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Estimated heritability and breeding programme outcome of lumbosacral transitional vertebra, including complete lumbarisation, in German shepherd dogs in Finland during 2013–2023

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Abstract

Lumbosacral transitional vertebra (LTV) is a congenitally malformed vertebra with variable prevalence and heritability in different dog breeds. German shepherd dogs (GSDs) have previously been shown to have a clear breed predisposition to LTV, but the protocols used for LTV assessment have not included evaluation of the true number of presacral vertebrae. The aim of this study was to evaluate heritability and breeding programme outcome of LTV in GSDs in Finland using results from a radiographic screening scheme that includes also complete lumbarisation (first sacral vertebra has morphology of a lumbar vertebra, L8) and sacralisation (last lumbar vertebra has morphology of a sacral vertebra, L6). Altogether 7,556 GSD LTV screening results from the Finnish Kennel Club (FKC) database from 2013 to 2023 were analysed. The FKC grading scheme includes grades LTV0 (normal), LTV1 (divided median sacral crest/some other mild lumbosacral abnormality), LTV2 (symmetrical),LTV3 (asymmetrical), and LTV4 (total or nearly total lumbarisation (L8)/sacralisation (L6)). Grading is based on the laterolateral radiographs of the thoracic and lumbar spine, in addition to extended ventrodorsal projection of the pelvis. Heritability was estimated by the restricted maximum likelihood (REML) method, and genetic trend was assessed from standardised estimated breeding values (EBVs) of individual dogs by comparing the mean EBVs of dogs born in different years. Approximately half (46%) of the GSDs born in 2014–2022 had been screened for LTV. The overall prevalence of LTV was 29% (2,194/7,556). The most common LTV morphology was LTV1 (22%, 1,694/7,556), followed by LTV4 (3%, 229/7,556), LTV3 (2%, 149/7,556), and LTV2 (2%, 122/7,556). Heritability estimate for LTV was moderate to high (0.49), and a slight favourable genetic trend was seen. Our results show that genetic improvement, based on LTV heritability estimate and genetic trend, is possible. In addition, the observed prevalence of LTV4 supports its inclusion in the classification scheme. However, LTV results should be used more vigorously when choosing breeding animals and EBVs included in the breeding programme for even better progress.

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Keywords Canine, Inheritance, LTV, Radiographic screening

Introduction

The German shepherd dog (GSD) is a breed known to be predisposed to hereditary lumbosacral transitional vertebra (LTV) [1–3], which is an anomalous vertebra in lumbosacral junction, manifesting both sacral and lumbar characteristics [1, 4–6]. Morphologically, LTV varies widely and different classification schemes based on radiographic features have been proposed [1, 6–8]. A five-grade LTV scheme modified from Lappalainen et al. [6] has been used for breeding selection since 2013 by the Finnish Kennel Club (FKC) [9]. This scheme utilises laterolateral radiographs of the thoracic and lumbar spine, including the sacrum, in addition to ventrodorsal radiograph of the pelvis, allowing determination of the true number of thoracic and lumbar vertebrae for identifying lumbarisation (first sacral vertebra has morphology of lumbar vertebra) (Fig. 1) and sacralisation (last lumbar vertebra has morphology of sacral vertebra). The minimum age for official screening is 12 months. The FKC scheme classifies LTV morphologies as LTV 0 = normal, LTV1 = divided median sacral crest or some other mild lumbosacral abnormality, LTV2 = symmetrical LTV, LTV3 = asymmetrical LTV, and LTV4 = total or nearly total lumbarisation (L8) or sacralisation (L6). All LTV screening results are published in the FKC public breeding database [10]. In 2014, the GSD club of Finland implemented mandatory radiographic LTV screening prior to breeding [11].

Depending on the population and morphological classification scheme used, the prevalence of LTV in GSDs varies between 4.3% and 40% [1, 3, 6, 12]. In previous studies, estimated heritability of LTV in GSDs has been moderate to high [2, 3, 7], but LTV classification schemes on which these estimates are based have not included LTV4. In addition, these studies have used hip dysplasia images for retrospective LTV morphology and prevalence assessment, not a structured LTV breeding scheme.

