedic disease in dogs, where the primary cause is excessive joint laxity (Flückiger, 2007), and genetic studies have reported a heritability of 0.2–0.7 (Hedhammar et al., 1979; Lingaas and Klemetsdal, 1990; Breur et al., 2012). Nevertheless, investigations performed so far have not identified a substantial association between LTV and hip dysplasia in dogs (Citi et al., 2005; Ledecký et al., 2007; Wigger et al., 2009; Komsta et al., 2015; Kuricová et al., 2018). Some forms of LTV might cause pelvis rotation over its longitudinal axis. This rotation has been observed more frequently with asymmetric hip scores (Morgan, 1999). A recent publication reported that distinct asymmetric LTV in dogs might predispose to developing asymmetric hip joints (Flückiger et al., 2017).

Furthermore, based on several studies in German shepherd dogs, LTV has been considered a predisposing factor for developing cauda equina syndrome (CES) through potentially altered biomechanics in the lumbosacral junction (Morgan et al., 1993; Fluckiger et al., 2006).

Both hip dysplasia and CES are common reasons for veterinary visits in dogs and can cause chronic pain, which might affect quality of life and be responsible for altered behaviour (Moore et al., 2001; Lindley, 2012; Belshaw and Yeates, 2018; Worth et al., 2019). Additionally, a recent paper reported that LTV significantly contributed to the risk of developing injuries among dogs performing agility (Inkilä et al., 2022). Hence, canine LTV could result in both immediate and prolonged discomfort and health issues, thereby diminishing overall animal welfare. Also, caring for dogs with chronic illnesses might cause emotional and financial distress for the owner and even reduce the owner's own activity level (Christiansen et al., 2013; Belshaw et al., 2020).

This study investigated the occurrence and potential risk factors for LTV among 14 dog breeds in Norway, and whether LTV predisposes to hip dysplasia, hypothesising that LTV increases the risk of hip dysplasia.

Materials and methods

Study sample

This retrospective, cross-sectional study was based on the evaluation of ventrodorsal (VD) radiographs from the Norwegian Kennel Club (NKK) database as part of the official radiographic screening program for canine hip dysplasia (CHD) in Norway. Radiographic records from February 2014 to January 2022 were used, this period was chosen because radiographs were most likely available as digital pictures for a thorough classification of LTV.

Breeds for the study were selected based on predefined criteria. A subgroup consisted of breeds with an a priori suspicion of a high occurrence of LTV, as NKK official radiologists had started to notify owners of a dog with an obvious distorted LTV when reporting results of hip dysplasia screening (Norwegian elkhound black, Brittany, Rough collie, Boxer, Rhodesian ridgeback, Eurasier and Portuguese water dog). The Norwegian elkhound grey was selected for comparison with the closely related Norwegian elkhound black. The four gundog breeds, Brittany, English setter, Gordon setter and Irish setter, were selected for interbreed comparison, as they are used for the same type of hunting in Norway. The German shepherd dog was chosen because of its high reported occurrence of LTV internationally. The Danish-Swedish farm dog and Bernese mountain dog were selected as variable-sized family pet dogs, with a minimum of 300 registered dogs in the database.

The inclusion criteria were dogs with an official identity number, complete records, including date of birth, sex, radiology date and official radiological CHD grade. Due to the official criteria for CHD grading, all dogs included were at least 12 months old at the time of radiography.

This study was conducted using pre-existing radiographic sources from a voluntary hip dysplasia screening program. Thus, no animals were included specifically for the purpose of this study.

Classification of LTV and hip dysplasia

LTV was classified, according to Flückiger et al. (2009), into three types. LTV type 1 is characterised by an independent spinosus process of the first sacral vertebra, which is separated from the medial sacral crest, LTV type 2 is a symmetrical form of a transitional vertebra, separated from the sacrum with an intervertebral space, and LTV type 3 is characterised by its asymmetrical morphology. LTV 0 designates a dog with normal lumbosacral anatomy radiologically. Radiographs were excluded if the penis bone or dense rectal fecal masses obscured relevant anatomy or if there was no reference point of a normal last lumbar vertebra. Two authors (JAB and CT) evaluated the radiographs and assessed the morphology of the lumbosacral spine for the classification of LTV individually, and consensus was reached on cases that diverged.

