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The Long and Short of It: Exploring IVDD and Goniometry in Miniature Dachshunds

Caminho Longo, Passos Curtos: Exploração da DDIV e Goniometria em Teckels Miniatura

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The Long and Short of It: Exploring IVDD and Goniometry in Miniature Dachshunds

Caminho Longo, Passos Curtos: Exploração da DDIV e Goniometria em Teckels Miniatura*

Área científica: Medicina de Animais de Companhia

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***Nota de tradução:**
O título original em inglês, *"The Long and Short of It: Exploring IVDD and Goniometry in Miniature Dachshunds"*, recorre a uma expressão idiomática com duplo sentido: por um lado, uma fórmula consagrada para apresentar uma síntese ("the long and short of it"); por outro, uma alusão morfológica à raça Teckel, conhecida pelo corpo alongado e membros curtos.
A tradução adotada - *"Caminho Longo, Passos Curtos"* - constitui uma adaptação estilística que visa manter o valor expressivo e o jogo de sentidos do original, de forma adequada ao contexto linguístico do português; pretende aludir simultaneamente à morfologia da raça e ao percurso científico a explorar.

Porto, 2025

ABSTRACT

The miniature Dachshund has seen a marked rise in popularity in recent years, increasing the clinical demand for breed-specific veterinary care. This chondrodystrophic breed is particularly predisposed to myelopathies, most notably intervertebral disc disease (IVDD), due to its distinctive body morphology. As such, the development of effective rehabilitation protocols tailored to Dachshunds has become increasingly important.

Goniometry is an accessible, cost-effective, and widely used method in veterinary practice for estimating joint range of motion (ROM). Despite its frequent application, breed-specific reference values remain limited, particularly for chondrodystrophic canine breeds with unique body morphology, which entails serious clinical implications. The current study aimed to establish baseline ROM values for several joints, including the shoulder, elbow, carpus, hip, stifle, and tarsus, in healthy adult miniature Dachshunds using goniometric assessment.

A total of sixteen miniature Dachshunds met the inclusion criteria for this investigation. The sample size was determined through power analysis based on existing literature. All measurements were conducted by a single examiner without sedation. Each joint was measured once.

No significant differences in joint angles or ROM were found between left and right limbs or between sexes. However, the results revealed significant differences in several joint angles when compared to published values for Labrador Retrievers. Additionally, notable differences were observed between healthy miniature Dachshunds and those reported in the literature with neurological impairments. These findings support the notion that miniature Dachshunds possess breed-specific ROM characteristics, highlighting the need for tailored reference values.

Although this study has some developmental limitations, for instance the absence of radiographic confirmation of joint health and relying on a single, unrepeated set of goniometric measurements performed by one examiner; these do not preclude the value of the results.

KEYWORDS: Goniometry; Dachshund; range of motion; rehabilitation; physiotherapy.

RESUMO

O Teckel miniatura tem registado um aumento de popularidade nos últimos anos, resultando numa maior procura por cuidados veterinários específicos. Esta raça condrodistrófica é particularmente predisposta a mielopatias, nomeadamente doença do disco intervertebral (DDIV), devido à sua morfologia corporal distinta. Assim, o desenvolvimento de protocolos de reabilitação eficazes e adaptados aos Teckel assume uma importância crescente.

A goniometria é um método acessível, económico e amplamente utilizado na prática veterinária para estimar a amplitude de movimento (ROM) articular. Apesar da sua aplicação frequente, os valores de referência específicos por raça permanecem limitados, especialmente para raças condrodistróficas com morfologias corporais únicas, acarretando importantes implicações clínicas. O presente estudo teve como objetivo estabelecer valores de referência da ROM para várias articulações, incluindo ombro, cotovelo, carpo, anca, joelho e tarso, em Dachshunds miniatura adultos saudáveis, utilizando a avaliação goniométrica.

Dezasseis Teckel miniatura cumpriram os critérios de inclusão deste estudo. O tamanho amostral foi determinado com base numa análise de poder estatística, baseada na literatura existente. Todas as medições foram realizadas por um único examinador, sem recurso a sedação. Cada articulação foi medida uma vez.

Não se verificaram diferenças estatisticamente significativas nos ângulos articulares ou na ROM entre os membros esquerdo e direito, nem entre sexos. No entanto, os resultados revelaram diferenças significativas em vários ângulos articulares quando comparados com os valores publicados para Labradores Retriever. Adicionalmente, observaram-se diferenças consideráveis entre Dachshunds miniatura saudáveis e indivíduos com défices neurológicos descritos na literatura. Os dados apurados sustentam a noção de que os Dachshunds miniatura possuem características específicas de ROM, reforçando a necessidade de valores de referência adaptados à raça.

Apesar deste estudo apresentar algumas limitações, como a ausência de confirmação radiográfica de saúde articular e depender de uma única medição goniométrica, realizada por um examinador; estas não invalidam o valor dos resultados obtidos.

PALAVRAS-CHAVE: Goniometria; Dachshund; amplitude de movimento; reabilitação; fisioterapia

CASE REGISTRY AND ACTIVITIES DEVELOPED DURING THE INTERNSHIP

During a 16-week internship at AniCura Restelo Centro Veterinário, I had the opportunity to observe and assist in the rehabilitation of 269 animals undergoing treatment for a variety of clinical objectives, including pain management and control, muscle strengthening, gait re-education, neurological regeneration, tissue healing, and the recovery of normal urinary and fecal functions. As this is a specialized veterinary medical facility, most of the patients were referrals from the neurology and orthopedics departments, either to pursue conservative treatment approaches or to support post-surgical recovery.

For each clinical case admitted, I assisted and participated in consultations within the aforementioned specialties—neurology, musculoskeletal system, and pain management. I was actively involved in the interpretation of diagnostic imaging examinations alongside the medical team, including computed tomography (CT), magnetic resonance imaging (MRI), and radiographs. Under the supervision of the attending professionals, I also participated in clinical evaluations and physical examinations. These assessments included pain evaluation, gait and mobility analysis, spinal reflex testing, passive joint movement assessment through goniometric measurements, and the monitoring of progress over time in all these parameters.

Throughout the course of the internship, I was actively involved in various kinesiotherapy exercises designed to enhance functional mobility and neuromuscular coordination. This included stair ascension and descension drills, navigation of obstacle courses incorporating cavaletti rails, quadrupedal weight-bearing activities, balance training routines, and active limb flexion through cycling-like movements, among others. Additionally, I engaged with a broad spectrum of therapeutic modalities. Notable among these were photobiomodulation using laser therapy, radiofrequency treatments, magnetotherapy, ultrasound therapy, hydrotherapy via an underwater treadmill, shockwave therapy, and both transcutaneous (TENS) and neuromuscular (NMES) electrical stimulation. I also participated in the administration of ozone therapy through both subcutaneous and rectal routes and regularly observed acupuncture sessions. Additionally, I had the opportunity to observe one mesotherapy session.

During this period, I gained substantial theoretical and practical knowledge concerning the mechanisms of action, clinical benefits, contraindications, and therapeutic indications of each modality. Furthermore, I was able to monitor and analyze the clinical progression of numerous animal patients, particularly noting improvements in gait patterns and pain reduction over the course of their treatment.

Of the 269 animals I assisted during the internship, 257 (approximately 96%) were dogs, while only 12 (approximately 4%) were cats. As illustrated in Figure 1, the sex distribution between males and females was not significantly different. In the canine population, the male-to-female ratio was approximately 61% to 39%, while in cats it was evenly distributed at 50% for each sex.

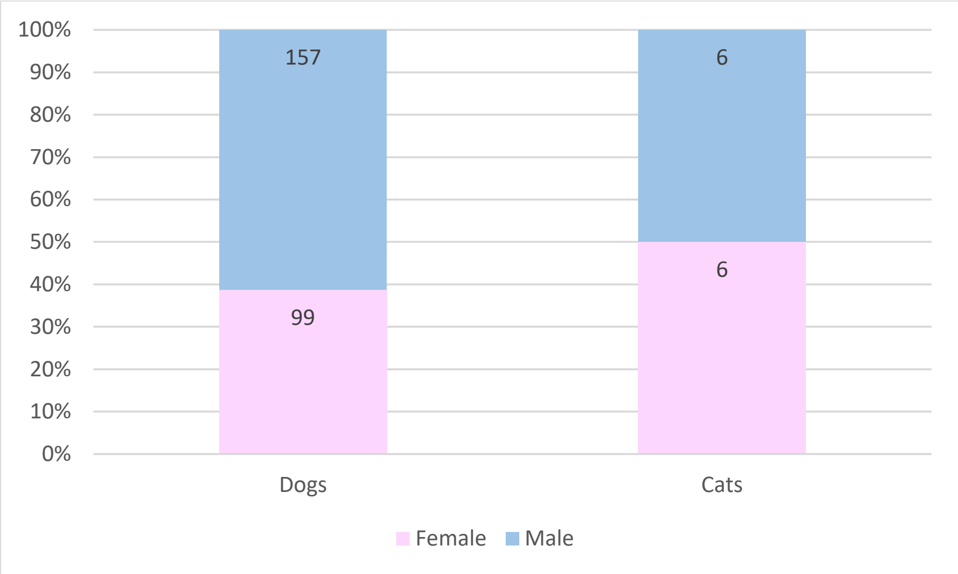

Figure 1. Distribution of observed animal by sex and species.

The age of the animals presented to the rehabilitation centre ranged from 1 to 18 years. The mean age of all patients observed was 8 years and 2 months, which was also the mean age when considering only canine patients. For feline patients, the mean age at the time of presentation was 7 years. The mode of the patients' age, both overall and specifically for dogs, was 9 years. In cats, the most frequently observed age was 7 years.

Figure 2 illustrates the distribution of patients by age, highlighting the relevance of rehabilitation across all life stages. These findings underscore that veterinary rehabilitation plays a vital role not only in improving the quality of life in senior patients, but also in supporting animals of various age groups.

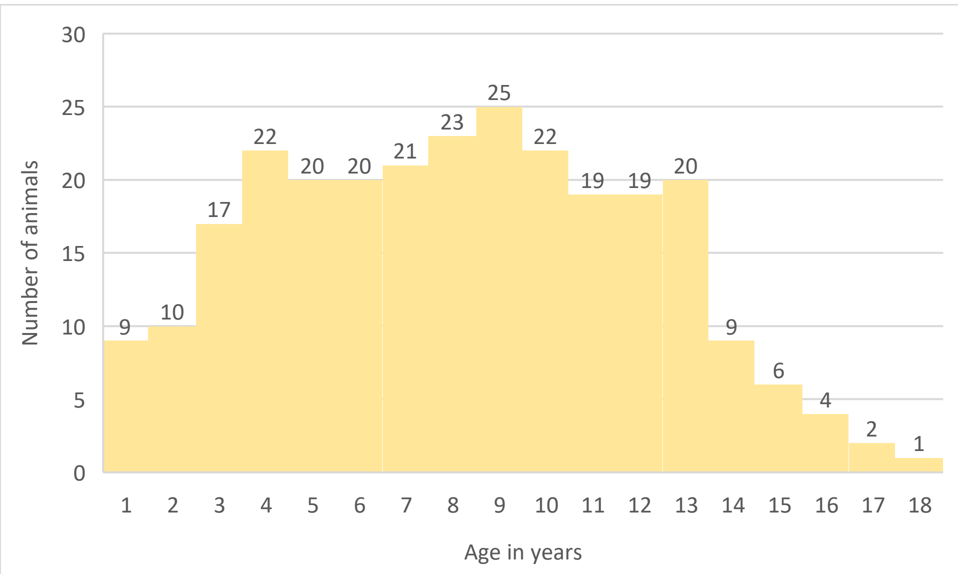

Figure 2. Distribution of observed animals by age.

Among the canine patients, I encountered 43 different breeds, with a clear over-representation of certain ones. As expected, mixed-breed dogs comprised the largest proportion of animals undergoing treatment (20.23%). This is likely attributable not to a particular predisposition to conditions requiring specialized rehabilitation, but rather to the high prevalence of mixed-breed dogs in the Portuguese canine population, their increased accessibility (e.g., financial ease of adoption), and the absence of defined morphological characteristics that would assign them to a specific breed.

Excluding mixed-breed dogs, only three other breeds exceeded the 5% threshold of the total canine population observed during the internship. These were the French Bulldog (17.9%), the Dachshund (14.01%), and the Labrador Retriever (9.73%). These figures clearly highlight the need for further investigation into degenerative conditions and rehabilitation protocols in chondrodystrophic breeds, as these animals are disproportionately represented among those seeking specialized care for severe neurologic and orthopedic conditions. Furthermore, it is important to consider the rising popularity of these breeds, a trend already well-documented in the case of the French Bulldog and now increasingly evident with miniature Dachshunds.

All feline patients were classified as domestic shorthair cats.

In terms of clinical case distribution, the vast majority were related to neurology and the locomotor/orthopedic system. Additionally, I had the chance to observe a small number of cases grouped under the category "Other Complications," which included dermatologic, infectious, and endocrinologic conditions. In these instances, rehabilitation aimed to reduce the impact of joint and muscular complications or to support wound healing and tissue repair. Figure 3 illustrates the distribution of clinical cases by veterinary specialty.

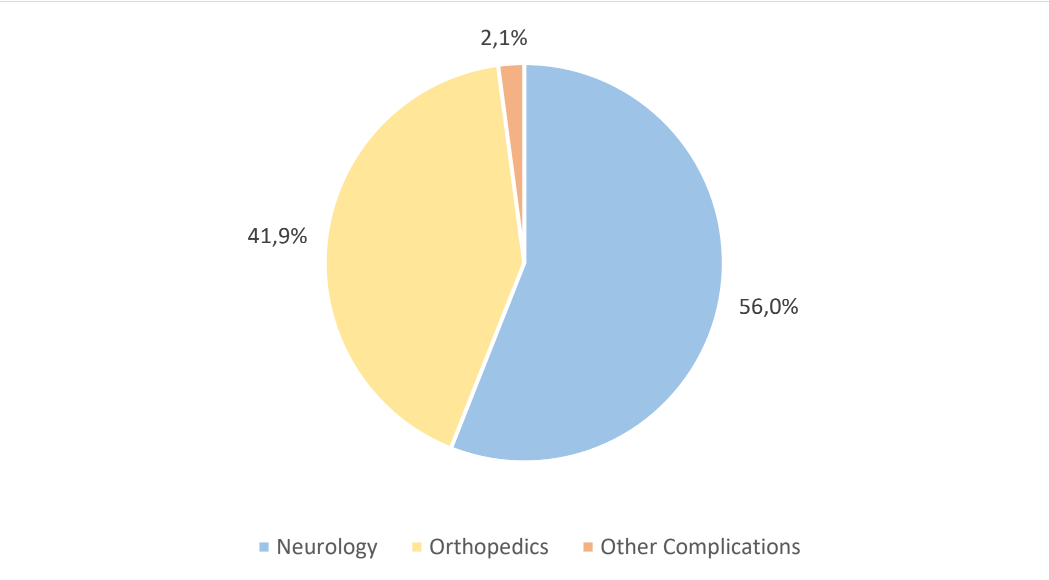

Figure 3. Distribution of clinical cases by veterinary specialty and respective percentages.

Neurology cases accounted for the majority of the clinical presentations observed during the internship, comprising a total of 190 cases, which represents 56.0% of all cases seen. Among these, intervertebral disc herniation was by far the most frequent reason for referral to the rehabilitation centre, representing 83.16% of all neurology-related cases.

More specifically, the four most common neurological presentations were: lumbar extrusive intervertebral disc herniation (16.32%), thoracic extrusive intervertebral disc herniation (12.63%), lumbar compressive intervertebral disc herniation (12.11%), and thoracolumbar extrusive intervertebral disc herniation (12.11%).

Table 1. Specifications of clinical neurology cases according to species and sex.

Neurology	Dog			Cat			Total	Total (%)
	Female	Male	Total	Female	Male	Total		
Ankylosing spondylosis	1	-	1	-	-	0	1	0,53%
Brachial plexus avulsion	-	1	1	-	1	1	2	1,05%
Brachial plexus schwannoma	-	1	1	-	-	0	1	0,53%
Cauda equina syndrome	-	2	2	-	-	0	2	1,05%
Chronic myelopathy	1	-	1	1	-	1	2	1,05%
Compressive cervical disc herniation	2	10	12	-	-	0	12	6,32%
Compressive lumbar disc herniation	5	17	22	-	1	1	23	12,11%
Compressive thoracic disc herniation	6	6	12	-	-	0	12	6,32%
Compressive thoracolumbar disc herniation	1	6	7	-	-	0	7	3,68%
Discospondylitis	2	-	2	-	-	0	2	1,05%
Discospondylosis	1	5	6	-	-	0	6	3,16%
Extrusive cervical disc herniation	6	16	22	-	-	0	22	11,58%
Extrusive lumbar disc herniation	10	20	30	1	-	1	31	16,32%
Extrusive thoracic disc herniation	11	13	24	-	-	0	24	12,63%
Extrusive thoracolumbar disc herniation	7	16	23	-	-	0	23	12,11%
Hydrocephaly	1	-	1	-	-	0	1	0,53%
Hydromyelia	-	1	1	-	-	0	1	0,53%
Meningoencephalitis	1	-	1	-	-	0	1	0,53%
Neuritis	-	2	2	-	-	0	2	1,05%
Polyradiculoneuritis	1	1	2	-	-	0	2	1,05%
Prevention of disc herniation through muscle strengthening	1	1	2	-	-	0	2	1,05%
Type III cervical disc herniation	1	-	1	-	-	0	1	0,53%
Type III lumbar disc herniation	-	1	1	-	-	0	1	0,53%
Type III thoracic disc herniation	1	-	1	-	-	0	1	0,53%
Type III thoracolumbar disc herniation	-	1	1	-	-	0	1	0,53%
Vestibular syndrome	2	4	6	-	-	0	6	3,16%
Wobbler syndrome	-	1	1	-	-	0	1	0,53%
Total	61	125	186	2	2	4	190	100,00%

Table 2. Specifications of clinical orthopedics cases according to species and sex.

