Aus der Klinik für kleine Haustiere
des Fachbereichs Veterinärmedizin
der Freien Universität Berlin

Lumbosacral Transitional Vertebrae in Dogs

Inaugural-Dissertation
zur Erlangung des Grades eines
Doktors der Veterinärmedizin
an der
Freien Universität Berlin

vorgelegt von
HE GONG
Tierärztin aus Baotou, VR China

Berlin 2018
Journal-Nr.: 4080

mbvberlin | mensch und buch verlag

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Deskriptoren (nach CAB-Thesaurus):
dogs, congenital abnormalities, radiology, morphology, incidence, hip dysplasia, canine (MeSH), cauda equina (MeSH), polyradiculopathy (MeSH)

Tag der Promotion: 16.07.2018

Bibliografische Information der *Deutschen Nationalbibliothek*
Die Deutsche Nationalbibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über <https://dnb.de> abrufbar.

ISBN: 978-3-86387-932-7
Zugl.: Berlin, Freie Univ., Diss., 2018
Dissertation, Freie Universität Berlin
D188

Choriner Str. 85 - 10119 Berlin
verlag@menschundbuch.de – www.menschundbuch.de

Contents

Abbreviations

ANOVA	Analysis of variance
AS	Articular Surface
BVA/KC	British Veterinary Association/ The Kennel Club
C	Cervical vertebrae
C 1-7	1.-7. Cervical vertebrae
Cd	Caudal vertebrae
Cd1	The first caudal vertebra
CES	Cauda Equina Syndrome
CHD	Canine Hip Dysplasia
CT	Computed Tomography
DI	Distraction Index
DJD	Degenerative Joint Disease
DLSS	Degenerative Lumbosacral Stenosis
et al.	et alii = and others
FCI	Fédération Cynologique Internationale
Fig.	Figure
FNSV	First Normal Sacral Vertebra
GSD	German Shepherd Dog
i.e.	id est = that is to say
IVD	Intervertebral disc
L	Lumbar vertebrae
L 1-7	1.-7. Lumbar vertebrae
LNLV	Last Normal Lumbar Vertebra
LS	Lumbosacral
LSJ	Lumbosacral Joint
LTV	Lumbosacral Transitional Vertebrae
MRI	Magnetic Resonance Imaging
n	Number
NA	Norberg Angle
OFA	Orthopedic Foundation for Animals

p.	Page
S	Sacral vertebrae
S 1-3	1.-3. Sacral vertebrae
SC	Sacrococcygeal
SCTV	Sacrococcygeal Transitional Vertebrae
SD	Standard Deviation
SI	Sacroiliac
SIJ	Sacroiliac joint
SP S1	Spinous process of the first sacral vertebra
SPSS	Superior Performing Software System
T	Thoracic vertebrae
T 1-13	1.-7. Thoracic vertebrae
TPA	Transverse Process Angle
VD	Ventrodorsal

1 Introduction

Lumbosacral transitional vertebrae (LTV) is the abnormally formed vertebra between the last normal lumbar vertebra (LNLV) and the first normal sacral vertebra (FNSV) (Morgan 1968). It is a congenital disorder the abnormal vertebra and has morphologic characteristics of both lumbar and sacral vertebrae (Morgan 1968, Morgan 1999 b). Due to the fact that the human and animal spinal loading are different both during standing and ambulation, the results from human studies cannot be directly transferred to dogs.

Several studies in English and German revealed different prevalence and classifications of LTV in dogs. The prevalence of LTV in dogs varies depending on the morphology of the vertebrae, the breed of the dogs, and the sample population. Different LTV classification systems have been used based on the morphological and radiological variations and different definitions of LTV. The morphology of LTV can vary, particularly with the transverse processes (Winkler 1985, Damur-Djuric et al. 2006), which depend on the development of the ventral ossification center for the sacral wings (Frenkel 1873, Rosenberg 1907, Winkler 1985).

The diagnosis of LTV is believed to have clinically relevance. LTV may affect the sacroiliac (SI) attachment (Morgan 1999 b, Morgan et al. 2000) and, when asymmetric, can result in angulation of the pelvis over its long or vertical axis with subsequent uneven hip joint development and coxarthrosis (Olsson and Kasstrom 1972, Morgan and Stephens 1985, Ziegler 1990). Moreover, LTV may cause weakening of the SI attachment and lead to premature IVD degeneration in the lumbosacral (LS) segment as well as occurrence of cauda equina syndrome (CES) (Morgan et al. 1993, Morgan 1999 b, Damur-Djuric et al. 2006).

The aims of the retrospective study is to further understand the clinical importance of LTV through studying the prevalence and morphological features of LTV, their association with canine hip dysplasia (CHD), coxarthrosis and radiographic predictors for CES in relevant cases from the Small Animal Clinic, Faculty of Veterinary Medicine at Freie Universität Berlin.

2 Literature

2.1 Anatomy

2.1.1 Vertebral column

The **vertebral column** *(columna vertebralis)* encloses and protects the spinal cord. In respect to the statics and dynamics of the animals body, the vertebral column has a supporting function (Budras et al. 2007). Knowledge of general vertebral development and the descriptive anatomy in caudal lumbar segments and sacrum are important in understanding the anomalies of lumbarization and sacralization.

The vertebral column normally consists of seven cervical (C1-7), thirteen thoracic (T1-13), seven lumbar (L1-7), three sacral (S1- 3) and up to twenty caudal (coccyggeal) vertebrae (Cd1-20) in dogs. The number of caudal vertebrae may vary. The three sacral vertebrae are fused to form the sacrum. A typical vertebra is composed of a **body** *(corpus vertebrae),* a **vertebral arch** *(arcus vertebrae*) which is made up of two **pedicles** *(pediculi arcus vertebrae)* basally and two **laminae** *(laminae arcus vertebrae)* dorsally, and various **vertebral processes** (*procesus vertebrae*) (Fig. 2-1) (Evans 1993, Evans et al. 2000, Budras et al. 2007, König et al. 2013).

The **body** is prismatic or cylindrical. It has a convex **cranial** *(extremitas cranialis)* and a concave **caudal** *(extremitas caudalis)* **extremity**. Between adjacent vertebrae are **intervertebral fibrocartilaginous discs** *(discus intervertebralis)*. Together with the body the vertebral arch forms a short tube, the **vertebral foramen** *(foramen vertebrale).* The serial vertebral foramina join to form the **vertebral canal** *(canalis vertebralis)*. The pair of pedicles extending from the dorsolateral surface present the **cranial** *(incisura vertebralis cranialis)* and **caudal vertebral notches** *(incisura vertebralis caudalis)*. When the vertebral column is articulated, the notches from adjacent vertebrae with the intervening fibrocartilage build the **intervertebral foramina** *(foramina intervertebralia)*. Dorsally most of the vertebral arches fit closely without leaving a space, however there are sites between the arches from adjacent vertebrae, where an **interarcual space** *(spatium interarcuale)* can be seen. Additionally, each vertebra has one **spinous process** *(processus spinosus)* at the mid-dorsal line of the vertebral arch, two **transverse processes** *(processus transversus)* that originate from the base of the vertebral arch and project laterally, four **articular processes** *(processus articulares)* positioned cranial and caudal to the root of the spinous process (Fig. 2-2) (Evans 1993, Evans et al. 2000, Budras et al. 2007, König et al. 2013).

2.1.2 Lumbar vertebrae

The vertebral column of the dog normally consists of seven **lumbar vertebrae** (*vertebrae lumbares)* in general. They have longer bodies than those of the thoracic vertebrae. The **spinous processes** are largest in the midlumbar region and directed slightly cranially. The **transverse processes** are bilateral and directed cranially as well as ventrolaterally. The **accessory processes** *(processus accessorii)* overlie the caudal vertebral notches and project caudolaterally. They are well developed on the first three or four lumbar vertebrae and absent on the caudal part of the lumbar vertebral column. The **articular processes** lie mainly in sagittal planes and permit movement only in a ventral and dorsal direction. The **cranial articular process** *(processus articularis cranials)* faces craniodorsally or medially, while the **caudal articular process** *(processus articular caudalis)* projects caudoventrally or laterally (Fig. 2-1). The **caudal articular processes** lie between the cranial ones of succeeding vertebrae and restrict lateral flexion. All cranial articular processes bear a **mammillary process** *(processus mammillaris*) (Fig. 2-1) (Evans 1993, Evans et al. 2000). The **lumbosacral interarcuate space** *(spatium interarcuale lumbosacrale)* is wider than other spaces in the lumbar region, which can be used to access the vertebral canal (Fig. 2-3) (König et al. 2013).

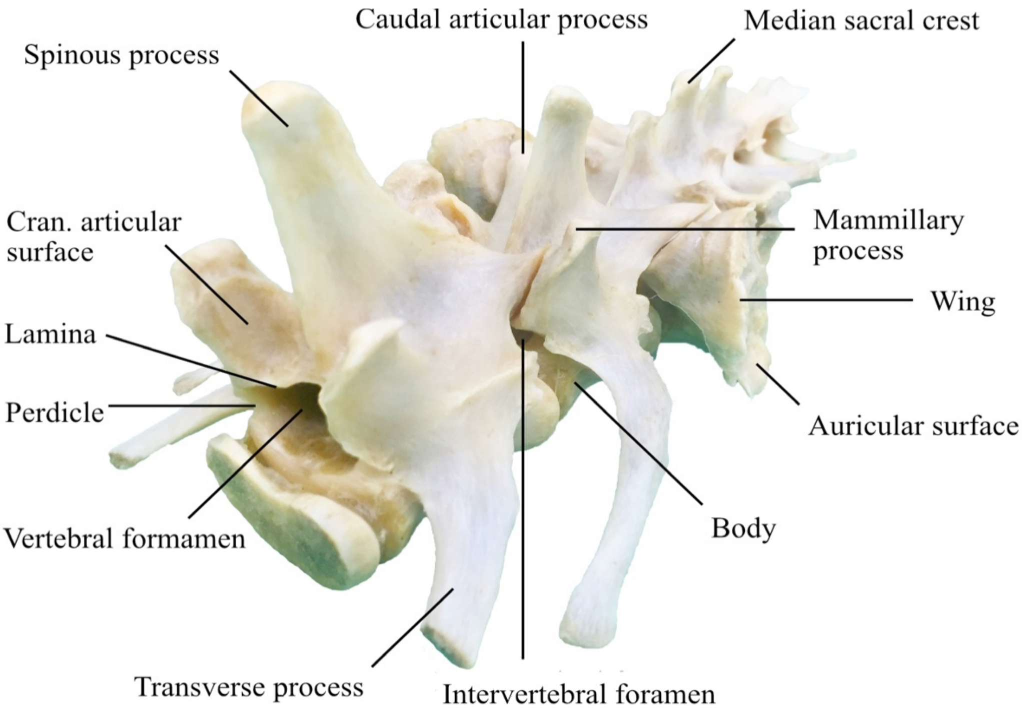


Fig. 2-1. Caudal lumbar vertebrae and sacrum, craniolateral aspect

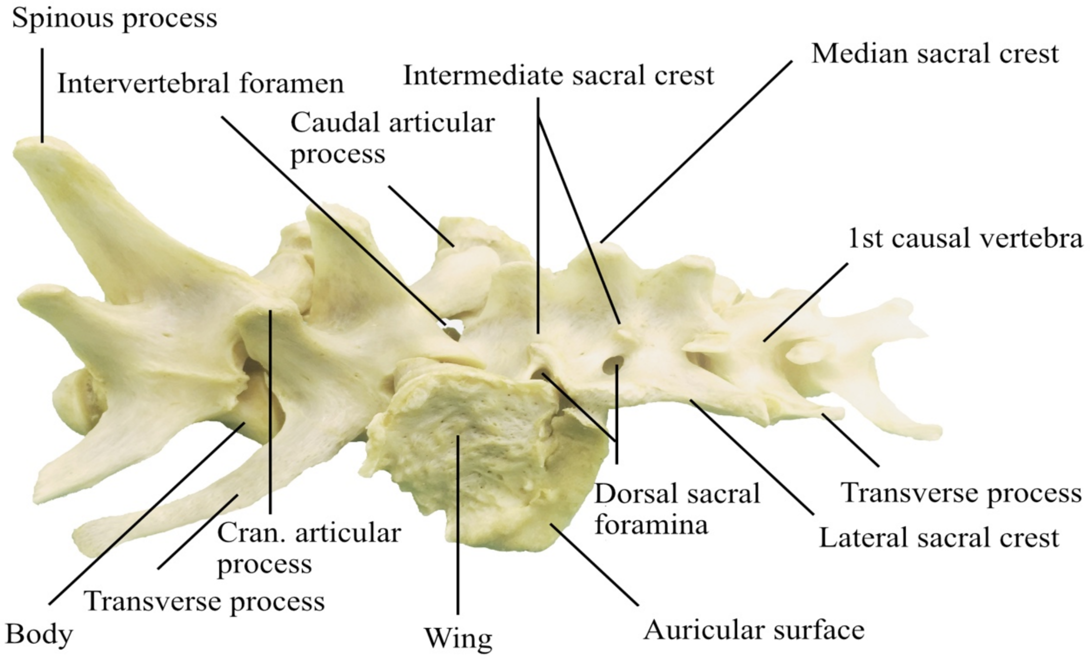


Fig. 2-2. Caudal lumbar vertebrae and sacrum, left lateral aspect

2.1.3 Sacral vertebrae

The **sacrum** *(os sacrum)* is formed from fused bodies and processes of the three **sacral vertebrae** *(vertebrae sacrales).* This bone is situated between the ilia and articulates with them. It has dorsal and pelvic surfaces, a cranially expanded **base** *(basis ossis sacri)* cranially, two **lateral parts** *(partes laterales)*, which enlarged by the sacral wings *(alae ossis sacri)* and a caudal extremity-apex *(apex ossis sacri)* (Fig. 2-2) (Adams 2003, König et al. 2013).

The **body** of the first segment is larger than the rest two bodies combined. These three bodies are united to present a concave ventral surface.

The **dorsal surface** *(facies dorsalis)* bears a **median sacral crest** *(crista sacralis mediana),* which is formed by the fusion of the three spinous processes; it also bears two pairs of **dorsal sacral foramina** *(foramina sacralia dorsalia)*, which transmit the dorsal branches of the sacral nerves and vessels (Fig. 2-3). The **intermediate sacral crest** *(crista sacralis intermedia)* represents the fused mamilloarticualr processes (Fig. 2-2). The caudal extremity of the sacrum, known as the **apex** *(apex ossis sacri),* articulates with the first caudal vertebra (Cd1). Occasionally the Cd1 is fused to the sacrum.

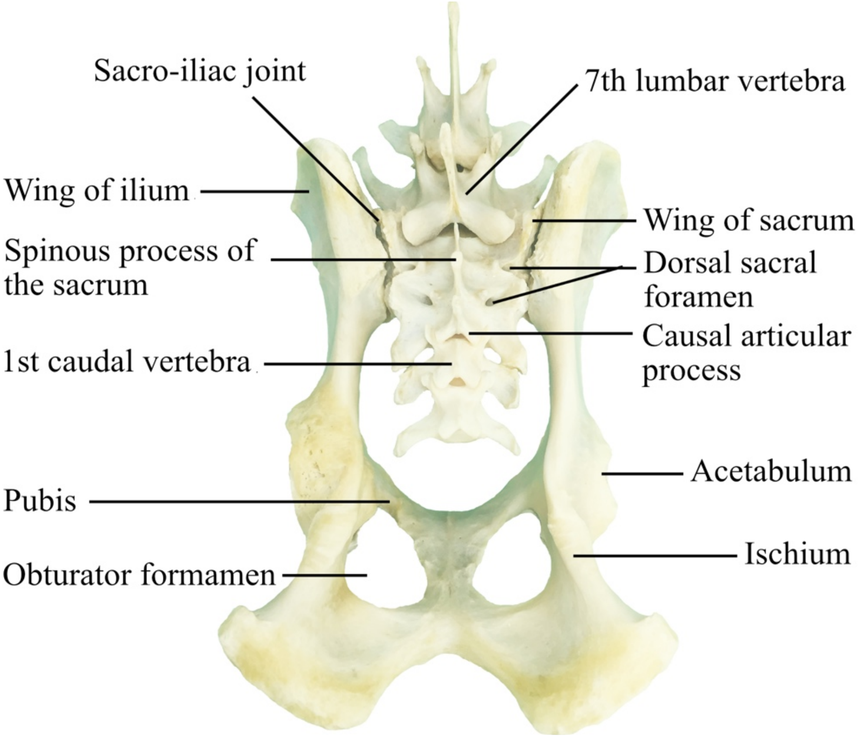


Fig. 2-3. Lumbar and sacral vertebrae with pelvis, dorsal aspect

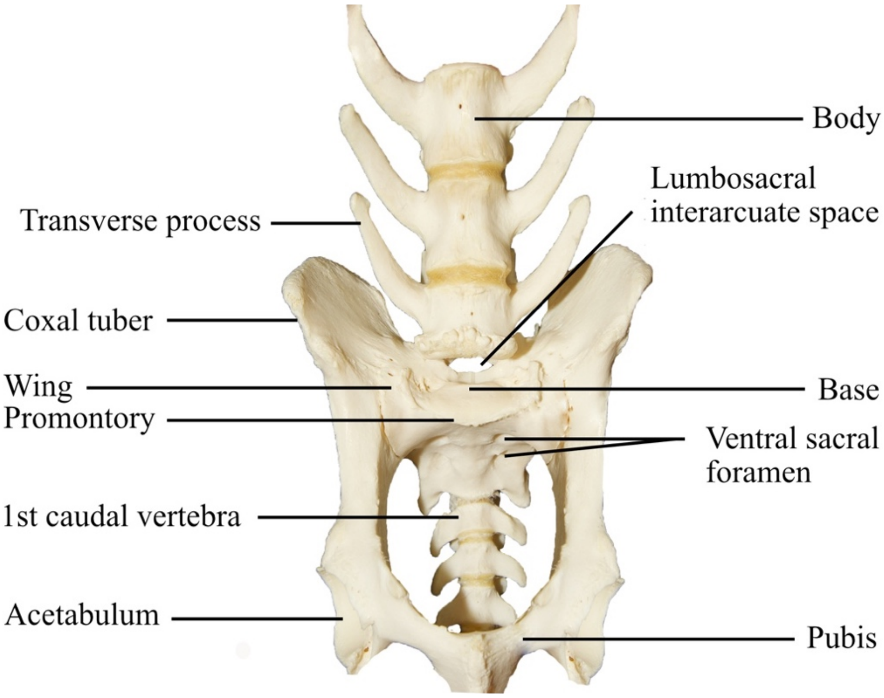


Fig. 2-4. Lumbar and sacral vertebrae with pelvis, ventral aspect

The **pelvic surface** *(facies pelvina)* of the sacrum is smooth and slightly concave. Two pairs of **pelvic sacral foramina** *(foramina sacralia pelvina),* larger than the dorsal foramina, are situated laterally to the fused sacral bodies (Fig. 2-4) (Evans 1993, Evans et al. 2000).

Lateral to the pelvic sacral foramina are the **lateral parts** *(pars lateralis)*, which are formed by three fused transverse processes of the sacral vertebrae. The first and part of the second sacral transverse processes are greatly enlarged and modified for articulation with the ilium. The third and part of the second segment form the narrow and thin **lateral sacral crest** *(crista sacralis lateralis)* (Fig. 2-2) (Evans 1993, Evans et al. 2000).

The **wing of the sacrum** *(ala ossis sacri)* is the enlarged lateral part that bears a large, rough semilunar surface, the **auricular surface** *(facies auricularis),* which articulates with the ilium. The **sacroiliac joint** *(articulatio sacroiliaca)* is a combined synovial and cartilage joint. The crescent-shaped synovial part of the joint lies caudoventral to the cartilaginous part. The roughened area of the cartilaginous joint is the sacral tuberosity, where an interosseous ligament unites the wing of ilium and sacrum. Instead of mobility, this joint is an articulation of stability. The stabilization is gained via the dorsal and ventral sacroiliac ligaments as well as the sacrotuberous ligament. The bilateral wings of the ilia articulate with the bilateral broad wings of the sacrum. The apposed **auricular surface** are covered by cartilage and their margins are united by a thin joint capsule (Fig. 2-1 and 2-2) (Evans 1993, Evans et al. 2000).

The **base of the sacrum** *(basis ossis sacri)* project cranially. The ventral part of the base has a transverse ridge, the **promontory** *(promontorium).* This, with the ilia, forms the dorsal boundary of the pelvic inlet (Fig. 2-4) (Evans 1993, Evans et al. 2000).

2.1.4 Pelvis

The pelvis of the dog consists two hip bones. Each **hip bone** *(os coxae)* is composed of four distinct bones: **ilium**, **ischium**, **pubis**, and **acetabular bone**. The **ilium** *(os ilium) is* the largest and most cranial of these bones, which articulates with the sacrum. The **ischium** *(os iscii)* is the most caudal bone, whereas the **pubis** *(os pubis)* is situated ventromedial to the ilium and cranial to the large obturator. The **acetabulum** *(os acetabuli)* is formed where these three bones meet and receives the head of the femur in forming the hip joint (Fig. 2-3) (Evans 1993, Evans et al. 2000).

2.1.5 Radiographic anatomy

For the purpose of observing the features of vertebrae in radiographs, Figure 2-5 (A and B) shows the radiographic anatomy in a 6-year-old female Labrador Retriever.

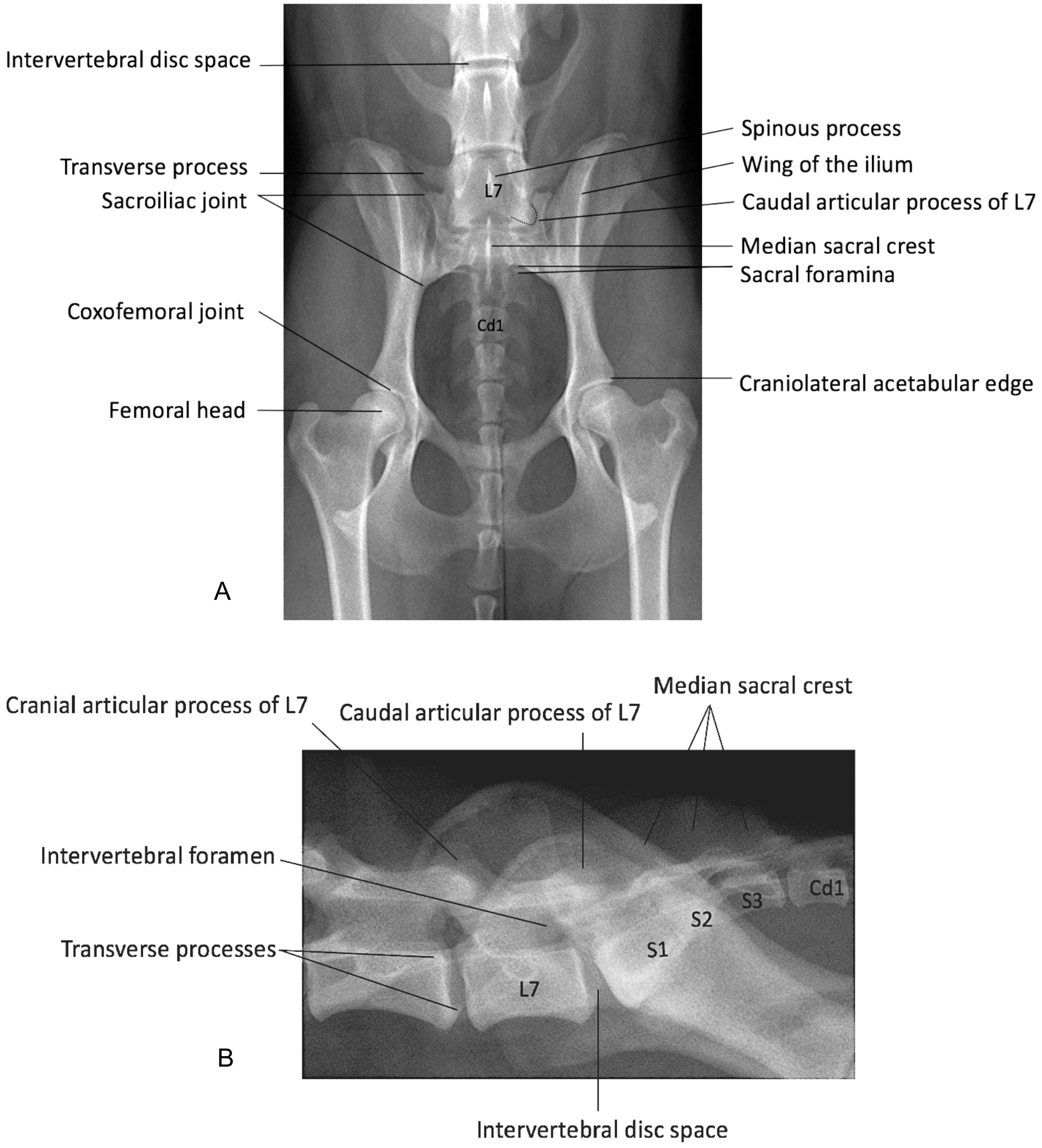


Fig. 2-5. VD (A) and lateral (B) views of labeled radiographs of a 6-year-old female Labrador Retriever

2.2 Development of the vertebrae

To understand the common congenital abnormalities, three aspects of the spinal column and spinal cord development are important. They are the formation of the neural tube, the segmentation of the somites and the ossification of the vertebrae (Bailey 1975).

In the early embryo, the three primary germ layers: endoderm, mesoderm and ectoderm are formed. Subsequently, induced by the notochord, an area of ectodem along the mid-dorsal line of the embryo thickens to form the neural plate. The neural pate folds and forms the neural tube, which develops into the spinal cord. As the neural tube is forming, transverse clefts divide the mesoderm into bilaterally paired segments, which are termed somites. Vertebrae and ribs are derived from the sclerotome of the somites. Each sclerotome split into two populations, the cranial and the caudal segments. The densely packed caudal half of one sclerotome joins the loosely packed cranial half of adjacent sclerotome to form the vertebral anlage. An image copied from FLETCHER and WEBER (2004) that represents this description optimally is seen in figure 2-6. This process is called resegmentation and explains why the spinal ganglia and ventral roots of the spinal nerves are situated between vertebrae, and the originally intersomitic arteries now penetrate and supply each vertebral body. The caudal, dense population give rise to the neural arch and related parts of each vertebra and also the IVD except its nucleus pulposus which is a remnant from the notochord. The cranial, less dense population forms the most of vertebral body. The development of sclerotomes as well as chondrification continue in a craniocaudal sequence (Bailey 1975, Fletcher and Weber 2004, Hyttel et al. 2016).

In the dog, vertebral ossification begins during the sixth week of gestation with three primary ossification centers: one for the centrum and one for each neural arch. Primary ossification centers are positioned in the middle of each vertebral body and laterally in the base of each neural arch. Subsequently, secondary ossification centers appear during the postnatal development to form the vertebral processes and end plates (Bailey 1975, Hyttel et al. 2016). Sacral vertebrae are slow to ossify. The additional ossifications are found lateral to the first sacral vertebra (S1) and the second sacral vertebra (S2), which develop into the ventral parts of the wings of the sacrum; and the dorsal portions of the sacral wings correspond to the transverse processes, which develop from the paired ossification centers out of the neural arches (Frenkel 1873, Winkler 1985). The additional ossification centers forming the ventral aspect of the transverse processes of S2 are present in large breeds, occasionally in midsized and small, but never in toy breeds (Breit and Künzel 2001). Three sacral vertebral segments are combined during subsequent growth and fusion. The sacrum is dominated by S1, which has a large auricular surface for the articulation with the ilium (Evans 1993).

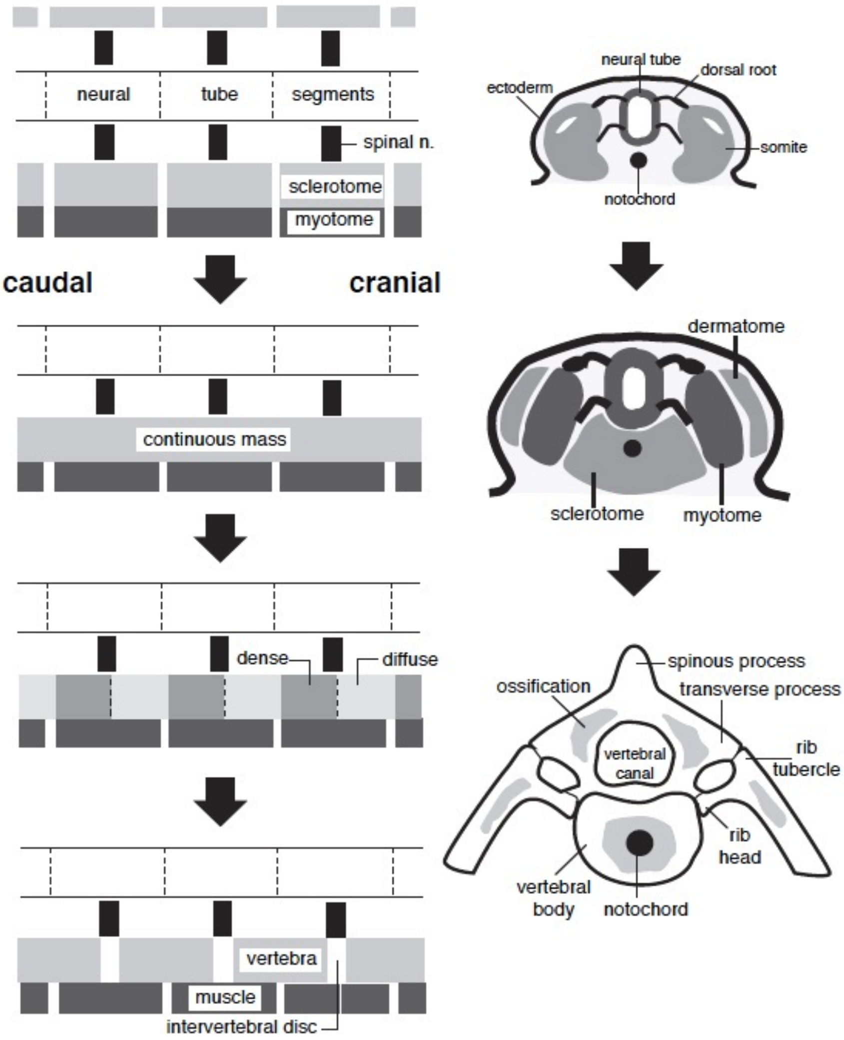


Fig. 2-6. The development of sclerotomes to vertebrae (figure copied from Fletcher and Weber 2004)

2.3 Biomechanics of lumbosacral vertebrae

The canine vertebral column has various functions: to support the head, to act as a place of attachment for the limbs, to transfer force from the limbs to the rest of the body, and to support the viscera (Currey 2014). In addition, the biomechanical functions allow movements between vertebral bodies, load bearing and transmission and protection of the spinal cord and nerve roots (Panjabi 1992, Mcgowan et al. 2008).

