ESCOLA UNIVERSITÁRIA VASCO DA GAMA

MESTRADO INTEGRADO EM MEDICINA VETERINÁRIA

Artigo de revisão

PHYSIOTHERAPY AND PHYSICAL REHABILITATION TO IMPROVE THE MOBILITY AND FOR PAIN MANAGEMENT IN POSTOPERATIVE DOGS WITH THORACOLUMBAR INTERVERTEBRAL DISK EXTRUSION

Marine Gautier

Coimbra, (junho 2024)

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Artigo de revisão

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Underwater Treadmill (UWTM)

Transcutaneous Electrical Neurostimulation (TENS)

Neuromuscular Electrical Stimulation (NMES)

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Glial Fibrillary Acidic Protein (GFAP)

Mechanical Sensory Thresholds (MST)

Physiotherapy and physical rehabilitation to improve the mobility and for pain management in postoperative dogs with thoracolumbar intervertebral disk extrusion

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Resumo

A extrusão do disco intervertebral toracolombar é uma condição neurológica comum na medicina veterinária. Ela ocorre quando o núcleo pulposo se projeta, comprimindo a medula espinhal e causando uma variedade de sinais clínicos, tais como dor toracolombar, paraparesia ou até mesmo paraplegia. Alguns cães não conseguem recuperar totalmente apenas com tratamento médico e/ou cirúrgico, evidenciando os limites das opções de tratamento disponíveis. Portanto, vários estudos avaliam novas estratégias que possam melhorar a recuperação e maneio da dor em cães com extrusão de disco intervertebral toracolombar. Entre estas novas estratégias, protocolos de reabilitação e fisioterapia estão a ser cada vez mais descritos e recomendados na medicina veterinária. O objetivo desta revisão é apresentar as técnicas fisioterapêuticas mais utilizadas e suas aplicações na extrusão do disco intervertebral toracolombar após hemilaminectomia. Estas técnicas incluem crioterapia, massoterapia, exercícios passivos e ativos, hidroterapia, eletroestimulação, campo eletromagnético pulsado, fotobiomodulação e ultrassons. A crioterapia é comumente usada após a cirurgia devido aos seus efeitos analgésicos, redução do edema e diminuição do espasmo muscular. A massoterapia, por sua vez, alivia a dor, promove a recuperação muscular através do aumento do retorno venoso e linfático, melhora a somatestesia e induz o relaxamento. Os exercícios passivos, ativos e a hidroterapia estimulam os movimentos voluntários, a coordenação, a força muscular, a rigidez articular e a proprioceção. Já a eletroestimulação é eficaz para aumentar a força, o tónus e a reeducação muscular, além de controlar a dor e auxiliar na cicatrização de feridas. O campo eletromagnético pulsado contribui para a redução da lesão da medula espinal, melhora a proprioceção e a incisão da dor após a cirurgia. A fotobiomodulação, por sua vez, estimula a regeneração axonal, acelera a cicatrização de feridas, reduz a inflamação e controla a dor. Por fim, os ultrassons são úteis no tratamento de condições musculoesqueléticas, como espasmo muscular, contratura, dor e cicatrização de feridas). Cada técnica pode ser usada isoladamente ou em conjunto para combinar a eficiência dos diferentes métodos. Estas técnicas são aplicadas diariamente, uma ou várias vezes ao dia, durante várias semanas. A análise de artigos científicos publicados demonstra a eficácia destas técnicas, as quais são cada vez mais utilizadas na prática médica atual. Estas técnicas permitem a recuperação dos animais mais eficiente e em menos tempo. Contudo, algumas revisões apresentaram limitações, tais como utilização de amostras pequenas nos estudos e avaliação simultânea de vários parâmetros , o que pode resultar em resultados não significativos. Desta forma, torna-se necessário a realização de mais estudos nesta área para avançar na utilização de fisioterapia na medicina veterinária.

Palavras-chave: campo electromagnético pulsado, crioterapia, electrostimulação, extrusão do disco intervertebral toracolumbar, fisioterapia, fotobiomodulação, hidroterapia, massoterapia, medicina veterinária, ultrasom.