Orthopedics	Dog			Cat			Total	Total (%)
	Female	Male	Total	Female	Male	Total		
Calcaneal tendon rupture	1	-	1	-	-	0	1	0,70%
Congenital deformity of the femur	1	-	1	-	-	0	1	0,70%
Corticosteroid sarcopenia	2	2	4	-	-	0	4	2,82%
Cranial cruciate ligament rupture	4	5	9	-	-	0	9	6,34%
Cranial trauma	-	1	1	-	-	0	1	0,70%
Elbow dysplasia	4	7	11	-	-	0	11	7,75%
Femoral head fracture	-	-	0	-	1	1	1	0,70%
Fragmentation of the medial coronoid process	0	1	1	-	-	0	1	0,70%
Generalized osteoarthrosis	4	9	13	-	-	0	13	9,15%
Hip luxation	2	1	3	-	-	0	3	2,11%
Hip dysplasia	14	14	28	-	-	0	28	19,72%
Humeral fracture	1	-	1	-	-	0	1	0,70%
Ileal fracture	-	1	1	-	-	0	1	0,70%
Osteoarthrosis of the carpus	-	1	1	-	-	0	1	0,70%
Osteoarthrosis of the elbow	-	8	8	-	-	0	8	5,63%
Osteoarthrosis of the hip	2	2	4	-	-	0	4	2,82%
Osteoarthrosis of the shoulder	2	2	4	-	-	0	4	2,82%
Osteoarthrosis of the stifle	5	4	9	-	-	0	9	6,34%
Osteoarthrosis of the tarsus	1	2	3	-	-	0	3	2,11%
Osteomalacia	-	1	1	-	-	0	1	0,70%
Patella luxation	6	8	14	-	-	0	14	9,86%
Pelvic fracture	2	1	3	1	-	1	4	2,82%
Radius fracture	-	2	2	-	-	0	2	1,41%
Rib fracture	-	1	1	-	-	0	1	0,70%
Sacral subluxation	-	-	0	1	-	1	1	0,70%
Septic arthritis	-	1	1	-	-	0	1	0,70%
Shoulder dysplasia	1	-	1	-	-	0	1	0,70%
Simple metaphyseal fracture of the femur	1	1	2	-	-	0	2	1,41%
Spinal luxation	1	1	2	-	-	0	2	1,41%
Spinal fracture	-	-	0	2	1	3	3	2,11%
Spinal trauma	-	1	1	1	1	2	3	2,11%
Tail fracture	-	-	0	-	1	1	1	0,70%
Ulnar fracture	-	2	2	-	-	0	2	1,41%
Total	54	79	133	5	4	9	142	100,00%

A total of 142 cases related to the orthopedic and locomotor system were observed during the internship, accounting for 41.9% of all cases followed. Hip dysplasia was by far the most frequently encountered condition, representing 19.72% of all pathologies addressed within this specialty. This was followed by medial patellar luxation (9.86%), generalized osteoarthrosis (9.15%), and elbow dysplasia (7.75%).

These findings suggest that within the domain of the locomotor system, veterinary physiotherapy and rehabilitation are primarily sought for the management of congenital, developmental, or degenerative disorders, rather than for the acute treatment of traumatic injuries.

In addition to the two primary specialties of neurology and orthopedics, I had the opportunity to observe the use of rehabilitation techniques in the management of complications related to dermatology, post-surgical wound healing, and sequelae of infectious or endocrine disorders.

Specifically, laser therapy and ozone oil dressings were employed to support wound healing in a case involving illegally cropped ears that had become infected, as well as in a post-surgical case following the removal of a cutaneous mass that resulted in suture dehiscence and necrosis of the skin flap. A similar therapeutic approach was used in the treatment of a case of pododermatitis that was unresponsive to conventional medical management.

In a case of calicivirus infection, laser therapy proved to be highly effective in the treatment of severe oral ulcers.

For a patient affected by severe leishmaniasis with articular involvement, a multimodal protocol was implemented to aid in pain management. The tetanus case required a comprehensive rehabilitation approach, in which a protocol was designed to reduce muscle spasticity and manage pain while minimizing sensory stimulation and preventing anxiety.

Additionally, I observed a suspected case of primary gigantism, in which skeletal, ligamentous, intervertebral disc, and conformational abnormalities had led to the development of paraplegia.

Table 3. Specification of clinical cases in various areas according to species and sex.

Other Complications	Dog			Cat			Total	Total (%)
	Female	Male	Total	Female	Male	Total		
Calicivirus infection	-	-	0	-	1	1	1	14,29%
Dermal nodule removal	-	1	1	-	-	0	1	14,29%
Ear cutting	-	1	1	-	-	0	1	14,29%
Gigantism	-	1	1	-	-	0	1	14,29%
Leishmaniasis	-	1	1	-	-	0	1	14,29%
Pododermatitis	1	-	1	-	-	0	1	14,29%
Tetanus	-	1	1	-	-	0	1	14,29%
Total	1	5	6	0	1	1	7	100,00%

Justification for the Discrepancy Between the Number of Patients and Clinical Diagnoses

During the internship in the field of veterinary physiotherapy and rehabilitation, it was observed that the total number of clinical diagnoses established (339) exceeded the number of patients treated (269). This discrepancy is attributable to the multifactorial nature of the neurological and orthopedic conditions frequently encountered in this specialty, where it is common for a single patient to present with multiple, interrelated clinical issues.

At the initial consultation, all diagnoses contributing to the patient's clinical presentation were identified and recorded. For instance, a patient might be diagnosed with hip dysplasia and, simultaneously, with elbow osteoarthritis resulting from compensatory mechanisms due to altered locomotor biomechanics. This compensatory phenomenon is well-documented in the literature as an adaptive response to a primary injury, often leading to secondary lesions in other anatomical regions.

Furthermore, the interdependence between the neurological and musculoskeletal systems means that dysfunction in one system can significantly impact the other, thereby exacerbating the clinical complexity of the patient. The identification of all relevant clinical conditions is essential for the development of a comprehensive and effective rehabilitation plan that addresses every dysfunction present.

Therefore, the recording of multiple diagnoses per patient reflects the holistic and thorough approach adopted during the internship, aimed at fully understanding the therapeutic needs of each animal.

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Dizem que os sentimentos mais importantes são frequentemente os mais difíceis de expressar. Assim sendo, perdoem as minhas palavras desengonçadas: são apenas o reflexo de um coração absolutamente cheio.

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“Não importa que não se lembrarão de mim. O que importa é que eu ajudei.”

- O Espírito da Compaixão, Dragon Age

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ABBREVIATIONS

%	Percent
<	Lesser than
=	Equal to
°	Degrees
BCS	Body condition score
CTR	Cutaneous trunci reflexes
CVDR	Calcified discs visible on radiographs
DDIV	Doença do disco intervertebral
DPP	Deep pain perception
FGF4	Fibroblast growth factor 4
FGF4L1	Fibroblast growth factor 4 retrogene insertion on chromosome 18
18-FGF4RG	Fibroblast growth factor 4 retrogene insertion on chromosome 18 (previous nomenclature)
FGF4L2	Fibroblast growth factor 4 retrogene insertion on chromosome 12
12-FGF4RG	Fibroblast growth factor 4 retrogene insertion on chromosome 12 (previous nomenclature)
IVD	Intervertebral disc
IVDD	Intervertebral disc disease
IVDE	Acute extrusive disc herniation
IVDH	Intervertebral disc herniation
LMN	Lower motor neuron
MRI	Magnetic resonance imaging
MSTs	Mechanical sensory thresholds
NSAIDs	Non-steroidal anti-inflammatory drugs
PROM	Passive range of motion
QOL	Quality of life
ROM	Range of motion
RR	Risk ratio
SCI	Spinal cord injury
TC-PT	Calcaneal tuberosity to midpoint of the patellar tendon
UMN	Upper motor neuron

1. INTRODUCTION

The Dachshund represents a paradigmatic example of a chondrodystrophic and chondrodysplastic canine breed, characterized by a unique body morphology which, although functionally adapted for hunting, entails serious clinical implications. The selection of the miniature Dachshund breed for the present study stems from two different, but complementary, motives: their markedly growing popularity (O'Neill *et al.*, 2023; Pinello *et al.*, 2025), as well as its well-documented genetic predisposition to a broad spectrum of orthopedic and neurological pathologies, with particular emphasis on intervertebral disc disease (IVDD) (Brown *et al.*, 2017; Batcher *et al.*, 2019; Reunanen *et al.*, 2023). This anatomical and physiological vulnerability frequently leads to debilitating clinical presentations that require prolonged therapeutic interventions and a significant need for physiotherapy and functional rehabilitation (Martins *et al.*, 2021). Thus, the early identification of functional limitations and the monitoring of therapeutic progress assumes particular importance in this population.

Goniometry, defined as the technique of measuring joint angles through the movement of bony segments, stands out as a simple, non-invasive, and cost-effective tool widely utilized in veterinary clinical practice (Norkin & White, 2017; Machado *et al.*, 2020). Beyond its diagnostic application, enabling the early detection of biomechanical alterations or sequelae of orthopedic and neurological injuries, goniometry plays an essential role in monitoring the efficacy of rehabilitation protocols and in establishing realistic, individualized therapeutic goals (Thomovsky *et al.*, 2016).

However, for goniometry to be employed as a reliable and reproducible instrument, it is imperative to have breed-specific reference values, given the considerable morphological diversity among different canine types (Jaegger *et al.*, 2002; Benson *et al.*, 2004; Reusing *et al.*, 2020). The lack of standardized data for chondrodystrophic breeds, such as the miniature Dachshund, compromises the clinical utility of this technique, limiting its applicability both in early diagnosis and therapeutic follow-up.

Therefore, the primary objective of the present study was to establish reference goniometric measurements in healthy miniature Dachshund dogs. This work aimed to contribute to the standardization of these measurements, providing veterinary clinicians with an objective and evidence-based tool for application in clinical and rehabilitative settings.

While goniometry is widely applied in the evaluation of joint mobility in orthopedic conditions, its use in neurological rehabilitation remains underappreciated in veterinary practice. However, growing clinical experience and evidence from human and veterinary medicine suggest that it can serve as a valuable tool to monitor functional outcomes even in neurologically compromised patients (Adams & Hicks, 2005; Yelnik et al., 2010; Bittar *et al.*, 2024). Given that IVDD is not only the most prevalent neurological disorder in miniature Dachshunds, but also one that frequently results in long-term disability (Sharp & Wheeler, 2005; Reunanen et al., 2023), the ability to objectively assess changes in joint mobility has critical clinical relevance.

1.1. The Dachshund: historical development and breed-characteristics

The Dachshund, also known as the Teckel or colloquially as the “sausage dog,” is a breed of German origin with a long historical background rooted in functional hunting. Emerging distinctly in the 17th century, the breed was primarily developed for pursuing and hunting burrowing animals, such as badgers. The very name derives from the German terms *Dachs* (badger) and *Hund* (dog), reflecting its original utilitarian purpose (United Kennel Club, 2008).

The breed’s physical structure, characterized by a long, muscular body, short and robust limbs, deep chest, and elongated head, was carefully refined to meet the demands of underground hunting. Its low profile and flexible spine enabled the dog to move easily through narrow tunnels, while strong, well-arched feet with sharp claws ensured effective digging (Whitwam, 2020). This unique anatomy, a manifestation of chondrodysplasia (more specifically, achondroplasia or disproportionate dwarfism), is a defining characteristic of the breed (Hansen, 1952; Packer *et al.*, 2013).

1.2. The Global and National Rise of Small and Chondrodystrophic Dog Breeds

Recent years have witnessed a marked rise in the popularity of small, chondrodystrophic, and brachycephalic dog breeds. This trend is particularly prominent in urban contexts and reflects broader shifts in human lifestyles, pet-keeping practices, and aesthetic preferences (Teng *et al.*, 2016; Anderson, 2021; Pinelllo *et al.*, 2025).

Among the various small breeds rising in popularity, the Teckel occupies a unique position due to its distinctive body morphology, long-standing cultural presence, and increasing demand. International data from the UK reveal that over 50% of purebred dogs under veterinary care in 2019 were classified as chondrodystrophic, reflecting the widespread appeal of such traits (O’Neill *et al.*, 2023). In Portugal, the Dachshund exemplifies this global pattern at a national scale, experiencing rapid growth in ownership, particularly in metropolitan areas (Pinello *et al.*, 2025). In fact, in the year 2023 the Dachshund had become one of the top 20 most owned breeds in Portugal (Pinello *et al.*, 2025).

The prioritization of aesthetic traits over health and functionality has led to intensified and sometimes irresponsible breeding practices, further amplifying the prevalence of hereditary diseases (Anderson, 2021). This trend is especially concerning in high demand breeds such as the Dachshund, where market pressures may outpace ethical breeding protocols. Moreover, the emotional attachment that many owners report, particularly for breeds with known health issues, can paradoxically reinforce demand, even when the animal suffers from chronic health problems (Sandøe *et al.*, 2017).

Although there is a growing emphasis on ethical breeding practices and reducing extreme conformational traits in dog breeds, we cannot ignore the clear trend of increasing popularity of such breeds (Teng *et al.*, 2016; Anderson, 2021; Pinelllo *et al.*, 2025). While the ultimate goal should remain the minimization of exaggerated features that lead to significant health issues, the current data suggest that it would be irresponsible to address this issue solely from that perspective.

Despite rising awareness and efforts towards healthier breeding standards, the sustained and even growing popularity of chondrodystrophic breeds highlights the necessity for a more pragmatic and inclusive approach. As veterinary professionals, it is crucial that we recognize and engage with the ongoing and specific health challenges faced by these breeds. Overlooking these issues not only fails to address the issue, but also hinders the advancement of targeted diagnostic tools and treatment strategies essential for improving their quality of life.

These animals often present with more frequent and severe health problems, making them regular patients in veterinary clinics. As such, they demand a tailored clinical approach and dedicated research efforts to better understand and address their unique medical needs.

The increasing popularity of breeds such as the miniature Dachshund, coupled with their known predisposition to significant neurological and orthopedic disorders, constitutes a primary rationale for the present study. This research aims to investigate the specific health challenges encountered by miniature Dachshunds and to promote the advancement of specialized diagnostic and therapeutic strategies designed to enhance their welfare and support their rehabilitation.

CHAPTER I: CHONDRODYSTROPHY, IVDD AND THE DACHSHUND

1. BASIC ANATOMY OF THE VERTEBRAL SPINE

The canine vertebral column consists of approximately 50 irregular bones known as vertebrae. These are organized into five segments: cervical, thoracic, lumbar, sacral, and caudal. Typically, dogs have 7 cervical vertebrae, 13 thoracic vertebrae, 7 lumbar vertebrae, 3 sacral vertebrae, which fuse to form the sacrum, considered a single bone, and approximately 20 caudal vertebrae. A typical vertebra consists of a body, a vertebral arch, and articular, transverse, and spinous processes (Evans & De Lahunta, 2020). The vertebral body is located ventrally to the spinal cord, with a core composed of cancellous bone surrounded by cortical bone margins. The spinal cord, in turn, is housed within the vertebral canal, which is dorsally and laterally bound by the vertebral arch (Sharp & Wheeler, 2005).

Except for the space between the first and second cervical vertebrae - the atlas and axis - and the sacral region, all intervertebral spaces contain intervertebral discs (IVDs) (Dyce *et al.*, 2010). From a biomechanical perspective, the IVD can be viewed as a cushioning system that mediates and transmits compressive forces between vertebral bodies, providing both mobility and stability to the vertebral column (Smolders & Forterre, 2015). In addition to the IVDs, several ligaments contribute to vertebral stability: three long ligaments (supraspinous, dorsal longitudinal, and ventral longitudinal), three short ligaments (interspinous, intertransverse, and ligamentum flavum), and the intercapital ligament (Johnston & Tobias, 2017). Among these, we can highlight the role of the dorsal longitudinal ligament, which covers the dorsal aspect of the vertebral bodies, whereas the ventral longitudinal ligament extends along the ventral aspect of the vertebral bodies from the axis to the sacrum; as well as the intercapital ligament, which connects contralateral ribs, passing over the dorsal longitudinal ligament along its course. This ligament is crucial in reducing the incidence of disc disease in thoracic spine but is absent at the 12^{th} and 13^{th} rib pairs. (Cecim, 2019; Fenn & Olby, 2020). A healthy IVD allows for separation of the vertebral bodies, thereby maintaining constant tension in the intervertebral ligaments and preventing displacements that could impose excessive stress on the vertebrae (Smolders & Forterre, 2015). The diameter of the IVDs is proportional to their thickness and tends to be narrower in the thoracic region compared to the cervical and lumbar regions (Verheijen & Bouw, 1982).

These discs are composed of four regions: the nucleus pulposus, the transitional zone, the annulus fibrosus, and the cartilaginous endplates. The nucleus pulposus is an ovoid, gelatinous structure located centrally within the disc; it is derived from the notochord and consists of proteoglycans and glycosaminoglycans aggregated with hyaluronic acid, complexes that, by exerting high osmotic pressure, enable retention of large quantities of water in the nucleus (Fenn & Olby, 2020). A healthy nucleus pulposus may be composed of approximately 80% water. The presence of type II collagen, with its capacity to interact with glycosaminoglycans, leads to the formation of collagen networks that confer stability against compressive forces (Smolders & Forterre, 2015; Fenn & Olby, 2020).

. The annulus fibrosus consists of concentric lamellar fibers and is organized into two regions: an inner region with a high density of chondrocytes, and an outer region characterized by a predominance of type I collagen fibers (Fenn & Olby, 2020). The cartilaginous endplates consist of approximately five layers of chondrocytes, anchoring the intervertebral disc to adjacent vertebrae and providing a shock-absorbing function (Fenn & Olby, 2020).

Innervation of the disc originates primarily from small-diameter fibers ("C" or A-delta) and is therefore mainly nociceptive in nature. The meningeal nerve is one of the main nerves responsible for innervating this region, supplying the posterior aspect of the disc, the dorsal longitudinal ligament, the ventral spinal dura mater, the articular facets, and the dorsal vertebral bodies, among other structures. Additional innervation may arise from communicating branches of the thoracolumbar sympathetic region (Rivera & Sprague, 2014).

Among various animal species, dogs are particularly susceptible to disc disease. In these animals, the intervertebral discs account for approximately 17.5% of the vertebral column length, while the vertebral canal diameter is only slightly larger than that of the spinal cord itself. Consequently, pathologies affecting the intervertebral discs almost inevitably result in spinal cord trauma (Verheijen & Bouw, 1982).

2. CHONDRODYSPLASIA AND CHONDRODYSTROPHY

Skeletal dysplasia is a general term used to describe abnormalities in the growth and development of cartilage and/or bone, which are associated with alterations in stature (Mortier *et al.*, 2019).