The health and welfare of GSDs has declined in recent decades, simultaneously with a decrease in popularity [13]. In Finland, although the number of registered puppies per year has decreased during 2013–2023, GSD still ranks among the ten most popular dog breeds [14]. In UK health data, the most common causes for death in GSDs were musculoskeletal disorders and inability to stand [13]. LTV has been shown to predispose dogs to canine hip dysplasia and, most importantly, to cauda equina syndrome, which causes pain and neurological signs in the pelvic limbs and lumbosacral spine [4, 15–17]. As the prevalence of LTV in GSDs is high and LTV poses a clear welfare risk, a more profound understanding of heritability and an evaluation of implemented LTV breeding schemes are needed. No reports on the outcome of any mandatory breeding scheme against LTV have been published, nor have heritability estimates for LTV types including LTV4, been reported.

This study aimed to evaluate breeding programme outcome and heritability of LTV in GSDs in Finland during 2013–2023.

Materials and methods

All GSD LTV results from the FKC register during 2013–2023 were retrospectively included in the study. All owners whose dogs participate in FKC LTV screening sign an informed consent for their dogs' results to be published in the public FKC breeding database and further used for research purposes.

The data obtained included identification number of the dog and pedigree data, dog´s birth date, sex, breed (short- or long-haired GSD), date of radiography, scrutineer ID, clinic taking the images, and the screening results. All images were screened according to the FKC LTV grading scheme protocol [9] by one of the authors (AL or VR), both of whom have extensive experience in diagnostic imaging and scrutinizing skeletal radiographs.

Variance components were estimated with the restricted maximum likelihood (REML) method using the average information (AI) algorithm [18] by the DMU package [19]. Variance components were estimated with the following model:

$$y_{ijklmnopq} = age_i + yrmonth_j + line_k + sex_l + radiologist_m + examinator_n + litter_o + a_p + e_{ijklmnopq},$$

where $y_{ijklmnopq}$ is LTV score, age_i is the fixed effect of age class at time of radiological examination (months, i = 5–145), yrmonth is the fixed effect of year+month combination of time of examination (j = 1–123), line is the fixed effect of genetic line of the dog (k = 1–2), sex is the fixed effect of sex of the dog (l = 1–2), radiologist is the fixed effect of radiologist (m = 1–681), examinator is the fixed effect of examinator of the radiological findings (n = 1–2), litter is the random effect of litter, a is the additive genetic effect of the dog, and $e_{ijklmnopq}$ is the residual effect. To estimate genetic change, the estimated breeding values (EBVs) were standardised and reversed (mean = 100, SD = 10), and average standardised breeding values were calculated by birth year. When all the pedigree information was traced back to dogs born 1980 or later, there were 10,417 dogs in the genetic analysis.