2.3.1 Lumbosacral joint (LSJ)

The lumbar facet joints are synovial joints that mostly display sagittal alignments interlocking of the caudal and cranial articular processes (Mcgowan et al. 2008). These facet joints provide stability during flexion and extension, and prevent axial angulation of the vertebral unit (Elder et al. 2009). Unlike sagittal aligned articular surface of other lumbar vertebrae, those of L7 are angled at approximately 50° to the sagittal plane. Flexion and extension is significant at this articulation (Grussendorf 1991, Mcgowan et al. 2008).

One study on osteological feature of LS junction of different breeds shows an inefficient facet geometry in large breeds, especially in the German Shepherd Dog (GSD). Craniolateral extension of the articular surface (AS) of S1 is significantly higher in large breeds than those in small breeds. In GSD, 45% of the AS extent cranially beyond the caudal vertebral endplates. This condition allows the cranial articular processes of S1 to reach the spinal ganglion, which is situated in the caudal vertebral notch of L7 and result in low back pain. Another value β L7 (degree of deviation of the AS from a sagittal in a horizontal plane) in GSD is also lower (11.1° + 4.6°) than other breeds, which indicate that the facet joint are more craniocaudally aligned. This condition does not prevent the cranial articular processes of S1 from gliding cranially which is facilitated by the absence of accessory processes (Grussendorf 1991, Breit and Künzel 2001). In addition, high $\alpha L7^1$ (degree of deviation of the plane aspect of the AS from a horizontal in a transverse plane) values indicate biomechanical inefficiency since force vectors inappropriately meet the lumbar AS. $\alpha L7^1$ is significantly lower in small breeds than large breeds. 63% of the small dogs and 50% of the large dogs show a flat AS ($\alpha L7^1 = \alpha L7^2$). 37% of the small dogs and 50 % of the large dogs show a convex AS ($\alpha L7^1 > \alpha L7^2$), which is the osteological evidence of axial angulation. Thus, an increased AS extension with a sagittal alignment (β L7＜; α L7＞) will result in hypermobility, which is frequently noticed in GSDs (Breit and Künzel 2001).

Another study found there are three types of facet joint shapes on CT scan: straight, angled and round (Fig. 2-7). The GSDs have almost exclusive straight facets at L5- S1, whereas other breeds have primarily rounded facet joint shapes at L5- L6 and straight facet joints at the LS level. Facet joint angle in the transverse plan2e at L5- S1 are significantly smaller in GSDs than in other breeds. However, the facet joint angles increase suddenly with a larger angle difference between L6- L7 and L7- S1 in GSDs (19.7°) than in other breeds (11.3°). They hypothesize that the large variation in the angel between the straight, vertically and sagittally oriented facet joints of the lumbar region and the wide open facet joint angles of the LS region may cause increased angulation load on the LS disk (Seiler et al. 2002).

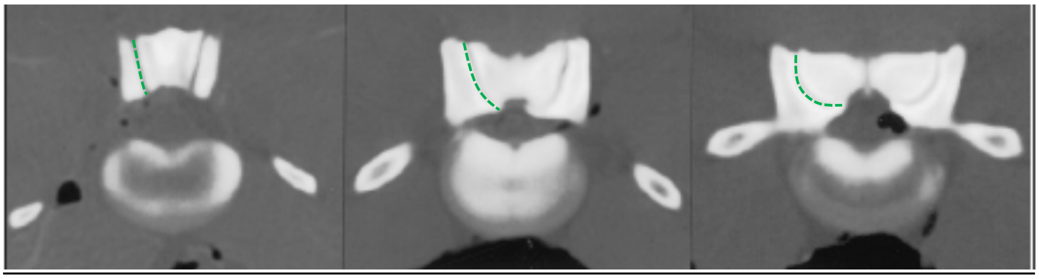


Fig. 2-7. CT scans through the middle of the IVD space in dogs (figures copied from Seiler et al. 2002). The green dotted lines show different shapes of the facet joint space which is classified into straight (left), angled (middle), or round (right).

An in vitro study of three-dimensional motion pattern describes the degree of main and coupled motion for the caudal lumbar and LS vertebrae (L4- S1) in 9 GSDs and 16 dogs of other breeds with similar body weights and body conditions. The degree of main motion from L4 to S1 is showed in table 2-1. The x, y and z axes are oriented as shown in figure 2-8. The highest degree of main motion in flexion- extension is at L7- S1; the greatest amount of the lateral bending is at L4- L5 and there is very little axial angulation at all lumbar segments (Benninger et al. 2004). A more recent in vitro study from the same authors determined that flexion-extension is coupled with slight axial angulation. It increases from cranial to caudal. Followed by L4- L5, the coupling of motion is greatest in the LS region during lateral bending and axial angulation (Benninger et al. 2006).

An in vivo kinematic study of canine lumbar vertebral column reveals the following values during gait: axial angulation 1.3°, lateral flexion 4.25°, and flexion-extension 1.8°. In addition, axial angulation is coupled with contralateral bending (Schendel et al. 1995, McGowan et al. 2008).

Table. 2-1. Mean ± SD values for main motion at all levels of the caudal lumbar and LS vertebral region of 25 dogs (Benninger 2004)

Vertebral level	Flexion-Extension (∠ °)	Axial rotation (∠ °)	Lateral bending (∠ °)
L4-5	7.2 ± 2.0	1.9 ± 0.9	19.0 ± 4.0
L5-6	6.8 ± 1.9	0.8 ± 0.6	4.1 ± 3.4
L6-7	11.8 ± 2.9	0.7 ± 0.5	7.1 ± 3.5
L7-S1	37.0 ± 5.7	2.0 ± 1.2	9.5 ± 2.6

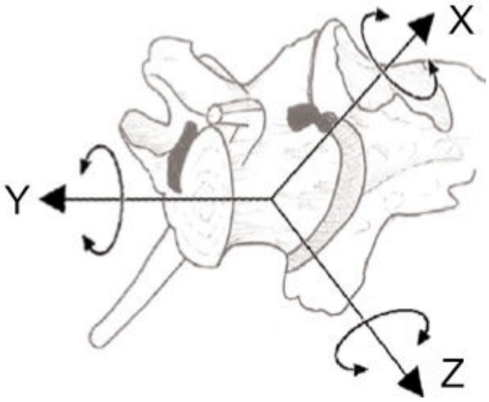


Fig. 2-8. Three-dimensional system of lumbosacral motion (modified based on figure from Benninger 2004). Motion around the x-axis is flexion (+x) and extension (-x), around the y-axis is axial angulation to the left (+y) and the right (-y), and around the z-axis is lateral bending to the right (+z) and left (-z).

2.3.2 Sacroiliac joint (SIJ)

The canine SIJ is formed by a synovial part and an interosseous part (Evans 1993). The function of SIJ is to bear the weight and transmits the propulsion from the pelvic limbs to the spine during locomotion (Breit and Künzel 2001). Studies based on the biomechanics of the hip joint have been made to indicate that in a 4-legged stance, approximately 30% to 40% of the body weight is distributed to the pelvic limbs (Prieur 1980, Arnoczky and Torzilli 1981, Budsberg et al. 1987). However, during locomotion, the hip joint is subjected to force approximately three times of body weight (Prieur 1980). Since weight bearing is transmitted through the coxofemoral joint, acetabulum, and the ilium to the sacrum and lumbar vertebrae, the load on SIJ is suspected to be similarly high and it is considerably dependent on body conformation, body weight and activity (Cook et al. 1996, Breit et al. 2002).

Alignment of the wings of the sacrum affects the mechanical properties and loading capacity of the SIJ. It is basically sagittal, with various obliquity of alignments between breeds. In dogs, the SIJ is aligned almost sagittal and may be more vulnerable to loading forces. The sagittal aligned wings of the ilium and sacrum make lateral translation nearly impossible; however, there may be some varying amounts of craniocaudal translation as accessory motion, which depends on the conformation of the dog (Breit and Künzel 2001). The sagittally aligned SIJs are firmly united by fibrocartilage and SI ligaments (Evans 1993). Functionally, the fibrous fascicles prevent the sacrum from excessive ventral slippage. When loading forces exceed the elastic limit of the supporting soft tissue, joint laxity may occur. It is manifested as loss of stability and ventral slippage of the sacrum (Gembardt 1974).

In a postmortem study, the sagittal inclination of the sacral wings is significantly lower and therefore, the SIJ is biomechanically less efficient in large breed dogs than in small breed dogs. In this study, it is found that the lowest inclination (almost sagittal alignment) of the sacral wings is evident in GSDs (Breit and Künzel 2001).

Stability and mobility of the SIJ are affected by the size of the SI contact area, the ratio between sacral tuberosity and auricular surface, the degree of coverage of the sacral alae by the wings (α Sac) and the degree of their craniocaudal interlocking (β Sac^1, β Sac^2) (Fig. 2-9). Relative to body weight, disproportionately low values of the size of the SI contact area are present especially in large dogs. This condition results in higher forces exerting on the SI ligaments. Also, in large dogs, a low proportion of sacral tuberosity with respect to auricular surface is present. Thus, less interosseous ligament area may place more strain on the SI ligaments during locomotion. Moreover, lower inclination angle of α Sac increases the potentiality for dorsoventral translation. Low values of β Sac^1 and β Sac^2 increase the potentiality for craniocaudal translation. These biomechanically inefficient low values of α Sac and βSac^1, which are found especially in large breed dogs, are combined with remodeling of the flat sacral contact area into a sacral concavity. This concavity improves interlocking between sacrum and ilium in order to reduce craniocaudal translation (Breit and Künzel 2001).

Measuring the ratio of ventral-to-dorsal transverse diameters between the wings of the sacrum on VD radiographic views, the VD ratio is significantly higher in Rottweilers than in Golden Retrievers and GSDs. It denotes a more oblique alignment of sacral wings in Rottweilers and an almost sagittal alignment in GSDs and Golden Retrievers (Breit et al. 2002).

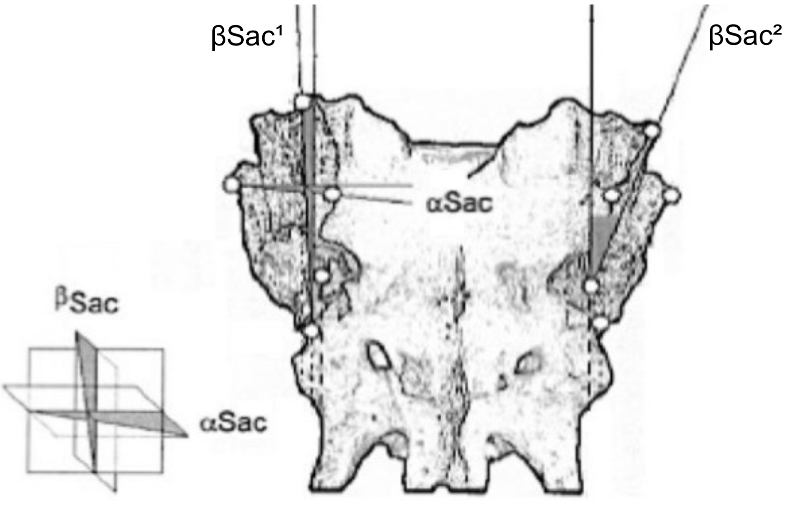


Fig. 2-9. Inclination angles of the wings of the sacrum in a dorsal view (modified based on figure from Breit and Künzel 2001)

2.4 Transitional vertebrae

2.4.1 Definition of transitional vertebrae

In domestic animals and human, it is common to find both numerical and morphological variation at the transitional point in the main vertebral junctions (Winkler 1985).

The transition, from one vertebral segment to the adjacent vertebral segment, results from phylogenetic variation. Two adjacent vertebrae that form the junction may be fixed imprecisely, which can lead to a slightly cranial or caudal shift (Ziegler 1990). At the junction of the major divisions of the vertebral column, a single vertebra may possess characteristics typical of both divisions This abnormal vertebra is termed a “transitional vertebra” and has been found at the cervicothoracic, thoracolumbar, lumbosacral (LS) and sacrococcygeal (SC) junctions (Morgan 1968, Morgan 1972, Larsen 1977). A transitional vertebra is a congenitally malformed vertebra. Anomalies are more commonly seen at the arches and transverse processes and rarely in the vertebral bodies. Changes of transitional vertebrae can be unilateral or bilateral (Morgan 1968). The transitional vertebrae may have varying abnormal segments, but the bone tissue remains normal regardless of the severity of change in the size or shape of the bone (Morgan 1999 a).

Variations in the cervicothoracic or thoracolumbar junction have not been found to be associated with clinical signs (Morgan 1968, Newitt et al. 2008), whereas, an increased incidence of LTV have been described in patients with CES (Morgan et al. 1993, Flückiger et al. 2006). Furthermore, unilateral changes of LTV is a risk factor for unilateral hip dysplasia (Larsen 1977, Morgan 1999 b, Newitt et al. 2008).

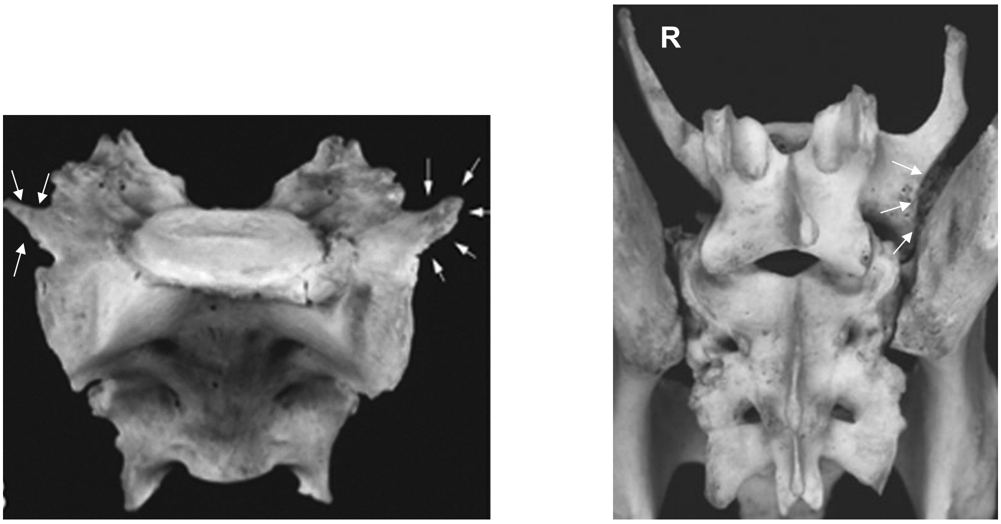
2.4.2 Location of transitional vertebrae

From MORGAN’s (1968) point of view, transitional vertebrae occurred more often in caudal direction than in cranial direction and the most common variation appeared at the SC junction. Some other studies detect that transitional vertebrae at the LS junction are observed more frequently than that at the thoracolumbar junction (Blumensaat and Clasing 1932, Morgan and Stephens 1985). On the contrary, some studies proposed that the incidence is higher at the thoracolumbar junction (Lang 1972, Ziegler 1990).

2.5 Lumbosacral transitional vertebrae (LTV)

2.5.1 Definition of LTV

The term “lumbosacral transitional vertebrae’’ is defined as an abnormal vertebra situated between the LNLV and the FNSV. It is a congenital anomaly and has morphological characteristics of both a lumbar and a sacral vertebra (Morgan 1968, Damur-Djuric et al. 2006, Flückiger et al. 2006). In case of LTV, alterations in the dorsal lamina and transverse processes have greater degrees (Fig. 2-10), while less changes are seen in the shape of the vertebral bodies. A unique feature of LTV is that a new disc space is created between the normally fused first and second sacral segments. Moreover, LTV are often seen in combination with variations in the length of the SI attachment (Fig. 2-10B). The nature of the SIJ at the level of the anomalous segment vary from a strong iliac attachment, with a wing-like lateral processes, to a weakened iliac attachment, with a lumbar-like lateral processes. Weakening of the SI attachment may lead to premature IVD degeneration in LS region as well as occurrence of CES (Morgan 1999 b).



A

B

Fig. 2-10. Variations of transverse processes of a LTV (modified based on figures from Breit et al. 2003). (A) cranioventral view of the sacrum in a 6-year-old female GSD. This dog has a lumbarized S1, which is categorized as bilateral rudimentary transverse processes (small arrows). These transverse processes are intermediate type with partial fusion to the ilium and their tips remains free. (B) ventral view of the sacrum in an 8-year-old female GSD with sacralization of L7. The transverse process of the last lumbar vertebra on the left side is partially fused to the ilium (intermediate type) (small arrows) and the one the right side is a lumbar type of transverse process This unilateral variation changes the length of the SI attachment.

2.5.2 Symmetry of LTV

LTV can be symmetric and asymmetric. Symmetry of LTV is usually based on morphological characteristics of transverse processes and its combination with variation in the length of the SI attachment. They may remain in alignment with the adjacent vertebrae or may be deviated to the right or to the left (Flückiger et al. 2006).

In light of DAMUR-DJURIC et al. (2006), the transverse processes of a LTV are classified as three types depending on their attachment to the ilium: Type 1 is a lumbar type with no attachment to the ilium. It is either a normal lumbar transverse process or it is shorter and wider based; the tip may be deformed and project cranially, laterally or even caudolaterally (Fig. 2-10B). Type 2 is an intermediate type. Its base is shorter and wider than that of in type

1, while the tip is narrower. The transverse process is partially attached to the ilium and often to the sacrum, but the tip always remains free (Fig. 2-10A and B). Type 3 is a sacral type. This transverse process is a complete sacral Process, which shows the characteristics of a sacral wing and has a broad attachment to the ilium and often to the wing of the sacrum. There is no free tip. Slight differences of the transverse processes within the same type are not subdivided further. Thus, LTV can be divided into six groups depending on the characteristics of the transverse processes Symmetric LTV have the same type transverse processes on both sides (1/1, 2/2, 3/3) , whereas asymmetric LTV have different type of transverse processes on the right and left side (1/2 or 2/1, 1/3 or 3/1, 2/3 or 3/2).

A marked asymmetry in the pelvic attachment of the anomalous segment is noted by one side being a large wing-like Process that fused with ilium, and a thin, lumbar-like transverse process that has no iliac attachment on the contralateral side. This type of SI attachment is weakened and the LS disc is stressed abnormally. It results in premature LS disc degeneration in combination with spinal canal stenosis, which can lead to CES. Furthermore, the degree of pelvic obliquity varies somewhat depending on the nature of the SI attachment. All asymmetric SI attachments may cause angulation and/ or angulation of the pelvis. If the dog has LTV with asymmetric SI attachments, the resulting pelvic angulation and/ or angulation influences the manner of the development of joint luxation or secondary osteoarthrosis associated with CHD (Morgan 1999 b, Morgan et al. 2000).

Distribution between symmetric and asymmetric LTV has been investigated as well. According to BREIT et al. (2003), out of 145 dogs 11 (7.6%) had symmetric and 14 (9.7%) had asymmetric LTV in their study. Another study observed that the incidence of both forms were similar, in which the prevalence of symmetric LTV was 49.3% and that of asymmetric LTV was 50.7% (Damur-Djuric et al. 2006). JULIER-FRANZ (2006) and WIGGER et al. (2009) found an even distribution of symmetric (12%) and asymmetric (10%) LTVs in GSDs. Contrary to these studies, KOMSTA et al. (2015) obtained the conclusion that symmetric LTV (15.6%) occurred more frequently than asymmetric LTV.

2.5.3 Lumbarization and sacralization

In LTV, the transition is either when the first sacral segment in some parts (cranial articular processes and transverse processes) similarities to a lumbar vertebra (lumbarization) or when the last lumbar vertebra possesses morphological characteristics of the sacral vertebrae (sacralization) (Winkler and Loeffler 1986). Complete symmetric lumbarization or sacralization contribute to increase or decrease in the number of presacral vertebrae (i.e. numerical vertebral variations) respectively (Blumensaat and Clasing 1932, Breit and Künzel 2002). Before either the term lumbarization or sacralization can be used, the total number of presacral segments must be known in order to determine the direction of the vertebral shift (Junghanns and Schmorl 1957, Morgan 1968, Morgan et al. 1993).

In lumbarization, the S1 is separated completely or incompletely from the sacrum and has acquired a typical transverse process of a lumbar vertebra on one or both sides (Junghanns and Schmorl 1957, Morgan 1968). In human, other varying degrees of SI segment lumbarization can be observed, such as the formation of an anomalous articulation of S1 rather than fusion to the remainder of the sacrum, well-formed lumbar-type facet joints, a more squared appearance in the sagittal plane as well as a well-formed fully-sized disk, rather than the smaller sized disk typically seen between S1 and S2 (Konin and Walz 2010).

In dogs, the dorsal lamina and transverse processes are affected to the greatest degree, but less alterations are seen in the shape of the vertebral body (Morgan 1999 b). With lumbarization of the first sacral segment, a cranial shift of the first caudal segment occurs often concurrently so that the number of sacral segments remains three (Morgan et al. 1993).

In human medicine, sacralization is defined as either the last lumbar vertebra in some parts, especially transverse processes, resembling the wing of the sacrum on one side or both sides, or completely posing the last lumbar segment as the sacrum (Blumensaat and Clasing 1932, Junghanns and Schmorl 1957). An intermediate stage in absorption of the last lumbar vertebra by the sacrum in the shortening Process, is characterized by enlarged transverse processes of the last lumbar vertebra and variation of the planes of the articular processes . from medial to transverse position (Willis 1929).

In cases of sacralization in dogs, transverse processes of the last lumbar vertebra take on characteristics of the sacral ala and fuse with the ilium. All changes can involve one or both sides and have different degree of the variations (Morgan 1968). A different definition of sacralization describes that bony fusion changes at the LS segment are caused by spondylosis deformans or ankylosing spondylitis (Pommer 1933). Another author defines sacralization as a fusion or ossification of the SIJ (Hoerlein 1965). However, these two definitions are based on degenerative changes or possible secondary changes to trauma, but not on congenital changes (Morgan 1968). When the sacralization of the last lumber vertebra is unilateral, an oblique pelvic axis is present with varying degrees. It makes it nearly impossible to obtain a perfect position for hip dysplasia evaluation (Larsen 1977).

2.5.4 Incidence of LTV

The prevalence of LTV in the dog population varies from 2.3% to 40.4% (Winkler and Loeffler 1986, Morgan 1999 b, Damur-Djuric et al. 2006, Wigger et al. 2009, Lappalainen et al. 2012). It results from the different LTV classification schemes, the breed of the dog and the sample population (Fialová et al. 2014). Among lumbarization and sacralization in dogs, MORGEN (1968) detected the incidence of lumbarization was lower (0.7%), comparing with that of sacralization (2.1%). LARSEN (1977) found that transitional vertebrae at LS junction was observed as an incidental finding in 552 of 24,463 (2.3%) pelvic radiographs submitted for CHD. Moreover, in his research, the most common type of LTV was sacralization of the seventh lumbar vertebra.

In one study, the prevalence of LTV among the dog population was 2.5% in the USA (Morgan 1999 b). In Europe, incidence may range from 3.5% in Switzerland (Flückiger et al. 2006), 5% in Germany (Winkler and Loeffler 1986), 10% in the Czech Republic (Fialová et al. 2014), 17.2% in Austria (Breit et al. 2003), to 40.4% in Finland (Lappalainen et al. 2012).

2.5.5 LTV and breed

The prevalence of LTV varies from 0% to 29% between breeds with 50 or more dogs per breed. The following table shows the occurrence of LTV in different breeds (Table. 2-2).

Table. 2-2. Literature review of the prevalence of LTV in various dog breeds (50 or more dogs per breed group)

Breed	Examined dogs	LTV (n)	LTV (%)	Literature
Airedale Terrier	448	7	1.6	Winkler (1985), Winkler et al. (1986)
Alaskan Malamute	90	4	4.4	Winkler (1985), Winkler et al. (1986)
Bernese Mountain dog	1588	182	11.5	Herling (1996)
Bobtail	624	44	7.1	Winkler (1985), Winkler et al. (1986)
Brittany Spaniel	643	38	6	Larsen (1977)
Chow-Chow	55	9	16.4	Ziegler (1990)
Cocker Spaniel	1315	56	4.3	Winkler (1985), Winkler et al. (1986)

Table. 2-2. Literature review of the prevalence of LTV in various dog breeds (50 or more dogs per breed group)

Breed	Examined dogs	LTV (n)	LTV (%)	Literature
Collie	71	6	8.5	Ziegler (1990)
	50	6	12	Fialova et al. (2014)
Dachshund	1034	113	11	Ziegler (1990)
Dobermann Pinscher	487	18	3.7	Larsen (1977)
	62	12	19.4	Ziegler (1990)
German Boxer	3300	167	5.1	Winkler (1985), Winkler et al. (1986)
	174	12	6.9	Ziegler (1990)
	2444	184	7.5	Herling (1996)
German Shepherd dog	2596	111	4.3	Larsen (1977)
	5682	632	11.1	Winkler (1985), Winkler et al. (1986)
	247	19	7.7	Morgan et al. (1985)
	974	152	15.6	Ziegler (1990)
	161	33	20.5	Morgan et al. (1993)
	4386	1270	29	Julier-Franz (2006)
	205	53	25.9	Fialova et al. (2014)
German Wirehair Pointer	69	7	10.1	Ziegler (1990)
Golden Retriever	2613	20	0.8	Larsen (1977)
	50	11	22	Breit et al. (2003)
	133	5	3.8	Fialova et al. (2014)
Great Dane	52	5	9.6	Ziegler (1990)
Hovawart	51	1	1.9	Fialova et al. (2014)
Hungarian Vizsla	51	4	7.8	Fialova et al. (2014)
Labrador Retriever	2735	49	1.8	Larsen (1977)
	1018	37	3.6	Morgan et al. (1999)
Leonberger	479	32	6.7	Winkler (1985), Winkler et al. (1986)
Miniature Schnauzer	69	7	10.1	Ziegler (1990)
Poodle	350	29	8.3	Ziegler (1990)

Table. 2-2. Literature review of the prevalence of LTV in various dog breeds (50 or more dogs per breed group)

Breed	Examined dogs	LTV (n)	LTV (％)	Literature
Rhodesian Ridgeback	191	15	7.9	Larsen (1977)
	89	14	15.7	Fialova et al. (2014)
Rottweiler	69	0	0	Ziegler (1990)
	50	2	4	Breit et al. (2003)
	68	5	7.4	Fialova et al. (2014)
Saint Bernhard	334	28	8.4	Herling (1996)
Samoyed	73	4	5.5	Winkler (1985), Winkler et al. (1986)
Siberian Husky	1020	7	0.7	Larsen (1977)
	486	19	3.9	Winkler (1985), Winkler et al. (1986)
Yorkshire Terrier	230	15	6.5	Ziegler (1990)

2.5.6 LTV and gender

In human medicine, it is thought that the occurrence of LTV in men is twice as high as women (Blumensaat and Clasing 1932). In dogs, however, one study in Labrador Retriever shows that transitional vertebral segments are found more frequently in the female (4.2%) than in the male (1%) (Morgan et al. 1999). In another study, male dogs have higher occurrence of LTV than female dogs (Ziegler 1990). But in most investigations of LTV, there is a nearly equal occurrence between genders (Larsen 1977, Winkler 1985, Ziegler 1990, Morgan 1999 b, Damur-Djuric et al. 2006).

2.5.7 Morphological and radiographic characteristics of LTV

Diagnosis of LTV is based on morphological findings seen on radiographs. The basic radiographic changes describe the morphology of the vertebral segments but do not represent any changes of bony tissue. Thus, changes of vertebral shape, LS alignment and segmental attachment are necessary for diagnosing LTV. LTV can be recognized on both lateral and VD views (Morgan et al. 2000, Damur-Djuric et al. 2006). The radiographic findings of LTV on both lateral and VD views are summarized in table 2-3.

Table. 2-3. Radiographic findings of LTV on both lateral and VD views (Morgan 1999 b)

Lateral view	
a	Separation of the first sacral segment and the second sacral segment
b	Newly created disc space between the anomalous segment and the newly formed first segment
c	Abrupt decrease in the height of the spinal canal between the anomalous segment and the newly formed first segment
d	Union between the last sacral segment and first coccygeal segment
e	Separation between the last sacral segment and the first coccygeal segment

VD view		
a	Separation of the spinous process of the anomalous segment and the newly formed first sacral segments	
b	Variations of transverse processes of the anomalous segment	
	ⅰ)	symmetrical
		Bilateral wing-like sacral transverse processes with a strong iliac attachment, without pelvic obliquity
		Bilateral lumbar-like transverse processes with weakening of the iliac attachment, without pelvic obliquity
	ii)	asymmetrical
		Unilateral wing-like sacral transverse process and unilateral lumbar-like transverse process, without pelvic obliquity
		Unilateral wing-like sacral transverse process and unilateral lumbar-like transverse process, with pelvic obliquity
		Bilateral wing-like sacral transverse processes with asymmetrical iliac attachment

2.5.7.1 Morphological and radiographic characteristics of LTV on the lateral view

On lateral radiographs, typical findings of LTV are characterized by the separation of what are normally the first and second sacral segments. It causes an apparent caudal shifting of the last lumbar segment or “lumbarization“ of the first sacral segment. The width of the disc space between the last lumbar segment and the now separated anomalous segment is either well preserved or narrowed (Morgan 1999 b).