The term chondrodysplasia encompasses many skeletal dysplasia disorders characterized by abnormal development of the endochondral components of the skeletal system (present at birth). It has been used to describe the extreme differences in limb length observed in various dog breeds such as Basset Hounds, Pekingese, and Dachshunds (Parker *et al.*, 2009). In canids, it typically manifests as limb shortening, angular limb deformities, and joint incongruence. This congenital disruption of endochondral ossification, the process by which cartilage is replaced by bone during development, primarily affects the long bones (Gustafsson, 2015; Pulkkinen, 2024).

In veterinary literature, chondrodystrophy has been used to describe short-limbed dogs with skeletal dysplasia that additionally suffer from progressive and early degeneration and calcification of the IVDs postnatally (Dickinson & Bannasch, 2020). This early degeneration and calcification predispose chondrodystrophic dogs to IVDD, a severe condition that can culminate in spinal cord compression, pain, and neurological deficits (Brown *et al.*, 2017; Batcher *et al.*, 2019).

3. PATHOPHYSIOLOGY OF IVDD

IVDD is a common condition in dogs that, although it may occur without apparent clinical signs, can lead to several serious problems such as intervertebral disc herniation (IVDH), degenerative lumbosacral stenosis, cervical spondylomyelopathy, among others (Bergknut, 2010). In fact, IVDD underlies the most common forms of IVDH (Fenn & Olby, 2020), and it is estimated to account for approximately 21% of all neurological cases reported in domestic dogs. The overall incidence of this pathology across all domestic canine breeds is estimated at 2% to 3.5% (Abouzeid *et al.*, 2025).

Although intervertebral disc degeneration is a natural and inevitable aging process (Jeffery *et al.*, 2013), it is highly influenced by a multitude of factors, including genetics, trauma occurrence, biomechanical stress, among others.

In general terms, this degeneration involves the replacement of the notochordal cells of the nucleus pulposus by chondrocytes with subsequent fibrocartilage transformation, as well as loss of proteoglycans and dehydration, in a process known as chondroid metaplasia. These changes lead to the formation of fissures in the annulus fibrosus and sclerosis of the endplates, with a substitution of type II collagen in the nucleus by large amounts of type I collagen, resulting in loss of elasticity and compressibility, which are properties essential for shock absorption (Cecim, 2019; Fenn & Olby, 2020).

It is believed that the initiating factor for IVDD in humans is related to the loss of diffusion capacity of blood vessels responsible for the nutrition of the nucleus pulposus. In dogs, this degeneration of blood perfusion is more likely associated with multigenic predispositions, either through genes related to vasculopathies or genes linked to selection for chondrodystrophy (Jeffery *et al.*, 2013).

As previously mentioned, IVDD is considered one of the main triggering factors for IVDH. In a seminal study published in 1952, Hansen described two primary forms of IVDD, now known as Hansen type I herniation (acute disc extrusion) and Hansen type II herniation (chronic disc protrusion). More recently, other types of IVDH have been identified, such as hydrated nucleus pulposus extrusion and non-compressive acute nucleus pulposus extrusion, among others. However, in these latter pathologies, cases have been reported in patients without signs of IVDD (Fenn & Olby, 2020). Throughout this work, we will primarily focus on Hansen type I herniations due to their high prevalence in Dachshund breeds.

4. GENETIC CAUSES – THE ROLE OF FGF4 RETROGENES

In recent years, two key genetic mutations have been identified as determining factors for chondrodysplasia and chondrodystrophy: fibroblast growth factor 4 (FGF4) retrogenes inserted on chromosome 18 (18-FGF4RG, currently also known as FGF4L1) and/or on chromosome 12 (12-FGF4RG, now also known as FGF4L2) (Parker *et al.*, 2009; Brown *et al.*, 2017; Sullivan *et al.*, 2025).

The FGF4L1 is linked to a short-limbed conformation but does not appear to increase the risk of IVDD on its own (Batcher *et al.*, 2019). This retrogene can be associated with chondrodysplasia and is linked to the occurrence of carpus valgus in dogs (Bannasch *et al.*, 2020; Bellamy & Lingaas, 2020).

FGF4L2 is strongly associated with IVDD and acts in a dominant manner, increasing the risk of disc degeneration and early herniation. Additionally, it has a moderate effect on limb shortening (Brown *et al.*, 2017; Batcher *et al.*, 2019). Thus, it is related to a chondrodystrophic phenotype.

The FGF4L1 has a greater impact on limb length than the FGF4L2, with two copies of the former reducing the length of the forearm by 25%, whereas two copies of the latter reduce it by only 10% (Bannasch *et al.*, 2020; Sullivan *et al.*, 2025).

In animals carrying both retrogenes, such as Dachshunds, Basset Hounds, and Corgis, the phenotypic effects are more severe, combining extreme limb shortening with a high risk of IVDD (Sutter *et al.*, 2008; Brown *et al.*, 2017).

4.1. The Dachshund: The “prototype” chondrodystrophic and chondrodysplastic breed

Dachshunds are consistently carriers of both FGF4L1 and FGF4L2 retrogenes, making them an excellent model for studying these traits (Batcher *et al.*, 2019). Furthermore, they are typically homozygous for both retrogenes, which explains their significantly increased predisposition for IVDD and limb deformities (Brown *et al.*, 2017; Batcher *et al.*, 2019; Dickinson & Bannasch, 2020).

These animals tend to exhibit moderate angular limb deformities, carpal valgus/varus, and mild elbow incongruence. Although they present with less radial head subluxation and external rotation compared to some other breeds, the clinical burden they face due to spinal disease should not be underestimated (Brown *et al.*, 2017; Reunanen *et al.*, 2023; Pulkkinen, 2024). Moreover, it is estimated that 19%-31% of these dogs will be affected by IVDD during their lifetime, with the highest incidence between 4 and 6 years of age (Fletcher *et al.*, 2023; Reunanen *et al.*, 2023). This corresponds to a 10 to 12-fold increased risk of IVDD compared to other breeds (Packer *et al.*, 2016). Additionally, a study based on insurance data from Sweden identified the miniature Dachshund as having the highest mortality rate associated with IVDD among all breeds (Bergknut *et al.*, 2012). Given that this is one of the most common neurological conditions encountered in clinical practice, as well as the disease that represents the greatest burden for these animals, it will be addressed in detail in the following sections.

Due to their body conformation, the occurrence of osteoarthrosis is also particularly frequent in Dachshunds, which can be especially problematic for these animals since they are already predisposed to joint and spinal problems (Mothé *et al.*, 2024). Osteoarthrosis is a chronic and progressive condition characterized by erosion of articular cartilage, leading to exposure of underlying bone, osteophyte formation, and synovial membrane inflammation (Silva *et al.*, 2017). This condition can be found in any dog breed but deserves special consideration in breeds like the Dachshund, which are especially susceptible to orthopedic problems. Symptoms of osteoarthrosis vary in intensity but frequently include lameness, joint stiffness, difficulty moving, reduced physical activity, evident pain upon manipulation, and muscle atrophy. In advanced cases, behavioral changes such as aggression toward people or other animals may occur as a result of chronic pain. In Dachshunds, the genetic predisposition to spinal problems like IVDD, the tendency for limb deformities affecting weight distribution, combined with other environmental factors, may increase the risk of developing arthritis in the vertebral joints and limbs (Silva *et al.*, 2017; Fossum, 2018).

The characteristic elongated spine of the Dachshund is also associated with susceptibility to fractures, particularly in the thoracolumbar region. Furthermore, the short limb length and slender bones may be related to an increased predisposition to limb fractures (Li *et al.*, 2000; Slatter, 2002; DeCamp *et al.*, 2016).

5. RISK FACTORS FOR THE DEVELOPMENT OF IVDD IN DACHSHUND DOGS

Dachshunds are particularly predisposed to the degeneration of IVDs, with macroscopic observation of calcified discs possible as early as 9 months of age (Hansen, 1952), reaching peak expression by 2 years (Jensen & Arnbjerg, 2001). The genetic and hereditary basis of IVD calcification has been demonstrated in several studies, being associated with the FGF4L2 (Mogensen *et al.*, 2012; Brown *et al.*, 2017; Batcher *et al.*, 2019). In a study conducted in 2008, Jensen *et al.* found a positive correlation between the number of calcified IVDs visible on radiographs (CVDR) and the risk of IVDD - results that were replicated by Lappalainen *et al.* in 2014. Furthermore, the latter study also identified a strong positive correlation between the number of IVD calcifications, and the severity and frequency of clinical signs associated with IVDD. However, the authors noted the potential for underestimation, as calcified discs can be reabsorbed over the animal's lifetime.

The reported tendency for more frequent extrusive disc herniations in highly mobile spinal regions, such as the thoracolumbar spine, suggests that biomechanical factors may play a significant role in the extrusion of degenerated discs (Hansen, 1952; Bray & Burbidge, 1998). Given that body morphometry is, at least in part, related to the distribution of biomechanical forces along the spine, it is logical to infer that the Dachshund's unique proportions may alter the frequency of disc extrusions (Resnick, 2002; Levine *et al.*, 2006). In 2006, Levine *et al.* conducted a study comparing morphometric data between 39 Dachshunds with thoracolumbar acute extrusive disc herniation (IVDE) and a control group of 36 healthy Dachshunds. The study concluded that dogs with a shorter distance between the calcaneal tuberosity and the midpoint of the patellar tendon (TC-PT distance), as well as a decreased distance from T1 to S1, were significantly more affected by IVDD. These findings may be explained by the notion that shorter limbs and a markedly shortened vertebral column may indicate more severe degrees of chondrodystrophy (Levine *et al.*, 2006). Additionally, several publications have reported that, compared to other breeds such as the German Shepherd, Dachshunds present a markedly increased spinal cord-to-vertebral canal width ratio, rendering them especially vulnerable to spinal trauma in the event of disc extrusion (Morgan *et al.*, 1987; Bray & Burbidge, 1998; Fourie & Kirberger, 1999). It has therefore been hypothesized that smaller Dachshunds may present even more exaggerated ratios (Levine *et al.*, 2006). Levine *et al.* (2006) also reported that dogs with a larger pelvic circumference presented a higher risk of being affected by IVDD, although, at the same time, seemed to be associated with less severe clinical signs. The authors were, at the time, unable to find an explanation for these findings.

In 2013, a study by Packer *et al.* concluded that relatively longer spines compared to limb length were associated with a higher risk of IVDD. At first glance, these findings may seem contradictory to the aforementioned study, which suggested that shorter spine length was a risk factor. However, it is important to highlight that while Levine *et al.* (2006) analyzed total spine length, the data from Packer *et al.* (2013) focused on the ratio between body length and height. Additionally, the results of this study also indicated that smaller dogs, such as miniature Dachshunds, were at higher risk for IVDD. Thus, both studies may be complementary: shorter vertebral columns may be associated with miniature breeds and therefore positively correlated with IVDD risk, while exaggerated body length-to-height ratios may also contribute to the condition's development. This study also examined the influence of body condition, with data suggesting that obesity is a particularly concerning risk factor for miniature Dachshunds - even moderately obese dogs were disproportionately affected.

In 2016, Packer *et al.* published a study analyzing data from an online questionnaire designed to assess various aspects of Dachshund lifestyle and identify risk factors for IVDD. The questionnaire received responses concerning 2,031 dogs, and the prevalence of IVDD was 15.7%. As in the previously mentioned studies, miniaturization was again identified as a risk factor. Older animals (8–10 years) were at greater risk compared to younger dogs (0–2 years), which is expected given the degenerative nature of the disease (Bergknut *et al.*, 2012; Packer *et al.*, 2013). Contrary to the 2013 study, this investigation did not find any association between body condition or disproportion between spine length and limb size and the risk of IVDD. However, since these data were self-reported by owners, their accuracy is questionable. It is possible that body condition scores were underestimated and that anatomical landmarks suggested for morphometric measurements proved difficult for owners to assess accurately. Regarding physical activity, Packer *et al.* (2016) reported that dogs described as substantially more active appeared to be at a lower risk for IVDD. These results may be interpreted in two ways: first, reverse causality may be at play - dogs experiencing subtle pain from IVDD may show less interest in physical activity. Additionally, since the questionnaire did not assess temporality, it is also possible that owners of dogs previously affected by IVDD reduced their dogs' activity levels post-diagnosis. Though not confirmed in this study, obesity has previously been correlated with IVDD risk and is more common in sedentary animals. Alternatively, more active dogs may develop better musculature supporting the spine, providing protection against disc extrusion or protrusion, and longer periods of exercise may enhance disc nutrition, reducing the likelihood of early mineralization (Packer *et al.*, 2016). Interestingly, avoiding jumping from elevated surfaces and the use of chondroprotective supplements were identified as risk factors, likely due to a failure to account for temporality. It is reasonable to assume these are not true risk factors but rather lifestyle modifications introduced after IVDD episodes requiring veterinary attention. According to Packer *et al.* (2016), the Dachshund variety least affected by IVDD was the wire-haired Standard Dachshund.

A 2023 study by Fletcher *et al.* compared the thoracic-to-lumbar spine length ratio between 47 miniature Dachshunds diagnosed with IVDD and 104 healthy controls. The study found that this ratio was significantly lower in affected dogs.

Fertility status and age at neutering have also been studied as potential risk factors for IVDD in Dachshunds. In a 2018 study by Dorn & Seath, early spayed females had a risk ratio (RR) of 2.12 for developing IVDD, and late-spayed females had an RR of 1.55 compared to intact females. Similar results were obtained by Hart *et al.* in a study published in 2020. Packer *et al.*, in 2016, also assessed fertility status, though without considering age at neutering, and found that intact animals had a significantly reduced likelihood of developing the disease (odds ratio: 0.38). However, the authors noted that the lack of temporality testing may have biased the findings; for instance, dogs diagnosed with IVDD might have been neutered post-diagnosis to avoid future breeding. A 2024 study by Doeven *et al.* concluded that while neutering is associated with increased IVDD risk, the data did not support the hypothesis that it also influences symptom severity.

Finally, participation in dog shows was found to be associated with a lower incidence of IVDD (Packer *et al.*, 2016). Selective breeding could explain this result; however, the authors also suggest other, less positive, explanations. It cannot be ruled out that IVDD episodes in show dogs may go unreported to maintain commercial value. Moreover, animals affected by IVDD may be disqualified from future competition, meaning the show population may be biased toward healthier individuals. Additionally, owners of show dogs may be more informed about breed-specific risks and more proactive in taking preventive measures. These factors and their effects are summarized in Table 4.

Table 4. Summary of risk factors for IVDD in Dachshund dogs.

CATEGORY	RISK FACTOR	EFFECT	DETAILS	CONTRADICTORY FINDINGS / FOOTNOTES	SOURCES
GENETIC	FGF4L1 (18-FGF4RG)	—	Limb length, not IVDD	—	Batcher *et al.*, 2019
GENETIC	FGFL2 (12-FGF4RG)	↑	Strongly linked to disc degeneration	—	Brown *et al.*, 2017; Dickinson *et al.*, 2020
GENETIC	CDVR (calcified discs)	↑	High heritability, strong predictor	Footnote 1	Lappalainen *et al.*, 2014; Reunanen *et al.*, 2023
ANATOMICAL	Short T1–S1 length	↑	2.1x increased risk	Footnote 2	Levine *et al.*, 2006
ANATOMICAL	Short TC–PT distance	↑	11.1x increased risk	—	Levine *et al.*, 2006
ANATOMICAL	Back:height ratio >1.5	↑	Chondrodystrophic body	Footnote 3	Packer *et al.*, 2013
ANATOMICAL	Thoracic:lumbar ratio	↑	Mechanical stress area	Footnote 4	Fletcher *et al.*, 2023
ANATOMICAL	Large pelvic circumference	↑	Associated in some	Footnote 5	Levine *et al.*, 2006
CONFORMATION	Miniaturization	↑	Seen in miniature types	—	Packer *et al.*, 2013; Packer *et al.*, 2016
ACTIVITY	<30 min/day exercise	↑	Higher IVDD odds	Footnote 6	Packer *et al.*, 2016
ACTIVITY	>1 hr/day exercise	↓	Protective factor	Footnote 7	Packer *et al.*, 2016

Activity	Shown in shows	↓	Lower prevalence	Footnote 8	Packer *et al.*, 2016
Movement	No jumping allowed	↑	Higher odds	Footnote 9	Packer *et al.*, 2016
Body Condition	Overweight	↑	Biomechanical load	Footnote 10	Packer *et al.*, 2013
Neutering	Early neuter	↑	RR 2.12 in one study in female dogs	Footnote 11	Packer *et al.*, 2016; Dorn & Seath, 2018; Hart *et al.*, 2020; Doeven *et al.*, 2024;
Age	Older age	↑	Degeneration with age	Footnote 12	Packer *et al.*, 2016; Reunanen *et al.*, 2023
Hair Coat Type	Wire-haired	↓	Lowest risk (7%)	—	Packer *et al.*, 2016
Nutrition	Supplementation with glucosamine or chondroitin	↑	Increased odds of IVDD	Footnote 13	Packer *et al.*, 2016

Footnotes for conflicting findings

1. CDVR resorption: Discs can calcify and later resorb after herniation, potentially underestimating lifetime degeneration.
2. T1–S1 vertebral length: Some studies failed to replicate this finding; results may depend on population sample. Severe degrees of chondrodystrophy may be associated with shortening of the vertebrae.
3. Back-to-height ratio: Logical biomechanical implications, however not universally associated with severity or onset; further validation needed.
4. Thoracic:lumbar ratio: New metric; biomechanical implications logical but not yet widely adopted.
5. Pelvic circumference: Correlated with IVDD in some but not predictive of severity.
6. Low activity: May be secondary to subtle undiagnosed IVDD, not causative.
7. High activity: Could reflect better overall health rather than causal protection.
8. Show dogs: Selective breeding for structurally sound individuals likely reduces risk; under-reporting of illness for monetary reasons; greater knowledge for prevention on the part of the owners.
9. No jumping: Often a precaution post-clinical signs, confounding interpretation.
10. Overweight: Association inconsistent; likely underreported or confounded by sample sizes.
11. Neutering: Some studies show effect; others find no statistically significant link.
12. Age: While older dogs degenerate naturally, studies show degeneration begins by 12-24 months of age in most Dachshunds.
13. Nutrition: The positive correlation between IVDD and joint supplementation does not seem to represent causality; the start of supplementation could be secondary to the occurrence of IVDD, as the study did not test temporality.