The official hip joint status was based on the classification of Federation Cynologique Internationale (FCI). The FCI classification is a five-grade scoring system from A, reflecting a normal hip joint, to E, indicating severe hip dysplasia. Grades are defined descriptively based on Norberg angle, degree of subluxation, shape and depth of acetabulum and secondary signs of osteoarthritis (Fédération Cynologique Internationale, 2023).

Statistical analysis

Continuous data are reported as median with interquartile range (IQR) and range (minimum and maximum), while categorical data are described as frequencies.

For the estimation of the potential risk factors, multinomial logistic regression models were used. For the potential risk of being born with LTV (LTV 0, LTV 1, LTV 2, LTV 3) as the outcome variable, from the effect of the categorical predictors' sex (male, female) and the 14 dog breeds, the following model was used:

$$\text{LTV} \sim 1 + \text{sex} + \text{breed}\cdot$$

Predicting the outcome variable CHD grades, CHD grades were reclassified from the original FCI grades to the following three grades CHD free (CHD=A, B), CHD mild (CHD=C), and CHD severe (CHD=D, E). This reclassification of hip status was done based on preliminary analysis of the data, in order to get a sufficient number of events for each individual CHD grade category (Malm et al., 2010). The following categorical predictor variables, LTV (LTV 0, LTV 1, LTV 2, LTV 3), sex (male, female), and the 14 breeds were included, with age in months at the time of radiography as a covariate. The final model was:

$$\text{CHD scores} \sim 1 + \text{LTV} + \text{sex} + \text{breed} + \text{age in months at radiography}\cdot$$

Both multinomial logistic regression models were statistically significantly predicting the outcome variables. There was no significant multicollinearity, and only the predictor variables that contributed significantly were kept in the models.

The odds ratio (OR) was calculated with 95% confidence intervals (CI). A $P < 0.05$ was rendered a significant association in all statistical models and the software Jamovi (Version 2.3) was used for the analyses (Jamovi, 2023).

Results

Descriptive findings

A total of 13,950 dogs were included in the study, 7627 females (54.7%) and 6323 males (45.7%). The median age at the time of radiography was 18 months, (IQR 14 – 24, range 12–123).

The overall occurrence of LTV was 18.5% ($n = 2579$), of which 850 dogs (32.9%) had type 1, 1178 (45.7%) type 2 and 551 (21.4%) type 3. Table 1 displays the distribution of LTV among the different breeds.

The frequencies of CHD grades were A: 43.1% ($n = 6017$); B: 31.4%

Table 1
The 14 included dog breeds, with the number of individuals within each breed and their percentage of the total (n = 13,950). Additionally, the frequencies of Norwegian Kennel Club (NKK) canine hip dysplasia (CHD) grades and lumbosacral transitional vertebra (LTV) types for each breed are reported.