The height of the spinal canal is narrowed at the anomalous segment and the newly formed first sacral segment. The effective height of the spinal canal may be further compromised due to ventral slippage of the sacrum and dorsal protrusion of the LS disc (Morgan et al. 2000). The angulation of the floor of the spinal canal at the junction of the LNLV and the anomalous segment remains, but in some cases, it can be flattened (Morgan 1999 b, Morgan et al. 2000).

The character at the SC junction changes. A common pattern is that a sacrum consists of three segment when the Cd1 is fused to the sacrum. An intermediate pattern is identified by partial fusion of these two segments, leaving a narrow to slit-like disc space and thin vertebral endplates. Another more common pattern is that a sacrum is composed of only two segments, indicating that the Cd1 remains separated (Morgan 1999 b).

Secondary bony changes can be seen as the degenerative changes within the end plates adjacent to the old LS disc and spondylosis deformans (Morgan et al. 2000). These changes are best seen on the lateral views and provide further evidence of the instability of both the SIJs and the original LS disc that might be associated with the development of CES (Morgan 1999 b).

2.5.7.2 Morphological and radiographic characteristics of LTV on the ventrodorsal view

On VD radiographs, the most common finding is the separation of the spinous process of the first sacral vertebra (SP S1) from median sacral crest. In radiographs, the most cranial round to oblong radiodense shadow is separated and the caudal two shadows remain connected or are possibly joined the spinous process of the Cd1 (Morgan 1999 b).

The variations of transverse processes of the anomalous segment can be divided into patterns due to their symmetry. In the first pattern, transverse processes appear as symmetric wing-like or lumbar-like transverse processes without pelvic obliquity. As pattern 2, asymmetry is noted as one side being wing-like transverse process that fused with the ilium, and the other side being a lumbar-like transverse process However, the wings sometimes present bilaterally having an asymmetric SI attachment in length or in position (Morgan 1999 b). Moreover, ZIEGLER (1990) descried that in cases of lumbarization, the ventral or dorsal sacral foramina may not exist due to the separation of lateral parts between the first and second sacral segment. On the other hand, in cases of sacralization, a ventral or dorsal sacral foramen may be shapeless or normal round shape because of the partially or completely developed ventral alar element.

In conclusion, identification of LTV can be made on either the lateral or VD radiographic view. The most common finding is an isolated vertebral segment on the lateral view or an the isolated dense shadow cast by the spinous process of the anomalous segment on the VD view. The characters of the disc space and spinal canal size, and the presence of spondylosis deformans and sclerotic end plates are seen more clearly on the lateral view. The characters of variation of the transverse processes on the anomalous segment, the nature of the pelvic attachment and the presence of pelvic obliquity or angulation are observed more easily on the VD view (Morgan 1999 b, Morgan et al. 2000).

2.5.8 Classification of LTV

2.5.8.1 Classification of LTV in human medicine

In 1984, a radiographic classification system was described to identify 4 types of LTV in human medicine, which were based on morphologic characteristics. Type I. dysplastic transverse process: a, unilateral; b, bilateral. This type presents a large transverse process triangular in shape, measuring at least 19mm in width (craniocaudal dimension). Type II. incomplete lumbarization/ sacralization: a, unilateral; b, bilateral. This type exhibits an enlarged transverse process, which appears to follow the contour of the sacral ala and has a diarthrodial joint between itself and the sacrum. Type III. complete lumbarization/ sacralization: a, unilateral; b, bilateral. This type has a true bony union between the transverse process and the sacrum, instead of exhibiting a diarthrodial joint in type II. Type IV. mixed: Patients in this category present type II on one side and type III on the contralateral side. They have used the terms “ lumbarization and sacralization” because this classification system does not provide information relevant to accurate enumeration of the involved segment (Castellvi et al. 1984).

2.5.8.2 Classification of LTV in dogs

Later, several classification schemes have been reported in dogs. Some classifications are focused on the morphological characteristics of transverse processes and their relationship to the ilium seen on the VD views (Damur-Djuric et al. 2006, Lappalainen et al. 2012), or on the variation of the costal processes (this is synonymous with the transverse process used commonly in veterinary medicine) and ventral alar (Breit et al. 2003).

Two other studies are based on both variation of the shape of transverse processes and the separation of the sacral spinous processes. One basic classification scheme divides LTV into 4 types: type 0-seen as a normal shaped LS vertebrae; type 1- exhibiting a separated SP S1 from the median crest; type 2- symmetric formed transverse processes and LTV is separated from the sacrum, and type 3- asymmetric formed transverse processes and LTV is separated from the sacrum. In type 2, the length of the transverse process contacting the ilium can vary or it is not in contact with the ilium. In type 3 , the difference of this attachment is much more severe (Flückiger et al. 2009).

In another study, LTV are divided into five categories, based on VD radiographs. Type 1 and type 2 are the same as the classification scheme from FLÜCKIGER et al. (2009). Type 3 exhibits a symmetric alteration of L7 and/ or S1. Changes of L7 vary from shortened, laterally projected transverse processes to a complete fusion of L7 to the sacrum. Changes on S1 show either rudimentary transverse processes sitting cranially to the SIJs or completely isolated transverse processes appearing as a lumbar shape. Type 4 and type 5 are asymmetric forms. LTV with different shapes of transverse processes that are not contacting the ilium are categorized as type 4, with those in contact with the ilium are categorized as type 5 (Wigger et al. 2009).

2.6 LTV and canine hip dysplasia (CHD)

2.6.1 Definition of CHD

CHD was first described by SCHNELLE in 1935 (Schnelle 1935, Smith 1997, Broeckx et al. 2013, Martins et al. 2016). A very descriptive definition was introduced later, ” hip dysplasia is a varying degree of laxity of the hip joint permitting subluxation during early life, giving rise to varying degrees of shallow acetabulum and flattening of the femoral head, finally inevitably leading to osteoarthritis” (Henricson et al. 1966, Smith 1997). Another definition was given to describe CHD as a “ biomechanical disease representing a disparity between primary muscle mass and too rapid growth of the skeleton” (Johnson 1959, Alexander 1992). It is a multifactorial disorder caused by hereditary and environment factors. Large and giant breeds are most commonly affected (Morgan and Stephens 1985, Smith 1997, Ginja et al. 2009).

2.6.2 Radiographic evaluation and grading systems for classifying CHD

Radiographic examination of the hip joint is a widely accepted method of CHD diagnosis, however, other diagnostic procedures have also been recommended (Brass 1989). Radiographic changes of CHD are subdivided into primary and secondary signs. Primary signs include: joint space divergence, shallowing of the acetabulum and poor coverage of the femoral head. Secondary signs are related to varying degrees of arthrotic changes: subchondral sclerosis at the cranial acetabular margin, Morgan-line at the femoral neck where the joint capsule inserts, a circumferential femoral head osteophyte at the cranial femoral head, remodeling of the femoral head and neck, and periarticular osteophyte on the craniodorsal acetabular margin (Kirberger and Mcevoy 2016).

Today, three major radiographic schemes are used for radiographic scoring of CHD (Flückiger 2007, Verhoeven et al. 2007, Ginja et al. 2009). The Orthopedic Foundation for Animals (OFA) is used in the United States of America and Canada. Dogs must be older than 24 months for official scoring. A 7 point scoring system is used, dividing dogs in 2 groups of 3 grades. In normal hip conformation, hips are classified into excellent, good and fair. In dysplastic hip conformation, hips are classified into mild, moderate and severe CHD (Morgan and Stephens 1985, Corley 1992). The British Veterinary Association /Kennel Club (BVA/KC) is used in Britain, Ireland, and Australia / New Zealand. 9 specific morphological parameters are evaluated for each hip joint and each parameter is given a score between 0 (ideal) and 6 (worst). Thus the total score ranges from 0 to 106 (Britishveterinaryassociation 1994, Gibbs 1997). And the Fédération Cynologique Internationale (FCI) is mostly used in European countries, Russia, South America and Asia. The scientific committee of the FCI proposed a 5 scoring system from A- normal hip joint to E- severe hip dysplasia in 1978 and was adapted in 1991 to fit most current theories (Brass et al. 1978, Brass 1989, Brass 1993, Flückiger 1995). These 5 grades are given descriptively based on the size of Norberg angle (NA) (Henricson et al. 1966, Henry 1992), degree of subluxation, congruity of the femoral head and acetabulum, and signs of osteoarthrosis. The FCI is applicable to dogs aged between 1 and 2 years and is evaluated on each hip joint using mainly the correct radiographic position with extended hind limbs. Final grading is based on the worst hip joint (Morgan and Stephens 1985, Flückiger 2007).

Furthermore, there are other screening and scoring methods, such as a more quantitative Swiss scoring system, which can be transferred into a FCI degree (Flückiger 1995, Genevois et al. 2007, Flückiger 2008); and PennHIP method, which requires incorporating three radiographic views of dogs in the supine position: hip-extended, compression and distraction. The distraction views using the PennHIP distractor are used to estimate hip joint laxity by calculating the distraction index (DI), which is the distance between the geometric centers of the acetabulum and the femoral head. The DI ranges from 0 to >1, with 0 indicating full congruency of the hip joint and 1 representing complete luxation. This system can be used as early as at 4 months of age (Smith et al. 1990, Ginja et al. 2010).

2.6.3 LTV and CHD

To date, the interdependence between the presence of LTV and a hip joint dysplasia is still controversial. A LTV with an asymmetric SI attachment may favor pelvic angulation over its vertical axis, resulting in one acetabulum being in an “open’’ position with inadequate femoral head coverage, while the other one is in a “closed’’ position with more femoral head coverage (Morgan et al. 2000, Flückiger et al. 2017). Inadequate coverage of the femoral head may result subluxation, malformation of the hip joint, and secondary osteoarthritis (Flückiger et al. 2017). Also, the pelvic angulation resulting from asymmetric LTV can contribute to an unilaterally increased load on the hip and a detrimental development of the hip joint (Olsson and Kasstrom 1972, Larsen 1977, Damur-Djuric et al. 2006, Flückiger et al. 2009).

Asymmetric LTV can make it nearly impossible to obtain a perfect or correct position for hip dysplasia evaluation (Larsen 1977, Morgan 1999 b, Breit et al. 2003). Efforts have been given to determine whether LVT increase the risk of CHD development (Winkler 1985, Ziegler 1990) and whether an asymmetric LTV is involved in the development of an unilateral CHD (Citi et al. 2005). A latest research finds that with an asymmetric LTV, the hip joint is significantly more predisposed to subluxation and malformation on the side of intermediate or sacral-like transverse process, and on the side of the elevated pelvis. The hip joint is less affected on the side featuring a free transverse process (Flückiger et al. 2017). Another study shows that dogs with LTV have a higher frequency of severe CHD (Komsta et al. 2015). On the contrary, no apparent correlation between LTV and CHD is found in some other studies (Winkler and Loeffler 1986, Wigger et al. 2009). Detailed differences in the conformation of the LTV and the hip joint are also not taken into account in one study of unilateral CHD (Citi et al. 2005).

2.7 LTV and coxarthrosis

2.7.1 Definition of coxarthrosis

Arthrosis (used as a synonym for degenerative joint disease) is a common disease affecting diarthrodial joints and is usually not related to infection or systemic disease. It occurs normally secondary to abnormal mechanical conditions in the joint and subsequent degrading changes in the articular cartilages (Grondalen 1979, Carrig 1997). Osteoarthrosis has been divided into primary and secondary types. Osteoarthrosis in coxofemoral joints named coxarthrosis, which is a common sequel to CHD. Many of the changes seen in radiography are associated with secondary form, which is resulted from abnormal stresses on a hip joint (Kealy et al. 2011). Generally, degenerative changes develop in joints as they age, whereas dogs with CHD have radiographic signs of coxarthrosis before the geriatric period (Kealy et al. 1997, Smith et al. 2006).

2.7.2 Radiographic evaluation and grading systems for classifying coxarthrosis

Radiographic signs of coxarthrosis on VD extended- hip radiographs are: narrowing of the joint space, sclerosis of the subchondral bone at the cranial acetabular margin, lipping of the joint margins with osteophyte, remodeling of the femoral head and neck, radiolucent cyst, soft tissue mineralization, and displacement of the periarticular fascial planes (Olsson 1971, Kealy et al. 2011).

The Kellgren and Lawrence scoring system for osteoarthrosis is frequently used in human (Kellgren and Lawrence 1957). Also some studies give scores for coxarthrosis evaluation in dogs. One study focuses on 4 criteria to evaluate the extent and severity of osteoarthritis based on radiographic features in coxofemoral joints. The 4 criteria include sclerosis of the craniodorsal portion of acetabular subchondral bone, osteophytes on the cranial aspect of acetabular margin, osteophytes on the caudal aspect of acetabular margin, and femoral periarticular osteophytes. For each category, each hip joint is scored as following: disease-free, 0; mild osteoarthritis, 0.1 to 1.0; moderate 1.1 to 2.0; and severe 2.1to 3.0. The most severe score is used to assess the extent of osteoarthritis in coxofemoral joints (Kealy et al. 1997). Similar to this scoring system, each hip joint is scored for the same four phenotypes. The severity of each of these phenotypes ranges from 0 (none) to 3 (most severe) and the total score varies from 0 to 22 (Chase et al. 2005).

Another scoring system is described to assess the osteoarthritis of the hip joints. Each hip joint is scored separately. Score 1 is slight degenerative joint disease (DJD) with periarticular osteophytes only. Score 2 is mild DJD with periarticular osteophytes with femoral head remodeling. Score 3 is moderate DJD; the femoral head and the acetabulum are remodeling and periarticular osteophytes are present. Score 4 is severe DJD; beside all signs above, sclerosis of the subchondral bone of the femoral head and the acetabulum are also visible (Budsberg et al. 1999).

Moreover, descriptive osteoarthrosis scores of each hip joint are assigned numeric values (disease free-0, mild-1, moderate-2, and severe-3). Grade 0 is a normal hip joint; the femoral head and the acetabulum are congruent, the joint space is even, the craniolateral acetabular rim appears sharp or slightly flattened, and the femoral head is deeply seated in the acetabulum. Grade 1 is mild coxarthrosis; the femoral head and the acetabulum are incongruent, craniolateral acetabular edge is flattened, osteophytes and/ or sclerosis at the cranial acetabular rim may be detectable. Grade 2 is moderate coxarthrosis; the joint space becomes divergent or narrow, the craniolateral acetabular rim is broadly sclerosed, the femoral head and neck is remodeling. Grade 3 is severe coxarthrosis; the joint space is markedly narrowed and femoral head is deformed with numerous osteophytes and cysts (Brunnberg 1987, Brunnberg et al. 2014).

2.7.3 LTV and coxarthrosis

Pelvic obliquity results in a reduced acetabular coverage of the femoral head and an increased risk of femoral head subluxation. Subluxation is considered as a major risk factor for CHD and subsequent coxarthrosis (Flückiger et al. 2017). ZIEGLER (1990) reported that 73% dogs with LTV presented coxarthrosis, In a symmetric form of LTV, coxarthrosis was usually presented bilaterally, while in an asymmetric form of LTV, coxarthrosis was shown mostly on the opposite side, which had a stronger transverse processes deviation and a longer SI attachment. In the conclusion, the author proposed that osteoarthrosis may be caused by the load failure of the hip joint, especially in an asymmetric form of LTV.

2.8 LTV and cauda equina syndrome (CES)

2.8.1 Definition of CES

The term cauda equina refers to the terminal portion of the spinal cord and adjacent nerve roots. It includes the seventh lumbar nerve, the three sacral nerves, and the five caudal nerves (Denny et al. 1982, Lenehan 1983, Schulman and Lippincott 1988). CES is a neurological condition resulting from the compression, displacement or destruction of the nerve roots or their accompanying vasculature in the region of cauda equina. Common clinical signs of CES are LS pain, hyperesthesia, reluctance to sit up or jump, pelvic limb lameness, unilateral or bilateral paresis, muscle atrophy, tail paresis, and urinary or fecal incontinence (Lenehan 1983, Ramirez and Thrall 1998). Possible causes of CES include vertebral malformation, infectious disease, neoplasia, IVD protrusion, vascular compromise, degenerative spinal arthritis and idiopathic stenosis (Lenehan 1983, Schulman and Lippincott 1988).

The most common cause of cauda equina compression is degenerative lumbosacral stenosis (DLSS), which is an acquired narrowing of the vertebral canal and/ or intervertebral foramina. DLSS may be caused by congenital vertebral anomalies such as transitional vertebrae, IVD herniation, LS instability or malalignment, and neural compression by hypertrophy of adjacent soft tissue (Indrieri 1988, Bailey and Morgan 1992, De Risio et al. 2001). When the spine extends, the vertebral canal is narrowed by infolding of the ligamentous structures. A similar mechanism develops in the intervertebral foramina in that narrowing occurs as the spine is extended and opening occurs as the spine is flexed. When spinal stenosis has developed and the ligaments have hypertrophied, extension of the spine will further compress the cauda equina (Tarvin and Prata 1980).

2.8.2 Radiographic findings of CES

Although plain radiography has a poor accuracy in diagnosing CES, it is a fast, simple and the most common used imaging technique that provides baseline information. The most common findings of CES or DLSS on survey radiography include: LS disc space collapse, sclerosis of endplates of L7 and S1,spondylosis deformans, attenuation of the LS spinal canal, LS malalignment, ventral displacement of the body of S1 relative to the last lumbar vertebrae; and symmetric or asymmetric transitional vertebral segments (Oliver et al. 1978, Schulman and Lippincott 1988, Morgan and Bailey 1990, Watt 1991, Barthez et al. 1994). Disk collapse, moderate and severe spondylosis deformans, wide LS angulation (>170°), LS malalignment were descried as radiographic predictors for CES (Mattoon and Koblik 1993). Another radiographic sign of CES, a radiolucency within the LS disc, called a vacuum phenomenon, has also been seen in dogs (Schwarz et al. 2000). In addition, one study finds that the most common finding of CES or DLSS on survey radiography is spondylosis deformans (71% of dogs). Ventral subluxation of the sacrum was presented in 6 (9%) dogs and LTV was seen in 5 (7%) dogs (3 GSDs) (De Risio et al. 2001).

Conversely, other studies demonstrated that these prominent changes were rarely associated with CES (Wright 1980, Schmid and Lang 1993, Scharf et al. 2004). One study demonstrated that even prominent radiographic LS abnormalities are of minimal value in the evaluation of LS disease (Scharf et al. 2004).

Spondylosis deformans is characterized by the formation of enthesophytes at the location where the annulus fibrosus is attached to the cortical surface of adjacent vertebral bodies. These enthesophytes expand ventrally and laterally but not dorsally. They vary from small bony spurs to bony bridges across the disk space (Langeland and Lingaas 1995, Thrall 2013) and are scored as absent, mild, moderate or severe (Eichelberg and Wurster 1982).

Attenuation of the LS spinal canal results from cranially elongating and sloping of the sacral lamina (“ telescoping ”) relative to the caudal spinal canal of L7. LS malalignment has been described previously as LS step formation, which is determined by the distance between the horizontal level of the spinal canal floor of L7 and that of the sacrum (Suwankong et al. 2008, Meij and Bergknut 2010).

End plate sclerosis has been associated with disc degeneration (Suwankong et al. 2008). In the same study, ventral subluxation of S1 was considered to be a sign of instability (Suwankong et al. 2008), while others found no significant differences between affected and unaffected dogs (Tarvin and Prata 1980, Schmid and Lang 1993, Scharf et al. 2004, Vezzoni et al. 2008). One study described that when the ventral subluxation of S1 was more than 4mm it was strongly suggestive of an abnormal LS junction (Schmid and Lang 1993). However, SUWANKONG et al. (2008) even suggested that a LS step as small as 2mm could be clinically relevant.

2.8.3 LTV and CES

Congenital LS anomalies such as symmetric and asymmetric LTV have been implicated as a cause of CES in dogs. LTV has been associated with LS disc degeneration at an early age (Morgan and Bailey 1990). In GSD, LTV has been reported to predispose to CES (Larsen 1977, Morgan and Bailey 1990, Morgan et al. 1993, Morgan et al. 2000, Flückiger et al. 2006).

One study reported that dogs with LTV are eight times more likely to develop CES than dogs without and LTV. GSDs are eight times more likely to develop CES compared with other breeds. Moreover, dogs with a LTV develop CES 1-2 years earlier than dogs without a LTV (Flückiger et al. 2006). Another study found all six dogs with asymmetric LTV exhibiting asymmetric cauda equina dysfunction and unilateral disk protrusion. Those authors hypothesized that LTV accelerate degeneration of the disk. Shorter SI attachment may cause greater stress on the disk in dogs with asymmetric LTV (Steffen et al. 2004).

The greatest mobility of normal lumbar vertebral column is located at the LS disk. Angulation dominates over the translation in the normal LSJ. Dogs with LTV have abnormal mobility and distribution of force in the LSJ. This means, translation is more dominant between the last lumbar vertebrae and the transitional vertebra. This results in additional shearing forces and possibly damage to the disk and ligaments, which could explain the increased incidence of CES with LTV (Burger and Lang 1992, Geissbühler 2000, Flückiger et al. 2006).

2.9 Imaging modalities

There are many imaging modalities available for evaluating the canine LS region, which include conventional radiography, stress radiography, myelography, epidurography, transosseous and intravenous venography, discography, linear tomography, computed tomography, and magnetic resonance imaging (Jones et al. 1995, Jones et al. 1996, Ramirez and Thrall 1998).

2.9.1 Conventional radiography

Conventional radiography is an important diagnostic method in evaluation LTV. Due to overlapping with the SIJ and the wing of the sacrum, an exact evaluation of the vertebral canal, the facet joints and the IVD space is difficult. Nevertheless, being a widely available modality it is still sufficient in evaluating bony malformations, such as block vertebrae and transitional vertebrae (Julier-Franz 2006). Special contrast procedures or other imaging modalities can then be selected based on findings from conventional radiographs (Ramirez and Thrall 1998).

The transitional vertebra is best visible on VD radiographs of the pelvis with pelvic limbs in extension. In this view, symmetry of the transverse processes and the SI attachment, the obliquity of the pelvis and the separation of SP S1 from the median sacral crest can be visualized. However, lateral radiographs may sometimes be more sensitive, as a rudimentary intervertebral space between a LTV and the sacrum, character of the vertebral end plates, narrowed height of the spinal canal and the LS misalignment are seen better in lateral projection (Morgan 1999 a and b, Morgan et al. 2000, Damur-Djuric et al. 2006).

2.9.2 Computer tomography (CT)

CT provides cross-sectional tomographic images of an object using x-rays and computer algorithms. There are three main advantages of CT over conventional radiography: better soft tissue contrast resolution, the tomographic or cross-sectional nature of the images and the ability to allow evaluation of the lateral processes, intervertebral foramina and articular processes (Jones et al. 1995, Jones et al. 1996, Ramirez and Thrall 1998). In addition, transverse CT images can be reconstructed into sagittal, dorsal, or oblique planes and computer processing technique also allows for 3-dimensional reconstructions (Meij and Bergknut 2010).

As a sensitive and noninvasive technique, CT is often used for evaluating the anatomy of the canine LS spine and for identifying the location (s) of compressive tissue in dogs with LS stenosis. The normal CT anatomy of LS spine consists of abundant epidural fat, well-visualized nerve tissues, concave or slightly convex IVD margins, symmetrical articular processes joints and smooth bone margins (Jones and Inzana 2000). Dogs exhibiting clinical signs of CES have abnormalities in CT images, which include loss of epidural fat, increased soft tissue opacity in the intervertebral foramen, bulging of the IVD, spondylosis, dural sac displacement, narrowed intervertebral foramen, narrowed vertebral canal, thickened articular processes, articular processes subluxation, and articular processes osteophytosis. In other words, when dogs have CES, compression should be suspected at the locations where there is an increase in perineural soft tissue opacity with the absence of epidural fat (Jones et al. 1996, Ramirez and Thrall 1998, Jones and Inzana 2000).

3 Materials and methods

3.1 Materials

This retrospective study has been conducted based on the pelvic radiographs of 1076 dogs. Collected data comes from the Small Animal Clinic, Faculty of Veterinary Medicine at Freie Universität Berlin between the years 2012 and 2016.

All the dogs have had at least standard VD radiographs of the pelvis with the pelvic limbs extended. Dogs that were evaluated for CHD have had especially correctly positioned VD radiographs- FCI position I. Additionally, 697 dogs had laterolateral radiographs and CT images of the LS spine were available in 171 dogs.

Radiographs were performed using a digital x-ray generator (Philips Bucky TH Optimus 50 Rad ACL). Image were evaluated using a dedicated computer software program (Horos v 2.2.0 DICOM Medical Image Viewer). CTs were performed using a third generation scanner (GE LightSpeed QX/i 4 Slice, AW 4.2 System, General Electric Medical System).

3.2 Methods

All images were reviewed by the author (HG) and a broad certificated radiologist (LB) using a dedicated computer software program (Horos v 2.2.0 DICOM Medical Image Viewer).

3.2.1 Identity

All 1076 dogs included in this study population had undergone radiographic examination to evaluate (1) the status of the hip joints, (2) possible pelvic trauma, or (3) the cause of pelvic musculoskeletal pain or hind limb lameness. Age, gender, breed and clinical history from all dogs included in this study were also available

3.2.2 Evaluability

For an effective diagnosis, radiographs of good technical quality, with optimum density, contrast and sharpness were essential. A good VD position for evaluating the LS vertebrae was required. In this position, the last two lumbar vertebrae, the sacrum and the entire pelvis with hip joints were visible; both lumbar and sacral vertebrae and pelvis were projected symmetrically; the spinous processes were located in the middle of the vertebral body; and both iliac wings and obturator foramina were equal in size.

From the total 1076 dogs which had pelvic radiographs, 46 dogs were excluded from this study due to poor radiographic technique, unacceptable. projection of the pelvis and the vertebrae, and superimposition with dense fecal mass and/ or dense penis bone.

3.2.3 Position for radiography

All 1030 dogs had the standard VD radiographs of the pelvis. For the radiographic examination, the dogs have been placed in a dorsal recumbency with hind limbs caudally extended. The projection area should include at least the last two lumbar vertebrae, the sacrum and the complete pelvis with hip joints. Additionally, 340 of 1030 dogs were brought for CHD evaluation; these dogs underwent general anesthesia to ensure complete muscle relaxation and correct positioning. According to FLÜCKIGER (2008), they were also placed in a dorsal recumbency. The femurs were held parallel to each other and the spine and slightly angulated inward until the patella project medial in the trochlea. This position is named standard FCI position I. The beam was centered over the caudal end of the pelvis so that the entire pelvis, the last lumbar vertebra and both stifles were included on the film. A left lateral radiograph which was centered at the LS junction with both femurs perpendicular to the lumbar spine was included in 697 dogs. CTs were performed in 171 dogs; the dogs were placed in dorsal recumbency with the hip joints extended as well.

3.2.4 Assessment criteria for LTV

3.2.4.1 Transverse processes

Type of transverse processes

In the present study, transverse processes were classified according to the method from DAMUR-DJURIC et al. (2006). Transverse processes were divided into three types depending on their attachment to the ilium: type 1 or lumbar type with no attachment to the ilium (Fig. 3-1), type 2 or intermediate type (Fig. 3-1), and type 3 or sacral type (Fig. 3-1). Moreover, in case where there was separation of SP S1 from the median sacral crest, the transverse processes were categorized as type 3 on both sides. Table 3-1 shows six subdivided groups depending on the characteristics and symmetry of the transverse processes.

Table. 3-1. Classification of different types of transverse processes

Symmetry of transverse processes	
1/1	Symmetric transverse processes with bilateral lumbar type
2/2	Symmetric transverse processes with bilateral intermediate type
3/3	Symmetric transverse processes with bilateral sacral type
1/2 or 2/1	Asymmetric transverse processes with lumbar type on one side and intermediate type on the other side
2/3 or 3/2	Asymmetric transverse processes with intermediate type on one side and sacral type on the other side
1/3 or 3/1	Asymmetric transverse processes with lumbar type on one side and sacral type on the other side

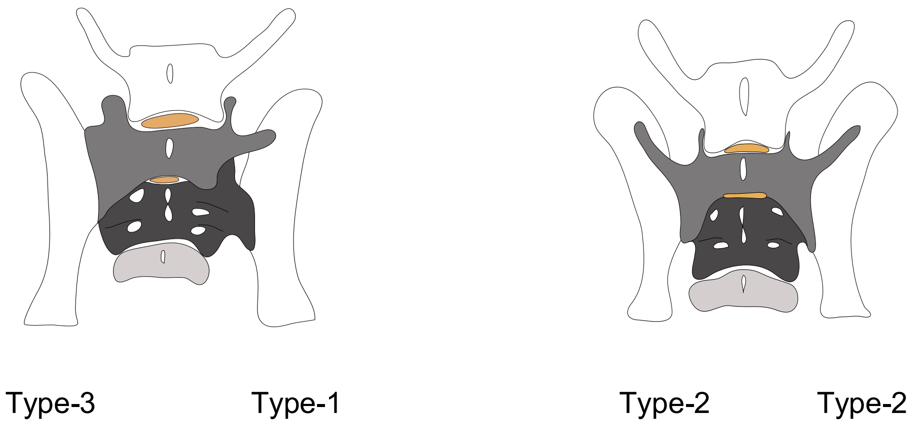


Fig. 3-1. Different types of transverse processes in schematic diagrams (normal grey: LTV, dark grey: sacrum, light grey: Cd1, yellow: IVD)

Length of transverse processes

Based on JULIER-FRANZ‘s (2006) study, the length of transverse processes LTVs were divided into four groups. In group 1, the transverse process was of normal lumbar shape. In group 2, the transverse process was shorter than a normal one. In group 3, the transverse process was rudimentary shaped and its tip remained free. While the transverse process was completely fused with the sacrum in group 4 (Table. 3-2).