6. CLINICAL SIGNS AND PROGRESSION OF IVDD

The clinical presentation of IVDD depends on several factors, including the location and size of the lesion, its progression, the time elapsed since onset, the degree of associated spinal cord compression, the volume of herniated disc material, and the force and velocity of the initial impact (Sharp & Wheeler, 2005; Arias *et al.*, 2007; Dewey & da Costa, 2015).

In the early stages, signs of hyperesthesia are commonly observed, along with behavioral changes and proprioceptive deficits (Dewey & da Costa, 2015; De Lahunta *et al.*, 2020). These alterations may include proprioceptive ataxia and/or deficits in one or more limbs - depending on the affected spinal segment - as well as varying degrees of paresis, which may progress from ambulatory to non-ambulatory and, in severe cases, culminate in plegia (Griffin *et al.*, 2009a; Dewey & da Costa, 2015).

From a clinical standpoint, the spinal cord can be divided into four functional segments, with lesions in each region producing distinct clinical syndromes. These are:

- The cervical segment (C1–C5)
- The thoracic intumescence (C6–T2)
- The thoracolumbar segment (T3–L3)
- The pelvic intumescence (L4–S3)

Depending on the affected region, clinical signs may be consistent with either upper motor neuron (UMN) or lower motor neuron (LMN) lesions (Dewey & da Costa, 2015). These characteristics are summarized in Table 5.

Table 5. Summary of upper (UMN) and lower motor neuron (LMN) lesions differentiating clinical signs.

SIGN	UMN	LMN
REFLEXES	Normal to increased	Decreased to absent
ATROPHY	Disuse: slow, moderate, gradual	Neurogenic: quick, severe, localized
MUSCLE TONE	Normal to increased	Decreased to absent
URINARY BLADDER	Increased tone; difficult to express	Decreased tone; easily expressed

Thus, when a lesion occurs in the cervical segment C1–C5, clinical signs are consistent with UMN involvement in all four limbs: paresis or paralysis, normal to increased spinal reflexes and muscle tone, and mild to moderate muscle atrophy in all limbs. A lesion affecting the thoracic intumescence (C6–T2) results in LMN signs in the thoracic limbs - paresis or paralysis, decreased to absent reflexes and muscle tone, and severe muscle atrophy - and UMN signs in the pelvic limbs. Lesions located within the T3–L3 segment typically affect only the pelvic limbs, which will exhibit UMN signs. Finally, if the pelvic intumescence (L4–S3) is compromised, the pelvic limbs will display LMN signs (Dewey & da Costa, 2015). These findings are summarized in Table 6.

Table 6. Summary of clinical signs based on the localization of the spinal lesion.

LOCALIZATION OF THE LESION	THORACIC LIMBS	PELVIC LIMBS
C1-C5	UMN	UMN
C6-T2	LMN	UMN
T3-L3	Unaffected	UMN
L4-S3	Unaffected	LMN

Another common clinical sign of IVDD is urinary dysfunction. Spinal cord lesions occurring between the pons (the brain's micturition center) and L7 have the potential to result in UMN bladder dysfunction. This scenario most typically arises from lesions between T3 and L3. In such cases, the animal loses the ability to fully empty the bladder, or may be entirely unable to urinate, due to disruption or complete abolition of the detrusor reflex (Dewey & da Costa, 2015). Loss of inhibition of pudendal nerve activity leads to hyperreflexia of the urethral sphincter. If the pelvic and pudendal nerves remain intact, reflexive contraction of the detrusor muscle may still occur; however, lack of coordination with sphincter relaxation results in incomplete voiding and urine retention (Perez, 2022). In these cases, the bladder is turgid, enlarged, and difficult to manually express (Dewey & da Costa, 2015).

Conversely, in LMN lesions, affecting the lower lumbar or sacral regions, animals exhibit continuous urine leakage, with the bladder being distended, flaccid, and easily expressible (Dewey & da Costa, 2015). In such lesions, the detrusor reflex may or may not be abolished, but incontinence primarily occurs due to loss of muscle tone. Damage to the pelvic nerve leads to loss of detrusor function and tone, while lesions involving the pudendal nerve result in loss of tone in the external urethral sphincter. Additionally, because sensory components are also affected in sacral lesions, the internal sphincter does not respond appropriately to increased intravesical pressure, ultimately leading to overflow incontinence (Granger *et al.*, 2020; Perez, 2022).

Fecal dysfunction is another severe consequence of IVDD that must be considered, as it represents one of the main reasons for euthanasia in affected animals (Granger *et al.*, 2020). In UMN lesions, the external anal sphincter remains closed, and feces accumulate in the rectum. Occasionally, involuntary reflex evacuation may occur when colonic and rectal pressure increases. This type of fecal incontinence is largely characteristic of thoracolumbar lesions (T3-L3) that cause paraplegia, while cervical lesions severe enough to cause fecal incontinence are extremely rare in dogs (Olby *et al.*, 2003; Aikawa *et al.*, 2012; Granger *et al.*, 2020). In LMN lesions (i.e., sacral segments), the anal sphincter is weak or absent, leading to continuous fecal leakage: an especially challenging condition for most pet owners to manage (Granger *et al.*, 2020).

The most common site of IVDD in Dachshunds is the thoracolumbar region, with the intervertebral discs most frequently affected by extrusion being T12–T13 (28%), T13–L1 (23%), T11–T12 (15%), and L1–L2 (10%) (Rohdin *et al.*, 2010). In thoracolumbar IVDD, the most frequently reported clinical signs include spinal hyperesthesia, reluctance to move, urinary dysfunction (sometimes accompanied by fecal incontinence), ataxia, kyphotic posture, and paraparesis or paraplegia (Sharp & Wheeler, 2005; Brisson, 2010).

6.1. Neuropathic pain

Chronic neuropathic pain is defined as pain caused by damage or dysfunction in the somatosensory nervous system, often described by human patients as burning, stabbing, tingling, or numbness sensations (Merkey & Bogduk, 1994). Unlike nociceptive pain, which results from direct tissue injury, neuropathic pain is a maladaptive and often chronic condition (Jensen *et al.*, 2011).

This condition is very common in humans with spinal cord injury (SCI), affecting approximately 50–80% of individuals following injury (Siddall *et al.*, 2003; Gilron *et al.*, 2015). Neuropathic pain in these patients is often underrecognized and significantly impairs QOL (Boldt *et al.*, 2014; Hatch *et al.*, 2018).

A study conducted by Zidan *et al.* in 2020 aimed to determine whether similar neuropathic pain occurs in dogs after spinal cord injury, specifically following surgery for thoracolumbar IVDE. Mechanical sensory thresholds (MSTs) were used as an objective measure of pain, collected using pressure algometry (Zidan *et al.*, 2020). The study followed 40 dogs with SCI over one year, comparing them with healthy controls.

The key findings revealed that while most dogs experienced normalization of pain thresholds within 6 months, approximately 15% of SCI dogs exhibited persistently low MSTs one year postoperatively, suggesting the development of chronic neuropathic pain (Zidan *et al.*, 2020). Additionally, up to 33% of dogs showed abnormally low MSTs at the 6-month mark. Dogs with low MSTs often had hyperesthetic cutaneous trunci reflexes (CTR), a sign suggestive of allodynia, which is a common symptom of neuropathic pain (Zidan *et al.*, 2020).

These findings underscore the importance of recognizing chronic pain in veterinary patients, particularly because signs may be subtle and underreported by owners (Belshaw & Yeates, 2018). Chronic neuropathic pain can negatively affect recovery, mobility, and overall QOL (Grubb, 2010), making its detection and management critical in dogs recovering from SCI.

The severity of these symptoms and their effect on QOL cannot be understated, highlighting the importance of the study and development of up-to-date diagnostic and treatment tools, particularly in vulnerable breeds like the miniature Dachshund.

7. DIAGNOSIS AND SCREENING

Imaging diagnostics play a crucial role in identifying Dachshunds that are particularly predisposed to IVDD. Radiographic imaging is routinely employed to assess the presence of CDVR, which serves as indicators of advanced disc degeneration. It has been demonstrated that the number of CDVR correlates significantly with overall disc degeneration as assessed by MRI, particularly when using a modified Pfirrmann grading system (Reunanen *et al.*, 2023). MRI offers the advantage of detecting early, non-mineralized stages of disc degeneration, providing a more sensitive and detailed assessment of intervertebral disc health compared to radiography alone (Reunanen *et al.*, 2023).

Genetic testing complements imaging diagnostics by identifying individuals carrying genetic variants associated with IVDD. As previously mentioned, Dachshunds universally carry two insertions of the FGF4 retrogene: one on chromosome 18 (FGF4L1), which defines their chondrodysplastic morphology, and another on chromosome 12 (FGF4L2), which is specifically associated with chondrodystrophy and a significantly increased risk of IVDD (Brown *et al.*, 2017). While the FGF4L1 insertion is fixed within the breed and is not directly associated with CDVR, the FGF4L2 variant shows a strong statistical and biological association with disc calcification and disease manifestation (Brown *et al.*, 2017; Reunanen *et al.*, 2023).

Studies have confirmed that the number of CDVR correlates with both MRI-based disc degeneration and the FGF4L2 genotype, making the combination of imaging and genotyping a powerful tool for identifying individuals with a lower phenotypic and genetic risk of IVDD (Reunanen *et al.*, 2023).

7.1. Prevention and selective reproduction

Selecting heterozygous individuals for the FGF4 retrogene insertion on chromosome 12 represents a promising strategy to reduce the risk of IVDD in Dachshunds while preserving the breed's characteristic chondrodystrophic phenotype - namely, shortened limbs and an elongated body.

This approach is grounded in the gene expression patterns and phenotypic effects of the FGF4RG allele, particularly its dose-dependent influence on skeletal morphology and disc degeneration. Dogs homozygous for this insertion exhibit more pronounced limb shortening and are at significantly greater risk for premature intervertebral disc degeneration due to accelerated chondroid metaplasia and calcification of the nucleus pulposus (Brown *et al.*, 2017; Reunanen *et al.*, 2023).

In contrast, heterozygous individuals (i.e., those carrying only one copy of the FGF4L2 insertion) display an intermediate phenotype: they retain sufficient expression of the chondrodystrophic morphology (shortened limbs and an elongated axial skeleton) while exhibiting reduced severity and prevalence of disc degeneration compared to homozygous dogs (Reunanen *et al.*, 2023). This finding supports a dose-dependent effect of the FGF4L2 allele on both limb length and disc pathology.

The retention of desirable breed characteristics in heterozygotes is supported by data indicating that even a single copy of the retrogene induces substantial morphological change (Brown *et al.*, 2017). Therefore, selective breeding of heterozygous individuals could moderate extreme chondrodystrophic expression while simultaneously reducing genetic liability for IVDD. This would enable breeders to maintain the distinctive Dachshund silhouette while striving for improved spinal health in future generations.

This breeding strategy aligns with broader objectives to reduce exaggerated conformations associated with increased disease risk: a concept increasingly supported within veterinary and animal welfare communities (Packer *et al.*, 2013).

In fact, in 2025, Sullivan *et al.* published a case report describing two Dachshunds that lacked any insertion of the FGF4 retrogene on chromosome 18 (FGF4L1) and consequently exhibited a "tall" phenotype (>40 cm). The taller dog, measuring 48 cm, had one insertion of FGF4L2, while the other, measuring 41 cm, had two. This suggests a cumulative effect of FGF4L2 but also indicates its relatively minor role. Moreover, no significant difference in height was observed between the dogs' parents, despite one carrying a single copy of FGF4L2 and the other two, with both possessing at least one copy of FGF4L1 (Figure 4.). These findings reinforce the effectiveness of selecting dogs with only one copy of FGF4L2 to reduce the incidence and severity of IVDD while maintaining the breed's defining features. The report also suggests that at least one copy of FGF4L1 is necessary to produce the short-limbed phenotype characteristic of Dachshunds, while FGF4L2 appears to be a less critical determinant of limb length and may be dispensable in generating the desired morphology (Sullivan *et al.*, 2025).

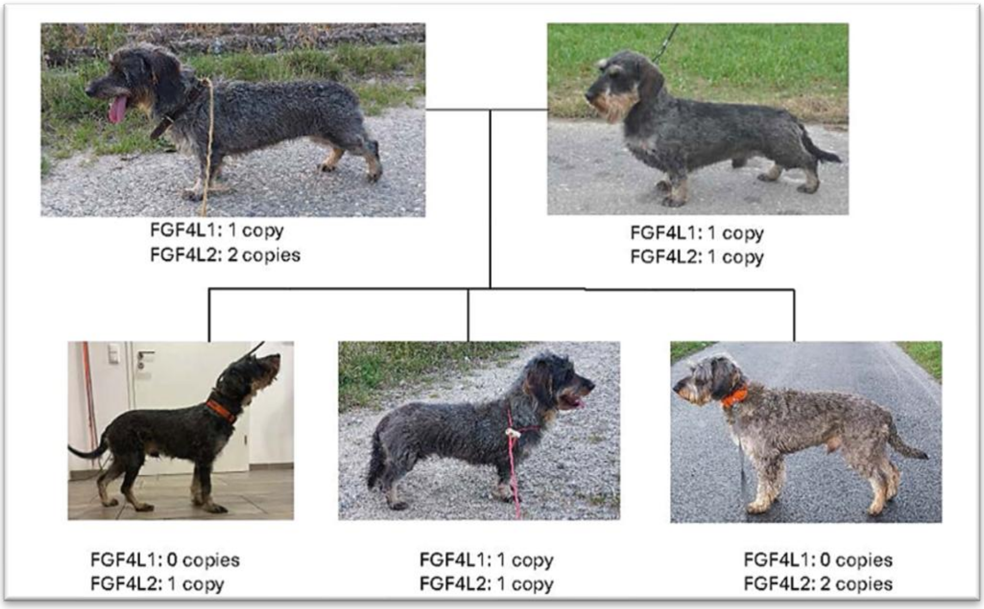

Figure 4. Family tree of the Dachshunds, including genotypes. (Adapted from Sullivan *et al.*, 2025).

Given that IVD calcification is a hallmark of disc degeneration in chondrodystrophic breeds such as the Dachshund, the presence of CVDRs serves as a reliable indicator of underlying disc pathology (Reunanen *et al.*, 2023). The predictive value of CDVRs is underscored by several longitudinal and epidemiological studies demonstrating that Dachshunds with a higher number of calcified discs between 24 and 48 months of age are significantly more likely to develop clinical IVDD later in life (Stingen, 1991; Lappalainen *et al.*, 2001). For instance, dogs with more than five calcified discs have been shown to have a substantially increased lifetime risk of experiencing at least one episode of IVDD (Brisson, 2010).

Moreover, the heritability of CDVR is high, estimated between 0.5 and 0.87, indicating strong genetic control over this trait (Jensen & Christensen, 2000; Jensen & Ersbøll, 2000). This makes CDVR an excellent target for selective breeding programs aimed at reducing the prevalence of IVDD. The Finnish Kennel Club and other national breeding organizations have implemented mandatory or voluntary screening programs for disc calcification, which have already demonstrated success in reducing the average number of CDVR among breeding populations over time (Reunanen *et al.*, 2023).

Although radiography can only detect mineralized discs and may fail to identify early-stage, non-calcified degeneration, it remains an affordable and widely accessible screening tool. When combined with MRI in research settings or high-risk cases, it allows for a comprehensive assessment of both calcified and non-calcified pathology (Bergknut *et al.*, 2012; Reunanen *et al.*, 2023).

In conclusion, radiographic detection of disc calcification serves as a valuable diagnostic and predictive biomarker for IVDD in Dachshunds, demonstrating strong correlation with MRI findings. This supports its continued use in structured breeding programs aimed at improving spinal health while preserving key breed characteristics (Brown *et al.*, 2017; Reunanen *et al.*, 2023). Furthermore, selective breeding of heterozygous FGF4L2 Dachshunds presents a promising strategy for maintaining the breed's characteristic conformation while reducing the risk of IVDD, due to the gene's dosage-sensitive effects on skeletal development and disc pathology (Packer *et al.*, 2013; Brown *et al.*, 2017; Reunanen *et al.*, 2023).

8. TREATMENT AND MANAGEMENT OF IVDD

If not promptly treated, IVDD may progress to irreversible spinal cord damage. The clinical consequences can include chronic pain, loss of proprioception, urinary and fecal incontinence, and complete loss of motor function in the limbs, among others. In severe cases, complications such as self-mutilation due to chronic neuropathic pain and the development of decubitus ulcers resulting from reduced mobility may occur (Martins *et al.*, 2021). The psychological impact on the animal's welfare, along with the emotional and financial stress imposed on the caregiver, are critical factors to consider (Martins *et al.*, 2021).

Studies have shown that dogs with untreated or delayed treatment for IVDD are at increased risk of developing progressive myelomalacia, which is a potentially fatal condition characterized by ascending and descending necrosis of the spinal cord (Aikawa *et al.*, 2012; Zidan *et al.*, 2020). The absence of or delay in intervention is also associated with significantly lower survival and recovery rates (Martins *et al.*, 2021).

8.1. Treatment options

The treatment of intervertebral disc herniation in dogs involves two main approaches: conservative medical management and surgical intervention.

Conservative management is primarily reserved for animals exhibiting mild neurological deficits. It typically includes moderate activity restriction, the administration of non-steroidal anti-inflammatory drugs (NSAIDs) or corticosteroids to reduce inflammation, pain management, and close monitoring (Olby *et al*., 2022).

Surgical intervention is generally indicated in patients presenting with non-ambulatory paresis, paraplegia (with or without preservation of deep pain perception), lack of response to medical management, or recurrence of clinical signs. In cases of thoracolumbar disc herniation, decompressive surgery is most often performed via hemilaminectomy and has been associated with significantly improved outcomes when carried out within the first 12–48 hours following the onset of clinical signs (Aikawa *et al.*, 2012; Jeong *et al.*, 2019). Disc fenestration is frequently performed concurrently with spinal decompression in order to reduce the risk of recurrence (Jeong *et al.*, 2019).