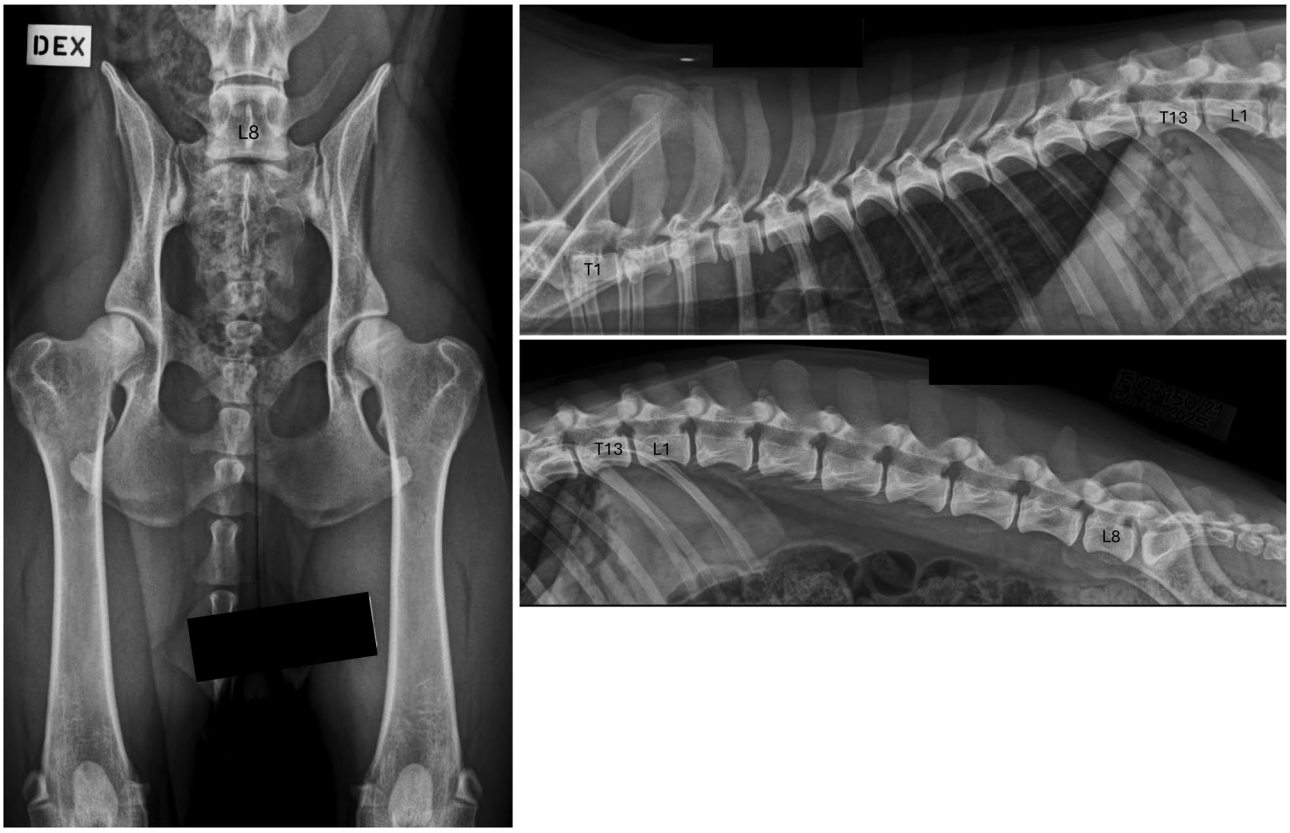


Fig. 1 Radiographic screening images used for lumbosacral transitional vertebra screening in the Finnish Kennel Club. The ventrodorsal pelvic and latero-lateral thoracic and lumbar spine radiographs of a German shepherd dog showing the eight lumbar vertebra (L8; lumbarisation). L1; first lumbar vertebra, T1; first thoracic vertebra, T13; thirteenth thoracic vertebra, L8; totally lumbarised first sacral vertebra. Image: Finnish Kennel Club

Results

Altogether 7,556 GSD LTV screening results recorded in the FKC database during 2013–2023 were included in the study, 4,063 female dogs (54%) and 3,493 male dogs (46%). Most (88%) of the dogs represented the short-coated GSD variant (6,641/7,556) and 12% (915/7,556) the long-coated variant. The median age at time of radiography was 19 months (range 5–145). Although minimum age for imaging is 12 months, FKC also records unofficial results from dogs having signs related to skeletal disorders, and therefore, also results from dogs aged under 12 months ($n = 3$) were included.

The proportion of dogs screened for LTV out of all dogs born in 2004–2022 is presented in Fig. 2. The overall prevalence of LTV, including LTV types 1- 4, was 29% (2,194/7,556). Distribution of different LTV types is shown in Table 1. Phenotypic trends for different LTV types are presented in Fig. 3 and genetic trend in Fig. 4. Additional information regarding the type of LTV4, i.e., L6 or L8, was available for 198 dogs. Of these, one dog had L6, and 197 had L8.

Estimated phenotypic standard deviation for LTV was 0.88. Heritability estimate was 49% with standard error (SE) 3%. The litter effect constituted 6% (SE 1%) of total variation in LTV.

Discussion

Our study shows moderate to high heritability of LTV in GSDs using an LTV classification scheme that allows identification of LTV4. Our study is the first to report LTV prevalence and genetic and phenotypic trends in a GSD population with a mandatory screening protocol for LTV.

Prevalence of LTV4 (3%, 229/7,556) in our study was similar to prevalence of LTV2 (2%, 122/7,556) and LTV3 (2%, 149/7,556), which together with moderate to high heritability supports its inclusion in screening schemes. The presence of eight lumbar vertebrae (L8) has been previously described in GSD [6]. In our study population, information on LTV4 type was available for 198 dogs, of which all but one had L8. Importance of including lumbarisation (L8) and sacralisation (L6) in LTV screening schemes has also been stressed in a study analysing LTV findings in a breeding colony of Labrador retrievers and Labrador crosses [20].