Abstract

Thoracolumbar intervertebral disc extrusion is a common neurological disease in veterinary medicine. It occurs when the nucleus pulposus protrudes, compressing the spinal cord and causing a variety of clinical signs, such as thoracolumbar pain, paraparesis or paraplegia. Some dogs cannot fully recover following just medical and/or surgical management, highlighting the limits of available treatments options. Therefore, several studies evaluate new strategies that can improve recovery and pain management in dogs with thoracolumbar intervertebral disk extrusion. Among these new strategies, rehabilitation and physiotherapy protocol are increasingly being described and recommended in veterinary medicine. The aim of this review is to present the most commonly used physiotherapy techniques and their applications in thoracolumbar intervertebral disk extrusion following hemilaminectomy. These techniques include cryotherapy, massage therapy, passive and active exercise, hydrotherapy, electrostimulation, pulsed electromagnetic field, photobiomodulation and ultrasound. Cryotherapy is commonly employed post-surgery due to its analgesic effects, reduction of edema, and muscle spasm alleviation. Massotherapy, on the other hand, helps alleviate pain promotes muscle recovery by enhancing venous and lymphatic return, improves somatosensory perception and induces relaxation. Passive and active exercises, along with hydrotherapy, facilitate voluntary movements, coordination, muscle strength, joint stiffness and proprioception. Electrostimulation is highly effective in increasing muscle strength, tone and re-education, while also aiding pain control and wound healing. Pulsed electromagnetic field therapy contributes to spinal cord injury reduction, improves proprioceptive placement, and decreases post-surgical pain. Photobiomodulation stimulates axonal regeneration, accelerates wound healing, reduces inflammation, and aids in pain management. Lastly, ultrasounds are useful in treating musculoskeletal conditions such as muscle spasm, contracture, pain, and wound healing. Each technique can be used alone or in synergy to combine efficiency of the different methods. All these techniques are applied daily, once or several times a day, for several weeks. The analysis of the published articles demonstrates the effectiveness of these techniques, which are increasingly prevalent in current medical practice. These technics allow for a more efficient recovery of animals and in less time. However, some reviews have limitations, such as very small samples and evaluate multiple parameters simultaneously, which can sometimes render the results non-significant. Further

studies need to be conducted in this area to advance the application of physiotherapy in veterinary medicine.

Key words: cryotherapy, electrostimulation, hydrotherapy, massotherapy, photobiomodulation, physiotherapy, pulsed electromagnetic field, thoracolumbar intervertebral disk extrusion, ultrasound, veterinary medicine.

1. INTRODUCTION

Intervertebral disk herniation is a common pathology in veterinary medicine (Moore, Early et Hettlich, 2016), drawing significant research attention over the years. With advancements in imaging technology and improved therapeutic approaches, the treatment of herniated discs in dogs has notably improved (Albertini et al., 2023). Clinical manifestations vary widely, ranging from simple pain to complete paralysis of the affected animal (Hébert et Bulliot, 2018). The efficacy of treatment, whether medical or surgical, is measured by the restoration of limb functionality in cases with neurological deficits and the effective management of pain (Olby et al., 2020). Complications such as joint ankylosis, severe muscle contractures and amyotrophy can impede the animal's ability to return to normal activities, highlighting the importance of comprehensive management strategies (Henea et al., 2023).

In human medicine, functional rehabilitation is widely employed for disc herniation. However, in veterinary medicine, its application is not consistently recommended, despite its increasing use in recent years (Lewis, Granger et Jeffery, 2020). Functional rehabilitation aims to restore functions post-injury or disease, facilitating better and faster motor and sensory functions recovery, accelerating wound healing and improving quality of life through pain management and incontinence control (Lewis, Jeffery et Olby, 2020). This involves utilizing both manual techniques such as thermotherapy, massage therapy, kinesitherapy, and hydrotherapy, and instrumental techniques, including electrostimulation, electromagnetic fields, photobiomodulation, and ultrasound (Le Bleis, 2022).

The aim of this review is to highlight the benefits of integrating physiotherapy for mobility improvement and pain management in postoperative dogs with thoracolumbar intervertebral disk extrusion (TL – IVDE). Indeed, TL – IVDE is one of the most prevalent forms of intervertebral disc herniation in dogs (Moore et al., 2020). This review will be structured into three sections. Firstly, it will provide an overview of intervertebral disk disease in dogs, covering anatomy, classification, pathophysiology, clinical signs, diagnosis and treatments. Secondly, it will explore manual physiotherapy techniques such as cryotherapy, massage therapy, passive and active exercises, and hydrotherapy. Lastly, it will discuss instrumental physiotherapy techniques such as electrostimulation, pulsed electromagnetic field, photobiomodulation, and ultrasound, focusing on their specific advantages in TL – IVDE cases.