Veterinary rehabilitation and physiotherapy, though sometimes viewed as merely adjunctive, are gaining increasing recognition as integral components of the primary treatment plan for such conditions. These modalities play a fundamental role in improving motor recovery and reducing complications such as muscle atrophy and joint stiffness (Martins *et al.*, 2021). Various therapeutic modalities are currently available, including passive range of motion exercises (PROM), neuromuscular electrical stimulation, hydrotherapy, cryotherapy, proprioceptive training, assisted gait and balance training, laser therapy, ultrasound, shockwave therapy, magnetotherapy, and local ozone administration, among others (Mills & Levine, 2014; Rivera & Sprague, 2014; Andrades *et al.*, 2018). These therapies broadly contribute to the maintenance of joint flexibility, stimulation of neural pathways, and preservation of muscle strength and coordination (Martins *et al.*, 2021). Moreover, techniques such as functional electrical stimulation and transcutaneous spinal cord stimulation have shown promise in promoting neuroplasticity and restoring motor function (Martins *et al.*, 2021). Physiotherapy is recommended to begin within 48 hours post-surgery, provided the patient is clinically stable. Protocols should be tailored to the individual needs of each patient, based on their neurological status and tolerance (Zidan *et al.*, 2018).

8.2. Prognosis factors

The prognosis in cases of IVDD depends on a combination of neurological, anatomical, and temporal factors. Over time, several prognostic indicators have been identified that can help predict the outcome of IVDD treatment in dogs, particularly in cases requiring surgical intervention. Among these, the presence or absence of deep pain perception (DPP) remains the most significant prognostic factor. In general, dogs that retain DPP have a markedly higher likelihood of regaining ambulatory function compared to those in which DPP is absent (Aikawa *et al.*, 2012). In a retrospective study involving over 800 dogs, 97.7% of animals with intact DPP regained the ability to walk, while only 52.1% of those without DPP achieved a comparable level of recovery (Aikawa *et al.*, 2012). Other studies report recovery rates between 72% and 100% in dogs with intact DPP, whereas recovery in DPP-negative animals ranges from 30% to 75%, depending on how rapidly surgical intervention is performed (Zidan *et al.*, 2018).

As previously mentioned, another critical prognostic factor is the time interval between the onset of paralysis and decompressive surgery. An interval greater than 12 hours is associated with an increased risk of progressive myelomalacia, a frequently fatal condition (De Lahunta *et al.*, 2020). Similarly, prolonged absence of DPP, particularly beyond 48 hours, is correlated with significantly worse outcomes. However, other studies have found that dogs with loss of DPP for over 72 hours still had a good functional outcome (Anderson *et al.*, 1991; Scott & McKee, 1999; Zidan *et al.*, 2018). Nonetheless, timely decompressive surgery can improve recovery chances even in dogs lacking DPP (Zidan *et al.*, 2018). These factors underscore the importance of rapid referral and intervention in acute IVDD cases.

Breed and age influence both susceptibility to IVDD and the severity of clinical signs. For instance, French Bulldogs and Dachshunds appear to have a higher predisposition to severe outcomes, especially in the absence of DPP (Jeffery *et al.*, 2013). Although no consistent correlation has yet been established between age or body weight and clinical outcome, younger and more active dogs tend to recover more effectively. This is likely due to enhanced neuroplasticity in younger animals and the absence of age-related comorbidities. Additionally, obese dogs may face more challenging recoveries due to increased surgical risk and greater biomechanical strain on the spine during rehabilitation (Fenn & Olby, 2020). Although not the most reliable of signs, the presence of voluntary tail movement may serve as an early indicator of retained or recovering DPP and is associated with a better functional prognosis (Olby *et al.*, 2000).

The anatomical location of the lesion can also influence clinical outcome. For example, lesions in the caudal lumbar spine, particularly in paraplegic dogs without DPP, are associated with a higher risk of progressive myelomalacia (Brisson, 2010).

From an imaging standpoint, a T2-weighted hyperintensity pattern on magnetic resonance imaging (MRI) may suggest necrosis, hemorrhage, or edema, although its prognostic value remains controversial (Mayhew *et al.*, 2004). Furthermore, in myelographic examinations, the absence of contrast over more than five vertebral bodies is considered a poor prognostic indicator (Lim *et al.*, 2010).

Rapid postoperative neurological improvement, particularly within the first 14 days, is a strong predictor of long-term recovery (Zidan *et al.*, 2020). Although postoperative rehabilitation may not directly influence prognosis in all cases, it remains a valuable adjunct in improving functional outcomes, especially in dogs with severe neurological deficits (Mills & Levine, 2014).

Finally, reflex locomotion (also known as spinal walking), although uncoordinated and spastic, can be developed in some DPP-negative animals and allows for a certain degree of mobility, albeit with variable QOL (McKee, 2000).

8.3. The importance of physiotherapy and rehabilitation

Several studies have demonstrated that animals undergoing decompressive surgery combined with specialized rehabilitation treatments achieve significantly better neurological outcomes compared to those treated with surgery alone. In a retrospective study involving 186 dogs, those that received physiotherapy achieved a success rate of 86.4%, in contrast to a 52.22% success rate in the group treated exclusively with surgery (Jeong *et al.*, 2019). This disparity was even more pronounced in animals with severe proprioceptive deficits (Jeong *et al.*, 2019).

Another case study showed that dogs with incomplete recovery three months post-surgery exhibited significant locomotor improvements following participation in a functional neurorehabilitation protocol (Martins *et al.*, 2021). The authors suggest that the integration of these patients into specialized neurorehabilitation programs could be an important strategy in mitigating the number of elective euthanasia procedures related to SCI in dogs.

While evidence remains variable regarding the superiority of intensive rehabilitation over more basic rehabilitation protocols (Zidan *et al.*, 2018), there is a general consensus that a structured, individualized physiotherapy plan is critical for optimal recovery. However, in order to achieve such a personalized protocol, veterinary doctors need standardized and breed-specific literature to rely on, specifically when regarding breeds with extreme morphologies, such as the Dachshund. Objective diagnostic tools that enable early identification of pathologies and reliable monitoring of treatment responses, such as the goniometric assessment of the joints, are essential for developing the most effective case-specific therapeutic protocols and ensuring optimal clinical recovery. Nonetheless, there remains a significant lack of breed-specific research in this area. The necessity to fill these particular gaps in literature played a key role in inspiring the development of the study that comprises the following sections of this paper.

CHAPTER II - GONIOMETRY

The term goniometry is derived from two greek words: *gonia*, meaning "angle," and *metron*, meaning "measurement." Thus, goniometry refers to the study and quantification of the angles formed at joints by the movement of bones (Norkin & White, 2017).

The total range of flexion or extension of a joint is measured using a goniometer (Mills & Levine, 2014). This is a simple, non-invasive, and low-cost technique that provides rapid information for the evaluation of joint disease or the postoperative progress of orthopedic patients (Alievi *et al.*, 2004). It is commonly used as an objective measure of joint and muscle disorders and is also employed in the assessment of patients following articular or muscular trauma (Alievi *et al.*, 2004).

In veterinary medicine, goniometry is used to objectively evaluate outcomes in canine and feline patients undergoing physiotherapy during recovery from orthopedic or neurological conditions (Thomovsky *et al.*, 2016). Accordingly, knowledge of joint ROM is essential for determining the prognosis of patients affected by articular or neurological injuries (Thomovsky *et al.*, 2016; Machado *et al.*, 2020).

Goniometry is also routinely used in human medicine as an objective method for monitoring recovery in cases of neurological rehabilitation. Specifically, it has been successfully applied in patients undergoing rehabilitation for a wide range of conditions, including cerebral palsy (Ashton *et al.*, 1978; Stuberg *et al.*, 1988), Duchenne muscular dystrophy (Pandya *et al.*, 1985), stroke (Andrews & Bohannon, 1989) and spinal cord injury (Cikajlo *et al.*, 2003; Bittar *et al.*, 2024), among others.

This broad application of goniometric analysis in various human neurological conditions underscores its untapped potential in veterinary clinical practice, particularly for a wide array of neurological disorders.

1. RANGE OF MOTION

The maximum flexion and extension angles correspond to the greatest range of joint excursions. Measuring these maximum joint angles may elicit some degree of discomfort. However, it is unlikely that an animal experiencing discomfort during full flexion or extension would naturally move the limb through those extremes during locomotion. Consequently, it may be more clinically relevant to assess the comfortable ROM (Mills & Levine, 2014).

To achieve this, the joint should be slowly flexed until the first sign of discomfort, such as muscle contraction, withdrawal of the limb, or movement of the head. Then, the joint should be slowly extended, again stopping at the first indication of discomfort (Mills & Levine, 2014).

Unlike in human medicine, where goniometric assessment is often performed with active patient participation, veterinary goniometric measurements are typically conducted passively, meaning that the joint movement is performed entirely by the clinician without voluntary assistance from the animal (Mann *et al.*, 1988; Jaegger *et al.*, 2002; Hesbach, 2007; Jaeger *et al.*, 2007; Araújo *et al.*, 2009; Liljebrink & Bergh, 2010; Gaiad *et al.*, 2011).

1.1. General impact of musculoskeletal and neurological disorders on joint ROM

ROM and flexibility are critical for normal locomotion and are regulated by the coordinated function of bones, cartilage, synovial membranes, ligaments, joint capsules, tendons, as well as the surrounding musculature (Millis & Levine, 2014). Pathologies that affect any of these structures can lead to either hypomobility (reduced ROM and stiffness) or hypermobility (increased ROM, laxity and instability), both of which can disrupt the normal biomechanics, predisposing the patient to further musculoskeletal dysfunction (Millis & Levine, 2014; Zink & Van Dyke, 2018).

Hypomobility typically results from conditions such as inflammation, fibrosis, joint effusion, osteophyte formation, muscular contractures and shortening of muscles and ligaments related to disuse (Millis & Levine, 2014). Inflammation, in particular, plays a critical role in the reduction of joint ROM, by increasing synovial fluid production and vascular permeability, therefore causing joint swelling and pain-mediated disuse (Johnston *et al.,* 2008; Millis & Levine, 2014).

Hypermobility, conversely, may result from ligamentous laxity, tendon rupture, congenital structural abnormalities, to name a few. By way of example, we can consider joint instability from ligament damage, resulting in abnormal joint motion. Over time, this can cause uneven loading of articular cartilage, contributing to early degenerative changes and secondary osteoarthritis (Smith *et al.*, 1990; Mostafa *et al.*, 2009; Millis & Levine, 2014).

Muscle weakness or neuromuscular dysfunction can also increase joint mobility beyond normal limits. These effects can mimic or exacerbate the mechanical consequences of ligamentous laxity (Kornegay, 2017). Golden Retriever Muscular Dystrophy represents a profound example of how neuromuscular pathology can affect joint function. Progressive myofiber degeneration and muscle atrophy lead to weakness, joint instability, and increased passive ROM (Kornegay et al., 2012). Over time, this excessive mobility causes joint strain, capsular damage, and fibrosis. Some joints become excessively mobile, while others develop contractures due to uneven muscle loss and fibrotic replacement (Kornegay *et al.*, 2012; Kornegay, 2017). These biomechanical deficits not only limit motion but also disrupt gait and predispose to secondary orthopedic problems (Kornegay, 2017).

Alterations in joint mobility, whether toward hypomobility or hypermobility, can therefore act both as primary drivers and secondary consequences of musculoskeletal disease. For instance, restriction in one joint often leads to compensatory overuse or maladaptive movement patterns in adjacent joints, fostering a cycle of dysfunction and pain (Millis & Levine, 2014). Objective gait analyses in dogs with naturally occurring osteoarthritis confirm these biomechanical shifts, with load redistribution and altered stance patterns evident even in early disease stages (Bockstahler et al., 2009). Goniometry offers a simple, reliable, and non-invasive method to objectively measure joint ROM, making it an invaluable tool for detecting early alterations in mobility, whether hypo- or hyper-mobile, and effectively tracking compensatory biomechanical changes associated with conditions like osteoarthritis (Jaegger *et al.*, 2002; Reusing *et al.*, 2020).

In veterinary clinical practice, maintaining or restoring appropriate joint ROM and flexibility is central to preventing degenerative disease, optimizing recovery from injury, and preserving functional QOL, particularly in aging animals, or high-risk breeds,

1.2. Disease-specific impacts on and of joint ROM

Osteoarthritis is among the most prevalent causes of joint hypomobility in dogs. The chronic, low-grade inflammation characteristic of osteoarthritis induces synovitis, capsular thickening, osteophyte formation, and cartilage degradation, collectively contributing to a progressive decline in joint flexibility and pain-mediated motion restriction (Robinson *et al*., 2016). Fibrotic remodeling of the joint capsule and periarticular tissues further exacerbates stiffness, creating a vicious cycle that discourages normal joint use and movement, thereby promoting disuse atrophy and joint contracture (Johnstons *et al.,* 2008; Millis & Levine, 2014; Robinson *et al*., 2016). Additionally, pro-inflammatory mediators such as interleukin-1β (IL-1β) and tumor necrosis factor-alpha (TNF-α) contribute to cartilage breakdown and periarticular tissue remodeling, reinforcing stiffness and avoidance of movement due to pain (Robinson *et al*., 2016). Although initially subtle, these biomechanical alterations are frequently quantified through objective gait analyses, which reveal compensatory load redistribution and decreased weight bearing (Bockstahler *et al.*, 2009). Notably, Corfield *et al*. (2007) investigated whether reductions in hip ROM, as measured by goniometry, could serve as predictors for the development of hip osteoarthritis in Labrador Retrievers. Despite inconclusive findings, this study laid important groundwork for further exploration in this area.

Hip dysplasia is defined by coxofemoral joint laxity arising from insufficient acetabular coverage and ligamentous insufficiency (Smith *et al.*, 1990). This abnormal laxity results in increased passive range of motion early in life, predisposing the joint to repetitive microtrauma (Millis & Levine, 2014). Progressive instability subsequently induces remodeling of the femoral head and acetabulum, cartilage degradation, and secondary osteoarthritis (Riser, 1985; Johnston *et al.*, 2008). Although initial joint hypermobility is observed, chronic pathological changes ultimately reduce ROM due to periarticular fibrosis and osteophyte formation (Millis & Levine, 2014). Hip dysplasia thus exemplifies how aberrant joint mechanics may evolve from excessive mobility to painful stiffness (Zink & Van Dyke, 2018).

Cranial cruciate ligament rupture results in dynamic stifle instability, characterized by abnormal cranial tibial thrust during weight-bearing (Mostafa *et al.*, 2009). This instability disrupts normal joint kinematics and increases shear stress on articular cartilage, accelerating degenerative changes and eliciting inflammatory responses (Comerford *et al.*, 2005). Partial ligament tears may initially evade detection but still induce subtle alterations in ROM and limb loading patterns (Pinna *et al.*, 2021). As osteoarthritis progresses, stifle ROM, particularly extension, becomes increasingly restricted (Millis & Levine, 2014).

Medial patellar luxation is a developmental disorder predominantly affecting small-breed dogs, marked by malalignment of the quadriceps mechanism and a shallow trochlear groove (Fauron & Perry, 2016; Perry & Déjardin, 2021). Recurrent or permanent patellar dislocation compromises normal patellar tracking during flexion and extension, resulting in abnormal stress on medial soft tissues (DeCamp *et al.*, 2016). Chronic luxation can induce fibrosis, joint capsule thickening, angular limb deformities, and pain-related movement adaptations, all of which contribute to reduced stifle flexibility and diminished ROM (Millis & Levine, 2014; Zink & Van Dyke, 2018).

1.2.1. IVDD, joint ROM and goniometry

SCI, whether traumatic or degenerative, profoundly affects neuromuscular control and joint function. IVDD is a well-documented cause of SCI, leading to spinal cord compression and a cascade of neuromuscular and biomechanical dysfunctions (Hansen, 1952; Brisson, 2010; Jeffery *et al.*, 2013). The pathophysiological consequences of SCI, including those secondary to IVDD, encompass both neural and structural impairments that contribute to altered muscle tone and restricted ROM.

In upper motor neuron injuries, such as those commonly seen in thoracolumbar SCI, damage to descending inhibitory pathways induces spasticity, defined by increased muscle tone, clonus, tendon hyperreflexia, and involuntary spasms (Decq, 2003; Adams & Hicks, 2005). These manifestations lead to substantial limitations in both passive and active joint mobility (Adams & Hicks, 2005; Yelnik *et al.*, 2010). Chronic muscle overactivity can further promote soft tissue adaptations, including muscle shortening, fibrosis, and joint contractures, which exacerbate stiffness and reduce flexibility (Adams & Hicks, 2005; Yelnik *et al.*, 2010).

In the context of IVDD-related SCI, degeneration of the annulus fibrosus and nucleus pulposus diminishes disc hydration and elasticity, weakening its shock-absorbing capabilities (Brisson, 2010). This structural breakdown often results in disc extrusion (Hansen Type I) or protrusion (Type II), both of which can compress neural elements and mechanically impair spinal segment motion (Hansen, 1952; Slatter, 2002). The ensuing inflammation and pain provoke reflexive paraspinal muscle guarding, reducing both passive and voluntary ROM (Millis & Levine, 2014; Zink & Van Dyke, 2018). Over time, these issues may be compounded by soft tissue fibrosis and facet joint osteoarthritis, which further restrict mobility (Jeffery *et al.*, 2013).

When spinal nerve roots are compressed, motor dysfunction and disuse contribute to measurable muscle atrophy and asymmetry, which is evidenced by reduced cross-sectional area of paraspinal stabilizers on imaging (Henderson *et al.*, 2015). This weakening undermines segmental spinal stability and can promote compensatory overuse of adjacent structures, contributing to postural changes and gait alterations (Zink & Van Dyke, 2018). In biomechanical terms, IVDD-induced degeneration alters spinal motion patterns. For example, in chondrodystrophic dogs with IVDD, increased spinal ROM and reduced stiffness have been observed compared to non-degenerated controls, which may predispose to further injury and musculoskeletal strain (Smolders *et al.*, 2012). Such adaptations can also lead to asymmetric loading, altered pelvic-limb kinematics, and chronic myofascial tension, particularly in active or working animals (Millis & Levine, 2014).

Given the multifactorial impact of SCI on joint mobility - encompassing neurological hyperactivity, structural restrictions, and compensatory adaptations - objective measurement tools are essential for clinical evaluation. In this context, goniometry serves as a fundamental tool in the clinical management of SCI (Cikajlo *et al.*, 2003). As demonstrated by Bittar *et al.* (2024), in a human medicine study following patients with SCI, goniometry enables clinicians to detect motion limitations and monitor changes over time, which is especially critical in populations with evolving neurological and musculoskeletal presentations. The study emphasized the clinical utility of goniometric assessments in distinguishing between functional impairments caused by neurological deficits versus those arising from structural or orthopedic conditions (Bittar *et al.*, 2024). Furthermore, the integration of goniometric data with other clinical findings, such as muscle strength grading and sensory mapping, contributes to a more comprehensive understanding of each patient's functional status and rehabilitation potential (Maynard *et al.*, 1997; Mazurek & Shin, 2001). Thus, goniometry remains a cornerstone of functional evaluation in SCI care, particularly in settings where advanced imaging or digital tools may not be available.