Reported prevalence of LTV in GSDs has varied considerably depending on the study and classification

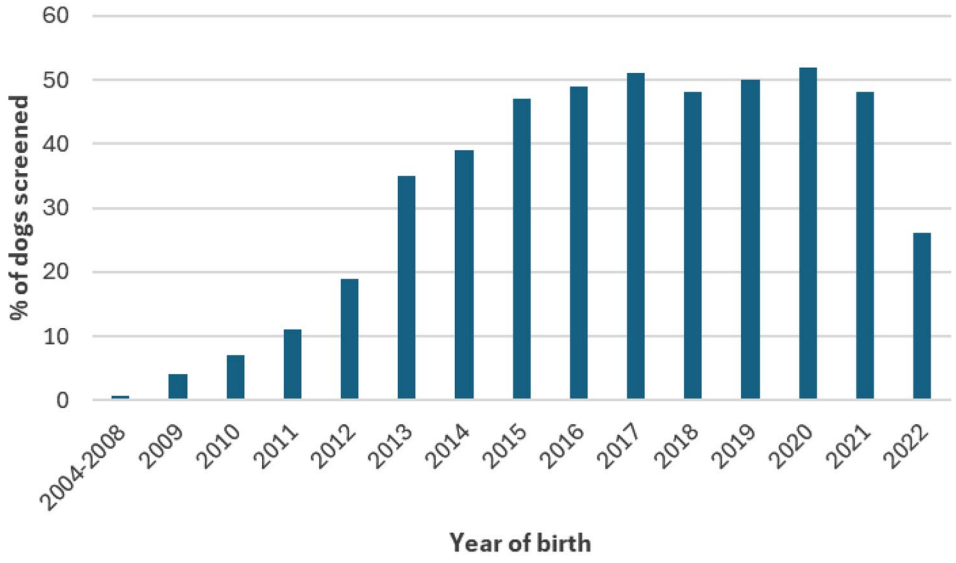


Fig. 2 Proportion of German shepherd dogs born 2004–2022 having a lumbosacral transitional vertebra (LTV) screening result

Table 1 Distribution of lumbosacral transitional vertebra (LTV) types* in German shepherd dogs

	LTV type					Total
	0	1	2	3	4	
Male	2582	708	51	61	91	3493
n (%)	(74%)	(20%)	(1%)	(2%)	(3%)	
Female	2780	986	71	88	138	4063
n (%)	(69%)	(24%)	(2%)	(2%)	(3%)	
Total	5362	1694	122	149	229	7556
n (% of all)	(71%)	(22%)	(2%)	(2%)	(3%)	

*According to the Finnish Kennel Club LTV grading scheme modified from Lappalainen et al. (2012)