Breed	NKK CHD score							LTV type				LTV type (1–3) Total % within breeds
	A	B	C	D	E	Total	% of total	0	1	2	3	
Brittany	248	269	231	82	5	835	6.0%	440 (53.8%)	103 (13.2%)	198 (23.7%)	85 (10.2%)	46.2%
Boxer	92	183	210	53	9	547	3.9%	412 (75.3%)	44 (8.0%)	76 (13.9%)	15 (2.7%)	24.7%
Bernese mountain dog	459	245	143	117	34	998	7.2%	903 (90.5%)	50 (5.0%)	27 (2.7%)	18 (1.8%)	9.5%
Danish-Swedish farm dog	337	336	275	61	18	1027	7.4%	878 (85.5%)	34 (3.3%)	78 (7.6%)	37 (3.6%)	14.5%
Rough collie	227	146	38	29	9	449	3.2%	258 (57.2%)	85 (19.8%)	90 (19.4%)	16 (3.6%)	42.8%
English setter	1012	637	257	86	15	2007	14.4%	1828 (91.1%)	81 (4.0%)	50 (2.5%)	48 (2.4%)	8.9%
Eurasier	444	204	94	37	15	794	5.7%	627 (79%)	32 (4.0%)	103 (13.0%)	32 (4.0%)	21.0%
Gordon setter	564	381	174	76	14	1209	8.7%	1095 (90.3%)	23 (2.2%)	59 (5.0%)	32 (2.5%)	9.7%
Irish setter	625	360	186	41	4	1216	8.7%	1088 (88.8%)	32 (2.8%)	52 (4.8%)	44 (3.6%)	11.2%
Norwegian elkhound grey	530	465	290	73	3	1361	9.8%	1121 (82.2%)	124 (9.0%)	95 (7.3%)	21 (1.5%)	17.8%
Rhodesian ridgeback	309	140	44	8	0	501	3.6%	285 (56.9%)	70 (14.0%)	116 (23.2%)	30 (6.0%)	43.1%
Portuguese water dog	300	200	127	32	5	664	4.8%	518 (78.0%)	38 (5.7%)	67 (10.4%)	41 (5.9%)	22.0%
German shepherd dog	492	621	423	112	15	1663	11.9%	1424 (84.4%)	104 (6.1%)	61 (4.1%)	74 (4.4%)	14,6%
Norwegian elkhound black	378	193	75	28	5	679	4.9%	485 (71.4%)	30 (4.4%)	106 (15.6%)	58 (8.5%)	28.6%
Total	6017 (43.1%)	4380 (31.4%)	2567 (18.4%)	835 (6.0%)	151 (1.1%)	13,950 (100%)	100%	11,371 (81.5%)	850 (6.1%)	1178 (8.4%)	551 (3.9%)	
LTV (1–3) total % from 2579 LTV cases									33%	46%	21%	

NKK, Norwegian Kennel Club; CHD, Canine Hip dysplasia, classified according to Federation Cynologique Internationale (FCI); LTV, Lumbosacral transitional vertebra classified according to Flückiger et al. (2009).

(n = 4380); C: 18.4% (n = 2567); D: 6.0% (n = 835); E: 1.1% (n = 151). After reclassification for the multinomial logistic regression analysis, 74.5% were CHD free (A, B), 18.4% had mild CHD (C) and 7.1% had severe CHD (D, E). The occurrence of CHD grades within the different breeds is given in Table 1.

The frequencies of LTV among the different CHD grades varied among different breeds, especially the potentially more severe forms of LTV (Table 1). Table 2 shows the distribution of LTV types among CHD grades. The distribution of the different LTV types according to sex is given in Table 3.

Multinominal logistic regression analysis

There were significant differences in predisposition to LTV among breeds (X^2 [39] = 1337.8; $P < 0.001$; Tables 4 and 5) compared to Brittany, but there was no association for the variable sex. There were no significant interactions between the predictors.

Table 2
The distribution of lumbosacral transitional vertebra (LTV) types according to Flückiger et al. (2009) among the reclassified canine hip dysplasia (CHD) grades (Malm et al., 2010).

LTV type					
CHD grade	0	1	2	3	Total
Free (A, B)[a]	8639	622	774	362	10,397
Mild (C)[a]	1996	168	272	131	2567
Severe (D, E)[a]	736	60	132	58	986
Total	11,371	850	1178	551	13,950

[a] CHD A-E, Canine Hip dysplasia, classified according to Federation Cynologique Internationale (FCI).

Table 3
The distribution of lumbosacral transitional vertebra (LTV) types (Flückiger et al., 2009), according to sex.