Table. 3-2. Different groups based on the length of transverse processes

Length of transverse processes	
Group 1	Normal lumbar transverse process
Group 2	Shorter but still lumbar shaped transverse process
Group 3	Rudimentary transverse process, free tip
Group 4	Complete fusion to the sacrum/ not formed

Orientation of transverse processes

According to JULIER-FRANZ (2006), variations of transverse processes were divided into three groups based on their orientation: group1, the transverse process was directed craniolaterally as a normal lumbar vertebra; group 2, the transverse process was directed more laterally; and group 3, the transverse process was totally fused with the sacrum and there was no direction (Table. 3-3).

Table. 3-3. Different groups based on the orientation of transverse processes

Orientation of transverse processes	
Group 1	Craniolateral
Group 2	Lateral
Group 3	No orientation, complete fusion

Attachment of transverse processes to the sacrum

According to JULIER-FRANZ (2006), the attachment of transverse processes of a LTV to the sacrum varies. In group 1, there was no contact between transverse processes and the lateral parts of the sacrum. The transverse process was either in a normal lumbar shape or it became wider and was directed more caudally, but there was no contact with the sacrum. In group 2, the transverse process was partially attached to the lateral part of the sacrum; it was a rudimentary shaped transverse process The transverse process was completely fused to the lateral parts of the sacrum in group 3 (Table. 3-4).

Table. 3-4. Different groups based on attachment of transverse processes to the sacrum

Attachment of transverse processes to the sacrum	
Group 1	No attachment
Group 2	Partially attachment, rudimentary shaped transverse process
Group 3	Complete fusion to the sacrum

3.2.4.2 Spinous processes of the sacrum

Normally on the VD view, sacral spinous processes are seen as three round to oblong radiodense shadows that are connected. With LTV cases, the most cranial of these three segments is separated and displaced cranially regardless of the number of spinous processes in the sacrum. The rest of the segments are fused together (Morgan 1999 b). Thus, the separation of three spinous processes depending on the distance between each two segments were divided into two group in this study. Group 1- no separation of SP S1 from the median sacral crest, the distance between each adjacent processes were the same length. Group 2- there was separation of SP S1, the distance between S1 and S2 was longer than that between S2 and S3 (Table. 3-5).

Table. 3-5. Two groups divided based on the distance between the spinous processes of the sacrum

Distance between spinous processes of the sacrum	
Group 1	Distance between S1-S2 and S2 -S3 is the same length with no separation
Group 2	Distance between S1-S2 is longer than S2 -S3 with separation of SP S1 from the median sacral crest

3.2.4.3 IVD space between LTV and the sacrum

Normally, the IVD space between the last lumbar segment and the sacrum has the same width as the IVD space between other adjacent lumbar vertebrae. And there is no IVD space in the sacrum. With LTV, a newly formed IVD space might be seen between the S1 and second sacral segments due to the separation of the S1 from the sacrum. Or the IVD space between the last lumbar vertebra and the sacrum becomes narrow as a result of sacralization of the last lumbar vertebra. According to JULIER-FRANZ (2006), variations in width of IVD space were subdivided into four groups in this study regardless of lumbarization and sacralization of the LTV. Group 1 had a normal developed IVD space between the transitional vertebra and the sacrum. Group 2 had a narrowed IVD space and lateral contact between the body of the LTV and body of the sacrum can appear. Group 3 had a slit-like IVD space, seen as a radiolucent line in radiograph. And there was no IVD space between the transitional vertebra and the sacrum in group 4, because of the complete fusion of the LTV to the sacrum (Table. 3-6).

Table. 3-6. Various widths of IVD space between an LTV and the sacrum

Various widths of IVD space between an LTV and the sacrum	
Group 1	Normal IVD space width
Group 2	Narrowed IVD space with lateral contact of the adjacent vertebrae
Group 3	Slit-like IVD space, as a radiolucent line
Group 4	Absence of IVD space

3.2.4.4 Ventral or dorsal sacral foramina

According to ZIEGLER (1990), the shape of ventral or dorsal sacral foramina varies during lumbarization and sacralization. In this study, ventral or dorsal sacral foramina between LTV and the sacrum were divided into three groups depending on the development of the ventral alar element (Table. 3-7). The shape of ventral or dorsal sacral foramen on the right side and left side were evaluated separately. No ventral or dorsal sacral foramen was visible when the ventral alar element of the LTV was absent (group 1) (Fig. 3-2B). The ventral or dorsal sacral foramen was shapeless or with a laterally opened slit when the alar element of the LTV developed partially (group 2) (Fig. 3-2B). A normal formed sacral foramen was seen when the alar element of the LTV developed completely (group 3) (Fig. 3-2A).

Table. 3-7. Various shapes of ventral or dorsal sacral foramina

Various shapes of ventral or dorsal sacral foramina	
Group 1	Absence
Group 2	Shapeless, or with a laterally opened slit
Group 3	Normal round shaped

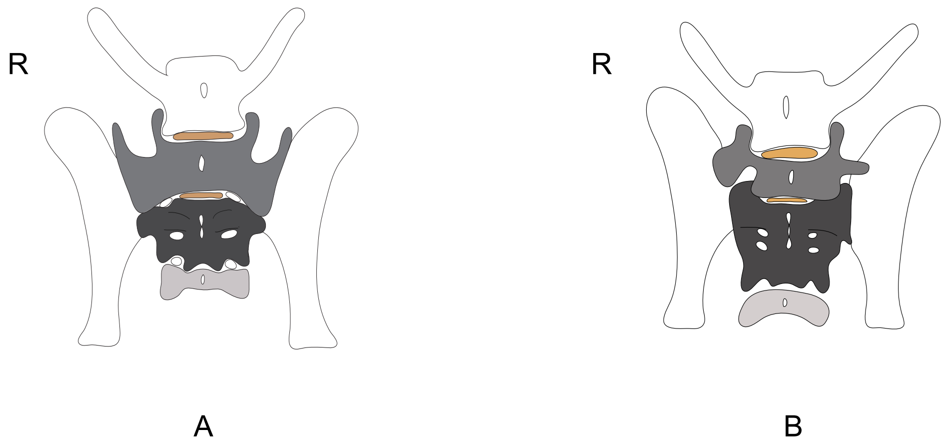


Fig. 3-2. Different shapes of ventral or dorsal sacral foramina in schematic diagrams (normal grey: LTV, dark grey: sacrum, light grey: Cd1, yellow: IVD). In (A), both sides have normal shaped ventral or dorsal sacral foramina between LTV and the sacrum. In (B)， the left side is a shapeless ventral or dorsal sacral foramen with a laterally opened slit and there is no sacral foramen between LTV and the sacrum on the right side.

3.2.4.5 Number of sacral segments

Normally , the sacrum consists of three segments. In the present study, the number of sacral segments varied from two to four (Table. 3-8), which was dependent on the character of the LS junction and that of the SC junction. 2 or 4 segments was considered an abnormal number (Fig. 3-3 and 3-5). Only when the vertebra was completely fused to the sacrum was it considered as a sacral vertebra. As soon as the separation of transverse processes or a slit-like rudimentary IVD between two adjacent segments was seen, this segment was excluded from the sacrum (Fig. 3-3 and 3-4).

Table. 3-8. Different groups based on the number of sacral segments

The number of sacral segments	
Group1	Two sacral segments
Group 2	Three sacral segments
Group 3	Four sacral segments

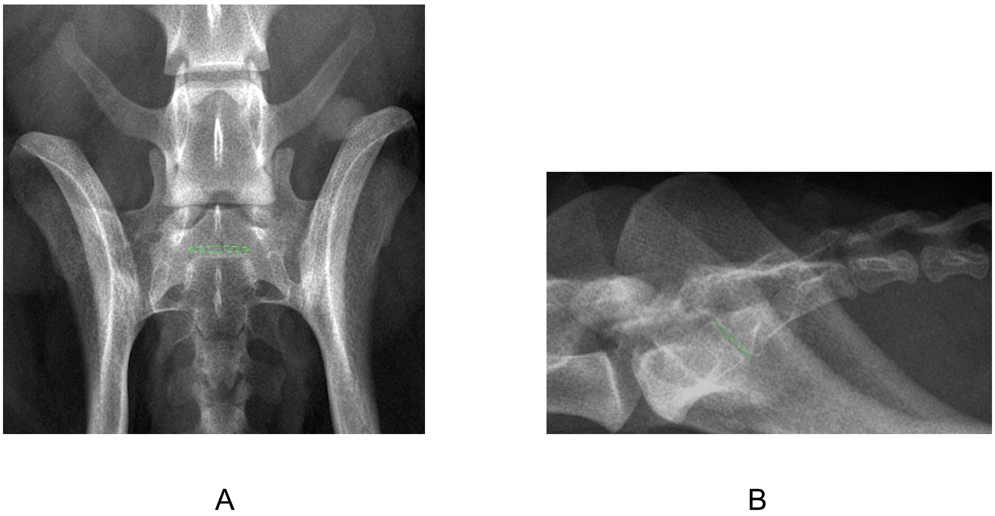


Fig. 3-3. The sacrum with two segments in VD (A) and lateral (B) view of an 8-yean-old female Tibetan Terrier. LTV is characterized by complete separation of the S1 vertebral body. The green dotted circle indicates a narrow IVD space presenting. between S1 and S2. There is a sacralized Cd1, but the body of Cd1 is not fused to the sacrum.

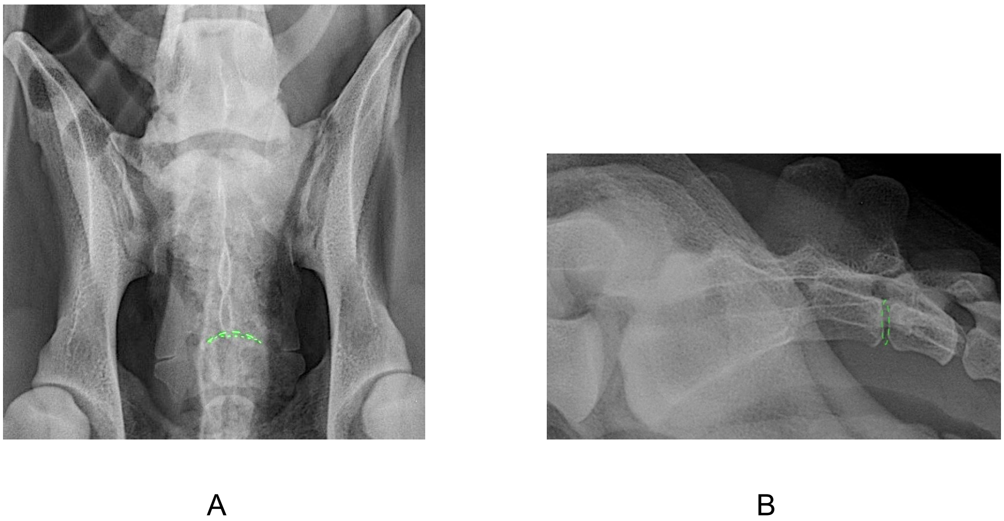
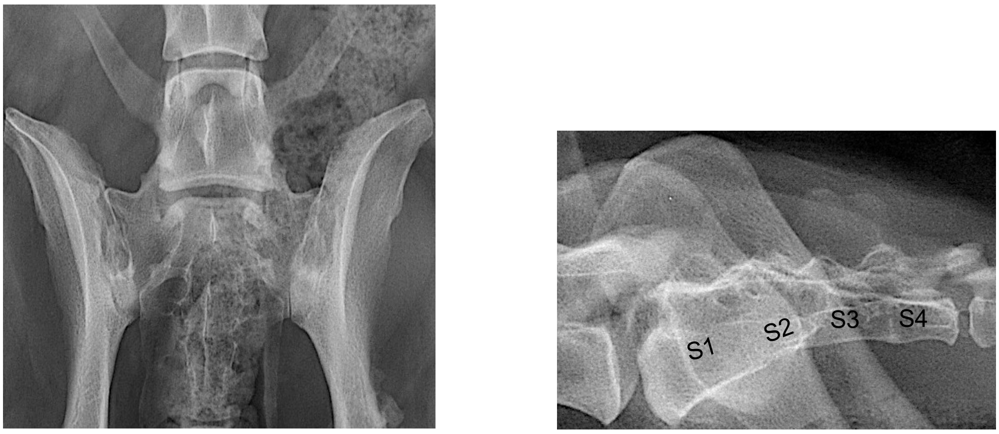


Fig. 3-4. The sacrum with three segments in VD (A) and lateral (B) views of a 5-year-old female GSD. LTV is characterized by separation of SP S1. Cd1 is partially sacralized with the body remains separated. The green dotted circle indicates the narrowing IVD space between S3 and Cd1.



A B

Fig. 3-5. The sacrum with four segments in VD (A) and lateral (B) view of a 6-year-old

3.2.4.6 Sacrococcygeal transitional vertebrae (SCTV)

The last sacral segment can be either completely or partially separated from the sacrum when there is a sacralized L7, or the first coccygeal vertebra (Cd1) can be completely or partially fused to the sacrum when there is a lumbarized S1 (Ziegler 1990). In this study, it is observed that sacrococcygeal transitional vertebrae (SCTV) was accompanied by LTV in some cases. Complete separation of S3 was a total separation of the vertebral body and the lateral parts. In cases of partial separation of S3, only the separation of lateral parts happened. Complete fusion of Cd1 to the sacrum meant fusion of both the body and the transverse processes (Fig. 3-5). Incomplete fusion was noted as an attachment or pseudoarticulation between the transverse processes of the sacrum and Cd1 (Fig. 3-4). Regardless of the shift direction, changes in SC junction can be divided into two groups: presence of SCTV and without SCTV (Table. 3-9).

Table. 3-9. Two groups divided based on the presence or absence of a SCTV

Presence of SCTV	
Group 1	Presence of SCTV
Group 2	Absence of SCTV

3.2.5 Classification of LTV

In this study, a classification scheme from FLÜCKIGER et al. (2009) was used. LTVs were divided into 4 types (Table. 3-10). Type 0 was normally shaped LS vertebrae (Fig. 3-6). The transverse processes were directed craniolaterally and had a regular shape, and they were not in contact with the ilium. The sacrum was formed by three fused segments and the spinous processes were fused together as well. The IVD space in the LS region was well developed, and there were two pairs of ventral or dorsal sacral foramina situated lateral to the bodies.

Table. 3-10. Different forms of LTVs based on their morphology

Forms of LTV	
Type 0	Normally shaped LS vertebrae
Type 1	Separation of SP S1 from the median sacral crest
Type 2	Symmetrically formed transverse processes
Type 3	Asymmetrically formed transverse processes

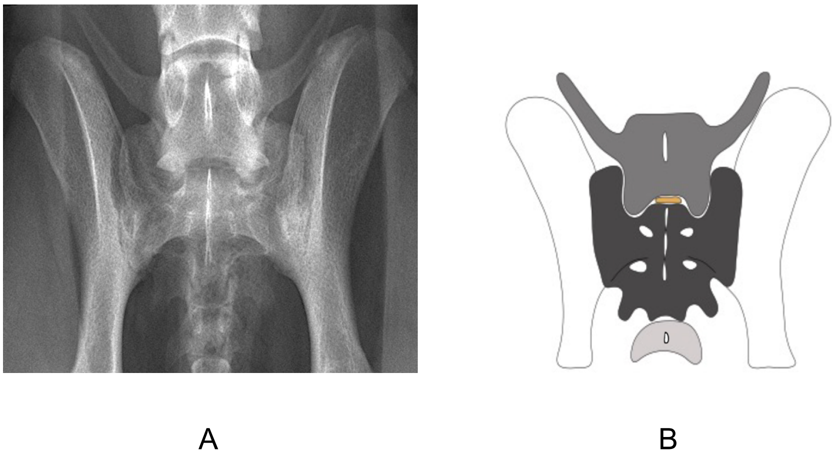


Fig. 3-6. Type 0- a normally shaped LS vertebrae in the (A) radiograph and (B) schematic diagram (normal grey: L7, dark grey: sacrum, light grey: Cd1, yellow: IVD) in a 6-year-old female Labrador Retriever

Type 1 exhibited a separated SP S1 from the median sacral crest (Fig. 3-7). The distance of the spinous processes between S1 and S2 was longer than that between S2 and S3. However, the sacral segments were kept fused together. Separation of the SP S1 was the only change in this type.

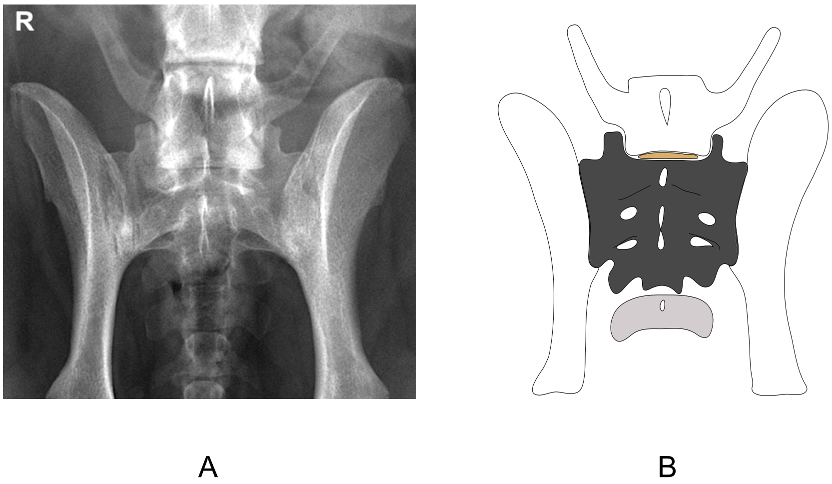


Fig. 3-7. Type 1-separation of SP S1 from the median sacral crest in the (A) radiograph and (B) schematic diagram (dark grey: sacrum, light grey: Cd1, yellow: IVD) in a 7-year-old female

In type 2, the LTV was separated from the sacrum. transverse processes had symmetric types, which was subdivided further into three patterns. In the first pattern, the transverse processes were lumbar-like on both sides (Fig. 3-8a). In the second pattern, both transverse processes were partially in contact with the ilium (Fig. 3-8b), but the length of the attachment to the ilium could vary. The transverse processes were completely attached to the ilium and had sacral-like shapes in the last pattern (Fig. 3-8c).

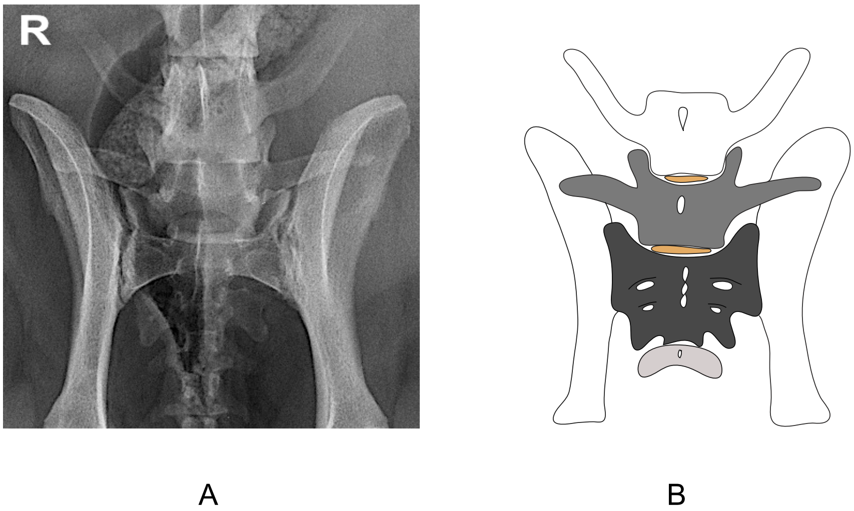


Fig. 3-8a. Type 2- lumbar type (1/1) symmetric transverse processes projecting laterally in the (A) radiograph and (B) schematic diagram (normal grey: LTV, dark grey: sacrum, light grey: Cd1, yellow: IVD) in a 9-year-old female mixed breed

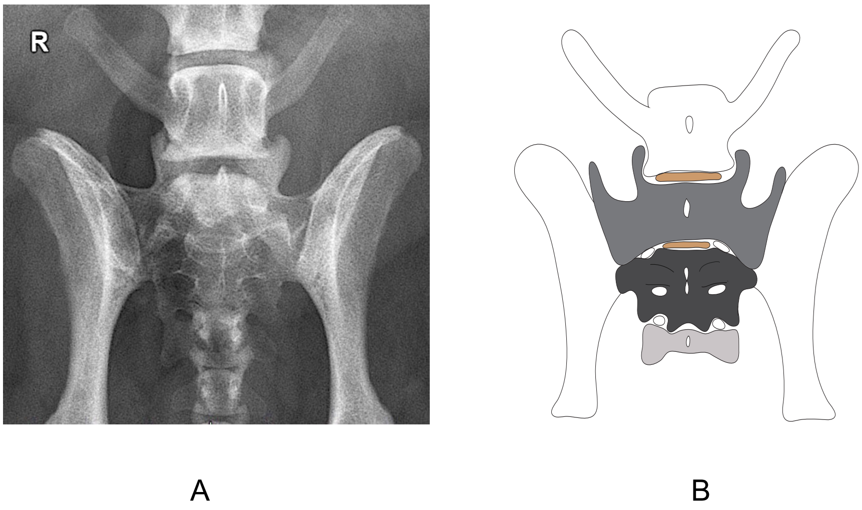


Fig. 3-8b. Type 2- intermediate type (2/2) symmetric transverse processes in the (A) radiograph and (B) schematic diagram (normal grey: LTV, dark grey: sacrum, light grey: Cd1, yellow: IVD) in a 13-year-old female Norwich Terrier

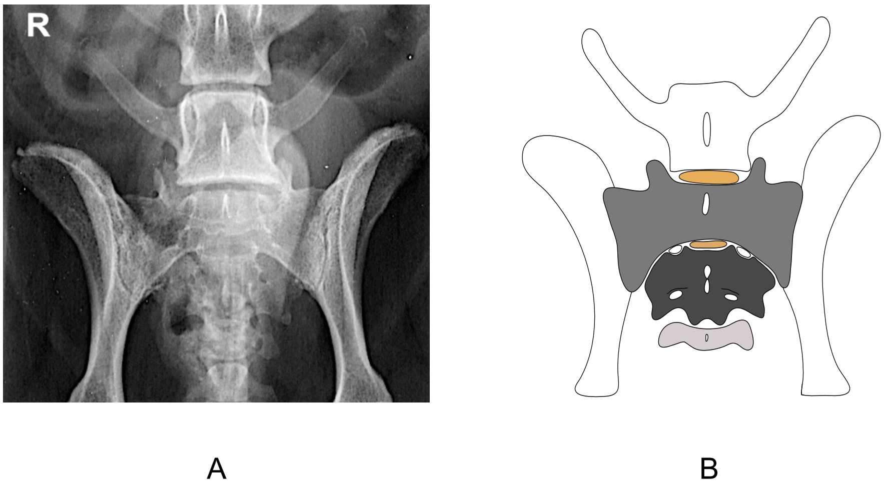


Fig. 3-8c. Type 2- sacral type (3/3) symmetric transverse processes in the (A) radiograph and (B) schematic diagram (normal grey: LTV, dark grey: sacrum, light grey: Cd1, yellow: IVD) in a 15-year-old male Papillon

Type 3 showed the asymmetrically formed transverse processes of a LTV and the LTV was separated from the sacrum. Asymmetric transverse processes were subdivided into three groups, according to the attachments of transverse processes to the ilium. In group 1, partial attachment of transverse process to the ilium was noted on one side, and on the other side there was no connection between them (Fig. 3-9a). In group 2, complete attachment of the transverse process to the ilium was seen on one side and on the other side the transverse process was a lumbar type (Fig. 3-9b). Both partial and complete contact of transverse processes with the ilium were detected in group 3 (Fig. 3-9c).

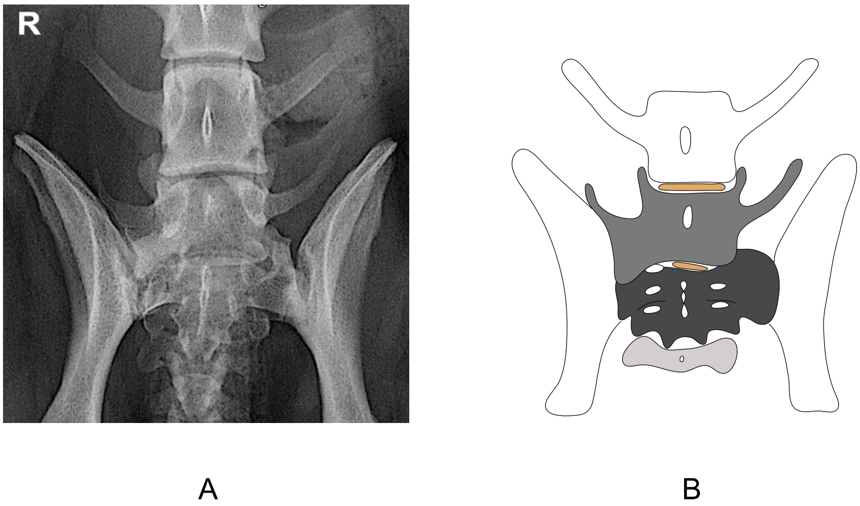


Fig. 3-9a. Type 3-asymmetric transverse processes (2/1) in the (A) radiograph and (B) schematic diagram (normal grey: LTV, dark grey: sacrum, light grey: Cd1, yellow: IVD) in a 6-year-old female Beagle

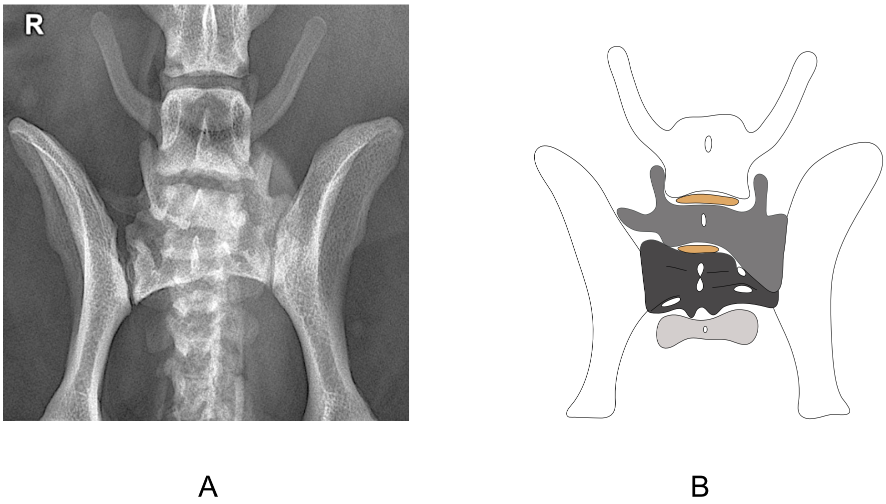
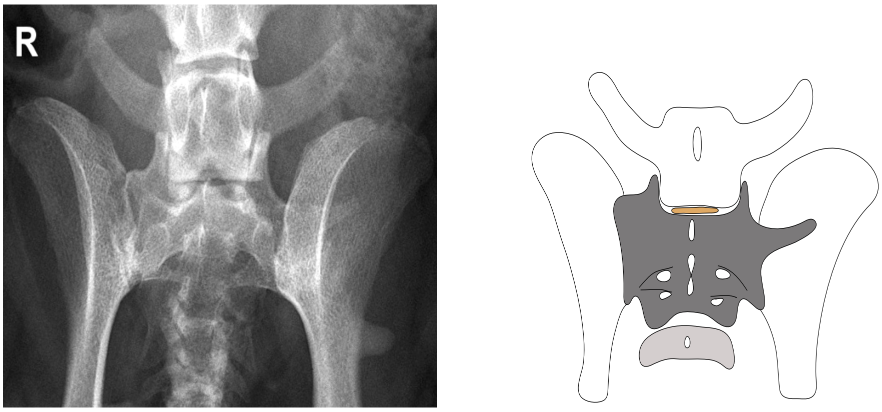


Fig. 3-9b. Type 3-asymmetric transverse processes (1/3) in the (A) radiograph and (B) schematic diagram (normal grey: LTV, dark grey: sacrum, light grey: Cd1, yellow: IVD) in a 6-year-old male Pug



A B

Fig. 3-9c. Type 3-asymmetric transverse processes (3/2) in the (A) radiograph and (B) schematic diagram (normal grey: lumbarized S1 with the sacrum, light grey: Cd1, yellow: IVD) in a 4-year-old female French Bulldog

3.2.6 CHD- grade

Dogs with standard FCI position radiographs for official CHD evaluation or other reasons were used in this study to evaluate CHD. The hip joints were assessed according to the Swiss scoring system using six parameters (Table. 3-11). These six parameters are divided into three groups. Parameter 1 and 2 evaluate the laxity of the hip joint, parameter 3 and 4 quantify the appearance of arthrotic changes of the acetabular cup whereas parameter 5 and 6 describe the corresponding changes on the femoral head and neck.

Each parameter was scored between 0 and 5 depending on the degree of severity present. More severe changes correlated to higher scores. The sum of the six scores was given separately for each hip joint. An excellent hip joint would score 0, while a severely dysplastic and arthrotic joint would reach a score of 30 (Table. 3-11). In accordance with FLÜCKIGER (2008), each hip joint could be transformed into a CHD grading according to FCI (Table. 3-12 and 3-13).