2. INTERVERTEBRAL DISK DISEASE IN DOGS

2.1. SPINE ANATOMY

The spine comprises numerous vertebrae and is divided into five regions: cervical, thoracic, lumbar, sacral, and coccygeal regions. In dogs, the spine consists of 7 cervical, 13 thoracic, 7 lumbar, 3 sacral and 18 to 22 coccygeal vertebrae. While all vertebrae share a common basic structure, they also exhibit morphological differences corresponding to their function. Each vertebra consists of a vertebral body and two vertebral arches, which enclose the vertebral foramen housing the spinal cord (Barone, 2020). The vertebrae articulate with each other through their bodies and form the intervertebral symphysis. The articular surfaces are connected by intervertebral discs and longitudinal ligaments. Each intervertebral disc (Figure 1) consists of two main components: the resilient and elastic anulus fibrosus, composed of concentric layers of collagen fibers in the peripheral part, and the gelatinous nucleus pulposus in the central part, characterized by mucoid connective tissue (Barone, 2017; Carayol et Ragetly, 2013; Bach et al., 2014).

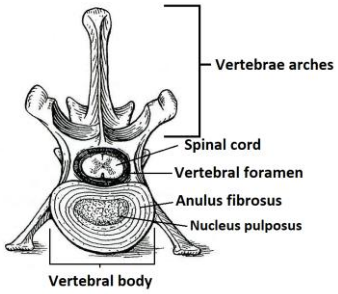

Figure 1: Structure of intervertebral disc and vertebra. Figure modified from (Sharp et Wheeler, 2004).

2.2. CLASSIFICATION

Intervertebral disc herniation is a neurological condition characterized by the extrusion of the nucleus pulposus (Hansen type I) typically presenting subacutely or acutely, or protrusion of the annulus fibrosus (Hansen type II), impacting the intervertebral discs. These classifications, introduced by Hansen in 1952, have evolved over time, with Hansen type I now subdivided into five different sub-types. These include intervertebral disc extrusion, acute intervertebral disc extrusion with extensive epidural hemorrhage, hydrated nucleus pulposus extrusion, acute non-compressive nucleus pulposus extrusion and traumatic intervertebral disc extrusion (Spitzbarth et al., 2020; Heblinski et Schmokel, 2018; Kristiansen, Schmökel et Vermeire, 2022; Fenn et Olby, 2020). There are also Hansen type III disc herniations (explosive herniation) corresponding to an extrusion of a small quantity of material but with a very high velocity (evolution similar to fibro-cartilaginous embolisms)

(Fournier, Lefebvre et Martinez-Martin, 2015). Disc herniations in dogs are most observed in the thoracolumbar region, spanning from T12 to L3, although occurrences in the cervical region are also noted (Spinella et al., 2022). This dissertation will specifically address extrusive disc herniation (Hansen type I) in thoracolumbar region.

2.3. PHYSIOPATHOLOGY

TL-IVDE affects more frequently chondrodystrophic breeds such as Dachshunds (Packer et al., 2016; Spitzbarth et al., 2020; Fenn et Olby, 2020; Jeffery et al., 2016; Bvetmed et al., 2016), Poodles, Cocker Spaniels, Bulldogs, Beagles and Basset hounds, with a peak incidence typically occurring between 3 and 6 years of age. Indeed, chondrodystrophic breeds often exhibit disorders in endochondral ossification arising from genetic, vascular, endocrine, mechanical or metabolic factors (De Decker et Fenn, 2018). These alterations reduce the disc's shock-absorbing capacity, rendering it more susceptible to rupture of the annulus fibrosus and subsequent extrusion of the nucleus pulposus, leading to spinal cord compression (Brown et al., 2017; Fenn et Olby, 2020; Dickinson et Bannasch, 2020).

2.4. CLINICAL SIGNS

Compression of the spinal cord manifests in various clinical signs, including pain, kyphosis, proprioceptive ataxia, paraparesis, and paraplegia, with or without loss of nociception. Additionally, it can result in complications such as urinary and fecal incontinence (Olby et al., 2022; Fournier, Lefebvre et Martinez-Martin, 2015). The severity is typically of intervertebral disc herniation is commonly categorized into six stages based on the following criteria (Table 1).

Table 1: Modified Frankel Score (MFS) (Heblinski et Schmokel, 2018; Draper et al., 2012).