Sex		LTV type 0	1	2	3	Total
Male	Observed	5045	381	639	258	6323
	% of total	36.2%	2.7%	4.6%	1.8%	45.3%
Female	Observed	6326	469	539	293	7627
	% of total	45.3%	3.4%	3.9%	2.1%	54.7%
Total	Observed	11,371	850	1178	551	13,950
	% of total	81.5%	6.1%	8.4%	3.9%	100.0%

There was a significant association between mild CHD and LTV type 2 (OR, 1.58; $P < 0.001$; 95% Cl, 1.35–1.85) and LTV type 3 (OR, 1.65; $P < 0.001$; 95% Cl, 1.33–2.04) compared to LTV type 0 and CHD free. Additionally, there was a significant association between severe CHD and LTV type 2 (OR, 2.18; $P < 0.001$; 95% Cl, 1.76–2.70) and LTV type 3 (OR, 2.14; $P < 0.001$; 95% Cl, 1.60–2.90) compared to LTV type 0 and CHD free (Table 6). There was no sex predilection. There were no significant interactions between the predictors.

There was a statistically significant association between hip dysplasia and age in months (OR, 1.02; $P < 0.001$; 95% Cl, 1.02–1.03), i.e. an annual increase OR = (1.02)^12 = 1.27. Additionally, significant differences in CHD grades between breeds (X^2 [26] = 802; $P < 0.001$) were identified (Table 6).

Table 4
The estimated marginal means indicate the influence of different breeds as a risk factor for the probability of being born with or without various types of lumbosacral transitional vertebra (LTV), according to Flückiger et al. (2009).

Breed	LTV type	Probability	SE	95% Confidence interval Lower	Upper
Brittany	0	0.5361	0.01724	0.50139	0.5708
	1	0.1231	0.01136	0.10019	0.1460
	2	0.2391	0.01476	0.20934	0.2688
	3	0.1018	0.01046	0.08069	0.1228
Boxer	0	0.7521	0.01846	0.71495	0.7893
	1	0.0804	0.01162	0.05698	0.1038
	2	0.1400	0.01485	0.11010	0.1699
	3	0.0275	0.00699	0.01339	0.0415
Bernese mountain dog	0	0.9040	0.00936	0.88515	0.9229
	1	0.0502	0.00692	0.03623	0.0641
	2	0.0277	0.00526	0.01713	0.0383
	3	0.0181	0.00423	0.00959	0.0266
Danish-Swedish farm dog	0	0.8534	0.01108	0.83110	0.8757
	1	0.0331	0.00558	0.02185	0.0443
	2	0.0774	0.00840	0.06045	0.0943
	3	0.0361	0.00583	0.02438	0.0479
Rough collie	0	0.5716	0.02335	0.52460	0.6187
	1	0.1887	0.01845	0.15154	0.2259
	2	0.2040	0.01909	0.16557	0.2425
	3	0.0356	0.00875	0.01802	0.0533
English setter	0	0.9103	0.00639	0.89746	0.9232
	1	0.0404	0.00440	0.03154	0.0493
	2	0.0253	0.00353	0.01818	0.0324
	3	0.0240	0.00342	0.01709	0.0309
Eurasier	0	0.7884	0.01451	0.75920	0.8176
	1	0.0403	0.00698	0.02623	0.0543
	2	0.1310	0.01200	0.10680	0.1551
	3	0.0403	0.00699	0.02627	0.0544
Gordon setter	0	0.9044	0.00851	0.88726	0.9215
	1	0.0190	0.00393	0.01112	0.0270
	2	0.0500	0.00634	0.03722	0.0627
	3	0.0266	0.00464	0.01724	0.0359
Irish setter	0	0.8936	0.00888	0.87573	0.9115
	1	0.0263	0.00460	0.01709	0.0356
	2	0.0437	0.00592	0.03178	0.0556
	3	0.0363	0.00538	0.02550	0.0472
Norwegian elkhound grey	0	0.8215	0.01044	0.80050	0.8425
	1	0.0911	0.00782	0.07538	0.1069
	2	0.0719	0.00709	0.05757	0.0861
	3	0.0155	0.00336	0.00874	0.0223
Rhodesian ridgeback	0	0.5656	0.02213	0.52102	0.6102
	1	0.1392	0.01545	0.10810	0.1703
	2	0.2354	0.01901	0.19707	0.2736
	3	0.0598	0.01060	0.03849	0.0812
Portuguese water dog	0	0.7806	0.01603	0.74826	0.8129
	1	0.0572	0.00902	0.03908	0.0754
	2	0.1005	0.01163	0.07707	0.1239
	3	0.0617	0.00934	0.04291	0.0805
German shepherd dog	0	0.8554	0.00865	0.83799	0.8728
	1	0.0626	0.00594	0.05061	0.0746
	2	0.0374	0.00469	0.02791	0.0468
	3	0.0446	0.00508	0.03443	0.0549
Norwegian elkhound black	0	0.7124	0.01738	0.67736	0.7474
	1	0.0441	0.00788	0.02825	0.0600
	2	0.1581	0.01404	0.12978	0.1863
	3	0.0855	0.01074	0.06384	0.1071