Table. 3-11. Radiographic criteria for CHD grading (The Swiss scoring mode)

Norberg Angle (JS = Joint Space)	Relation of FHC* and DAE*, Width of Joint Space (JS)	Craniolateral Acetabular Edge (CAE)	Cranial Subchondral Acetabular Bone	Femoral Head (H), Femoral Neck (N)	Morgan-Line	HD-Score
≥ 105º, JS congruent	FHC medial to DAE (> 2 mm), JS narrow	parallel to femoral head	fine, even	H: round, smooth N: well demarcated	not visible	0
≥ 105º, but JS widened slightly, or ＜105º, but JS narrow	FHC medial to DAE (1-2 mm), JS minimally divergent	horizontal on lateral 1/4	even	H: round N: poorly demarcated (cylindrical)	edged shoulder on view with stifles abducted care: smooth bump not scored	1
≥ 100º	FHC super-imposed on DAE, JS slightly divergent	slightly flattened, or mild exostosis	slightly thickened laterally, slightly reduced medially	H: slightly flattened N: mild exostosis	fine linear spur (up to 1 mm wide)	2
≥ 90º	FHC lateral to DAE (1-5 mm), JS moderately divergent	moderately flattened, mild exostosis, two part surface	moderately thickened laterally, moderately reduced medially	H: moderately flattened N: mild exostosis	well defined spur (up to 3 mm wide)	3
≥ 80º	FHC lateral to DAE (6-10 mm), JS markedly divergent	markedly flattened, moderate exostosis	markedly thickened laterally, may not be present medially	H: moderately flattened N: moderate exostosis	broad irregular spur (> 3 mm wide)	4
＜80º	FHC lateral to DAE (> 10 mm), or Luxation	DAE absent, acetabulum markedly deformed	blending with lateral pelvic rim or absent	H: severely deformed N: massive exostosis	spur incorporated in or superimposed by general exostosis	5

* FHC = Femoral Head Centre; DAE = Dorsal Acetabular Edge

Table. 3-12. CHD grading key (Flückiger 2008)

Total score per hip joint	Degree of CHD (according to FCI)	
0-2	A	Normal, no evidence of CHD
3-6	B	Borderline
7-12	C	Mild CHD
13-18	D	Moderate CHD
>18	E	Severe CHD

Table. 3-13. FCI scheme for grading CHD

A	No signs of CHD	The femoral head and the acetabulum are congruent. The craniolateral acetabular rim appears sharp or slightly rounded. The joint space is narrow and even. The NA is about 105º. In excellent hip joints, the craniolateral rim encircles the femoral head somewhat more in the laterocaudal direction.
B	Near normal hip joints	The femoral head and the acetabulum are slightly incongruent and the NA is 105º or more. Or the femoral head and the acetabulum are congruent and the NA is less than 105º.
C	Mild CHD	The femoral head and the acetabulum are incongruent. The NA is about 100º, and/or there is slight flattening of the craniolateral acetabular rim. No more than slight signs of OA on the cranial, caudal, or dorsal acetabular edge or on the femoral head and neck may be present.
D	Moderate CHD	There is obvious incongruity between the femoral head and the acetabulum with subluxation. The NA is more than 90º (only as reference). Flattening of the craniolateral rim and/or osteoarthritic signs are present.
E	Severe CHD	Marked dysplastic changes of the hip joints, such as luxation or distinct subluxation are present. The NA is less than 90º. Obvious flattening of the cranial acetabular edge, deformation of the femoral head (mushroom shaped) or other signs of osteoarthrosis are noted.

3.2.7 Scoring system for coxarthrosis

The scoring system descried by BRUNNBERG in 1987 was used in this study. Each hip joint was given a score indicating normal joint (grade 0) to severe coxarthrosis (grade 3). Table. 3-14 shows the details of this scoring system.

Table. 3-14. Radiographic scoring system for coxarthrosis (Brunnberg 1987)

0	Normal hip joint
	The femoral head and the acetabulum are congruent. The joint space is even. The craniolateral acetabular rim appears sharp or slightly flattened. The acetabulum is deep. The femoral head is clearly distinguished from the neck and seated deeply in the acetabulum.
1	Mild coxarthrosis
	The femoral head and the acetabulum are incongruent. The acetabulum is flattened or the contour of the acetabulum is unsharp. Osteophytes and /or sclerosis at the cranial acetabular margin may be present.
2	Moderate coxarthrosis
	The acetabulum is flattened and the contour of the acetabulum is unsharp. The craniolateral acetabular rim is broadly sclerosed. The joint space is divergent. The femoral head is deformed and loss its roundness, or the femoral neck becomes cylindrical. The bone structure of the femoral neck is loosened.
3	Severe coxarthrosis
	The acetabulum is markedly flattened with osteophytes on the craniolateral acetabular rim. The joint space is narrowing. The femoral head is severely deformed with numerous osteophytes and cysts.

3.2.8 Radiographic abnormalities on the lateral view

Additional lateral radiographs of the LS region in dogs with LTV were also evaluated in the present study. Abnormalities which were considered radiographic predictors for CES, were detected between the LNLV and the LTV. Identifiable changes included spondylosis deformans, endplate sclerosis, ventral subluxation of LTV, collapse of the IVD space, downward elongation of the sacral lamina, vacuum phenomenon and calcified nuclear material (Table. 3-15). According to LANGELAND and LINGAAS (1995), spondylosis deformans were divided into four degrees, which varied from grade 0 (no spondylosis deformans) to grade 3 (the most severe form of spondylosis deformans).

Table. 3-15. Radiographic abnormalities on the lateral view

Radiographic abnormalities on the lateral view
• Ventral and lateral spondylosis deformans: Grade 0- no spondylosis deformans Grade 1- small osteophytes, but not exceeding the vertebral edge Grade 2-osteophytes extend beyond the edges of endplate with no union between opposing osteophytes Grade 3-osteophytes extend beyond the edges of endplates forming bony bridges between vertebrae
• Endplate sclerosis
• Ventral subluxation of LTV
• Narrowed IVD space
• Downward elongation of the sacral lamina
• Calcified nuclear material
• Vacuum phenomenon

3.2.9 Measurements

In the present study, some measurements were used to describe the transverse process angle (TPA), the length of SI attachment, the NA and the ventral subluxation of the sacrum.

3.2.9.1 Transverse process angle

The TPA was used to evaluate symmetry of these the transverse processes. A baseline was drawn connecting the spinous processes of normal lumbar vertebrae. The cranial tip of transverse process and the cranial margin of the attachment of the transverse process to the sacral body are then identified. A second line was drawn through these two points creating an angle. In this study, both transverse processes of the LNLV and those of the LTV were measured (Fig. 3-10).

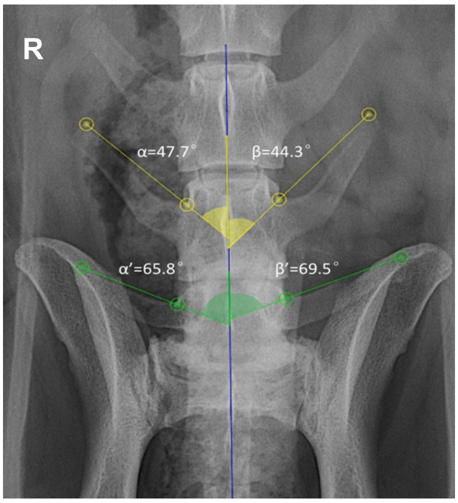
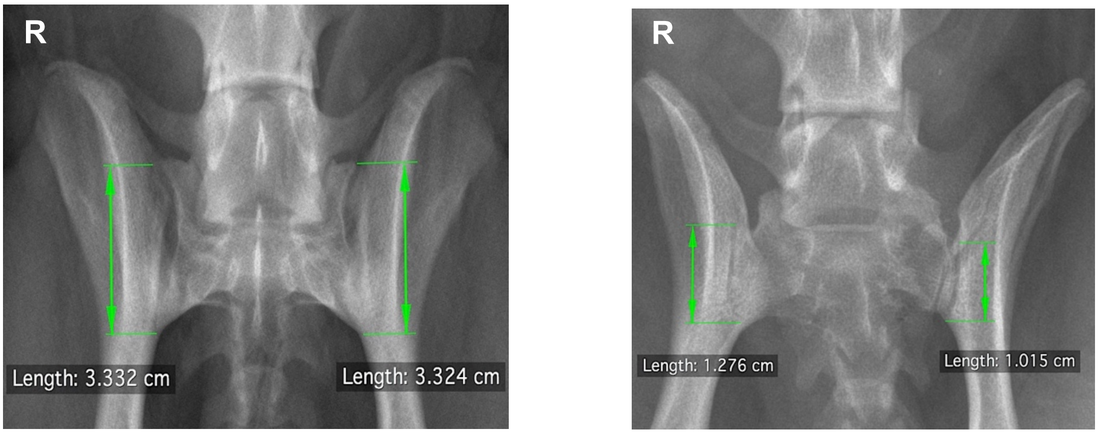


Fig. 3-10. TPA in a normal lumbar vertebra and a LTV of a 15- year-old male Labrador Retriever. The blue line is the baseline connecting the spinous processes of the normal lumbar vertebrae. The yellow lines form the transverse process angel of the LNLV (α and β are angles on right and left side respectively). The yellow points indicate the cranial margin of transverse processes and the cranial attachment of the transverse processes to the sacral body. Similarly, the green lines show the TPA in a LTV (α’ and β’ are angles on right and left side respectively) and the green points are the cranial tips of the transverse processes and the cranial attachment to the sacral body.

3.2.9.2 Length of the SI attachment

To measure the length of the SI attachment, a vertical line was drawn between the cranial margin and caudal margin of the SIJ (Fig. 3-11A and B). This vertical distance shows the length of the SI attachment. When the transverse process of a LTV is in partial contacted with the ilium, this part of the attachment was not included into the SI length. Only when the transverse process was completely fused with the sacrum, could the measurement be determined; it was measured from the cranial point of the connection of the transverse process to the ilium to the caudal point of SIJ. According to DAMUR-DJURIC et al. (2006), the reference points for measuring the length could not always be determined accurately, thus, asymmetry was defined in this study only by an arbitrarily chosen difference of >2mm between the right and left side (Fig. 3-11B).

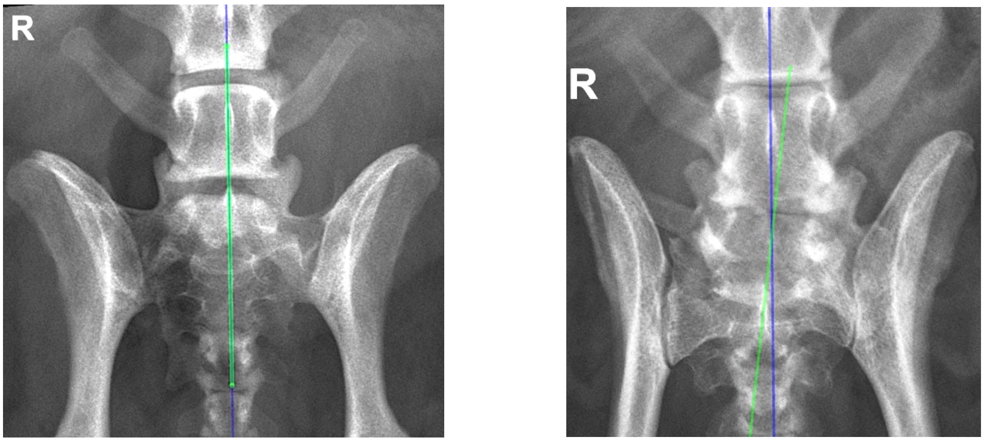


A B

Fig. 3-11. The length different of SI attachments. (A) VD view of a 1-year-old female Labrador Retriever with symmetric SI attachments of normal LS vertebrae. (B) VD view of a 9-year-old female Jack Russell Terrier with asymmetric SI attachments in an asymmetric LTV. The SI attachment is longer (>2mm) on the left side than the right side.

3.2.9.3 Angulation of LTV

According to ZIEGLER (1990), a method has been described to indicate the deviation of the spinal longitudinal axis on VD views. A baseline was drawn connecting the spinous processes of normal lumbar vertebrae. A second line then was drawn through the spinous processes of the abnormal lumbar or sacral segments (Fig. 3-12A and B). The same method was used in this study to determine the angulation of LTV. If two lines coincided, there was no angulation of the LTV. Conversely, if they were not aligned with each other, then the LTV was considered angulated. The direction of angulation was depended on the line drawn though the spinous process of LTV relative to the baseline (Fig. 3-12B).



A B

Fig. 3-12. Angulation of a LTV. The blue line is the longitudinal axis through the spinous processes of normal lumbar vertebrae and the green line is the one through the LTV. (A) VD view of a 13-year-old female Norwich Terrier. Two lines coincide indicating there is no angulation of the LTV. (B) VD view of a 10-year-old female Fox Terrier with a angulation of the LTV relative to the longitudinal axis to the right side.

3.2.9.4 Norberg angle

The NA is used to evaluate the hips for subluxation and shallow acetabulum; it is also used as a parameter in FCI scoring system for CHD. According to HENRICSON et al. (1966) and HENRY (1992), the NA is a measurement of the relationship between the femoral head and the acetabulum. A baseline was drawn connecting the center of the femoral heads, and the second line was drawn from the center of the femoral heads through the craniodorsal acetabular margin creating an angle of greater than 105° in normal dogs (Fig. 3-13). Subluxation would cause the femoral heads to shift laterally, so in dysplastic dogs the angle would be less than 105°.

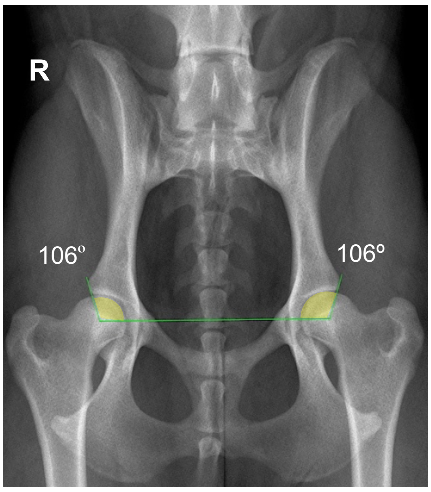


Fig. 3-13. The NA measurement in normal hip joints of a 1-year-old female Labrador Retriever. The NA is formed by the straight line (green line) between the two femoral heads and the line (green line) drawn from the center of each head to the cranial rim of the ipsilateral acetabulum. Yellow angle is the NA.

3.2.9.5 Ventral subluxation of LTV

For this measurement, LTV was considered the abnormal S1. According to SUWANKONG et al. (2008), the ventral subluxation of S1 (LTV) in respect to L7 (LNLV) was measured. Two lines were drawn along the ventral aspect of the spinal canal floor of the last lumbar vertebra (LNLV) and that of the sacrum (LTV) (Fig. 3-14). The distance in millimeters between these two lines shows a subluxation.

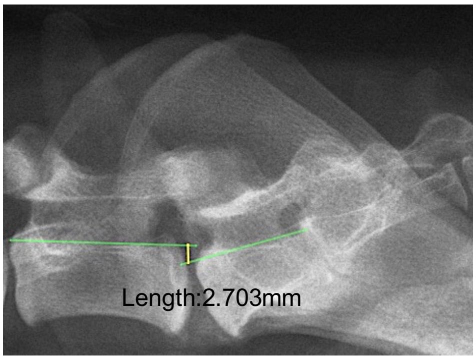


Fig. 3-14. Ventral subluxation of S1 in a 9-year-old female GSD. This subluxation is measured as the distance (yellow line) between the ventral aspect of the spinal canal floor of the LNLV and that of the LTV (green lines).

3.2.10 Statistics evaluation

Statistical analysis was performed with a computer software (SPSS Statistics 24.0). For tables larger than 2x2, the Chi-square distribution with the appropriate degrees of freedom provides a good approximation to the sampling distribution of Pearson's chi-square when the null hypothesis is true. Thus, the categorical data were tested for statistical differences using Chi-square test (Fisher’s exact test for small sized sample) in this study. A Chi-square test was used for analysis of LTV in relation to gender, angulation of LTV, length of the SI attachment, pelvic obliquity, sclerosis of SIJ, CHD grade, coxarthrosis grade, spondylosis deformans degree and endplate sclerosis among LTV cases.

One way analysis of variance (ANOVA) provides a statistical test to determine whether the means in several groups are equal. ANOVA is useful when comparing three or more means (groups or variables) using F-distribution, and two-group cases can be covered by t-test. In the present study, mean and standard deviation of CHD score were calculated separately on the right and left hip joint. The type of LTV and the length of the SI attachments were divided into more than two groups. As a result, ANOVA test was performed to evaluate the correlation between the difference of CHD score (mean ±SD) among the right and left side and type of LTV and length of the SI attachments. Moreover, according to symmetric or asymmetric LTV, the average of CHD score was given for those two groups, thus, a t-test was tested for statistical significance. P-value <0.05 is considered significant in this study.

4 Results

4.1 LTV and gender

Among the sampled population, the gender distribution was only slightly different between male (48.3%) and female (51.8%) dogs. A LTV was noted in 95 out of 1030 (9.2%) dogs in this study. Among the dogs found with a LTV, 48 (50.5%) were male and 47 (49.5%) were female indicating there was no gender predisposition for LTV (P>0.05) (Fig. 4-1).

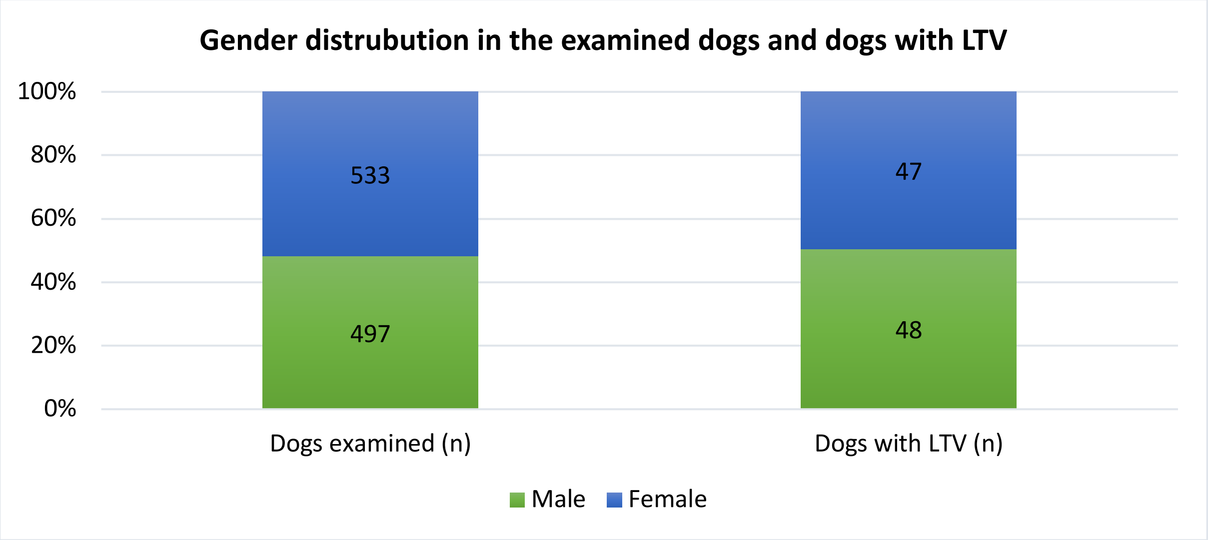


Fig. 4-1. Diagram of gender distribution in the examined dogs and dogs with LTV

4.2 LTV and breed

In this study, a certain breed was excluded when there were less than 4 dogs in the breed group and these dogs were categorized in the Other Breeds group. These breeds include the Andalusian Hound, the Dutch Shepherd Dog, the Finnish Spitz, the Havanese, Hovawart, the Japanese Chin, the Kangal, the Majorca Ratter, the Norwich Terrier, the Papillon, the Parson Russell Terrier, the Pointer, the Sloughi, the Vizsla, the Whippet the and White Shepherd. Among the 1030 dogs, there were a total of 63 breeds; 79 dogs from 27 breeds (660 dogs) were affected by LTV; and 16 dogs from the Other Breeds group (27 dogs in this group) were affected.

The prevalence of LTV varied from 5% to 63.6% between different breeds. The incidence of LTV in Pugs (63.6%) and Fox Terriers (42.9%) was higher in comparison to that of all the other breeds. Rottweiler (5%), Mixed breeds (5.3%), Boxer (5.6%), and GSD (5.7%) had lower frequency than other breeds (Fig. 4-2) (Table. 4-1).

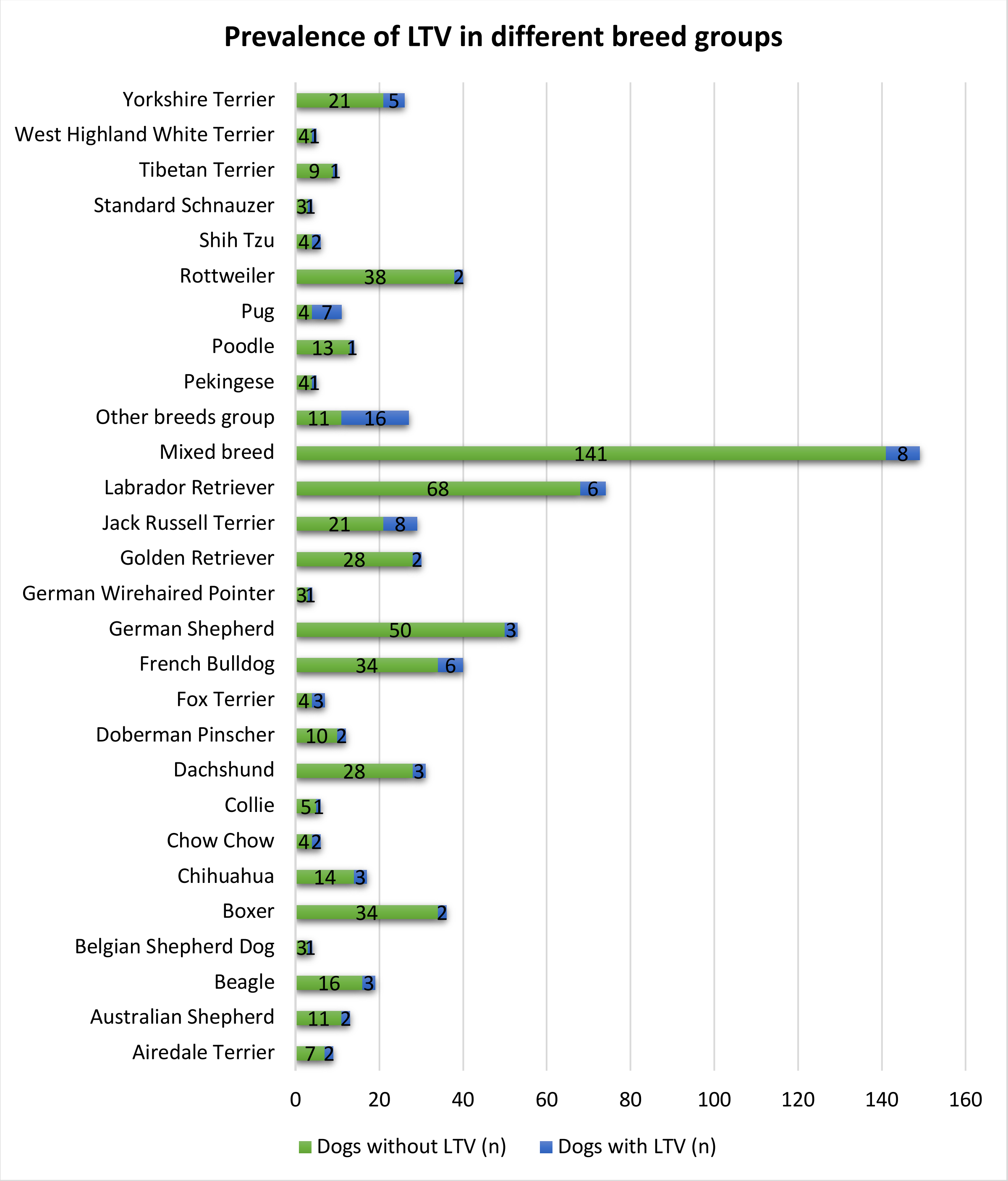


Fig. 4-2. Diagram of prevalence of LTV in different breed groups

Table. 4-1. Prevalence of LTV in different breed groups

Breed	Examined dogs (n)	Dogs with LTV (n)	Dogs with LTV (%)
Airedale Terrier	9	2	22.2
Australian Shepherd	13	2	15.4
Beagle	19	3	15.8
Belgian Shepherd Dog	4	1	25
Boxer	36	2	5.6
Chihuahua	17	3	17.7
Chow Chow	6	2	33.3
Collie	6	1	16.7
Dachshund	31	3	9.7
Doberman Pinscher	12	2	16.7
Fox Terrier	7	3	42.9
French Bulldog	40	6	15
German Shepherd	53	3	5.7
German Wirehaired Pointer	4	1	25
Golden Retriever	30	2	6.7
Jack Russell Terrier	29	8	27.6
Labrador Retriever	74	6	8.1
Mixed breed	149	8	5.4
Pekingese	5	1	20
Poodle	14	1	7.1
Pug	11	7	63.6
Rottweiler	40	2	5
Shih Tzu	6	2	33.3
Standard Schnauzer	4	1	25
Tibetan Terrier	10	1	10
West Highland White Terrier	5	1	20
Yorkshire Terrier	26	5	19.2
Other breeds group	27	16	59.3
Total	687	95	12

4.3 Morphological characteristics of LTV

4.3.1 Type of transverse processes

There were nine combinations of transverse processes in the 95 dogs with LTV. Symmetric transverse processes were seen in 62 (65.3%) dogs; type 1/1 and 3/3 accounted for more than half (51.6%) of all dogs with LTV. Asymmetric transverse processes were observed in 33 (34.7%) dogs with type 1/2 and 2/1 predominating in 15 of 33 (45.5%) dogs. Only 7 dogs with type 1/3 and 3/1 were seen in the asymmetric form and these two types were also the smallest group in all affected dogs (7.4%) (Table. 4-2).

Table. 4-2. Combination of types of transverse processes in the 95 dogs with LTV

Type of transverse processes (R/L)*	n	n (%)
Symmetric	62	65.3
1/1	14	14.7
2/2	13	13.9
3/3	35	36.8
Asymmetric	33	34.7
1/2 or 2/1	15	15.8
1/3 or 3/1	7	7.4
2/3 or 3/2	11	11.6
Total	95	100

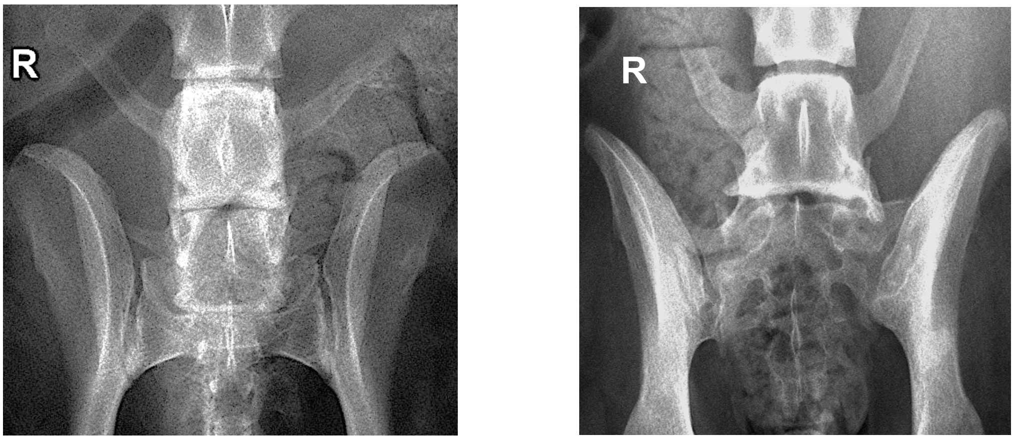
*R= right side, L= left side.

4.3.2 Length of transverse processes

Each LTV has a pair of transverse processes situated on either side of the vertebra, which makes the total number of transverse processes 190. Among them, 88 (46.3%) of them were completely fused to the sacrum; only 13 out of 190 (6.8%) had the same length of a normal lumbar vertebra; transitional form transverse processes, which had the length between a normal lumbar and a sacral one, were seen in 89 (46.8%) cases (Table. 4-3) (Fig. 4-3).

Table. 4-3. Incidence of different transverse process lengths in the LTV cases

Length of transverse processes	n	n (%)
Normal lumbar transverse process	13	6.8
Shorter but still lumbar shaped transverse process	40	21.1
Rudimentary transverse process, free tip	49	25.8
Complete fusion to the sacrum, transverse process is not formed	88	46.3
Total	190	100



A B

Fig. 4-3. Variation in length of transverse processes. (A) bilateral shorter and smaller lumbar-like transverse processes of a 9-year-old male Beagle. (B) a 8-year-old female Golden Retriever with a rudimentary transverse process on the right side and a completely fused transverse process to the sacrum on the left side.

In addition, the transverse process length distribution among the asymmetric LTVs was observed. The numbers in the upper row indicate different length groups of the right transverse processes and the left column is that of the left ones. The bold numbers indicate the number of asymmetric LTVs that have the same type of transverse processes on both sides. Only 1 (3%) pair from an asymmetric LTV belonged in the same length group, which was shorter than a normal lumber transverse process, which was shorter than a normal lumber transverse process 32 out of 33 (97%) asymmetric LTVs had transverse processes different in lengths (Table. 4-4).

Table. 4-4. Distribution of different transverse process lengths in the asymmetric LTVs

Length of transverse processes	I-L*	II-L*	III-L*	IV-L*
Normal lumbar transverse process (I)-R*	**0**	0	2	0
Shorter but still lumbar shaped transverse process (II)-R*	2	**1**	5	5
Rudimentary transverse process, free tip (III)-R*	0	5	**0**	4
Complete fusion to the sacrum, transverse process is not formed (IV)-R*	0	2	7	**0**

*I-IV (R) indicate group 1-4 classified in material and methods on the right side and I-IV (L) indicate group 1- 4 on the left side. Other details are seen in text above (p. 61).

4.3.3 Orientation of transverse processes

The occurrence of different transverse process orientations in the 95 dogs with LTV was analyzed in the present study. 88 out of 190 (46.3%) transverse processes were fused to the sacrum completely, thus, no orientation was noted in this group. 60 (31.6%) transverse processes projected laterally (Table. 4-5) (Fig. 4-4).