2. MEASUREMENT INSTRUMENTS

Although various instruments exist for measuring joint motion, the universal goniometer is by far the most commonly used in clinical practice due to its versatility, low cost, widespread availability, and ease of use (Norkin & White, 2017).

Constructed from either plastic or metal and available in various sizes, the universal goniometer always follows a basic design, which includes a body, similar in shape to a protractor, and two narrow ruler-like extensions, known as arms (Cole, 1990; Queiroga, 2005; Araújo *et al.*, 2009; Norkin & White, 2017). The body of the instrument may be semicircular or circular in shape. Measurement scales may be present on one or both sides of the body, typically ranging from 0 to 180 degrees for semicircular or circular designs, and up to 360 degrees in full-circle goniometers. The scale intervals can vary between 1 and 10 degrees, depending on the model (Cole, 1990; Norkin & White, 2017).

Traditionally, the goniometer features a stationary arm, fixed to the body of the instrument, and a movable arm, which is attached to the center of the body by a pivot that allows free rotational movement. The length of the arms can range from 2 cm to 40 cm, reflecting efforts by manufacturers to adapt the instrument to the size of different joints (Norkin & White, 2017).

3. OBTAINING MEASUREMENTS AND GONIOMETER ALIGNMENT

Goniometer alignment refers to the positioning of the instrument's arms in relation to the proximal and distal segments of the joint being assessed. As a general rule, the stationary arm of the goniometer should be aligned parallel to the longitudinal axis of the proximal joint segment, while the movable arm should be aligned similarly with the distal segment. To increase the accuracy and reliability of the measurements, bony anatomical landmarks should be used as reference points. Additionally, the central axis (fulcrum) of the goniometer should be positioned over the approximate axis of rotation of the joint being measured (Queiroga, 2005; Norkin & White, 2017).

The following principles for obtaining goniometric measurements in companion animals were described by Jaegger *et al.* (2002) in a study conducted on Labrador Retrievers:

- Shoulder flexion (Figure 5A.) and extension (Figure 5B.) were determined by measuring the angle between the spine of the scapula and the longitudinal axis of the humerus.
- Elbow flexion (Figure 6A.) and extension (Figure 6B.) were measured by assessing the angle between the longitudinal axis of the forearm and the longitudinal axis of the humerus, defined by a line drawn from the lateral epicondyle of the humerus to the insertion point of the infraspinatus muscle on the greater tubercle of the humerus.
- For the carpus, flexion (Figure 7A.) and extension (Figure 7B.) were measured by the angle formed between the longitudinal axis of the fourth metacarpal bone and the longitudinal axis of the forearm, using a line from the styloid process of the ulna to the lateral epicondyle of the humerus.
- In the hind limb, hip flexion (Figure 8A.) and extension (Figure 8B.) were evaluated by measuring the angle between the longitudinal axis of the femur (from the lateral femoral epicondyle to the greater trochanter) and the line connecting the sacral and ischiatic tuberosities.
- Stifle (knee) flexion (Figure 9A.) and extension (Figure 9B.) were assessed by measuring the angle between the longitudinal axes of the tibia and femur.

- Tarsal (hock) flexion (Figure 10A.) and extension (Figure 10B.) were determined by measuring the angle between the longitudinal axis of the third and fourth metatarsal bones and the tibial axis.

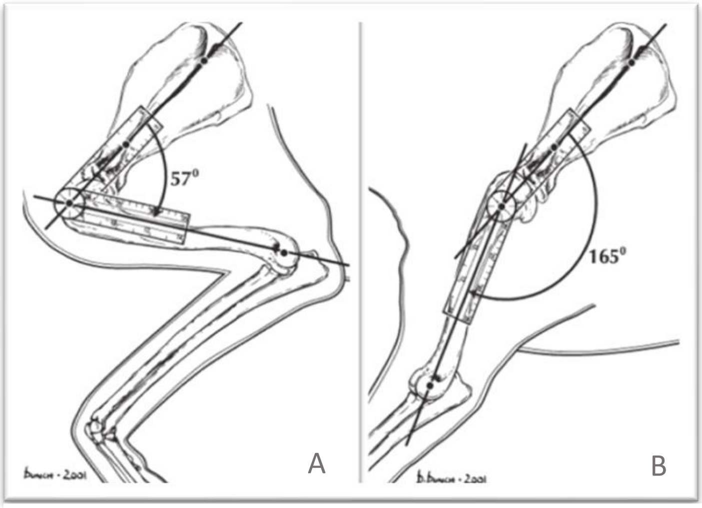

Figure 5. Goniometric evaluation of the shoulder joint of a canine in flexion (A) and extension (B) positions. (Adapted from Jaegger *et al*., 2002).

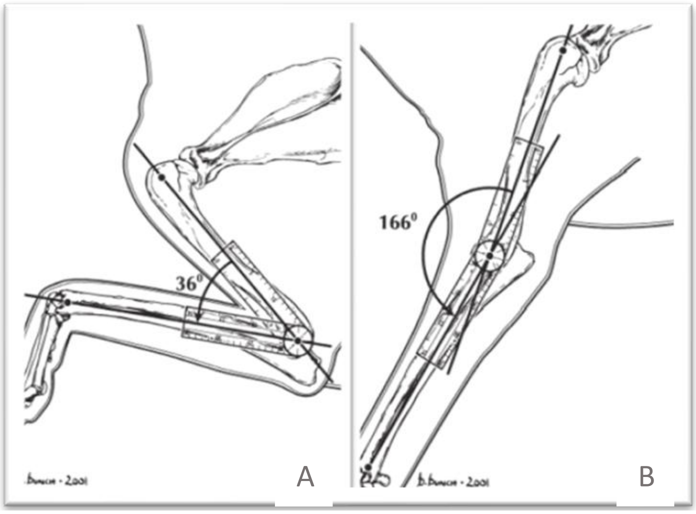

Figure 6. Goniometric evaluation of the elbow joint of a canine in flexion (A) and extension (B) positions. (Adapted from Jaegger *et al*., 2002).

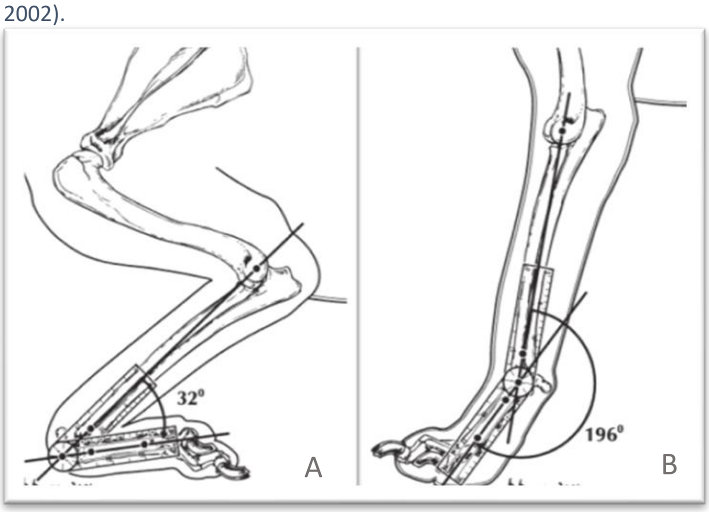

Figure 7. Goniometric evaluation of the carpal joint of a canine in flexion (A) and extension (B) positions. (Adapted from Jaegger *et al*., 2002).

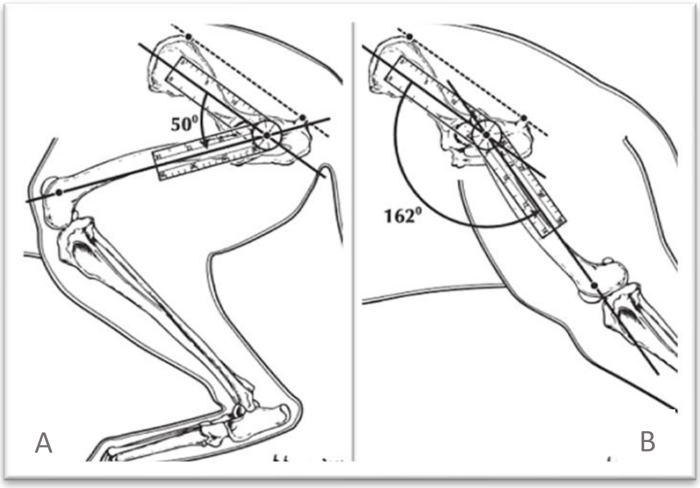

Figure 8. Goniometric evaluation of the hip joint of a canine in flexion (A) and extension (B) positions. (Adapted from Jaegger *et al*., 2002).

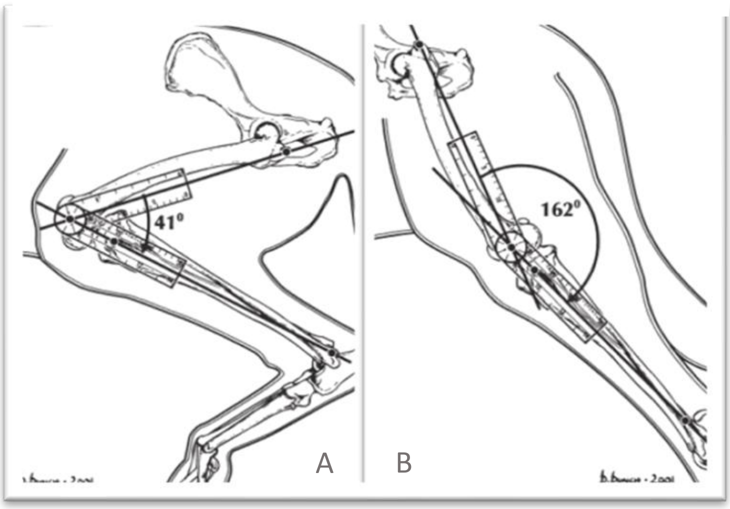

Figure 9. Goniometric evaluation of the stifle joint of a canine in flexion (A) and extension (B) positions. (Adapted from Jaegger *et al*., 2002).

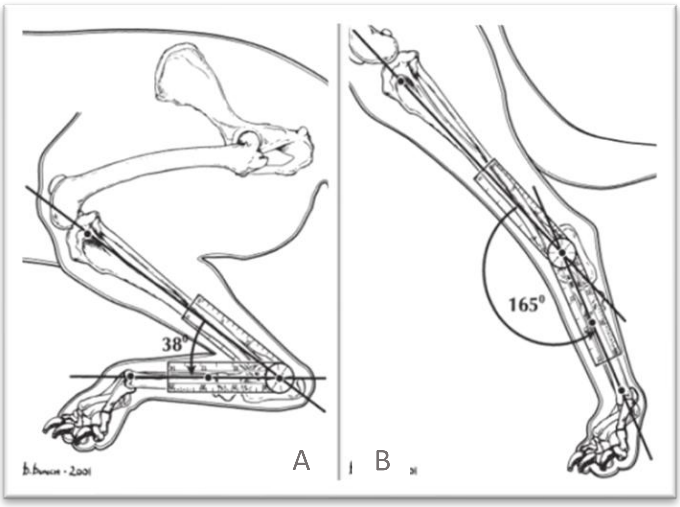

Figure 10. Goniometric evaluation of the tarsal joint of a canine in flexion (A) and extension (B) positions. (Adapted from Jaegger *et al*., 2002).

4. OVERVIEW OF THE EXISTING VETERINARY MEDICAL LITERATURE

Currently, normal joint mobility angles have been reported for Labrador Retrievers (Jaegger *et al.*, 2002) and cats (Jaeger *et al.*, 2007). These studies also reported excellent intra and inter-tester reliability, as well as strong correlations with measurements obtained through radiographic examinations. Furthermore, studies conducted in dogs, cats, and sheep demonstrated that measurements obtained with or without sedation were both valid and reliable (Jaegger *et al.*, 2002; Jaeger *et al.*, 2007; Mendonça (2009); Govoni *et al.*, 2012; Machado *et al.*, 2020). A study conducted on horses in 2010 by Liljebrink & Bergh also reported high to excellent intra-tester reliability when measuring the passive flexion of the forelimb fetlock, carpus and hock.

In 2004 Benson and colleagues compared joint angles between two dog breeds: Basset Hounds and Irish Wolfhounds. The findings revealed considerable variability between the values of both breeds, leading to the conclusion that a universal reference chart for normal joint angle values may not be applicable across different breeds. This highlights the need to publish ROM measurements across a variety of canine breeds (Thomovsky *et al.*, 2016). Additionally, in 2020, Reusing *et al.* compared joint motion values obtained through goniometry in chondrodystrophic and non-chondrodystrophic dogs of various sizes, concluding that statistically significant differences were observed both between chondrodystrophic and non-chondrodystrophic breeds, as well as across different size categories (miniature, small, medium, large, and giant).

Thomas *et al.* (2006) conducted a study aiming to establish joint motion values in German Shepherds and to compare them with those validated for Labradors. They also assessed the reliability of using an electrogoniometer versus a universal goniometer. The study concluded that joint motion values were largely similar between the two breeds, except for the tarsal joint, which showed significantly lower values in German Shepherds. Moreover, the universal goniometer was found to be the more reliable measurement tool in dogs.

In 2009, Mendonça obtained goniometric measurements in Rottweilers. However, due to the small sample size, the authors emphasized the need for further studies involving a greater number of animals to validate the results. Similarly, in 2020, Machado *et al.* conducted a goniometric study on small mixed-breed dogs. Nonetheless, the lack of consistent breed standards and defined anatomical features in these animals made it impossible to standardize the measurements obtained.

In 2016, Thomovsky *et al.* carried out a goniometric and perimetric study of the hindlimbs in miniature Dachshunds with varying degrees of neurological dysfunction. This study concluded that, due to the unique pelvic morphology and muscle distribution in this breed, obtaining such measurements poses particular challenges. Additionally, when comparing the three groups tested - ambulatory paraparesis, non-ambulatory paraparesis, and paraplegia - no significant differences were detected in the values obtained within 24 hours of the onset of acute neurological signs. Still, the need for reference measurements from healthy individuals exists, and is of critical importance.

A study conducted on French Bulldogs by Formenton *et al.* (2019) compared their data with previously reported values for Labrador Retrievers, cats, and miniature Dachshunds with neurological dysfunction. This study did not identify statistically significant differences among these groups. However, these findings appear to contradict the conclusions of Benson *et al.* (2004) and Reusing *et al.* (2020), who reported significant differences between chondrodystrophic and non-chondrodystrophic breeds, as well as between dogs of different size categories.

CHAPTER III – GONIOMETRIC ASSESMENT IN HEALTHY MINIATURE DACHSHUNDS

1. OBJECTIVES

Throughout the course of this work, a deeper understanding of the unique genotype of the Dachshund and its phenotypic consequences was gained, as well as regarding the severe pathologies to which this breed is predisposed, most notably IVDD, and the resulting negative impact on their QOL. These health challenges contribute to the Dachshund being one of the most frequently referred dog breeds for veterinary physiotherapy and rehabilitation, making them among the most observed patients within this clinical field (O'Neill *et al.*, 2023).

Given the clear and continuing trend of increasing popularity of this breed (Teng *et al.*, 2016; Anderson, 2021; Pinelllo *et al.*, 2025), it is reasonable to anticipate that veterinary professionals will encounter Dachshunds and their associated health issues with growing frequency in clinical practice.

As discussed in previous sections, goniometry remains one of the most objective, straightforward, and widely used methods in veterinary rehabilitation (Alievi *et al.*, 2004). However, there is a notable lack of literature regarding breed-specific joint ROM values, particularly for the miniature Dachshund, despite the well-documented need for breed-specific clinical data in this context (Benson *et al.*, 2004; Reusing *et al.*, 2020).

In this regard, the main objective of the present study was to develop a reference table of joint ROM values for healthy miniature Dachshunds, with the aim of providing a clinically useful tool that can be applied in veterinary practice.

1.1. General objective

The present study aimed to obtain and standardize the angular values of flexion and extension of the shoulder, elbow, carpal, hip, stifle, and tarsal joints in healthy Miniature Dachshund dogs using a universal goniometer.

1.2. Secondary objectives

- Comparison of joint ROM angles between male and female dogs.
- Comparison of the results obtained with the validated values for Labrador Retrievers (Jaegger *et al.*, 2002).
- Comparison of the results obtained with those published in Miniature Dachshunds with neurological dysfunction (Thomovsky *et al.*, 2016).

2. MATERIALS AND METHODS

2.1. Sample characterization

A total of 16 Miniature Dachshund dogs were included in the study, all of which participated voluntarily in the project conducted at Anicura Restelo Veterinary Center – Veterinary Physiotherapy. The participants were recruited through a social media survey and signed consent forms explaining the nature of the study, its objectives, and highlighting that no invasive or painful procedure would be conducted. The project was approved by UTAD's ethics committee, ref. 106-CE-UTAD-2024.

The mean age of the animals was 4 years and 6 months, ranging from 1 to 10 years of age. The average body condition score (BCS), based on a 9-point scale, was 5.25/9, with individual scores ranging from 4/9 to 7/9. Of the dogs included in the study, 9 were females, all of which had been surgically sterilized, and 7 were males, of which 3 were neutered and 4 remained intact. Regarding coat type, short smooth hair was by far the most common, observed in 12 of the 16 dogs. Additionally, 2 dogs had long hair and 2 had wire-haired coats.

Inclusion criteria required that animals had no history of lameness or orthopedic trauma and exhibited normal findings on both orthopedic and neurological examinations. Furthermore, no animals under the age of one year were included, as this is the age at which closure of the cartilaginous epiphyseal plate - indicating the end of bone growth - is generally considered to occur (Moore & Persaud, 2000).

Clinical evaluation was carried out in several stages: collection of the animal's medical history; standing inspection to assess muscle asymmetry, musculoskeletal deformities, and even weight distribution across limbs; gait inspection with special attention to signs of lameness; palpation of limb joints to confirm absence of crepitus, edema, instability, or pain; palpation of the spine and surrounding musculature, including careful manipulation of the cervical spine through its full ROM to ensure absence of pain; proprioceptive testing of all four limbs; and specific orthopedic tests such as the drawer test (Flo, 2000; Bennet & May, 2004).