SE, Standard error

Discussion

This study reports an overall occurrence of LTV of 18.5% in a sample of 13,950 Norwegian dogs, ranging from 9.5% to 46.2% among the 14 included dog breeds. The study relies on a large database, encompassing registrations from February 2014 until January 2022, to provide insight into the current status of both LTV and CHD occurrence in a sample of 14 dog breeds in Norway. In some of the included breeds, such as the Danish-Swedish farm dog and the Portuguese water Dog, the occurrence of LTV is not previously reported. The prevalence of LTV in the two Norwegian elkhound breeds differed substantially from the occurrence reported by Larsen (1977), although it was not specified whether the study was investigating the black or grey Norwegian elkhound.

Table 5
Comparing breeds at risk for being born with lumbosacral transitional vertebra (LTV) types (Flückiger et al., 2009).

LTV[a]	Breed[b]	*P*	OR	95% CI	
1 – 0	Boxer	< 0.001	0.4654	0.3190	0.6788
	Bernese mountain dog	< 0.001	0.2415	0.1691	0.3449
	Danish-Swedish farm Dog	< 0.001	0.1688	0.1127	0.2529
	Rough collie	0.029	1.4378	1.0383	1.9909
	English setter	< 0.001	0.1931	0.1418	0.2630
	Eurasier	< 0.001	0.2224	0.1469	0.3367
	Gordon setter	< 0.001	0.0916	0.0576	0.1459
	Irish setter	< 0.001	0.1283	0.0850	0.1936
	Norwegian elkhound grey	< 0.001	0.4828	0.3637	0.6410
	Rhodesian ridgeback	0.687	1.0721	0.7646	1.5031
	Portuguese water dog	< 0.001	0.3193	0.2155	0.4730
	German shepherd dog	< 0.001	0.3184	0.2377	0.4266
	Norwegian elkhound black	< 0.001	0.2697	0.1761	0.4131
2–0	Boxer	< 0.001	0.4155	0.3087	0.5593
	Bernese mountain dog	< 0.001	0.0681	0.0448	0.1035
	Danish-Swedish farm dog	< 0.001	0.2018	0.1516	0.2687
	Rough collie	0.134	0.7990	0.5958	1.0714
	English setter	< 0.001	0.0617	0.0445	0.0856
	Eurasier	< 0.001	0.3706	0.2835	0.4844
	Gordon setter	< 0.001	0.1229	0.0900	0.1678
	Irish setter	< 0.001	0.1087	0.0785	0.1505
	Norwegian elkhound grey	< 0.001	0.1947	0.1488	0.2546
	Rhodesian ridgeback	0.618	0.9327	0.7092	1.2267
	Portuguese water dog	< 0.001	0.2869	0.2114	0.3894
	German shepherd dog	< 0.001	0.0971	0.0715	0.1319
	Norwegian elkhound black	< 0.001	0.4957	0.3787	0.6489
3–0	Boxer	< 0.001	0.1922	0.1092	0.3380
	Bernese mountain dog	< 0.001	0.1053	0.0625	0.1773
	Danish-Swedish farm dog	< 0.001	0.2227	0.1489	0.3330
	Rough collie	< 0.001	0.3283	0.1884	0.5723
	English setter	< 0.001	0.1385	0.0958	0.2002
	Eurasier	< 0.001	0.2693	0.1762	0.4116
	Gordon setter	< 0.001	0.1545	0.1014	0.2355
	Irish setter	< 0.001	0.2138	0.1462	0.3127
	Norwegian elkhound grey	< 0.001	0.0993	0.0608	0.1620
	Rhodesian ridgeback	0.010	0.5573	0.3582	0.8669
	Portuguese water dog	< 0.001	0.4160	0.2806	0.6167
	German shepherd dog	< 0.001	0.2745	0.1975	0.3814
	Norwegian elkhound black	0.012	0.6315	0.4416	0.9031