Table. 4-5. Incidence of various orientations of transverse processes in the LTV cases

Orientation of transverse processes	n	n (%)
Craniolateral	42	22.1
Lateral	60	31.6
No orientation, complete fusion to the sacrum	88	46.3
Total	190	100

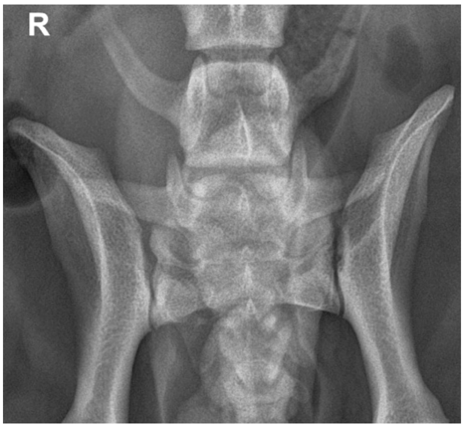


Fig. 4-4. A 5-year-old male Pug with transverse processes projecting laterally on both sides

Moreover, the orientation of both transverse processes on each asymmetric LTV was also observed. The upper row indicated the different orientation groups of the right transverse processes, and the left column is that of the left ones. The bold numbers indicate number of symmetric LTVs with equal orientation of transverse processes on both sides. In dogs with asymmetric LTV, 15 out of 33 (45.5%) pairs of transverse processes had the same orientation, in which 7 pairs of transverse processes projected craniolaterally and 8 pairs oriented laterally. 18 (54.6%) asymmetric LTVs had different orientation between the right and left transverse processes (Table. 4-6).

Table. 4-6. Distribution of various orientations of transverse processes in the asymmetric LTVs

Orientation of transverse processes	I-L*	II-L*	III-L*
Craniolateral (I)-R*	**7**	0	7
Lateral (II)-R*	0	**8**	2
No orientation, complete fusion to the sacrum (III)-R*	1	8	**0**

*I-III (R) indicate group 1-3 classified in material and methods on the right side and I-III (L) indicate group 1- 3 on the left side. Other details are seen in text above (p. 63).

4.3.4 Attachment between transverse processes and sacrum

Out of 190 transverse processes, 88 (46.3%) transverse processes were in complete contact with the sacrum, while 50 (26.3%) transverse processes had no contact with the sacrum. 73.7% of the transverse processes were partially or completely attached to the sacrum (Table. 4-7) (Fig. 4-5).

Table. 4-7. Incidence of different attachment types between the transverse process and the sacrum in the LTV cases

Attachment types between the transverse processes and the sacrum	n	n (%)
No attachment	50	26.3
Partial attachment	52	27.4
Complete fusion to the sacrum	88	46.3
Total	190	100

Fig. 4-5. VD view of a 3-year-old male German Wirehaired Pointer. The transverse process on the right side has no attachment to the ilium. On the left side, there is partial attachment between the transverse process and the ilium.

Furthermore, the incidence of different attachment types between the transverse process and the sacrum in the asymmetric LTVs were analyzed. The upper row shows the various type of attachments between the transverse process and the sacrum on the right side, and the left column is that of the left side. The bold numbers indicate equal degree of attachments on both sides of an asymmetric LTV. In all asymmetric LTVs, the attachments on both sides differed (Table. 4-8).

Table. 4-8. Incidence of different attachment types between the transverse process and the sacrum in the asymmetric LTVs

Attachment types between the transverse process and the sacrum	I-L*	II-L*	III-L*
No attachment (I)-R*	**0**	8	4
Partial attachment (II)-R*	9	**0**	4
Complete fusion to the sacrum (III)-R*	1	7	**0**

*I-III (R) indicate group 1-3 classified in material and methods on the right side and I-III (L) indicate group 1-3 on the left side. Other details are seen in text above (p. 64).

4.3.5 Shape of ventral or dorsal sacral foramina

Just as it is with the transverse processes, normally, ventral or dorsal sacral foramina are located bilaterally. Thus the total number of ventral or dorsal sacral foramina was 190. 126 out of 190 (66.3%) ventral or dorsal sacral foramina were normal round shaped (Fig. 4-13), while only 3.7% were abnormal in the LTV cases (Table. 4-9) (Fig. 4-6 and 4-14).

Table. 4-9. The incidence of various ventral or dorsal sacral foramen shapes in the LTV cases

Various shapes of ventral or dorsal sacral foramina	n	n (%)
Absence	57	30
Shapeless, or with a laterally opened slit	7	3.7
Normal round shaped	126	66.3
Total	190	100

Fig. 4-6. Variation in ventral or dorsal sacral foramen shapes of a 13-year-old male Jack Russel Terrier. On the right side, the ventral or dorsal sacral foramen is not round and there is a lateral opened slit (black arrow). On the left side, no sacral foramen is seen between the transverse process of LTV and the sacrum.

In addition, the incidence of different shapes of ventral or dorsal sacral foramina was demonstrated in the asymmetric LTVs. The upper row shows three different shapes of ventral or dorsal sacral foramina on the right side and the left column is that of the left side. The bold numbers indicate the ventral or dorsal sacral foramina were symmetrical in an asymmetric LTV. 9 (27.3%) pairs were symmetrical, in which 8 pairs had two normal round shape and one asymmetric LTV had no ventral or dorsal sacral foramina on either sides (Table. 4-10).

Table. 4-10. The incidence of various shapes of ventral or dorsal foramina between the LTV and the sacrum in the asymmetric LTVs

Various shapes of ventral or dorsal sacral foramina	I-L*	II-L*	III-L*
Absence (I)-R*	**1**	1	10
Not round, with a laterally opened slit (II)-R*	2	**0**	3
Normal round shaped (III)-R*	8	0	**8**

*I-III (R) indicate group 1-3 classified in material and methods on the right side and I-III (L) indicate group 1-3 on the left side. Other details are seen in text above (p. 65).

4.3.6 Distance between the spinous processes of sacrum

In the present study, the incidence of two distance groups between the spinous processes of the sacrum were observed in the LTV cases. Separation of SP S1 from the median sacral crest was noted in 44.2% of all dogs with LTV (Table. 4-11).

Table. 4-11. Incidence of different distances between the spinous processes of the sacrum in the LTV cases

Distance between the spinous processes of the sacrum	n	n (%)
Distance between S1-S2 and S2-S3 is the same length with no separation	53	55.8
Distance between S1-S2 is longer than S2-S3 with separation of SP S1 from the median sacral crest	42	44.2
Total	95	100

4.3.7 Various IVD space widths between LTV and sacrum

The occurrence of various IVD space widths between the LTV and the sacrum were observed in this study. The normal width of IVD space between a LTV and the sacrum was found in 22 (23.2%) LTV cases (Fig. 4-7), while 39 out of 95 (41.1%) LTV cases had narrowed (Fig. 4-8) or rudimentary IVD spaces (Fig. 4-9). The LTV was completely fused to the sacrum in 34 (35.8%) of the LTV cases (Table. 4-12).

Table. 4-12. Occurrence of various IVD space widths between a LTV and the sacrum in the LTV cases

Width of IVD spaces between the LTV and the sacrum	n	n (%)
Normal IVD space width	22	23.2
Narrowed IVD space with lateral contact of the adjacent vertebrae	27	28.4
Slit-like IVD space, as a radiolucent line	12	12.6
Absence of IVD space	34	35.8
Total	95	100

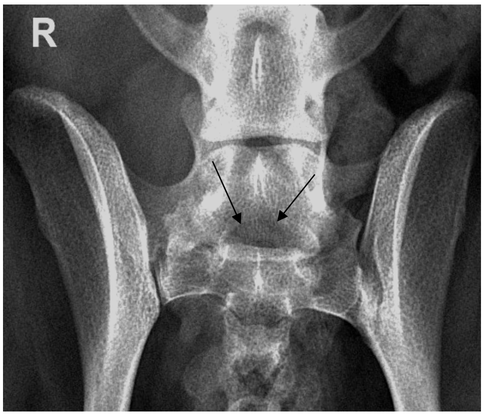


Fig. 4-7. Presence of a normal IVD space width between the LTV and the newly formed S1 (black arrows) in a 5-year-old female Jack Russel Terrier. SCTV is not present, as a result, the sacrum consists of only 2 segments.

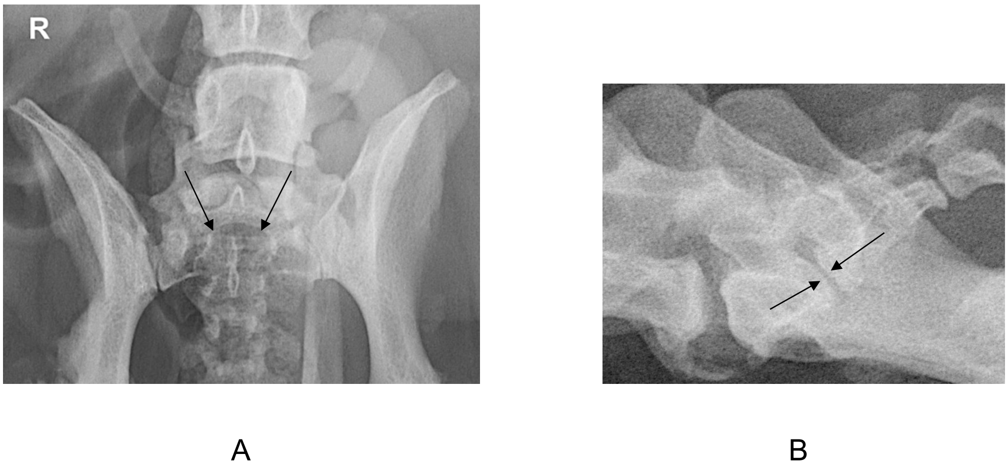


Fig. 4-8. VD (A) and lateral (B) views of a 13-year-old male Pug. Narrowed IVD space between the LTV and the sacrum are noted on both views (black arrows). SCTV is not presented, as a result, the sacrum consists only 2 segments.

Fig. 4-9. VD (A) and lateral (B) views of a 12-year-old male Fox Terrier. The IVD space between the LTV and the newly formed S1 appears as a slit-like, radiolucent line (black arrows). The sacrum consists of 3 segment due to a completely fused Cd1.

4.3.8 Number of sacral segments and SCTV

In the present study, the occurrence of SCTV in the 95 LTV cases with different number of sacral segments was analyzed. There was a statistically significant association between the number of sacral segments and the presence of a SCTV (P<0.001). Out of all the cases with abnormal numbers of sacral segments (2 or 4 sacral segments), 17 out of 22 (77.3%) LTV cases also had a SCTV (Fig. 4-9) and only 5 (22.7%) were without a SCTV (Fig. 4-7 and 4-8).

When 3 sacral segments were present, 23 (31.5%) of the 73 LTV cases were combined with a SCTV (Fig. 4-9) (Table. 4-13).

Table. 4-13. The occurrence of SCTV in LTV cases with different number of sacral segments

Number of sacral segments	SCTV	No SCTV	Total
2 sacral segments	10	2	12
3 sacral segments	23	50	73
4 sacral segments	7	3	10
Total	40	55	95

4.3.9 LTV forms

Normal LS vertebrae were present in 935 (90.8%) dogs, while LTV occurred in 95 (9.2%) dogs. The occurrence of symmetric LTV (3.5%) was slightly higher than that of asymmetric LTV (3.2%). In 26 (2.5%) of the LTV cases, separation of SP S1 was the only morphological change (Table. 4-14).

Table. 4-14. Different forms of LTVs based on their morphology

Forms of LTV	n	n (%)
Normal LS vertebrae	935	90.8
Separation of SP S1 from the median sacral crest	26	2.5
Symmetric LTV	36	3.5
Asymmetric LTV	33	3.2
Total	1030	100

4.4 Transverse process angle (TPA)

4.4.1 LTV and TPA difference between LTV and the last normal lumbar vertebra

Using the measurement method mentioned in material and method, TPA differences between the LTV and the last lumbar vertebrae on both the right and left side of different types of LTV were analyzed There was a statistically significant association between type of LTV and transverse process angel difference ($P<0.001$). In all types of LTV, the angle differences were positive on both sides, which indicates there was a bigger TPA in the LTV (Table. 4-15).

Table. 4-15. TPA difference between the LTV and the LNLV in different types of LTV.

Type of LTV (R/L)*	TPA difference between the LTV and the LNLV (°) (mean±SD)		n
	(α′- α) **	(β′- β) **	
1/1	25.66±9.17	23.66±10.52	14
2/2	29.92±17.09	31.48±20.45	13
1/2	30.40±16.00	36.69±12.58	7
2/1	26.49±15.64	12.18±13.41	8
1/3	40.54±22.93	48.38±4.13	5***
3/1	53.45±0.92	32.20±2.26	2***
2/3	29.43±33.38	49.55±4.34	4***
3/2	48.14±8.17	25.33±8.43	7
3/3	49.13±5.79	45.88±7.16	35

*R= right side, L= left side. ** α′ and β′ are the TPAs of a LTV on the right and the left side respectively. α and β are the angles of the LNLV on the right and left side respectively. A positive angle difference means the TPA on the same side is larger in the LTV than that of the LNLV; conversely, a negative angle difference means the angle of the LTV is smaller than that of the LNLV. In type 3, the transverse process is perpendicular to the pelvis, thus, the angle is 90°. *** Although some of the sampling numbers were small (n=2, 4 or 5), it is still meaningful to look at the mean ± SD in scattered data.

4.4.2 LTV and difference between the right and left side TPA differences

There was a significant association between the type of LTV and the mean angle difference between the right and left TPA differences of the LTV and the LNLV ($p<0.001$). In dogs with symmetric LTVs, angles in right and left were identical or had minimal differences. In contrast, in dogs with asymmetric LTVs, particularly with type 3/1, 2/3 and 3/2, angle difference between both sides differed more than those in symmetric LTVs. Intermediate type or sacral type transverse processes had bigger angles (Table. 4-16) (Fig. 4-10).

Table. 4-16. Correlation between the type of LTV based on the transverse process morphology and the mean difference between the right and left TPA differences of the LTV and the LNLV

Type of LTV (R/L)*	The difference of the transverse process angel differences between the right and left side (º) (mean±SD)	n
	(α′-α)-(β′-β)**	
1/1, 2/2, 3/3	1.98±8.39	62
1/2	-6.29±19.42	7
2/1	14.31±10.47	8
1/3	-7.84±21.95	5***
3/1	21.25±3.18	2***
2/3	-20.13±32.68	4***
3/2	22.81±11.74	7

*R= right side, L= left side. ** α′ and β′ are the TPAs of a LTV on the right and the left side respectively. α and β are the angles of the LNLV on the right and left side respectively. A positive angle difference means the angle difference between the transverse process of the LTV and that of the LNLV on the right side is bigger than that on the left side. A negative angle difference indicates the angle difference on the right side is smaller than that on the left side. *** Although some of the sampling numbers were small (n=2, 4 or 5), it is still meaningful to look at the mean ± SD in scattered data.

4.4.3 Angle difference and the contact zone between transverse process and pelvis

According to the above data sheet, ±16º was calculated as a cutoff value for determining the symmetry of contact zone between transverse processes of LTV and pelvis. The difference between the right and left TPA differences of the LTV and the LNLV was not significant associated with symmetry of the contact zone. When the absolute value of the angle difference was less than or equal to 16º (⩽16º, or ⩾-16º), 40 out of 70 (57.1%) transverse processes were attached to the pelvis symmetrically. When the absolute value of the angle difference was more than 16º (>16º, or <-16º), 22 out of 25 (88%) transverse processes had an asymmetric contact zone, and 18 (72%) of them had a bigger angle on the side where the contact zone between the transverse process and the pelvis was longer (Table. 4-17) (Fig. 4-10).

Table. 4-17. Correlation between the difference of TPAs and symmetry of the contact zone between the transverse process and the pelvis

Difference of TPA (α'-α)-(β'-β)*	Symmetry of contact zone between transverse process and pelvis				Total
	Symmetric contact	Asymmetric contact		Bilateral no contact	
		R>L**	R<L**		
-16 -- 0	14	1	6	6	27
0 --16	26	7	3	7	43
< -16	0	1	7	0	8
>16	2	11	3	1	17
Total	42	20	19	14	95

*α' and β' are the TPAs of a LTV on the right and the left side respectively. α and β are the angles of the LNLV on the right and left side respectively. **R= right side, L= left side.

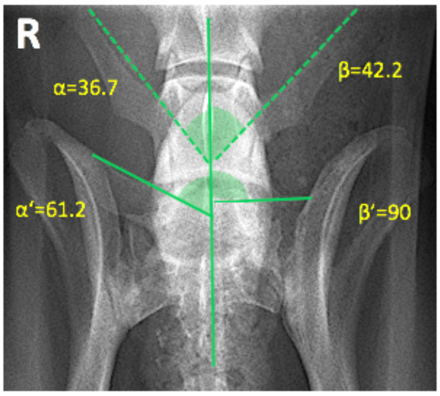


Fig. 4-10. VD view of the LS junction of a 2-year-old male Boxer. The transverse process angles are measured and the difference of the right and left side TPA is less than -16° (-23.3°). It indicates that the angle is bigger on the left side where the length of the contact zone the between transverse process and the pelvis is longer. The LTV is slightly angulated to the side where the TPA is bigger. A different position of the SI attachment between the right and left side is noted.

4.4.4 Angle difference and LTV angulation

±16° was calculated as the cutoff value for determining LTV angulation. There was no statistically significant association between the angle difference and LTV angulation. When the absolute value of the angle divergence was less than or equal to 16° (0° --16° or -16° --0°), 53 out of 70 (75,7%) LTV were not angulated. When the absolute value was more than 16º (>16º, or <-16º), 92% LTV were angulated, and 56% of these were angulated toward the side where TPA was bigger (Fig. 4-10) (Table. 4-18).

Table. 4-18. Correlation between the difference of the right and left transverse process angel differences and the angulation of LTV

Difference of TPA (α'-α)-(β'-β)*	Angulation of LTV			Total
	No angulation	To L**	To R**	
-16 -- 0	22	4	1	27
0 --16	31	10	2	43
< -16	0	7	1	8
>16	2	8	7	17
Total	55	29	11	95

*α′ and β′are the TPAs of a LTV on the right and the left side respectively. α and β are the angles of the LNLV on the right and left side respectively. **R= right side, L= left side.

4.5 LTV and subsequent variations

4.5.1 Type and angulation of LTV

No correlation between the type of LTV based on the morphology of the transverse processes and the angulation of LTV over its vertical or sagittal axis was found. Of the symmetric LTVs, only 10 (16.1%) were angulated, while 90.9% of the asymmetric ones were angulated. Asymmetric LTVs could be further divided into two groups, one with longer transverse process attachment to the pelvis on the left side (1/2, 1/3 and 2/3) and the other with longer contact on the right side (2/1, 3/1 and 3/2). Among the 29 cases of left rotating LTVs, 13 (44.8%) dogs had a longer contact zone between the transverse process and the pelvis on the same side. In cases where the LTVs angulated towards the right, 8 (72.7%) cases had a longer contact zone on the right side. Thus, 70% of the asymmetric LTVs angulated towards the side where the length of the contact zone between the transverse process and the pelvis was longer (Table. 4-19) (Fig. 4-11).

Table. 4-19. Correlation between the type and the angulation of LTV

Type of LTV (R/L)*	Angulation of LTV			Total
	No angulation	To L*	To R*	
1/1, 2/2, 3/3	52	8	2	62
1/2, 1/3, 2/3	2	13	1	16
2/1, 3/1, 3/2	1	8	8	17
Total	55	29	11	95

*R= right side, L= left side.

Fig. 4-11. VD view of the LS junction of a 10-year-old female Fox Terrier. The asymmetric transitional LS segment is categorized as a lumbar type transverse process on the right side and a sacral type transverse process on the left side (1/3). The SI attachment on the left side is shorter and project more cranially. The LTV is slightly angulated towards the left side relative to the lumbar spine where the contact zone between the transverse process and the pelvis is longer and SI attachment is shorter. The pelvis is tilted over its vertical axis to the right side where the SIJ is longer. Also the sclerosis is worse the right side.

4.5.2 LTV and length of SI attachment

The type of LTV was not significantly associated with the length of SI attachment. The lengths of SI attachments were the same on each side in 52 (83.9%) dogs with symmetric LTVs. When asymmetric LTVs were noted, 32 (97%) dogs had unequal length of SI attachments on both sides. In cases where longer contact zones between the transverse process and the pelvis were on the left side, a shorter SI attachment on the same side was predominant (10 dogs; 62.5%). Also, among the dogs with longer contact zones on the right side, 12 (70.6%) dogs had shorter SI attachments on the right side. Thus, when the LTV was asymmetric, 22 (66.7%)

of the cases had shorter SI attachment on the side where the transverse process of the LTV had a longer contact zone with the pelvis (Fig. 4-11) (Table. 4-20).

Table. 4-20. Correlation between the type of LTV and the length of the SI attachment.

Type of LTV (R/L)*	Length of the SI attachment			Total
	R=L*	R>L*	R<L*	
1/1, 2/2, 3/3	52	4	6	62
1/2, 1/3, 2/3	1	10	5	16
2/1, 3/1, 3/2	0	5	12	17
Total	53	19	23	95

*R= right side, L= left side.

4.5.3 LTV angulation and length of SI attachment

The angulation of the LTV was not significantly associated with the length of the SI attachment The SI attachments were of the same length in 48 of 55 (87.3%) LTV cases that were not angulated. In the angulated ones, 35 out of 40 (87.5%) LTVs had unequal SI contact. When the LTV was angulated towards the left side, the SI attachment was shorter on the same side in 16 of the 29 (55.2%) cases. Similarly, when the LTV was angulated towards the right side, 10 of the 11 (90.9%) cases were shorter on the right. Thus, in the 26 of the 40 (65%) cases with angulated LTVs, the SI attachments were shorter on the side where the LTVs angulated towards (Fig. 4-11) (Table. 4-21).

Table. 4-21. Correlation between the angulation of the LTV and the length of the SI attachment

Angulation of LTV	Length of the SI attachment			Total
	R=L*	R>L*	R<L*	
No angulation	48	2	5	55
To L*	5	16	8	29
To R*	0	1	10	11
Total	53	19	23	95

*R= right side, L= left side.

4.5.4 LTV and pelvic obliquity

The type of LTV was not significantly associated with pelvic obliquity. The pelvic orientation was normal in 42 of the 62 (67.7%) dogs with symmetric LTV. There was no normal pelvic orientation in dogs with asymmetric LTV. When the transverse process had a shorter contact zone with the pelvis on the right side, 56.3% of the pelvises were also tilted to the right side. When the transverse process had shorter contact zone on the left side, 14 (82.4%) pelvises were tilted to the same side. Thus, in 23 (69.7%) of the asymmetric LTVs, pelvic obliquity was noted towards the side that had the shorter contact zone with the transverse process (Table. 4-22) (Fig. 4-12).

Table. 4-22. Correlation between the type of LTV and pelvic obliquity

Type of LTV (R/L)*	Pelvic obliquity			Total
	No obliquity	To L*	To R*	
1/1, 2/2, 3/3	42	7	13	62
1/2, 1/3, 2/3	0	7	9	16
2/1, 3/1, 3/2	0	14	3	17
Total	42	28	25	95

*R= right side, L= left side.

Fig. 4-12. VD view of the LS junction of a 7-month-old male Parson Russell Terrier. The left transverse process has no contact with the ilium, while the right one is completely fused to the ilium (3/1). A newly formed ventral or dorsal sacral foramen between the anomalous segment and the sacrum is noted on the right side (black arrow). The SI attachment is shorter but the total attachment between the spinal vertebrae and the ilium is longer on the right side. The SI attachment is projected cranially on the right side. The pelvis is tilted over its vertical axis to the left side where the transverse process has no contact.

4.5.5 LTV and SIJ sclerosis

The type of LTV was not significantly associated with symmetry of the SIJ sclerosis. 33 out of 62 (53.2%) dogs with symmetric LTV had equal severity of sclerosis in both SIJs (Fig. 4-13). While 28 out of 33 (84.9%) dogs with asymmetric LTV had unequal severity of sclerosis between the right and left side (Fig. 4-14). More interestingly, sclerosis in SIJs were present in all asymmetric LTV cases, while 8 of the dogs with symmetric LTV had no occurrence of SIJ sclerosis (Table. 4-23).

Table. 4-23. Correlation between the type of LTV and symmetry of the SIJ sclerosis.

Type of LTV (R/L)	Symmetry of the SIJ sclerosis				Total
	Equal sclerosis on both sides	Worse on the right side	Worse on the left side	No sclerosis on both sides	
1/1, 2/2, 3/3	33	14	7	8	62
1/2, 1/3, 2/3	4	6	6	0	16
2/1, 3/1, 3/2	1	11	5	0	17
Total	38	31	18	8	95

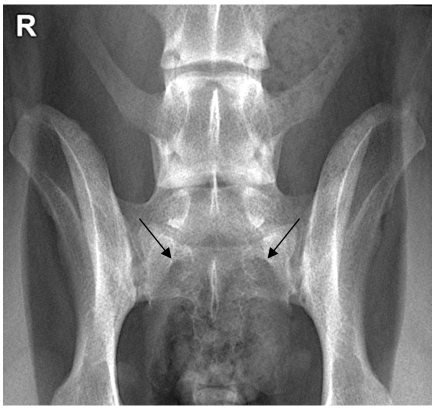


Fig. 4-13. VD view of the LS junction of a 2-year-old female Belgian Shepherd Dog. Both transverse processes are broad based and seem to in contact the ilium. Their tips remain free (2/2). Ventral or dorsal sacral foramina are seen on both sides between the anomalous segment and the sacrum (black arrows). There is no difference in length and position of the SI attachment. Pelvic obliquity is not noted. mild sclerosis might be present bilaterally.

Fig. 4-14. VD view of the LS junction of a 6-year-old female Finnish Spitz. The right transverse process is broad based and has partial contact with the ilium and the sacrum. Its tip remains free. The left one is a normal lumbar transverse process A ventral or dorsal sacral foramen between the anomalous segment and the sacrum is noted on the right side (black arrow). The SI attachment is longer on the left side. LTV is angulated slightly relative to the lumbar vertebra. The pelvis is slightly rotated over its vertical axis to the left side. SIJ sclerosis is noted on the right side.

4.6 LTV and CHD

4.6.1 CHD and age in the dogs with LTV

In the present study, the incidence of CHD among dogs with LTV in various age groups was observed. Dogs older than 4 months old were available for CHD evaluation in this study. 41 dogs met the requirement of age and radiographic position for CHD evaluation . In the 95 dogs with LTV, 31 (32.6%) of them had CHD. The prevalence of CHD in dogs with LTV was higher in the age group of less than 2 years old when comparing to the other age groups (Table. 4-24).

Table. 4-24. Incidence of CHD among dogs with LTV in various age groups

Age (months)	Dogs with LTV (n)	CHD positive *(n)	CHD positive* (%)
4-11	8	4	50
12-23	12	7	58.3
24-47	8	2	25
48-95	27	8	29.6
⩾96	40	10	25
Total	95	31	32.6

*CHD positive means at least one hip joint is grade C, D or E

4.6.2 LTV and occurrence of CHD

Symmetry of LTV was significantly associated with the occurrence of CHD (P<0.01). Among the 26 dogs with symmetric LTV, CHD was absent in 10 of them (Fig. 4-15). Interestingly, all dogs with asymmetric LTV exhibited radiographic changes related to CHD (Table. 4-25).

Table. 4-25. Correlation between symmetry of the LTV and the occurrence of CHD

Symmetry of LTV	Occurrence of CHD		Total
	No CHD (A or B)*	CHD positive (C, D or E)**	
Symmetric	10	16	26
Asymmetric	0	15	15
Total	10	31	41

*No CHD includes that both hips are categorized as grade A or B, or one hip is grade A and the other is grade B. **CHD positive means at least one hip joint is grade C, D or E.

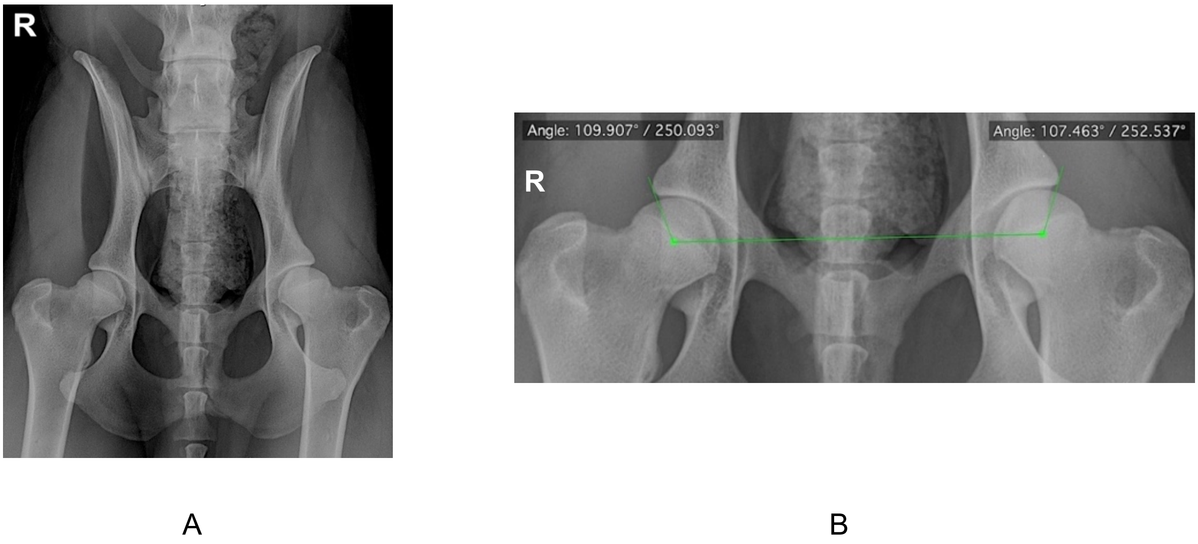


Fig. 4-15. VD pelvic views of a 10-month-old male Dutch Shepherd Dog. In A, a symmetric LTV is categorized by the separation of the SP S1 from the sacral median crest. B shows the NA in both hip joints, which in this case indicates bilateral near normal hip joints (B/B). The femoral heads and acetabulums are slightly incongruent. NA on both sides are more than 105°. No coxarthrosis is noted in either hip joints.