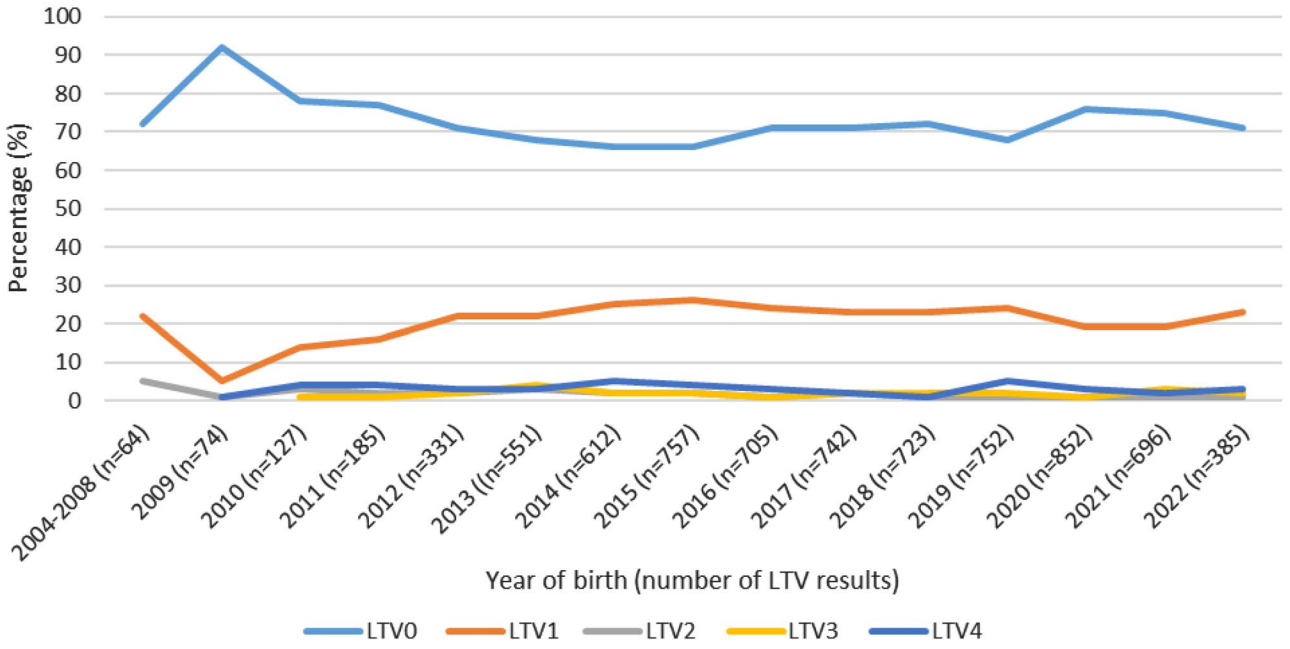
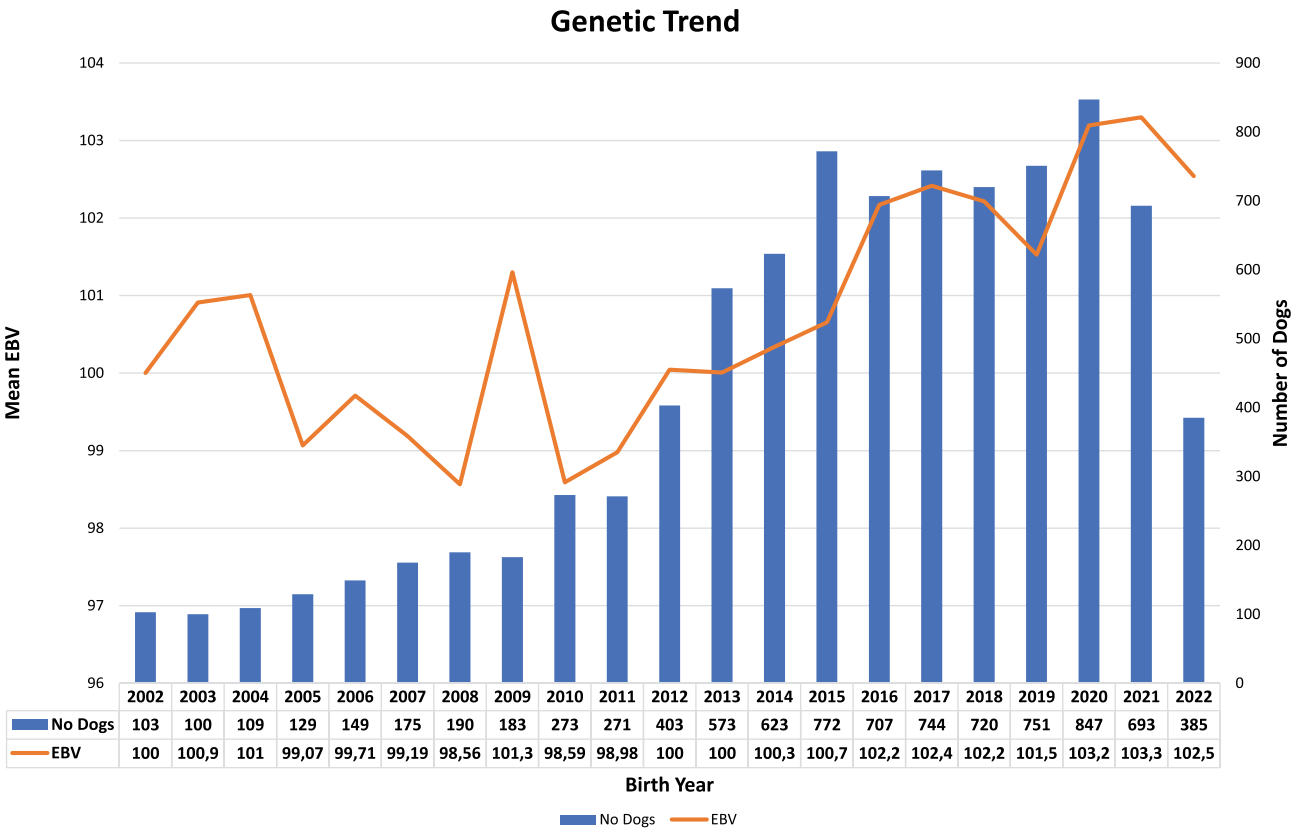