2.2. Study design

Goniometric assessments were conducted with the dogs positioned on a comfortable surface on the floor in lateral recumbency. The choice to conduct the evaluation on the floor instead of an examination table took into account animal welfare and the management of stress levels, since most animals show markedly greater discomfort when examined on top of a table, compared to on a bed or blanket on the ground. The animals were manually restrained, and no sedation was required. A universal plastic goniometer with 15 cm arms, a 360-degree head and a 1º grading scale (MSD BAND) was used for all measurements.

Each dog was placed in lateral recumbency, and the flexion and extension angles of the non-weight-bearing limbs were measured at the shoulder, elbow, carpus, hip, stifle, and tarsus. All measurements were performed once per joint by a single examiner to ensure consistency. The dog was then repositioned onto the contralateral side, and the same procedure was repeated for the opposite limbs. To improve measurement accuracy, goniometric evaluations followed the anatomical landmarks and methods outlined by Jaegger et al. (2002), as detailed in Chapter II, Section 3.

2.3. Statistical analysis

All statistical analyses were conducted using GraphPad software version 10.4.2. Descriptive statistics, including mean, standard deviation (SD), standard error of the mean (SEM), confidence interval of the mean (CI) and median values, were calculated for joint flexion and extension angles. Paired t-tests were used to compare the mean and median flexion and extension angles between the right and left limbs. As no statistically significant differences were observed between sides ($p < 0.05$), each limb was subsequently treated as an independent variable in further analyses (for example, shoulder extension of the left limb of Dog 1 was considered a separate variable from the right limb).

Comparisons of joint flexion and extension angles between male and female dogs were conducted using unpaired t-tests with Welch's correction to account for unequal variances. The same statistical test was applied to compare our data with published results for Labrador Retrievers (Jaegger *et al.*, 2002) and Finnish miniature Dachshunds diagnosed with neurologic dysfunction (Thomovsky *et al.*, 2016). Statistical significance was set at $p < 0.05$.

Joint angle comparisons were performed for the shoulder, elbow, carpus, hip, stifle, and tarsus, in both flexion and extension. "The sample size of animals was decided using the free software Sample Size Calculator (ClinCalc.com, Chicago, IL, USA, https://clincalc.com/stats/samplesize.aspx, accessed on 02 February 2025) based on a power of 95%, a significance level of 0.05, and an estimated effect size of 4-6, derived from preliminary data published in another dog breed "Reliability of goniometry in Labrador Retrievers." doi: 10.2460/ajvr.2002.63.979. PMID: 12118679.

3. RESULTS AND DISCUSSION

The median and mean flexion and extension angles for the shoulder, elbow, carpus, hip, stifle, and tarsus are presented in Table 7. The greatest variability in flexion angles was observed at the shoulder, with mean values ranging from 34,3° to 42,1°, whereas the least variability was noted at the carpus, with mean values between 10,1° and 12,3°. For extension, the greatest variation occurred at the stifle, where mean values ranged from 158,8° to 163,2°, while the smallest difference was observed at the carpus, with mean values between 195,2° and 197,6°.

Our results show that the carpal joint had the least variability in both flexion and extension measurements. This may reflect anatomical or biomechanical differences between thoracic and pelvic limb joints or could also suggest a greater ease in identifying reliable anatomical landmarks in the carpus, as compared to more proximal joints, particularly in breeds with shorter limbs or more musculoskeletal mass obscuring joint structures (Thomovsky *et al.*, 2016; Brown *et al.*, 2017).

Table 7. Median and mean (with standard deviation) flexion and extension angles of thoracic and pelvic limb joints measured by Goniometry in miniature Dachshunds.

Joint	***Position***	***Mean***	***SD***	***95% CI of the Mean***	***Median***
Shoulder	Flexion	38,2º	10,75	34,3º - 42,1º	39,5º
	Extension	156,9º	4,45	155,3º - 158,5º	158,0º
Elbow	Flexion	34,4º	6,77	31,9º - 36,8º	34,5º
	Extension	157,9º	5,92	155,8º - 160,1º	160,0º
Carpus	Flexion	11,2º	2,98	10,1º - 12,3º	10,0º
	Extension	196,4º	3,38	195,2º - 197,6º	195,5º
Hip	Flexion	48,8º	4,06	47,3º - 50,2º	49,0º
	Extension	159,1º	5,17	157,3º - 161,0º	160,0º
Stifle	Flexion	40,1º	3,70	38,7º - 41,4º	40,0º
	Extension	161,0º	6,05	158,8º - 163,2º	162,0º
Tarsus	Flexion	38,2º	4,32	36,7º - 39,8º	38,5º
	Extension	162,7º	4,57	161,0º - 164,3º	165,0º

3.1. Comparative study between goniometric measurements obtained in male and female miniature Dachshunds

Comparisons of joint flexion and extension angles between male and female dogs were performed using unpaired t-tests with Welch's correction to account for unequal variances. No statistically significant differences were observed in any of the evaluated joints for either flexion or extension. These results can be observed in Figures 11 to 14.

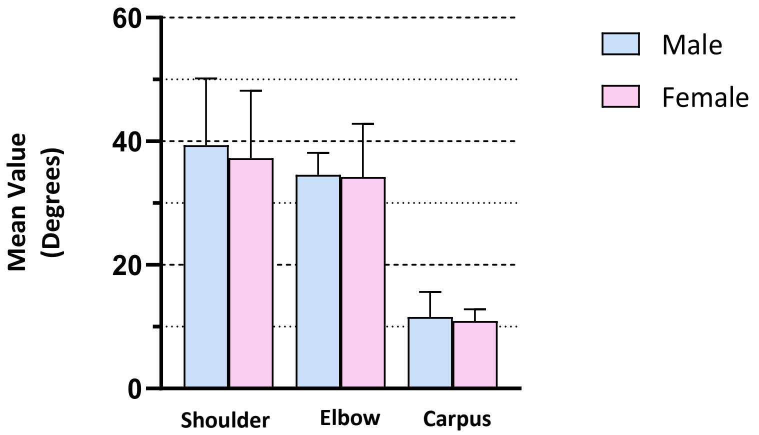

Figure 11. Mean value and SD (degrees) of thoracic limb joints (shoulder, elbow, carpus) flexion angles in males and females.

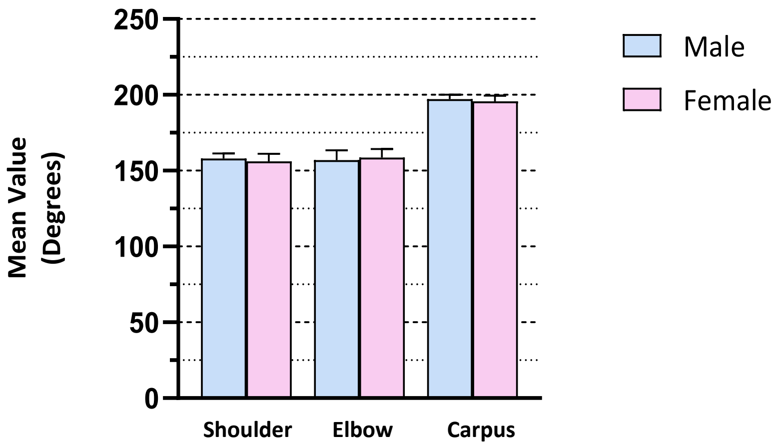

Figure 12. Mean value and SD (degrees) of thoracic limb joints (shoulder, elbow, carpus) extension angles in males and females.

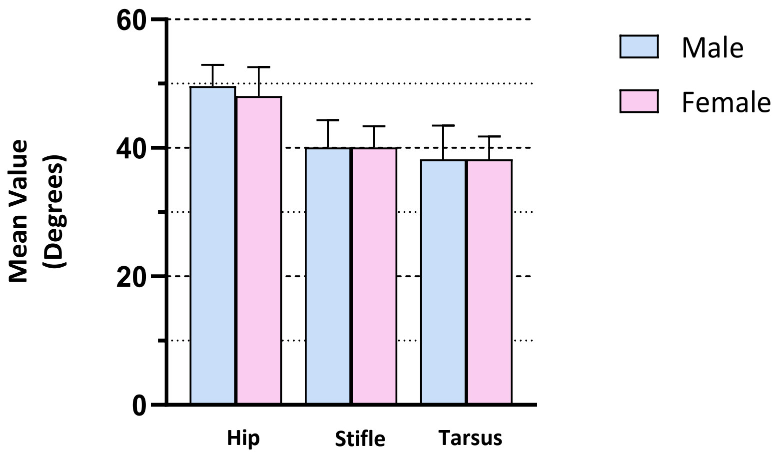

Figure 13. Mean value and SD (degrees) of pelvic limb joints (hip, stifle, tarsus) flexion angles in males and females.

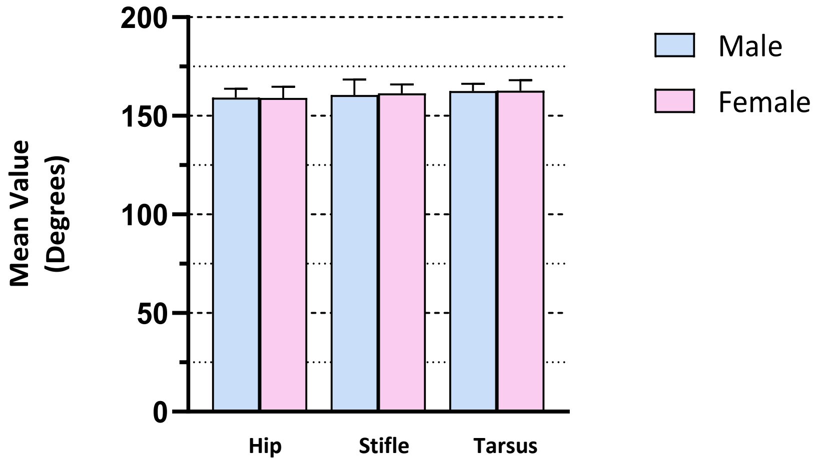

Figure 14. Mean value and SD (degrees) of pelvic limb joints (hip, stifle, tarsus) extension angles in males and females.

Regarding human medicine, numerous studies and clinical assessments have shown that women generally exhibit greater joint flexibility and a wider ROM compared to men across most joints. This difference is most pronounced in movements involving the hips, shoulders, wrists, and spine (Alter, 2004; Hwang & Jung, 2015; Czuppon *et al.,* 2017).

Hormonal influences, particularly the effects of estrogen, are thought to increase ligament laxity, which enhances joint mobility in women (Hoge et al., 2010). Anatomical differences such as relatively wider pelvic morphology and lower muscle mass also contribute to increased flexibility and spinal extension in females (Nigg & Herzog, 1999). For example, in asymptomatic college athletes, females demonstrate significantly greater hip flexion, internal rotation, and external rotation compared to their male counterparts (Czuppon *et al.,* 2017). Similar trends are seen in shoulder abduction and external rotation, where women consistently outperform men in range of motion assessments (Hwang & Jung, 2015).

In veterinary medicine, evidence regarding sex-related differences in joint ROM and flexibility is limited but emerging. Most available data suggest that, unlike in human populations, sex does not consistently produce significant differences in joint angles in dogs. In a master's thesis evaluating Rottweilers, Mendonça (2009) reported that while females showed slightly greater mean ROM in certain joints, these differences were not statistically significant in most cases. One potential explanation for the reduced impact of sex on ROM in dogs, compared to humans, may relate to anatomical and hormonal differences between species. In dogs, joint mobility appears to be more strongly influenced by breed conformation, limb length, and size, rather than by sex-specific hormonal profiles (Millis & Levine, 2014; Reusing *et al.*, 2020). Thus, while subtle trends may exist, such as females occasionally showing marginally greater flexibility, the current consensus in veterinary literature suggests that sex alone is not a reliable predictor of goniometric ROM differences in clinically healthy dogs. The results obtained in this work are in accordance with this.

3.2. Comparative study between goniometric measurements obtained in miniature Dachshunds and Labrador Retrievers

Unpaired t-tests with Welch's correction were utilized to compare our data to the goniometric values reported by Jaegger *et al.* (2002) in Labrador Retrievers. Our hypothesis was that joint angles would differ significantly, based on three primary considerations: the pronounced anatomical and conformational differences between Labrador Retrievers and chondrodystrophic breeds such as the miniature Dachshund; previous work by Benson *et al.* (2004), which demonstrated significant joint angle differences between Irish Wolfhounds and Basset Hounds, representing non-chondrodystrophic and chondrodystrophic extremes, respectively; and previous work by Reusing et el. (2020), who reported significant different in joint ROM angles between dogs of chondrodystrophic and non-chondrodystrophic breeds, as well as between size categories.

Statistically significant differences were observed for shoulder flexion ($p < 0.0001$), shoulder extension ($p < 0.0001$), elbow extension ($p < 0.0001$), carpus flexion ($p < 0.0001$), hip extension ($p = 0.0182$), and stifle flexion ($p = 0.0228$). In contrast, elbow flexion, carpus extension, hip flexion, stifle extension, and both flexion and extension of the tarsus did not differ significantly. These results can be observed in Figures 15 to 18.

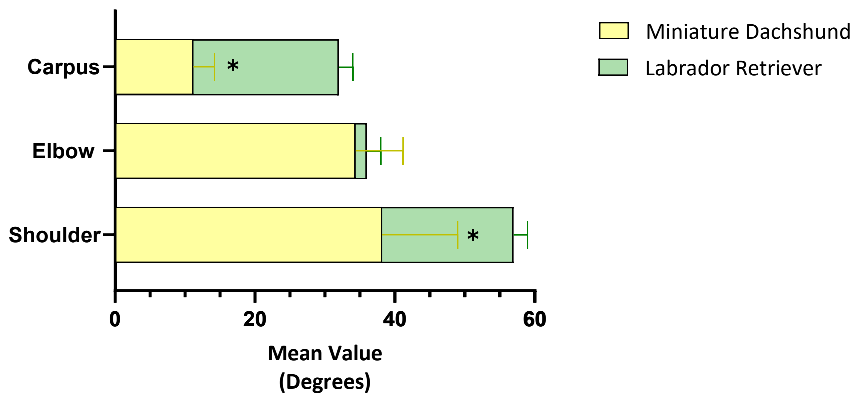

Figure 15. Comparison of mean value (degrees) and SD of thoracic limb joints (shoulder, elbow, carpus) flexion angles between Miniature Dachshunds and Labrador Retrievers. * Statistical difference ($p < 0.05$).

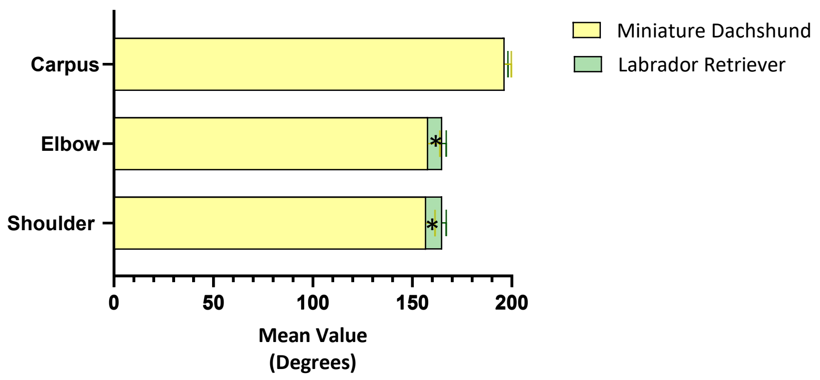

Figure 16. Comparison of mean value (degrees) and SD of thoracic limb joints (shoulder, elbow, carpus) extension angles between Miniature Dachshunds and Labrador Retrievers. * Statistical difference ($p < 0.05$).

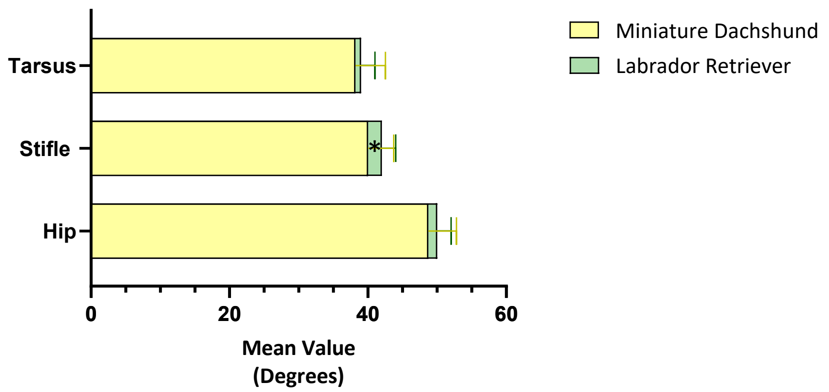

Figure 17. Comparison of mean value (degrees) and SD of pelvic limb joints (hip, stifle, tarsus) flexion angles between Miniature Dachshunds and Labrador Retrievers. * Statistical difference ($p < 0.05$).

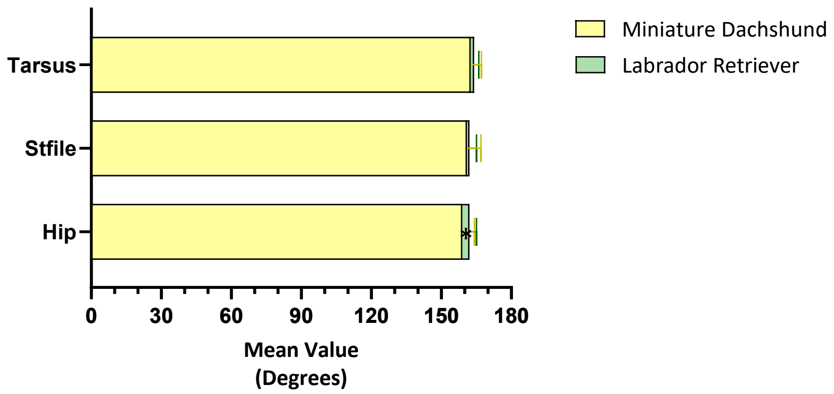

Figure 18. Comparison of mean value (degrees) and SD of pelvic limb joints (hip, stifle, tarsus) extension angles between Miniature Dachshunds and Labrador Retrievers. * Statistical difference ($p < 0.05$).