OR, odds ratio; CI, confidence interval. a Reference group LTV: LTV 0.
b Reference group breed: Brittany.

The high overall occurrence of LTV in this study is partly due to the selected breeds included, some of which were chosen because of a priori knowledge of a potential high prevalence of LTV. The prevalence found in these seven specific breeds ranged from 21.0% (Eurasier) to 46.2% (Brittany), and their inclusion could obviously lead to an overall high prevalence of LTV in the present study. The reported occurrences of LTV in pure-breed dogs range from 2.3% to 66.86%, although most breeds have an occurrence between 4% and 12% (Larsen, 1977; Damur-Djuric et al., 2006; Ledecký et al., 2007; Lappalainen et al., 2012; Fialová et al., 2014; Kuricová et al., 2018; Bertram et al., 2019; Gong et al., 2020). Nevertheless, a direct comparison of prevalence reported in different studies is not feasible as different classification systems and breed selection criteria have been used (Larsen, 1977; Damur-Djuric et al., 2006; Wigger et al., 2009; Lappalainen et al., 2012; Fialová et al., 2014; Gong et al., 2020). However, the high occurrence of LTV within specific breeds reported herein indicates that genetic differences exist between the populations. The general difference in occurrence between dog breeds also supports this. This finding agrees with previous publications (Wigger et al., 2009; Moeser and Wade, 2017; Gluding et al., 2021).

Our findings with respect to the prevalence of the different CHD

Table 6
Comparing breeds at risk for developing hip dysplasia (CHD). CHD reclassified according to Malm et al. (2010).

CHD[a]	Breed[b]	*P*	OR	95% CI	
Mild - free	Boxer	< 0.001	1.9554	1.5366	2.488
	Bernese mountain dog	< 0.001	0.5645	0.4426	0.720
	Danish-Swedish farm dog	0.911	1.0124	0.8169	1.255
	Rough collie	< 0.001	0.2297	0.1587	0.333
	English setter	< 0.001	0.3543	0.2868	0.438
	Eurasier	< 0.001	0.3361	0.2568	0.440
	Gordon setter	< 0.001	0.4092	0.3246	0.516
	Irish setter	< 0.001	0.4529	0.3611	0.568
	Norwegian elkhound grey	< 0.001	0.5561	0.4491	0.689
	Rhodesian ridgeback	< 0.001	0.2237	0.1579	0.317
	Portugues water dog	< 0.001	0.5917	0.4596	0.762
	German shepherd dog	0.874	1.0161	0.8343	1.237
	Norwegian elkhound black	< 0.001	0.2784	0.2083	0.372
Severe - free	Boxer	0.007	1.6467	1.1456	2.367
	Bernese mountain dog	< 0.001	1.8052	1.3380	2.436
	Danish-Swedish farm dog	0.291	0.8357	0.5987	1.166
	Rough collie	0.026	0.6298	0.4187	0.947
	English setter	< 0.001	0.4013	0.2926	0.550
	Eurasier	< 0.001	0.5149	0.3565	0.744
	Gordon setter	0.002	0.6002	0.4332	0.832
	Irish setter	< 0.001	0.3148	0.2144	0.462
	Norwegian elkhound grey	< 0.001	0.3997	0.2839	0.563
	Rhodesian ridgeback	< 0.001	0.1090	0.0522	0.228
	Portuguese water dog	< 0.001	0.4796	0.3186	0.722
	German shepherd dog	0.520	0.9058	0.6700	1.224
	Norwegian elkhound black	< 0.001	0.3252	0.2129	0.497