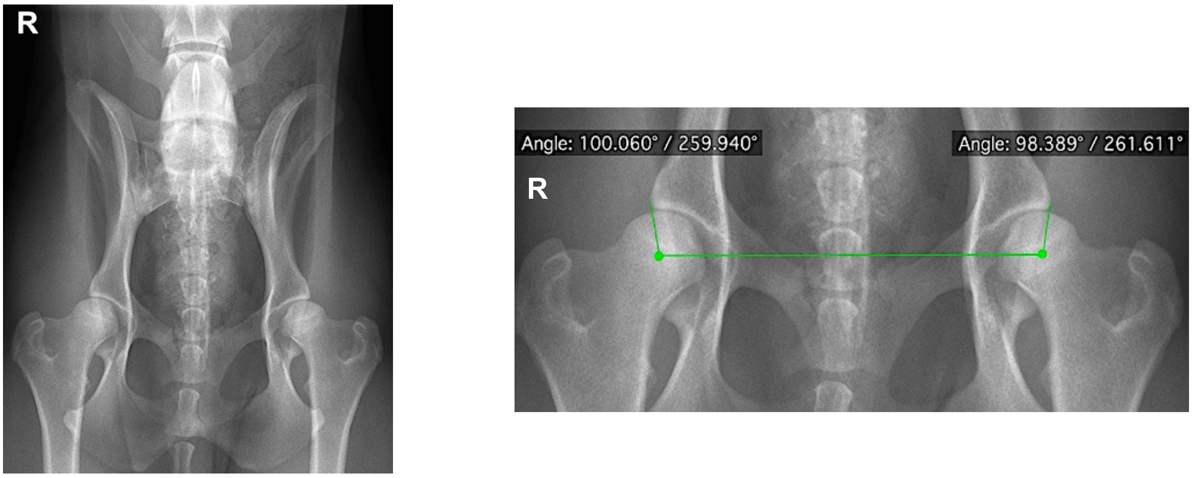
4.6.3 LTV and symmetry of CHD

There was a significant association between symmetry of LTV and the symmetry of CHD ($p<0.05$). In dogs with symmetric LTV, only 9 out of 16 (56.3%) dogs had bilateral CHD; while all the dogs with asymmetric LTV had CHD on both sides (Table. 4-26) (Fig. 4-16).

Table. 4-26. Correlation between symmetry of the LTV and the symmetry of CHD

Symmetry of LTV	Symmetry of CHD		Total
	Bilateral C,D or E*	Unilateral C, D or E**	
Symmetric	9	7	16
Asymmetric	15	0	15
Total	24	7	31

*Bilateral C, D or E indicates CHD grade C, D or E are detected on both sides. **Unilateral C. D or E indicates that CHD grade C, D or E is detected on only one side and the other side is CHD free.



A B

Fig. 4-16. VD pelvic views of the same dog in Fig. 4-8. In A, an asymmetric LTV is categorized as lumbar like Proc. transversus type on the right side and wing like type on the left side (1/3). The pelvis is slightly tilted to the left side where the SI attachment is longer. The NA is drawn on both hip joints in B. The radiograph shows mild signs of CHD on the right hip and moderate CHD on the left hip (C/D). In the right joint, the femoral head and the acetabulum are incongruent. NA is about 100°. Mild signs of osteoarthrosis may be present on the femoral head. In the left joint, there is obvious incongruence between femoral head and acetabulum with subluxation. NA is more than 90°. Osteoarthrosis is noted on femoral head and small osteophytes at the craniolateral acetabular rim is visible. CHD is worse on the side towards where the pelvis is tilted.

4.6.4 LTV and CHD score

Differing from the CHD grade, Swiss scoring system give each hip a score from 0 (excellent hip joint) to 30 (the most severe CHD) to define the severity of hip joint malformation. We observed the difference between symmetry of the LTV and the average CHD score of its right and left sides. There was a significant association between symmetry of the LTV and the average of CHD score of its right and left hip joints ($P<0.05$). An asymmetric LTV had a higher average CHD score than that of a symmetric LTV (Table. 4-27).

Table. 4-27. Correlation between symmetry of the LTV and the average CHD score of its right and left hip joints

Symmetry of LTV	Average CHD score of its right and left hip joints (mean±SD)	n
	(R+L)*/2	
Symmetric	8.635±6.095	26
Asymmetric	13.133±3.346	15

*R= right side, L= left side.

4.6.5 Type of LTV and CHD score difference

There was no significant association between the type of LTV and the CHD score difference between the right and left hip joint ($p>0.05$). In dogs with type 2/1, 3/1 and 3/2, the score difference between the two hip joints differed more than that of a symmetric LTV (Table. 4-28).

Table. 4-28. Correlation between the type of LTV and the mean score difference between the right and left hip joints

Type of LTV (R/L)*	Right and Left hip joint CHD score difference (mean±SD)	n
	R-L**	
1/1, 2/2, 3/3	-1.58±2.63	26
1/2, 1/3, 2/3	-1.50±2.00	8
2/1, 3/1, 3/2	-3.43±4.76	7

*R= right side, L= left side. **A positive score difference indicates the right hip is more severe; a negative score difference means that the left hip is more severe.

4.7 LTV and coxarthrosis

4.7.1 Coxarthrosis and age in the dogs with LTV

The incidence of coxarthrosis among dogs with LTV in various age groups was revealed in this study. There was no significant association between coxarthrosis and age in the LTV cases. In all 95 dogs with LTV, 75 (79%) dogs had coxarthrosis. The prevalence of coxarthrosis in dogs with LTV was lower at the age group of less than 12 months (3.2%) and higher at the age group of more than or equal to 96 months (33.7%) on comparing each of these groups with all others combined (Fig. 4-17).

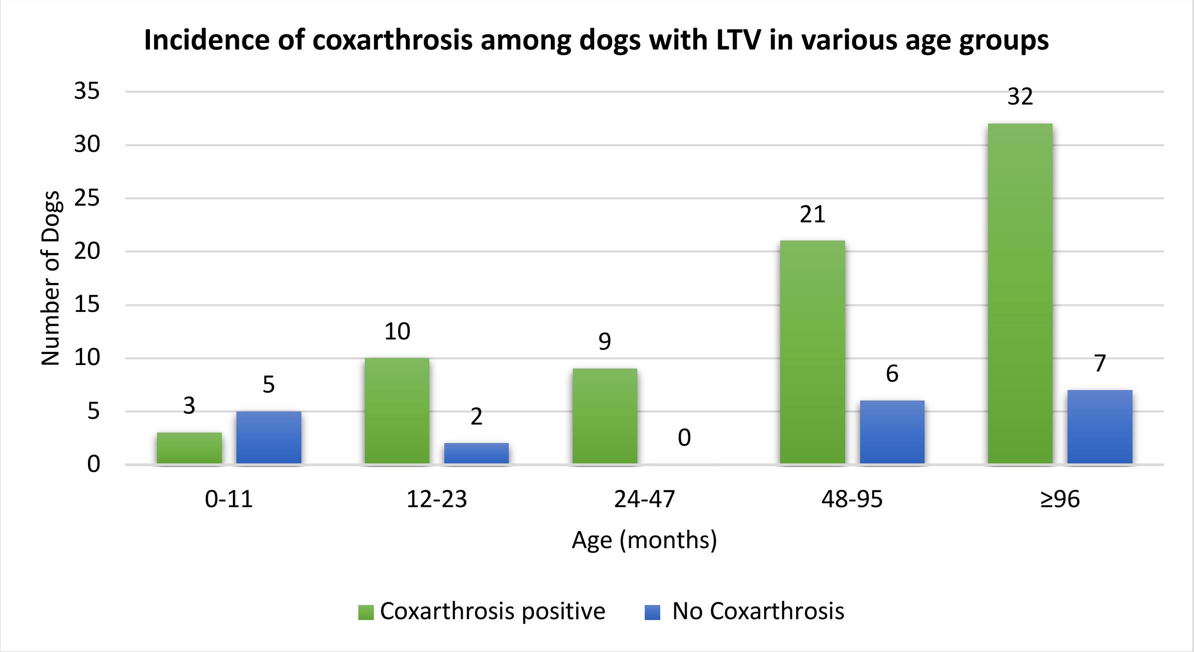


Fig. 4-17. Incidence of coxarthrosis among dogs with LTV in various age groups

4.7.2 LTV and occurrence of coxarthrosis

There was a significant association between symmetry of the LTV and the occurrence of coxarthrosis ($P<0.05$). Of the symmetric LTV, 17 (27.4%) dogs are free of coxarthrosis (Fig. 4-15 and 4-18A). In dogs with an asymmetric LTV, 30 (90.9%) dogs have coxarthrosis (Table. 4-29).

Table. 4-29. Correlation between symmetry of the LTV and the occurrence of coxarthrosis

Symmetry of LTV	Occurrence of coxarthrosis		Total
	No coxarthrosis *	Coxarthrosis positive**	
Symmetric	17	45	62
Asymmetric	3	30	33
Total	20	75	95

*No coxarthrosis indicates that both hip joints were categorized as grade 0. **Coxarthrosis positive means at least one side was categorized as grade 1, 2 or 3.

4.7.3 LTV and coxarthrosis grades

There was a significant association between symmetry of the LTV based on transverse process morphology and the equality of coxarthrosis grades between both hips ($p<0.05$).Of dogs with symmetric LTV, 50 (80.7%) dogs had equal coxarthrosis grade, in which 17 (27.4%) dogs were free of coxarthrosis and 33 (53.2%) dogs had coxarthrosis (Fig. 4-18B). Among the asymmetric LTV cases, 14 (42.4%) dogs had different coxarthrosis grade on both sides (Fig. 4-19). Among the cases where an unequal degree of coxarthrosis between the right and left side was noted, 14 (53.9%) of the LTVs were asymmetric (Table. 4-30).

Table. 4-30. Correlation between symmetry of the LTV and the equality of coxarthrosis grade on both sides

Symmetry of LTV	Equality of coxarthrosis grade on both sides			Total
	Equal 0*	Equal 1, 2 or 3**	Unequal 1, 2 or 3***	
Symmetric	17	33	12	62
Asymmetric	3	16	14	33
Total	20	49	26	95

*Equal 0 indicates that there is no coxarthrosis on both sides. **Equal 1, 2 or 3 indicates that both sides have the same degree of coxarthrosis, which is grade 1, 2 or 3, respectively. ***Unequal 1, 2 or 3 indicates that both hips have coxarthrosis but are in different grades.

A B

Fig. 4-18. VD pelvic views of two dogs with symmetric LTV. (A) is a radiograph of a 7-year-old female Australian Shepherd with bilateral normal hip joints. No coxarthrosis is presented in this dog (0/0). Separation of SP S1 from the sacral median crest in noted (black arrow). (B) is a radiograph of a 5-year-old male Majorca Ratter with severe bilateral coxarthrosis (3/3). The acetabulums are markedly flattened with osteophytes on the craniolateral acetabular rims. The joint spaces are uneven. The femoral heads and necks are markedly deformed with numerous osteophytes and cysts. It is the same as type of LTV as in A, a symmetric LTV is categorized as separation of the first spinous process from the sacrum (black arrow). In both (A) and (B), the length of the SI attachments between the right and left side are the same.

4.7.4 LTV and symmetry of coxarthrosis

There was no significant association between the type of LTV and symmetry of coxarthrosis ($P>0.05$). Of the dogs with symmetric LTV, 39 (86.7%) of them had bilateral coxarthrosis (Fig. 4-18B). Of the dogs with asymmetric LTV, 6 (20%) dogs had unilateral coxarthrosis (Table. 4-31) (Fig. 4-19).

Table. 4-31. Correlation between the type of LTV and symmetry of coxarthrosis in the right and left hip joints

Type of LTV (R/L)*	Symmetry of coxarthrosis in the right and left hip joints			Total
	Bilateral 1,2 or 3**	Unilateral 1, 2 or 3 on R***	Unilateral 1, 2 or 3 on L***	
1/1, 2/2, 3/3	39	1	5	45
1/2, 1/3, 2/3	9	1	3	13
2/1, 3/1, 3/2	15	2	0	17
Total	63	4	8	75

*R= right side, L= left side. **Bilateral 1, 2 or 3 indicates that both hips have coxarthrosis, but not necessarily to the same degree. ***Unilateral 1, 2 or 3 on R or L indicates that only the right or left hip, respectively, has grade 1, 2 or 3 coxarthrosis and the other side is normal.

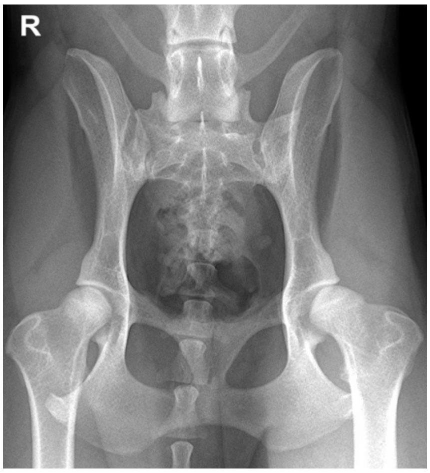


Fig. 4-19. VD pelvic view of a 2-year-old female German Shepherd. An asymmetric LTV with a sacral type transverse process on the right side and an intermediate type on the left side (3/2) is noted. The length of the true SIJs might be shorter on the right side and it is projected cranially. This radiograph shows unilateral coxarthrosis with moderate grade on the left side (0/2). In the left joint, the acetabulum is flattened. Sclerosis of the subchondral bone appears along the cranial acetabular edge. The femoral head is deformed and lost its rounded appearance. Osteophytes are noted on the femoral head and neck, as well as the craniolateral acetabular rim. Coxarthrosis is present on the side towards where pelvis is titled.

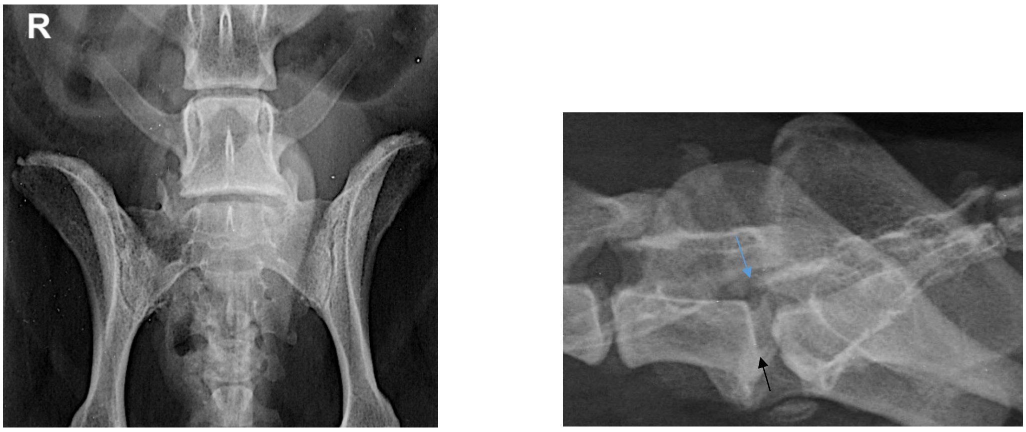
4.8 LTV and CES

4.8.1 Lateral radiographs of lumbosacral abnormalities in dogs with LTV

Lateral radiographs were available for analysis in 66 of the 95 dogs with LTV. Radiographic abnormalities between the LNLV and the LTV were seen in 53 (80.3%) dogs (Fig. 4-20 and 4-21). Endplate sclerosis was the most common finding, which was present in 56.1% of the dogs. Spondylosis deformans was present in 23 (34.9%) dogs with different grades, in which 6 (9.1%) dogs were seen with the most severe grade of spondylosis deformans. The occurrence of ventral subluxation of LTV, IVD space narrowing and downward elongation of the sacral lamina was similar. Calcified nuclear material and vacuum phenomenon indicated the condition of the disc. 21 (31.8%) dogs had anomalies of the disc, in which vacuum phenomenon was only 2 of them (Table. 4-32).

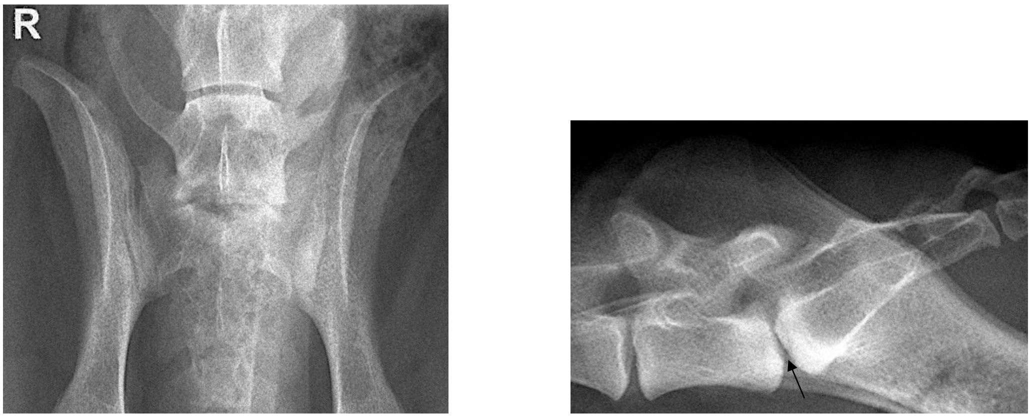
Table. 4-32. Imaging findings on conventional lateral radiography in dogs with LTV

Radiography (n=66)	n	n (%)
Normal radiographic findings	13	19.7
Abnormal radiographic findings	53	80.3
Spondylosis deformans:	23	34.9
Grade-1	9	13.6
Grade-2	8	12.1
Grade-3	6	9.1
End plate sclerosis	37	56.1
Ventral subluxation of LTV	9	13.6
Narrowed IVD space	11	16.7
Downward elongation of the sacral lamina	12	18.2
Calcified nuclear material	19	28.8
Vacuum phenomenon	2	3



A B

Fig. 4-20. VD (A) and lateral (B) views of a 15-year-old male Papillion. In (A), a symmetric LTV (3/3) and a S1 separated from the sacrum are noted. In (B), there is moderate ventral spondylosis deformans and endplate sclerosis between the LNLV and the LTV. Elongation of the sacral lamina in the caudal aperture of L7 (blue arrow), calcified nuclear material in the IVD space (black arrow) and slight ventral subluxation of LTV are noted. A newly formed IVD between the S1 and S2 are seen in both (A) and (B).



A B

Fig. 4-21. VD (A) and lateral (B) views of an 1-year-old male Airedale Terrier. In (A), separation of the first spinous process from the sacral median crest is present. In (B), a narrowed IVD space and endplate sclerosis between the LNLV and the LTV are noted. Vacuum phenomenon might be present in the IVD space (black arrow).

4.8.2 LTV and endplate sclerosis

No significant association between symmetry of LTV and the occurrence of endplate sclerosis was found (P>0.05). When the LTV was symmetric, endplate sclerosis was present in 26 (60.5%) of the cases. When the LTV was asymmetric, endplate sclerosis was notes in (47.8%) of the dogs. Of the dogs with endplate sclerosis, the occurrence of symmetric LTV was two times higher than that of asymmetric LTV (Table. 4-33).

Table. 4-33. Correlation between symmetry of LTV and the occurrence of endplate sclerosis

Symmetry of LTV	Occurrence of endplate sclerosis		Total
	No endplate sclerosis	With endplate sclerosis	
Symmetric	17	26	43
Asymmetric	12	11	23
Total	29	37	66

4.8.3 LTV and spondylosis deformans

There was no significant association between symmetry of LTV and the severity of spondylosis deformans (p>0.05). Of dogs with symmetric LTV, 30 (69.8%) dogs had no spondylosis. Of dogs with asymmetric LTV, 10 (43.5%) dogs showed spondylosis, in which 4 of them were graded as severe spondylosis (Table. 4-34).

Table. 4-34. Correlation between the symmetry of LTV and the severity of spondylosis deformans

Symmetry of LTV	Severity of spondylosis deformans				Total
	Grade-0*	Grade-1*	Grade-2*	Grade-3*	
Symmetric	30	6	5	2	43
Asymmetric	13	3	3	4	23
Total	43	9	8	6	66

*Spondylosis deformans are divided into four degrees, which varied from grade 0 (no spondylosis deformans) to grade 3 (the most severe form of spondylosis deformans).

4.8.4 CT views of LTV and CES

In dogs with LTV, only 5 (5.3%) dogs were diagnosed with CES through CT imaging and neurological findings. Due to the low population, no correlation between LTV and CES could be drawn in this study. One of the 5 cases is presented below (Fig. 4-22). This case had changes consistent with symmetric LTV and CES in CT views available.

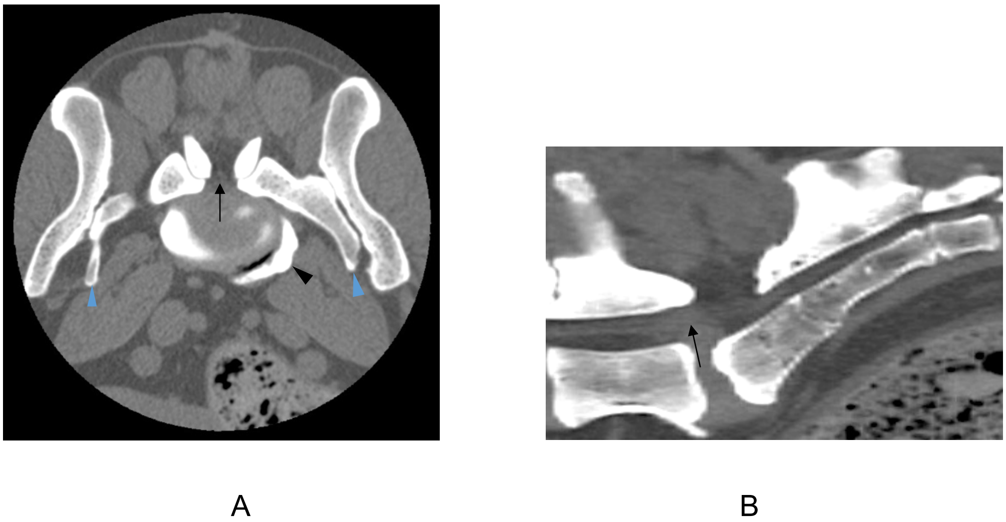


Fig. 4-22. CT views of a 1-year-old White Shepherd with symmetric LTV (2/2) and CES. (A) transverse CT imaging indicates bilateral intermediate type transverse processes (blue arrowheads). There is compression of the dural sac and nerves by a dorsally protruding IVD (black arrow). Ventral and lateral spondylosis deformans are also noted (black arrow head). (B) Sagittal CT imaging shows dorsal protrusion of the IVD between the last lumbar vertebra and the sacrum (black arrow), narrowing of the vertebral canal and attenuating of the dural sac around the cauda equine.

5 Discussion

5.1 Literature

Variation of the total number of vertebral segments as well as the number of vertebral segments in the individual junctions occur frequently in dogs and humans. The mechanism of increased or decreased presacral vertebral segments have not been clearly explained in dogs. BLUMENSAAT and CLASING (1932) and SCHULTZ and WATSON (1995) used the term transitional vertebrae to explain this condition. Conversely, MOTGAN (1968) and LARSEN (1977) referred to merged vertebras as increased vertebral segments.

Transitional vertebrae can occur within the spine at the junction of all major divisions (Morgan 1968). They could vary in segment numbers, and also possess characteristics from both adjacent divisions (Rosenberg 1907, Junghanns 1939). In dogs when the transitional vertebra occurs at cervicothoracic division, its morphological variation corresponds strongly to the degree of movement disorder the dog exhibits, since this junction normally has the most mobility. In thoracolumbar and LS regions, stronger stability is achieved through stronger tendons, ligaments and muscle. Variation at the SC junction normally has no clinical relevance.

The terms lumbarization and sacralization were used in some earlier studies to describe the characteristics of the transitional vertebra at LS junction. However, since the definition of lumbarization and sacralization varies among different authors, to have a clear classification guideline is often impossible. LARSEN (1977) defined a complete separation of S1 from the sacrum as lumbarization, whereas a fusion of L7 to the sacrum is defined as sacralization. In addition, according to LARSEN (1977) and WINKLER (1985) the presence of transverse processes has been classified as “lumbarization”. However, since an incomplete sacralization of L7 could have the same appearance, this classification criteria can be quite misleading. This might be the reason why some authors describe “lumbarization” less obvious than “sacralization” on the radiographs, which has been defined by these authors as a shift of the ventral alar element.

WINKLER and LOEFFLER (1986) and BREIT and KÜNZEL (1998) proposed additional anatomical features to distinguish between lumbarization and sacralization, such as the different position and angle of the cranial articular processes of transitional vertebral segments, but these findings cannot be identified on radiographs.

JUNGHANNS and SCHMORL (1957) used the term assimilation disorder instead of LTV to describe a LS transitional vertebral segment if the total number of the vertebra was unknown in human medicine, while ZIEGLER (1990) did the same in dogs. To date, more authors (Morgan 1999 b, Damur-Djuric et al. 2006, Flückiger et al. 2006, Flückiger et al. 2009) preferred to use the term LTV to describe this anomaly since most data for identifying transitional vertebrae in LS region were from CHD evaluation, which included only the caudal lumbar vertebrae and the sacrum in radiographs. For the same reason, LTV was used in the present study.

There are two different hypotheses to explain the development of the LTV. According to ROSENBERG’s hypothesis of LTV formation in humans, when the pelvis contacts the vertebrae slightly more cranial or caudal of the normal point, the formative stimulus to the adjacent vertebrae influences the development of the transverse processes. Normally, the pelvis contacts the vertebrae at the same level on both sides so that the formative stimulus is the same. If the pelvis contacts the spinal column slightly obliquely, the formative stimulus will differ on the left and right side. This might explain the presence of numerous morphological variations of LTV, especially those that are asymmetric. This hypothesis can be supported by the present study. A different hypothesis is described as homeotic transformation. The concept of modulating the expression of Cdx and Hox genes were proven experimentally in the mouse and drosophila (Van Den Akker et al. 2002). So far, no literature regarding such studies in dogs have been found.

In the past, LTV was considered an incidental finding by some authors (Morgan 1968, Morgan 1972, Larsen 1977), therefore the clinical significance of this alteration was underestimated. However in more recent years, more and more studies have mentioned the suspected clinical importance of LTV when trying to understand the aetiology of CES. Moreover, MORGAN (1999), MORGAN et al. (2000) and FLÜCKIGER et al. (2017) reported that LTV may contribute to abnormal development of the hip joints through affecting the SI attachments. In the present study, it is believed that LTV may affect the SI attachment and , when asymmetric, may lead to rotation of the pelvis over the vertical axis. When the pelvis is elevated on one side, a smaller area of the ipsilateral femoral head is covered by the acetabulum, which can elicit abnormal hip joint development and subsequent secondary changes.

The morphological variations of LTV can cause instability at the LS junction which may result in clinical signs. More in depth research about the variations of LTV should be performed to confirm its correlation to the abnormal development of hip joints as well as CES. Since LTV is a congenital disorder and GSDs are predisposed to LTV, it is important to understand its clinical relevance for selective breeding.

5.2 Material and methods

Population: Canine pelvic radiographs were collected from the Small Animal Clinic, Faculty of Veterinary Medicine at Freie Universität Berlin between the years 2012 and 2016. 1030 cases qualified for this study. LARSEN (1977) examined 24463 cases from the OFA, and DAMUR-DJURIC et al. (2006) and FLÜCKIGER et al. (2017) used the 4000 dogs from the dysplasia committee in the same population for their research. In the present study, the cases were not exclusively from official CHD evaluation, but also included cases from the clinic that had VD radiographs taken for other reasons. This makes the sample population different although all these studies analyzed the prevalence of LTV in various breeds.

Age : In the present study, the age was calculated from the date of birth to the date of radiographic examination. They were divided into 5 groups: 0-11months, 12-23 months, 24-47months, 48-95 months and ≥ 96 months. The occurrence of LTV in various age group was not analyzed since LTV is considered an congenital disorder of the vertebrae and no age association were found in any previous studies. This age division was used to study the correlation between age and CHD as well as coxarthrosis in dogs with LTV. Because CHD is evaluated mostly at the age between 1 and 2 years old, the age groups were designed to be before 11 months old and between 1-2 years old. Furthermore, since coxarthrosis has been reported to be age associated, the interval was wider when dogs were older than 2 years old. It is assumed in this study that under this age classification in dogs with LTV, the distribution difference between CHD and coxarthrosis in various ages could be clearly separated since the occurrence of LTV is not related to age.

Radiographic evaluation : When evaluating LTV, this research was based solely on VD radiographs with pelvic limbs in extension. BREIT et al. (2003) believed that LTV was best visible on VD radiographs with pelvic limbs in extension. DAMUR-DJURIC et al. (2006) observed that IVDs were more visible on VD views with pelvic limbs abducted rather than extended, which resulted in better identification of LTVs. Due to the limitation of the nature of this retrospective study, it could not be determined which position is better for detecting LTV; however both VD projections provided information related to SI attachments and pelvic obliquity. There were some difficulties when examining LTV characteristics in the present study. Firstly, the appearance of the tip of transverse processes seemed to be factitious, and its visibility on radiographs was influenced by the projection and superimposition of the ilium. Secondly, some alterations resembled the radiographic characteristics of LTV according to BREIT et al. (2003), such as calcification of the dorsal and ventral SI ligaments, which might be misinterpreted as a transverse process of S1; and osteophyte formation at the LS junction, which simulated separation of the cranial articular processes from the assembly of the sacral wings. LAPPALAINEN et al. (2012) has scrutinized the radiographic and CT features of the LTV. With CT, the shape of transverse processes and median crest of the sacrum were easily identified. However, CT was not a standard method for LTV evaluation in the present study. It is questionable whether radiographic LTV classifications would be suitable to use for CT diagnosis.