These results are consistent with our initial hypothesis that joint angle values would differ significantly between our study population of healthy chondrodystrophic dogs (miniature Dachshunds) and the non-chondrodystrophic Labrador Retrievers evaluated by Jaegger *et al.* (2002). This hypothesis is supported by previous literature highlighting substantial anatomical and functional differences between chondrodystrophic and non-chondrodystrophic breeds.

Chondrodystrophic dogs such as Dachshunds exhibit early physeal closure due to overexpression of FGF4 retrogenes, resulting in shortened long bones, disproportionate limb conformation, and often exaggerated joint angulations (Parker *et al.*, 2009; Brown *et al.*, 2017). This results in altered joint geometry and restricted ranges in some movements, while potentially exaggerating others due to compensatory mechanisms or structural alterations (Reusing *et al.*, 2020). For instance, exaggerated limb torsion and carpal valgus common in chondrodystrophic breeds may increase flexibility in some joints while restricting it in others (Reusing *et al.*, 2020).

Shoulder and elbow angles are influenced by scapular orientation, humeral length, and thoracic limb alignment. In Dachshunds, the shortened humerus and altered scapular positioning relative to the ribcage likely increase the excursion necessary for limb function, leading to larger flexion and smaller extension angles compared to Labradors (Millis & Levine, 2014). Similarly, greater carpal flexion in Dachshunds may be a consequence of increased limb angulation or compensatory hypermobility at the distal joints, which is commonly observed in chondrodystrophic breeds and has been linked to increased joint laxity (Reusing *et al.*, 2020).

Significant differences in hip extension and stifle flexion further support the notion that breed-specific limb morphology affects joint mobility. Dachshunds typically exhibit higher pelvic limb muscle mass and a different pelvic orientation, which may reduce the capacity for hip extension compared to longer-limbed breeds like Labradors (Jaegger *et al.*, 2002; Reusing *et al.*, 2020).

However, not all joint measurements differed significantly. Elbow flexion, carpus extension, hip flexion, stifle extension, and both tarsus flexion and extension showed no statistically significant differences between the two groups. Several explanations may account for this. First, these joint angles may be less sensitive to skeletal conformational differences, especially in the absence of neurologic or orthopedic pathology. For example, elbow flexion and carpal extension are often constrained by soft tissue tension and joint capsule integrity, which may not vary dramatically between breeds despite differences in limb proportion (Millis & Levine, 2014; De Lahunta *et al.*, 2020).

Second, measurement consistency and methodology may play a role. Jaegger *et al.* (2002) demonstrated high intra-observer reliability in goniometric measurements in Labrador Retrievers. If both studies used similarly rigorous measurement protocols with experienced observers, it is possible that true inter-breed differences in these specific angles are minimal and fall within normal physiological variation. However, the study protocol, although similar, was not completely identical.

Third, functional demands on joints such as the stifle and tarsus during locomotion may naturally constrain their passive range across breeds. The stifle, in particular, must remain relatively stable for weight-bearing and propulsion; therefore, its extension angle may be conserved to maintain gait efficiency (Sabanci & Ocal, 2016).

Additionally, while Dachshunds are chondrodystrophic, they may not exhibit extreme deviations at all joints. For example, Reusing *et al.* (2020) found that despite differences in shoulder, elbow, and carpal angles, ROM values at the stifle and tarsus often overlapped between chondrodystrophic and non-chondrodystrophic dogs, particularly in small-to-medium size categories.

Finally, biological variability within and across studies, even in controlled environments, can limit the ability to detect differences in more functionally constrained joints. This includes factors such as slight differences in limb positioning, examiner technique, or subject compliance during measurements.

3.3. Comparative study between goniometric measurements obtained in miniature Dachshunds and miniature Dachshunds with neurological disorders

Unpaired t-tests with Welch's correction were utilized to compare our data to that reported by Thomovsky *et al.* (2016) in a goniometric study of the hindlimb joints of miniature Dachshunds with neurological disorders. Our hypothesis was that our values with be significantly different, since our study population consisted of only healthy dogs. Significant statistical difference was achieved for hip flexion ($p=0.0017$), hip extension ($p<0.0001$), stifle flexion ($p<0.0001$) and tarsus extension ($p<0.0001$). In contrast, no significant differences were detected in stifle extension or tarsus flexion. These results can be observed in Figures 19 and 20.

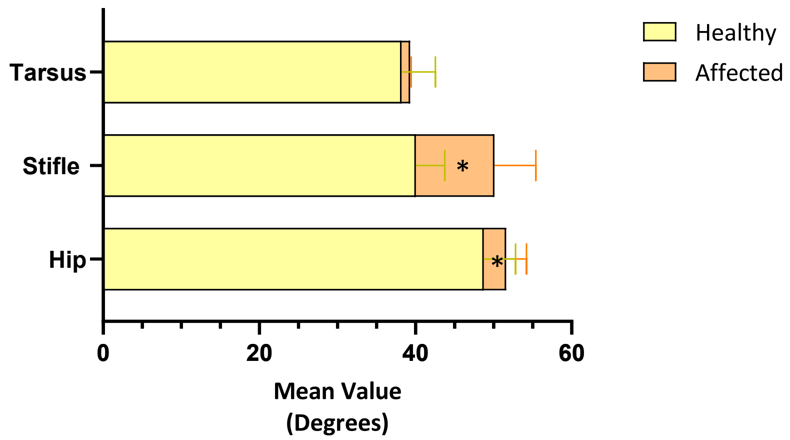

Figure 19. Comparison of mean value (degrees) and SD of pelvic limb joints (hip, stifle, tarsus) flexion angles between healthy Miniature Dachshunds and Miniature Dachshunds affected with neurological disorder. * Statistical difference ($p < 0.05$).

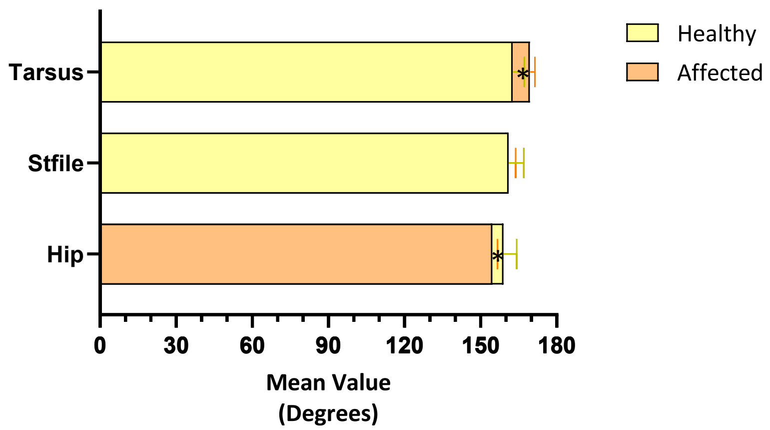

Figure 20. Comparison of mean value (degrees) and SD of pelvic limb joints (hip, stifle, tarsus) extension angles between healthy Miniature Dachshunds and Miniature Dachshunds affected with neurological disorder. * Statistical difference ($p < 0.05$).

The findings in our study differ in several respects from those reported in a previous study conducted on miniature Dachshunds with neurologic disorders, evaluating only the hindlimb, where it was observed that measurements at the tarsus demonstrated less variability than those at the hip or stifle joints (Thomovsky *et al.*, 2016). When comparing joint movement angles from only the hindlimb in our study, no great variability was found between the measurements taken in each joint. Despite this fact, the greatest variability in flexion was observed at the tarsal joint (mean value of 36,7º to 39,8º) and the smallest variation occurred at the hip (mean value of 47,3º to 50,2º). Extension angles varied the most at the stifle joint (mean value of 158,8º to 163,2º) and the least at the tarsus joint (mean value of 161,0º to 164,3º). These results are presented in Table 7.

Thomovsky *et al.* (2016) suggested that the reduced variability at the tarsus could be due to clearer anatomical landmarks and reduced interference from surrounding musculature, particularly when compared to the more complex morphology of the pelvic limbs in this chondrodystrophic breed. Furthermore, the prior study reported challenges in consistently palpating bony landmarks in the Dachshund's pelvic limb, possibly contributing to higher variability in hip and stifle measurements.

Our study did not include neurologically compromised dogs, and thus our findings reflect baseline joint mobility in a neurologically normal population. This distinction may further explain differences in variability and measurement reliability between our work and the study published in 2016 by Thomovsky *et al*. This might reflect the fact that in neurologically normal dogs, the tarsus may naturally exhibit a wider range of passive flexion due to reduced soft tissue resistance or greater mechanical freedom, whereas in dogs with neurologic dysfunction, compensatory stiffness, muscle hypertonicity, or reduced use may limit this range, thereby reducing variability at the tarsus (Jaegger *et al.*, 2002; Millis & Levine, 2014; Thomovsky *et al.*, 2016).

Moreover, our data suggests that significant differences are present between healthy miniature Dachshunds and those suffering from neurological disorders, achieving statistical significance in hip flexion and extension, stifle flexion and tarsus extension.

These findings support our original hypothesis that joint angles in neurologically normal dogs would differ from those in neurologically affected Dachshunds. Several physiological and anatomical factors likely account for these differences. Neurological disorders, particularly those involving spinal cord injury or compression, are known to result in altered muscle tone, proprioceptive deficits, and impaired neuromuscular control, all of which can influence passive joint ROM (Millis & Levine, 2014; De Lahunta *et al.*, 2020). However, it is important to clarify that in the acute phase of an UMN lesion, particularly within the first 24 hours after injury, spinal shock may occur, leading to a transient reduction in muscle tone and reflexes (Bagley, 2010; De Lahunta *et al.*, 2020). This period of hypotonia could increase passive joint mobility rather than restrict it. Once spinal shock resolves, increased muscle tone and spasticity, classic signs of UMN injury typically develop and may limit joint movement.

The hip joint is particularly susceptible to changes in neuromuscular tone due to its deep musculature and proximity to UMN pathways. Increased tone in the iliopsoas, gluteal, or hamstring muscle groups, once it develops, can significantly reduce hip flexion and extension range in dogs with UMN dysfunction (Millis & Levine, 2014). Similarly, the stifle joint is surrounded by complex muscle groups (quadriceps, gastrocnemius, hamstrings), which can respond rapidly to neurologic injury through changes in tone, thus influencing flexion (De Lahunta *et al.*, 2020). The tarsus is influenced by the gastrocnemius and cranial tibial muscles, which are innervated by nerves often affected in thoracolumbar spinal lesions, potentially explaining the significant differences seen in tarsal extension (Thomovsky *et al.*, 2016). These statistically significant findings raised the question of how such differences may be applied in the clinical management of IVDD, particularly in rehabilitation settings.

Interestingly, stifle extension and tarsus flexion did not differ significantly between groups. Several factors could explain this. Biologically, it is possible that these specific joint movements are less influenced during the early stage of neurologic dysfunction, particularly if measurements were taken during spinal shock. For example, stifle extension relies heavily on the quadriceps femoris muscle, which may not yet be affected by spasticity or atrophy within 24 hours of acute onset (De Lahunta *et al.*, 2020). Similarly, tarsus flexion may be less sensitive to early neurological changes, or may be subject to a mechanical ceiling, beyond which additional tone or stiffness has minimal observable effect (De Lahunta *et al.*, 2020).

Another plausible explanation is measurement variability or observer error. While both studies followed a comparable goniometric protocol, Thomovsky *et al.* (2016) acknowledged the inherent challenges of landmark identification in chondrodystrophic breeds. In particular, the bony landmarks of the pelvic limb in miniature Dachshunds may be obscured by musculature or altered conformation, leading to reduced precision and potential variability, especially for complex joints like the stifle and tarsus (Thomovsky *et al.*, 2016). If this variability disproportionately affected these joints, it may have masked true differences or inflated variance, reducing statistical power.

Furthermore, although the clinical onset of paraparesis or paraplegia in the Thomovsky *et al.* (2016) study occurred within 24 hours of measurement, the underlying spinal pathology, such as intervertebral disc herniation or chronic degenerative changes, likely began developing subclinically days or weeks earlier. Even in the absence of overt neurologic signs, early spinal cord compression can cause subtle changes in muscle activation patterns, joint loading, and tone regulation (Jeffery *et al.*, 2013). Therefore, it is plausible that joint angle differences observed in the Dachshund population reflect not only the acute neurologic episode but also the early biomechanical consequences of underlying spinal cord disease.

3.3.1. Clinical relevance of goniometry in neurological patients

The results obtained in this study provide compelling evidence that goniometric measurements are sensitive to the functional impairments caused by IVDD, even within the first 24 hours of acute symptom onset. Statistically significant differences ($p < 0.0001$) were observed in almost all joint angles when comparing healthy miniature Dachshunds to those presenting with clinical signs of disc herniation. These findings support the hypothesis that goniometry can detect subtle biomechanical alterations associated with early neurological dysfunction, well before more obvious motor deficits or muscle atrophy become apparent. While often perceived as a tool restricted to orthopedic evaluation, goniometry has clear potential in the context of neurological rehabilitation, where ongoing, non-invasive assessment is essential for guiding therapeutic decisions and tracking recovery. This broader application aligns with practices in human rehabilitation medicine, where range of motion is routinely monitored to evaluate neurological recovery following spinal cord injury, stroke, or neuromuscular disorders (Andrews & Bohannon, 1989; Adams & Hicks, 2005; Yelnik et al., 2010; Bittar *et al.*, 2024). Therefore, the present study not only establishes breed-specific reference values but also underscores the role of goniometry as a practical, low-cost, and clinically valuable tool in managing neurologic disease in dogs.

3.4. Study limitations

For the characterization of the animals in the sample, a body condition scoring system was preferred over expressing weight in kilograms, with the aim of facilitating the extrapolation of the results to different breeds. Canine breeds can exhibit marked disparities in size, body conformation, and morphology, meaning that two dogs of the same weight may have significantly different body fat percentages (Laflamme, 1997). BCS provides a standardized assessment of body fat, aiding in more accurate comparisons between breeds (Laflamme, 1997). Thus, focusing on BCS rather than weight may allow researchers to extrapolate and compare data across breeds with greater precision.

This study was designed with a strong emphasis on animal welfare and comfort. To ensure good tolerance of the procedure by the subjects, it was decided that each joint would be measured only once, rather than multiple times. This consideration is particularly relevant given the typically anxious temperament of the breed and the inherent challenges in comfortably restraining small dogs. Repeating measurements could not only impose unnecessary stress on the animal but also compromise the reliability and quality of the data due to increased resistance or movement. While most goniometric studies in companion animals typically repeat measurements to reduce potential human error (Jaegger *et al.*, 2002; Jaeger *et al.*, 2007; Mendonça, 2009; Thomovsky *et al.*, 2016; Machado *et al.*, 2020), such repetition is often offset by assessing only two limbs per animal. In contrast, the present study prioritized a greater number of joint assessments across all limbs, relying on the well-documented intra-tester reliability of goniometry when performed by an experienced professional (Jaegger *et al.*, 2002; Jaeger *et al.*, 2007; Liljebrink & Bergh, 2010). Accordingly, all measurements were conducted by a single examiner with several years of experience in veterinary physiotherapy and rehabilitation, and in the use of goniometric techniques. The consistency provided by a single trained examiner may also help minimize stress in canine patients and supports technical uniformity across all evaluations (Jaegger *et al.*, 2002; Liljebrink & Bergh, 2010). Moreover, while the inclusion of multiple evaluators is generally encouraged to strengthen external validity, existing literature suggests that goniometric measurements performed by different experienced practitioners do not differ significantly (Jaegger *et al.*, 2002; Liljebrink & Bergh, 2010). The use of a single, experienced examiner in this study, therefore, not only ensured consistency in measurement technique but also likely reduced the stress experienced by the animals during the procedure.

Radiographic imaging was not performed, and while none of the animals showed clinical signs of pain or orthopedic abnormality, the presence of subclinical conditions such as early arthritis cannot be completely ruled out. Nonetheless, radiographic assessment of joint angles is uncommon in clinical physiotherapy settings and is not considered standard practice. Goniometric evaluation in lateral recumbency remains the method of choice in such contexts (Corfield *et al.*, 2007; Freund *et al.*, 2016; Formenton *et al.*, 2019). Although studies have shown that sedation does not significantly influence radiographic joint measurements in dogs (Jaegger *et al.*, 2002; Jaeger *et al.*, 2007), no sedation was used in this study, in order to maintain animal welfare, avoid introducing confounding variables, and because it was considered unnecessary for the procedure.

Finally, it should be noted that technical challenges are inherent in goniometric assessments of dogs with well-developed thoracic and pelvic limb musculature, as is characteristic of the Miniature Dachshund breed. Additionally, the lack of comparable studies focusing specifically on clinically healthy Miniature Dachshunds limits the ability to benchmark the results against breed-specific norms. Nonetheless, comparison with findings from other studies contributes to the overall reliability and interpretability of the data (Jaegger *et al.*, 2002; Thomovsky *et al.*, 2016).

4. CONCLUSION

This study proposes a reference value table for the assessment of joint mobility in healthy miniature Dachshund dogs, using goniometry, a simple method that is easily replicable in routine clinical practice.

The evaluation of mobility is particularly relevant in this breed, as its chondrodystrophic nature predisposes it to a range of lesions. Early identification of such conditions enables more effective intervention, particularly using non-invasive techniques such as physiotherapy and rehabilitation. Given the increasing popularity of the Dachshund breed, these topics assume even greater significance.

The study demonstrates that the reference table validated for the Labrador Retriever breed is not applicable to miniature Dachshunds supporting the need for breed-specific reference values in clinical and rehabilitative settings. Additionally, this study identified significant differences in joint angles between healthy miniature Dachshunds and those affected by IVDD, even within 24 hours of clinical onset. These findings support the application of goniometry beyond orthopedic cases, demonstrating its clinical relevance in neurological conditions such as IVDD, particularly for progress monitoring during rehabilitation.

Although the number of subjects used in the study, sixteen, may appear limited, it is consistent with sample sizes commonly reported in the literature. Similarly, the decision to conduct the evaluation using an isolated measurement for each joint, with the dog unsedated, is well supported by previous studies.

Further research is needed to determine whether each chondrodystrophic breed requires its own specific reference table, based on its unique anatomical characteristics, or whether these values may be applicable to breeds with similar traits. The data presented highlights the importance of incorporating objective, reproducible tools in individualized veterinary rehabilitation protocols, especially in predisposed breeds.

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