OR, odds ratio; CI, Confidence interval.
[a] Reference group CHD, CHD free (A, B).
[b] Reference group breed, Brittany.

grades as well as a lack of association between CHD and sex aligns with previous studies from Norway and Sweden (Krontveit et al., 2010; Hedhammar, 2020).

A lumbosacral transitional vertebra as a predisposing factor for the development of CHD has been reported inconsistently (Morgan, 1999; Citi et al., 2005; Ledecký et al., 2007; Wigger et al., 2009; Komsta et al., 2015; Flückiger et al., 2017; Kuricová et al., 2018). To the authors' best knowledge, this is the first reported finding of a significant association between LTV type 2 and LTV type 3 and mild and severe CHD.

Additionally, dog age at the time of radiography is reported to influence CHD grades, most likely due to development of secondary changes in the hip joints (Smith et al., (2012). Our results confirmed a statistically significant increase in the CHD grades due to increased age (OR=1.02) per month (i.e., annual increase OR=1.27).

The large number of dogs included in this study combined with the variety of breeds has probably been essential to identify the association of LTV type 2 and type 3 and the development of hip dysplasia. However, it is important to note that not all LTV types 2 and 3 are associated with hip dysplasia (Table 2), which reflects the complex relationship between LTV and CHD that is not fully understood. Still, questions arise concerning which mechanisms are responsible for the association between LTV and CHD and whether these mechanisms are global among dog breeds. To answer this, we need to compare dog breeds. In the future, cross-sectional imaging (Brocal et al., 2018) and three-dimensional kinematic analysis of dogs with LTV could improve our understanding of the potential effect of LTV on CHD (Fischer et al., 2018).

In the present study, only VD radiographs were available to interpret and classify LTV. We used the Fluckiger et al. (2009) classification system for LTV. This classification system was chosen as it is a straightforward system based on only one radiograph of the hips in extended VD projection. We also considered the classification system developed by Damur-Djuric et al., (2006), but ultimately decided against it. This decision was influenced by the potential for discrepancies in their classifications due to the superimposition of the ilium on the transverse processes, as observed in the study by Lappalainen et al. (2012). Other classification systems were also considered but rejected because of higher complexity or the need for additional radiographic projections or more complex diagnostic modalities (Wigger et al., 2009; Lappalainen et al., 2012; Bertram et al., 2019). The terminology lumbarisation and sacralisation were not used for the same reasons (Morgan, 1968). The extended VD projection might be prone to misinterpretation of LTV type 1 and type 2 as the rudimentary intervertebral space can be hard to identify. Nevertheless, this potential misclassification would not influence the reported overall prevalence of LTV but potentially the prevalences of different types. If so, a possible bias would probably be in disfavour of the classification of LTV type 2, so there should be no conflict with our findings related to LTV type 2 and its association with hip dysplasia (Lappalainen et al., 2012; Gong et al., 2020).

Conclusions

The present study confirms substantial differences in the prevalence of LTV among breeds. This supports initial data on the heredity of LTV, the diverse occurrence of LTV among breeds, and anecdotal information on genetic disposition (Moeser and Wade, 2017; Gluding et al., 2021). Our results indicate that LTV type 2 and type 3 are associated with the development of mild and severe CHD. Therefore, this study has potentially identified an additional risk factor for the development of CHD.

CRediT authorship contribution statement

J.A.Berg: Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

None of the authors has any financial or personal relationships that could inappropriately influence or bias the content of the paper.

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