Angulation of LTV and pelvic rotation over its vertical axis could be misleading on VD views due to axial malpositioning of the dog during radiographic examination. This can result in rotation of the caudal lumbar vertebrae and the pelvis in the same direction. It was determined that if the degree and/or the direction of the rotation between the lumbar vertebrae and the pelvis were different, an inherent malposition should be considered. Lateral projection can be helpful in distinguishing the cause of rotation.

Furthermore, because of the diagonal direction of the rudimental space towards the radiograph surface, rudimental IVD between the LTV and the sacrum can be easily overlooked on VD views. In human medicine, Ferguson’s radiograph is used to solve this problem. In veterinary medicine, a comparable solution is to perform lateral radiographs of the LS junction. However, 66 (69.5%) dogs with LTV had additional lateral radiographs in the present study, which may make the determination of different types of IVD between LTV and the sacrum difficult. It is strongly suggested by the author that lateral projection be included into the routine screening protocols for LTV in later studies.

In addition, morphological variations of LTV were only evaluated on radiographs. WINKLER (1985) demonstrated the characteristics of LTV on both radiographs and anatomical bone specimens. BREIT and KÜNZEL (1998) studied anatomical features of vertebrae through 228 spinal specimens. Since some anatomical features could not be detected on radiographs, CT imaging can help to identify these features. However, it is not an option for mass screening in this study. It is suggested that CT technique should be applied to detect minimal bony malformations and changes of articular processes of LTV. A new classification system based on the morphological variations of LTV in CT imagines may be required for further study.

Classification : The forms of LTV was classified according to FLÜCKIGER et al. (2009). This classification seemed more comprehensible since they included normal LS vertebrae in their classification and the separation of spinous process of S1 from the median sacral crest was categorized as an independent feature separated from the morphological variations of transverse processes. However, it remains unproven that separation of the spinal dorsal process of S1 is a mild form of a true LTV. In this study, this feature could be overread on plain radiographs.

In addition, symmetry of LTV were defined as the attachment of the transverse processes to the ilium based on DAMUR-DJURIC et al. (2006). In this study. transverse processes of different lengths, widths, orientations on each side but identical attachments to the ilium were not considered asymmetric. This definition differed from WIGGER (2009), who defined LTVs with different appearances of transverse process on both sides that are not contacting the ilium as asymmetric LTV. It is believed in this study, that the symmetry of the transverse process attachments to the ilium is more clinically relevant, because it may contribute to angulation of LTV, asymmetric length of SI attachments and pelvic obliquity.

Furthermore, the term lumbarization and sacralization were not used in the present study. Since the shift of abnormal vertebra without any bony malformation do not play a role in increasing the risk of the clinical disease such as CHD, coxarthrosis and CES, the validity of the results in this study are not affected by the lack of total number of presacral segments.

Statistics : In this study, more than 20 % of the expected counts of some tables larger than 2x2 were less than 5. They couldn’t meet the assumption of Chi-Square test , which was 1) each observation is independent of all the others, 2) no more than 20% of the expected counts are less than 5 and 3) all individual expected counts are 1 or greater. Therefore the tests were not significant. Further studies on larger populations are required to confirm the correlations. However, all tables using AVONA-test or t-test met the assumptions for these tests, which were normality, homogeneity of variance and homoscedasticity, and independent observations. Thus, when the p value from these tests was less than 0.05, there is a statistical significance.

5.3 Results

5.3.1 LTV and gender

In most studies, there was a nearly equal occurrence between male and female dogs (Larsen 1977, Winkler 1985, Morgan 1999 b, Damur-Djuric et al. 2006, Fialová et al. 2014). This study has also shown that LTV has no sex predisposition, which is in agreement with the results of these authors above. Conversely, MORGAN et al. (1999) demonstrated that female Labrador Retrievers (4.2%) have a higher occurrence rate of LTV than male Labrador Retrievers (1%). This may because they only analyzed the gender of Labrador Retrievers instead of various breeds of dogs. Moreover this study did not look into the correlation between castration and the development of LTV. One reason being LTV is considered an congenital disorder and it is hypothesize that hormone does not play a role in this.

5.3.2 LTV and breed

Previous works have documented the prevalence of LTV ranges from 2.3% to 40.4% (Winkler and Loeffler 1986, Morgan 1999 b, Damur-Djuric et al. 2006, Wigger et al. 2009, Lappalainen et al. 2012). LAPPALAINEN et al. (2012) considered the eighth lumbar vertebra a LTV, which could explain the higher incidence (40%) of LTV in their study. In the present study, the incidence of LTV was 9.2%. This discrepancy may reflect natural fluctuations of different study populations and more importantly, the difference in inclusion criteria. Most data in this study, VD radiographs have been obtained to evaluate the status of the hip joints. Some data, however, were obtained from dogs with CES, which probably resulted in an increased prevalence of LTV, as LTV is suspected to contribute to the development of CES.

A significantly higher occurrence of LTV in GSDs has been reported in the literature (Winkler and Loeffler 1986, Morgan et al. 1993, Damur-Djuric et al. 2006, Flückiger et al. 2006, Wigger et al. 2009). These previous works showed the incidence of LTV in GSDs to be as high as 29%, suggesting a genetic predisposition. Calculated values for heritability estimates have been performed in the GSD from WIGGER et al. (2009) and ONDREKA et al. (2013). Breeding selection against traits of LTV is suggested.

Interestingly, in the present study, small breed dogs, such as Pugs (63.6%) and Fox Terriers (42.9%) had higher prevalence of LTV, while GSDs (5.7%) and Rottweilers (5%) had a lower prevalence comparing to all other breed groups. No other previous studies could support this results. One explanation is the markedly different numbers of examined dogs in each breed group. Although the minimal breed groups (less than 4 dogs in the group) have been removed from this study, obvious unequal levels of involvement between breeds still remain. Due to this marked distribution difference, the breed prevalence in our study may not accurately reflect the reality. A larger small breed population should be studies to confirm whether certain small breeds have a higher incidence of LTV.

5.3.3 Morphological variations of LTV

In the present study, the variation of LTV transverse process length and orientation, transverse process to sacrum attachment and ventral or dorsal sacral foramen were evaluated on the right and left side separately in asymmetric LTV.

Asymmetric transverse process attachments to the sacrum and asymmetric transverse process lengths could contribute to the development of asymmetric LTV, since all transverse processes had different sacral contact types on the right and left side, and 32 (97%) pairs had different lengths in the asymmetric LTV cases. However, 45.5% of the asymmetric LTVs had transverse processes in the same orientation. It seemed that orientation of transverse processes were less important in developing an asymmetric LTV. This is why orientation was not included when classifying the symmetry of transverse processes.

In the present study, variations of ventral or dorsal sacral foramina were divided into three groups (absent, shapeless or laterally opened and normal round shaped) based on the development of the ventral alar element of the LTV. This description is more reasonable comparing to that from ZIEGLER (1990), which is the shape of sacral foramina vary due to a shift of the ventral alar element during lumbarization and sacralization, because the shifting direction of the ventral alar element cannot be confirmed when the total number of presacral vertebrae is unknown. An unexpectedly high incidence of symmetrical shaped ventral or dorsal sacral foramina pairs (27.3%) in asymmetric LTVs may be due to sacral positioning and its overlapping with transverse processes of the LTV in radiographs causing the exact shape of the sacral foramina to be difficult to identify.

A LTV can be symmetric or asymmetric. In this study, symmetric LTV (65.3%) was more common than asymmetric LTV (34.8%). Of the asymmetric LTV, most had combinations of type 2 transverse process, while types 1/3 and 3/1 (7.4%) were less common. These results support ROSENBERG’s hypothesis for development of a LTV. The pelvis normally contacts the vertebra at the same level on both sides resulting in identical formative stimulus. Accordingly, higher variations of transverse processes (type 1/3 or 3/1) would occur only when one contact point is markedly displaced.

Moreover, it was noted that asymmetric LTV may cause LTV angulation, asymmetric length of SI attachment, pelvic rotation over its vertical axis and SIJ sclerosis.

In the present study, only 16.1% of the LTVs were angulated in the symmetric form. Of the asymmetric LTVs, 90.9% of them were angulated. Angulation was common towards the side where the transverse process had a longer contact zone with the ilium. In addition, the length of SI attachments were identical on both sides in 52 (83.9%) dogs with symmetric LTV and they were unequal in 32 (97%) dogs with asymmetric LTV. From both results, a tendency can be seen that asymmetric LTV increased the risk of LTV angulation and asymmetric SI attachments. These results can also support the previous study (Damur-Djuric et al. 2006), which suggested that the type of LTV was associated with the angulation of the LTV and the length of SI attachments. The true SI attachment was more often shortened on the side where the transverse process of LTV was completely or partially attached to the ilium. This may be because the transverse processes of LTV assumed a part of the SI attachment when they were completely attached to the ilium. Thus, of the extremely asymmetric types 1/3 and 3/1, it was impossible to measure the true SIJ. As sacral type transverse processes took the characteristics of SIJ, the caudally adjoining true SIJs decreased in length and the total SI attachments projected cranially. The type of LTV changed not only the length, but also the position of the SI attachment. The asymmetric position of the SIJ seemed to be the direct reason causing pelvic obliquity.

In the present study, in 23 (69.7%) dogs with asymmetric LTV, the pelvis was elevated on the side where the transverse process had a larger contact zone with the ilium. The type of LTV was not subdivided into symmetric and mildly asymmetric LTV (1/1, 2/2, 3/3, 2/3, 3/2) and markedly asymmetric LTV (1/2, 2/1, 1/3, 3/1) as the previous study from FLÜCKIGER et al. (2017) described, but into symmetric (1/1, 2/2, 3/3), more severe transverse process alteration on the left side (1/2, 1/3, 2/3), and more severe transverse process alteration on the right side (2/1, 3/1, 3/2). This explains why these results showed a potential direction where the pelvis rotated towards when there was an asymmetric LTV.

Sclerosis was observed to be an incidental finding of the SIJ when diagnosing LTV in this study. No other studies had been done to determine a correlation between LTV and SIJ sclerosis. All 33 dogs with asymmetric LTV had SIJ sclerosis either on one side or both sides. 28 (84.9%) of them had unequal severity of the sclerosis. Since SIJ sclerosis may be age-associated, it has not been analyzed whether LTV causes the occurrence of SIJ sclerosis. However, there was a tendency in the results that suggest asymmetric LTV may increase the risk of unequal severity of sclerosis in SIJs. Moreover, 70 % of the dogs had worse sclerosis on the side where the pelvis rotated towards. It is assumed that pelvic obliquity may be another factor causing unequal degree of sclerosis between the right and left SIJ. Further investigations with larger sample populations should be conducted to study the nature of the correlations between the equality signs of SIJ sclerosis or the symmetry of SIJ sclerosis and the symmetry of LTV and pelvic obliquity.

A new measurement TPA is introduced in the present study. In dogs with LTV, all of the angle differences between the LTV and the LNLV were positive, indicating the transverse process of the LTV trended to project laterally. This positive value between the LTV and the LNLV became higher on the side where transverse process had a longer contact zone with the pelvis. Furthermore, the mean angle difference on the right and left side in a symmetric LTV was lower than that of an asymmetric LTV; it differed more when the LTV was a markedly asymmetric. The value of transverse process angle difference between the LTV and the LNLV was higher on the side where the contact zone between the transverse process and the pelvis was longer. These results revealed that the value of the TPA of a LTV is a numeral reflection of its contact to the pelvis, and it is higher on the side where it has a longer contact zone to the pelvis.

In addition, when the value of the difference between the right and left transverse process angel differences of the LTV and the LNVL was >16º or <-16º, it may indicate an asymmetric contact zone between the transverse process and the pelvis and angulation of the LTV. When this angle difference was >16º or <-16º, the results show a tendency of asymmetric LTV and the angulation of LTV occurring more frequently. Using ± 16º as a cutoff point to separate symmetric and asymmetric LTV and the presence or absence of LTV angulation may not be reliable based on merely 95 examined samples. Thus, using the same measurement in further investigations should be done to determine whether using ± 16º as cutoff points has clinical relevance. And if not, a new cutoff point might be determined in a larger population study.

5.3.4 Number of sacral segments and SCTV

In the present study, 40 (42.1%) dogs had both LTV and SCTV. The common occurrence of LTV and SCTV together confirmed that the transitional vertebrae are not just morphological variations, but it could also be regarded as shifting of the individual vertebral segments.

In previous studies, BREIT and KÜNZEL (1998) reported that of the dogs with LTV 20 (8.7%) dogs had 4 sacral vertebral segments and 1 (0.4%) dog had 2 sacral vertebral segments. JULIER-FRANK (2006) found 108 (8.5%) dogs with LTV had a decreased number of sacral segments and 35 (2.8%) dogs had an increased number of sacral segments. Compared to these two studies, the present study showed a higher incidence of variation in number of sacral segments in LTV cases. Sacrum consisting of 2 segments were found in 12 (12.6%) dogs and 10 (10.5%) dogs had 4 sacral segments. The number of sacral segments may be misleading on VD views due to superimposition of the fecal material and/ or penis bone. This higher incidence may be explained by the absence of additional lateral projections to determine the number of sacral segments in a portion of dogs in this study.

In addition, 77.3% of the dogs with abnormal number of sacral segments also had a SCTV, while 68.5% of the dogs that had three sacral segments had no SCTV. The occurrence of both LTV and SCTV were more common when the number of sacral segments was abnormal. Thus, it is hypothesized that when the presence of LTV results in an abnormal number of sacral segments, there is a tendency for the body to maintain 3 segments in the sacrum, regardless of the origin of the vertebrae. Again, since the total number of the presacral segments was unknown, it is unclear whether the 2 sacral vertebrae in the dogs with LTV and SCTV were due to an incomplete sacralized L7 with a complete separation of S3 from the sacrum, or a complete lumbarized S1 with an incomplete sacralization of Cd1. 4 Segments could be caused by a complete sacralized L7 with an incomplete separation of S3 from the sacrum, or a complete fusion of Cd1 to the sacrum with an incomplete lumbarized S1. These conditions can also support this hypothesis.

5.3.5 LTV and CHD

To date, the correlation between the presence of LTV and the development of hip joint dysplasia is still debatable. LARSEN (1977) and WIGGER et al. (2009) did not find a correlation between these two conditions. However, in the present study, all dogs with asymmetric LTV had signs of CHD. Asymmetric LTV was considered a factor in the development of CHD in these cases.

CHD can occur unilaterally or bilaterally. In one study from CITI et al. (2005) of 891 dogs, 16.7% of the dogs showed unilateral CHD.; of these, 5.4% were also diagnosed with LTV. The highest proportion of unilateral CHD were in dogs with LTV. However, their results were somewhat crude because they did not subdivide the LTV based on their morphological variations. In another study from WIGGER et al. (2009), asymmetric conformation of the hip joints was observed in 19.3% of the dogs with asymmetric LTV whereas it was only observed in 14.4% of those with symmetric or normal LS vertebrae. However, they misclassified a type 1/1 case as asymmetric LTV. These differences made comparison with the present study difficult.

Interestingly, all dogs with asymmetric LTV had bilateral CHD in this study. In dogs with symmetric LTV, 56.3% had bilateral CHD and 43.8% had unilateral CHD. There were no other works to support this result. Although there was a statistically significant difference, this result was based on analysis of only 31 dogs with LTV and CHD and must be interpreted with caution.

Furthermore, the Swiss scoring system was used to give each hip joint a score so that mild variations in hip joints could be distinguished. This time the study focused more on the development of asymmetric joint conformation due to asymmetric LTV. Dogs with types 2/1, 3/1 and 3/2 LTV had a higher CHD score difference than dogs with symmetric and types 1/2, 1/3 and 2/3 LTV. According to this result, it could not be confirmed that pronounced asymmetric LTV may favor asymmetric hip joint development since there was almost no score difference between symmetric LTV and type 1/2, 1/3 and 2/3 asymmetric LTV. This could also possibly be explained by the small sample group.

FLÜCKIGER et al. (2017) found that the scores between two hip joints differed more in dogs with markedly asymmetric LTV than in dogs with symmetric or mildly asymmetric LTV. Moreover, they confirmed a significant correlation between the type of LTV and the mean score difference between the right and left hip joint. The worse hip was seen generally on the side where the LTV contacted the pelvis. Since LTV cases in this study were not classified into symmetric, mild asymmetric and markedly asymmetric forms; and at the same time, separation of SP S1 from the median sacral crest was defined as LTV, results from this study may not be comparable to the previous results.

On the other hand, there was a correlation between the symmetry of LTV and the average CHD score of the right and left hip joint ($p<0.05$) in this study. Dogs with asymmetric LTV had more severe average CHD score of both sides. However, because the average CHD score was not directly related to the symmetry of hip joint conformation. this correlation alone was not enough to conclude that asymmetric LTV may contribute to asymmetric hip joint conformation.

Since LTV is a congenital anomaly and CHD is also a genetically determined anomaly, the occurrence of both these conditions may not be directly associated with age. In the present study, the prevalence of CHD among dogs with LTV was higher in age groups 4-11 months (50%) and 12-23 months (58.3%) compared with other groups. It seems that young dogs with LTV are more likely to development CHD than old dogs with LTV. Further investigations should be done to confirm whether young dogs with LTV increase the risk of CHD.

5.3.6 LTV and coxarthrosis

ZIEGELR (1990) divided the dogs into two groups: less than one year old and more than one year old. It is reported that 73% of the dogs with LTV had coxarthrosis. In the dogs with LTV that were less than one year old, only 27% of them had coxarthrosis. In dogs with LTV that were more than one year old, 82% of them had coxarthrosis. Similarly, in the present study, there was a high occurrence (79%) of coxarthrosis in dogs with LTV. The prevalence of coxarthrosis in dogs with LTV was lower (3.2%) in the age group of less than 12 months and higher (33.7%) in the age group of more than or equal to 96 months when comparing to the other age groups. Since this study used a more detailed age category, the results showed a tendency of older dogs with LTV having an increased occurrence of coxarthrosis. It is questionable though, whether the occurrence of coxarthrosis is associated more with age or LTV.

In addition, in dogs with asymmetric LTV, 30 (90.9%) dogs had coxarthrosis in this study. Asymmetric LTV may contribute to coxarthrosis. Since age has been associated with coxarthrosis and no control group was used. It could not be determined whether asymmetric LTV was a direct cause for coxarthrosis. Further study is required to confirm whether there is a correlation between LTV and the occurrence of coxarthrosis after excluding the age factor.

In the same previous study, 71% of the dogs with symmetric LTV had identical coxarthrosis grades on both hips while 60 % of the dogs with asymmetric LTV had different grades. Results from the present study did not contrast those from ZIEGLER (1990). Of dogs with symmetric LTV, 50 (80.7%) dogs had identical coxarthrosis grades on both sides whereas 14 (42.4%) of the dogs with asymmetric LTV presented with different grades in both hips. Neither study could establish a direction relationship between asymmetric LTV and coxarthrosis. There was a slight difference when evaluating coxarthrosis in the two studies. In the present study, additional to the variation of the acetabulum, the femoral head and the femoral neck, the width of joint space was analyzed too. However, this difference did not influence the evaluation of the equality of coxarthrosis on both hips, which makes the two studies still comparable.

Furthermore, when focusing on the risk of unilateral coxarthrosis, only 6 (20%) of the dogs with asymmetric LTV had unilateral coxarthrosis. It is assumed that asymmetric LTV has a weak influence on the developing unilateral coxarthrosis. Again, further investigation with a larger population is needed to exclude the age interference and to determine the main cause of unilateral coxarthrosis.

During the period of growth, the effect of asymmetric LTV can be compensated mainly by lighter body weight, more flexible tendons and ligaments as well as better formed muscle mass. Pelvic obliquity due to asymmetric LTV causing coxarthrosis through uneven acetabular coverage of the femoral head probably occurs later in life. The direct effect of LTV is seen more on the SIJs and the LSJs than the hip joints.

5.3.7 LTV and CES

In the present study, LS abnormalities were considered radiographic predictors for CES. However, since no clinical signs were followed up, LS abnormalities on a lateral radiographic view do not represent relevant clinical findings in regard to the diagnosis or possible subsequent development of CES. Previous studies have been done to describe a correlation between LTV and CES in GSDs, but no studies have focused on LTV and the radiographic predictors for CES in various breeds. It is hypothesized that the combination of these abnormalities including endplate sclerosis, spondylosis deformans, ventral subluxation of LTV, downward elongation of the sacral lamina and IVD prolapse in the LS region may hasten and worsen the resulting clinical syndrome.

In the lateral radiographs of the present study, all 66 dogs with LTV had abnormalities occurring between the LNLV and the sacrum. This result supports the theory from FLÜCKIGER et al. (2006) that in LTV cases the disc between the LNLV and LTV sustains excessive stress, whereas the disc between the LTV and the sacrum remains protected.

End plate sclerosis (56.1%) was the most common anomaly on lateral projection. It could not be concluded that asymmetric LTV favor the development of endplate sclerosis as the cause of this radiographic abnormality is multifactorial.

In the present study, 23 of the 66 (34.9%) dogs with LTV showed evidence of spondylosis deformans on lateral projection. It is hypothesized that spondylosis deformans may compensate for the instability caused by asymmetric LTV. 13 (30.2%) dogs with asymmetric LTV had spondylosis deformans. This result did not support the hypothesis. Since degeneration of IVD is thought to be a prerequisite for spondylosis deformans, one explanation may be that LTV is not strongly related to degeneration of IVD. Another explanation may be spondylosis is more directly associated with age than with LTV. Further investigation should be done to determine whether there is a correlation between LTV and spondylosis deformans using a control group.

It is assumed that LTV is one reason for ventral subluxation and downward elongation of the sacral lamina. However, a meaningful statistical analysis between LTV and ventral subluxation and downward elongation of the sacral lamina could not be performed due to limitations of the retrospective nature of this study.

In the present study, the degree of ventral subluxation of LTV varied. One author described that when the ventral subluxation of S1 was more than 4mm it was strongly suggestive of an abnormal LS junction (Schmid and Lang 1993), but SUWANKONG et al. (2008) suggested that a LS step as small as 2mm may be clinically relevant. Dogs in these previous studies were clinically abnormal or were not followed up clinically, statements about the predictive value of this finding were not possible. Since the clinical signs of the dogs were not taken into account in this study, ventral subluxation of S1 was only regarded as a radiographic abnormality; the clinical relevance of the step measurement is not within the scope of this study. Furthermore, since this study only include neutral lateral radiographs, dynamic alignment between flexed and extended lateral projections could not be detected.

In the present study, the vacuum phenomenon were difficult due to the superimposition of the pelvis and the lower soft tissue contrast resolution in radiographs compared with advanced imaging modalities such as CT and magnetic resonance imaging. This can explain a low occurrence of the vacuum phenomenon (3%) in LTV cases. The role of LTV in the occurrence of CES should be studied further in various breed dogs.

6 Summary

Lumbosacral Transitional Vertebrae in Dogs

This study examines the prevalence and morphological features of lumbosacral transitional vertebrae (LTV) and their association with canine hip dysplasia (CHD), coxarthrosis as well as radiographic predictors for cauda equina syndrome (CES).

The overall prevalence and the prevalence of different types of LTV were determined by reviewing the pelvic radiographs of 1030 dogs among 63 breeds. LTV was observed in 95 (9.2%) dogs. There was no gender predisposition. Symmetric LTV (65.3%) were more common than asymmetric LTV (34.7%). Most of the asymmetric LTVs had an intermediate type transverse process combined with either a lumbar or sacral type transverse process. The results of the present study indicated that morphological variations of sacroiliac joints, angulation of LTV and pelvic obliquity were common findings in dogs with asymmetric LTV.

Moreover, the measurement of transverse process angle (TPA) was first introduced in this study. The value of TPA indicated the contact degree between the transverse process and the pelvis. The difference between the right and left TPA differences of the LTV and the last normal lumbar vertebra was significantly associated with type of LTV ($p<0.001$). There was a tendency that when this angle difference is $>16^\circ$ or $<-16^\circ$, asymmetric and angulated LTV occurred more frequently. However, the number of cases was too small to have any statistical significance.

By using the FCI system to evaluate CHD, a significant association between the LTV and the occurrence and symmetry of the CHD was seen ($p<0.01$). When each hip joint was given a score to describe hip joint conformation, dogs with type 2/1, 3/2 and 3/1 LTV had higher CHD score difference than other types of LTV. Asymmetric LTV cases had higher average CHD scores of the right and left hips ($p<0.05$). However, these results were only based on the analysis of only 31 dogs with LTV and CHD, and must be interpreted with caution.

There was a statistically significant association between LTV and coxarthrosis ($p<0.05$). In dogs with asymmetric LTV, 30 (90.9%) dogs had coxarthrosis.

In addition, only 5 (5.3%) dogs with LTV had CES. This number was too low for meaningful statistical analysis for the correlation between LTV and CES. 66 of the 95 cases with LTV that had lateral pelvic radiographic were evaluated for lumbosacral (LS) abnormalities. The common occurrences of LS abnormalities were endplate sclerosis (56.1%) and spondylosis

deformans (34.9%). There was no correlation between LTV and endplate sclerosis and spondylosis.

In conclusion, this study supported the conclusion of other researches, which proposed LTV to be of clinical importance. It is recommended that the presence of LTV and its classification to be an integral part of CHD evaluation for breeding. Both VD and lateral projections should be taken during routine evaluation of LTV.

7 Zusammenfassung

Lumbosakrale Übergangswirbeln bei Hunden

In dieser Studie werden Häufigkeiten und morphologische Merkmale von lumbosakralen Überganswirbeln (LÜW) und deren etwaiger Zusammenhang mit einer Hüftgelenksdysplasie (HD), Coxarthrose sowie röntgenologischen Anzeichen eines Cauda equina Kompressionssyndrom (CES) beim Hund untersucht.

Zur Häufigkeit allgemein sowie zu den einzelnen LÜW Typen, wurden über 1030 Röntgenaufnahmen des Beckens von Hunden 63 verschiedener Rassen ausgewertet.

Nur 9.2% (95/1030) hatten einen LÜW. Es konnte kein Zusammenhang zwischen Geschlecht und LÜW festgestellt werden. LÜWs waren zu 65.3% (62/95) symmetrisch und zu 34.7% (33/95) asymmetrisch ausgeprägt. Am häufigsten konnte ein intermediärer Typ des Proccessus transversus in Kombination mit einem lumbalen oder einem sakralen Typ des Proccessus transversus gefunden werden. Die Ergebnisse der Studie ergaben, dass die morphologischen Variationen der Iliosakralgelenke, sowie die vermehrte Winkelung von LÜW und Becken häufiger bei Hunden mit asymmetrischem LÜW auftreten.

Desweiteren wurde in dieser Studie erstmals die Messung des Proccessus tranversus Winkelung (PTW) eingeführt. Die Wert der PTWs konnte als ein Indikator für das Maß des Kontaktes in Grad zwischen Proccessus transversus und Becken genutzt werden. Es konnte eine signifikante Korrelation zwischen dem Typ des LÜW und dem Unterschied von rechtem und linken PTW sowie dem Unterschied von LÜW und dem letzten normalen Lendenwirbel gemessen werden ($p<0.001$). Falls diese Winkeldifferenz >16° oder < -16° war, bildete sich eine erhöhte Wahrscheinlichkeit für das Auftreten von asymmetrischen und gewinkelten LÜW heraus. Durch die geringe Fallzahl der Studienkohorte, konnte dies jedoch nicht statistisch bewiesen werden.

Zur HD-Analyse wurde das FCI System zugrunde gelegt. Es konnte eine signifikante Korrelation sowohl zur LÜW und Häufigkeit als auch zur Symmetrie der HD entdeckt werden ($p<0.01$). Um die Konfomation der Hüftgelenke zu beschreiben, wurde das Schweizer Punktesystem genutzt. Hunde mit LÜW Typen 2/1, 3/2 und 3/1 hatten einen höheren HD Score als andere LÜW Typen. Asymmetrische LÜWs bildeten durchschnittlich einen höheren HD score der rechten und linken Hüfte aus ($p<0.05$). Dieses Ergebnis basiert auf der Auswertung von 31 Hunden mit LÜW und HD und sollte kritisch hinterfragt werden.

Eine weitere statistische relevante Korrelation konnte zwischen der LÜW und der Coxarthrose festgestellt werden ($p<0.05$). 30/33 (90.9%) der Hunde mit asymmetrischem LÜW hatten eine Coxarthrose.

Zusammenfassend unterstützt diese Arbeit das Ergebnis anderer Studien, die einen LÜW als klinisch relevant ansehen. Um HD bei der routinemäßigen Zuchtuntersuchung zu evaluieren, sollten etwaige LÜWs mit dokumentiert und typisiert werden. Um dieses sicher vornehmen zu können sollte das Becken bei Routineuntersuchungen immer im Röntgengrundbildpaar abgebildet werden.

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Acknowledgments

On the completion of this work I would like to express my appreciation to all the people who have made this dissertation possible.

Firstly, my thanks go to Prof. Dr. L. Brunnberg for the permission and support to this dissertation and his professional supervision and training in the field of radiology.

Secondly, my thanks go to Dr. M. Brunnberg for the helpful comments and feedback to mature this study.

Thirdly, my thanks go to Dr. R. Merle from the institute of veterinary epidemiology and biometry and P. Walter from the institute of statistics and econometrics for the statistical consultation required for this study.

I would also like to extent appreciation to Dr. T. Ripp for the help on literature management with the software Endnote.

Additional thanks go to R. Obst from the radiology department and T. Kuhn from the clinical information system department of the Small Animal Clinic of Freie Universität Berlin for their supporting during my study.

Lastly, I would like to express my gratitude to my beloved family for their loving considerations and great confidence in me all through these years.

Declaration of Authorship

I, He Gong, declare that this thesis titled, “Lumbosacral Transitional Vertebrae in Dogs” and the work presented in it are my own. I confirm that:

- This study was done wholly or mainly while in candidature for a research degree at this University.
- Where I have quoted from the works of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.
- I have acknowledge all main sources of help.

Berlin, den 16.07.2018

He Gong

9 783863 879327
mbvberlin | mensch und buch verlag
49,90 Euro | ISBN: 978-3-86387-932-7