Fig. 3 Phenotypic trends of lumbosacral transitional vertebra (LTV) types* in German shepherd dogs born 2004–2022. *according to the Finnish Kennel Club LTV grading scheme modified from Lappalainen et al. (2012)



	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
No Dogs	103	100	109	129	149	175	190	183	273	271	403	573	623	772	707	744	720	751	847	693	385
EBV	100	100,9	101	99,07	99,71	99,19	98,56	101,3	98,59	98,98	100	100	100,3	100,7	102,2	102,4	102,2	101,5	103,2	103,3	102,5

Fig. 4 Genetic trends for different lumbosacral transitional vertebra (LTV) types* in German shepherd dogs born 2002–2022. * According to the Finnish Kennel Club LTV grading scheme modified from Lappalainen et al. (2012). EBV, estimated breeding value

scheme used [1, 3, 6, 12]. Our study offers a highly reliable estimate of LTV prevalence, 29%, in Finnish GSDs based on a large sample size and data from a pre-breeding mandatory LTV screening programme. Approximately half of the GSDs born in Finland in 2014–2022 had been screened for LTV. In addition, variation in screening results due to multiple scrutinisers is minimal, as only two scrutinisers evaluated all images.

Although no limitations regarding use of any LTV types for breeding are in effect in Finland, a slight favourable genetic trend was seen in our study. This might be because both the FKC and GSD club in Finland recommend mating dogs with an abnormal LTV result with a dog having LTV0 [21, 22]. At the moment, insufficient information regarding the clinical effects of different types of LTV exists, but as clear heritability is seen, phenotypic breeding selection using only dogs with no or minor LTV malformations and combining them with dogs having normal morphology is recommended. Our results showing a slight favourable genetic trend are encouraging, but even better progress can be achieved by using EBVs for mating [3, 23]. As EBV is based on the dog's own as well as its relatives' results and accounts for environmental factors, such as dog sex, scrutiniser, and litter effect, it gives a more reliable estimation of an individual´s hereditary value. Based on the findings of this study, the FKC implemented EBVs on 1 January 2026 for GSD LTV breeding selection.

In conclusion, as LTV heritability was moderate to high and prevalence of LTV4 was similar to that of LTV2 and LTV3, a screening programme including LTV4 is warranted in GSDs. Slight genetic improvement was seen, but more effective use of LTV results in the selection of breeding animals, together with the inclusion of EBVs in the breeding programme, would enable even greater progress.

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Author contributions
LLM compiled the data obtained from the Finnish Kennel Club (FKC). TS performed the variance component analysis. LLM performed the descriptive statistics, and LLM wrote the first draft of the manuscript. AL and VR scrutinised all radiographs as part of the FKC LTV screening programme. All authors contributed to the study design, interpretation of data, and writing of the manuscript. All authors read and approved the final version of the manuscript.

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Data availability

The data supporting the findings of this study are available from the Finnish Kennel Club (FKC), but restrictions apply to data availability, as the data were used under licence for the current study, and thus, are not publicly available. However, data are available from the authors upon reasonable request and with permission from the FKC.

Declarations

Ethical approval

This study did not require official or institutional ethics approval. LTV screening results were obtained from the FKC register. All owners whose dogs participate in the FKC LTV screening sign an informed consent for their dogs´ results to be published in the FKC public breeding database and further used for research purposes. The retrospective data obtained from the FKC have been handled in accordance with data processing regulations at the FKC and the University of Helsinki, Finland.

Consent for publication

LTV screening results were obtained from the FKC register. All owners whose dogs participate in the FKC screening sign an informed consent for their dogs´ results to be published in the FKC public breeding database and further used for research purposes. Individual animals cannot be identified from the data presented here.

Prior publication

Data included in this article have previously been published as a poster abstract (less than 250 words) in the Proceedings of the Finnish Veterinary Symposium, Helsinki, Finland, 12–14 November 2025.

Competing interests

The authors declare no competing interests.

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