Grade MFS	**Description**
5	Spinal hyperaesthesia only
4	Ambulatory with paraparesis and /or ataxia
3	Non-ambulatory paraparesis
2	Paraplegia with entire superficial nociception in the pelvic limbs
1	Paraplegia with entire deep nociception in the pelvic limbs
0	Paraplegia with absent nociception in pelvic limbs

2.5. DIAGNOSIS

TL - IVDE should be suspected based on signalment, history, physical examination, and neurologic findings. A complete neurological examination is crucial for localizing the lesion within a specific region of the spinal cord (Nelson et Couto, 2014). Diagnosis typically involves the use of magnetic resonance imaging (considered the gold standard) (Figure 2), computed tomography, and/or myelography (Albertini et al., 2023; Robertson et Thrall, 2011; Reynolds, Brisson et Nykamp, 2013; Da Costa et al., 2020). These imaging modalities not only aid in diagnosis but also facilitate in surgical planning and prognosis assessment (Olby et al., 2022).

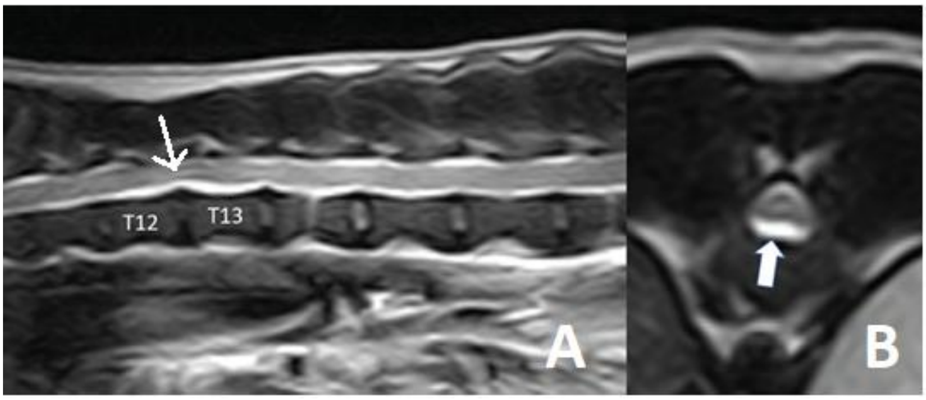

Figure 2: Magnetic resonance imaging of a dog with T12-T13 IVDE reveals spine compression due to the extruded disc material, as depicted in sagittal **(A)** and transversal planes **(B)**. Figure modified from (Kristiansen, Schmökel et Vermeire, 2022).

2.6. TREATMENT

For the treatment of TL – IVDE, both medical (conservative) and surgical methods are available.

Medical treatments typically involve the administration of anti-inflammatory such as carprofen and meloxicam, analgesics like opioids such as codeine, and other analgesics such as gabapentin (Zidan, Medland et Olby, 2020). These can be prescribed along with benzodiazepines like diazepam, combined with rest and restricted activity (Levine et al., 2007). The goals are to provide pain relief, prevent further disc herniation to minimize additional damage, allow the extruded disc material to dissipate gradually by phagocytosis and leave the ruptured disc annulus to seal by fibrosis over time (Lewis, Granger et Jeffery, 2020). Neuroprotective strategies such as methylprednisolone sodium succinate (MPSS), dexamethasone and polyethylene glycol are contraindicated (Moore et al., 2020; Fournier, Lefebvre et Martinez-Martin, 2015), as they can lead to complications such as gastrointestinal disease and urinary tract infection, without demonstrating positive effects (Olby et al., 2016; Levine et al., 2008; Fehlings et al., 2017; McCartney, Ober et Dublin, 2021). However, despite the latest recommendations, many veterinary clinicians including surgeons and neurologists, continue to use them routinely at lower anti-inflammatory doses (Moore, Early et Hettlich, 2016).

Surgical interventions, such as hemilaminectomy, with or without disc fenestration, are commonly used in TL – IVDE cases. This procedure provides direct access to the dorsal and lateral portions of the vertebral canal, facilitating the removal of herniated material and complete spinal cord decompression (Spinella et al., 2022; Hady et Schwarz, 2015). Fenestration involves removing disc material *in situ* with the aim of preventing future extrusion. Fenestration can be performed at the site of extrusion or at adjacent disc spaces as a prophylactic measure (Olby et al., 2022; Skytte et Schmökel, 2018).

The decision to opt for medical and/or surgery depends on many factors including pain levels and neurological symptoms. Medical treatment is typically chosen for dogs with a Modified Frankel Score (MFS) of 5 or 4. Surgical treatment is recommended for dogs with an MFS of 3 or less, or for those dogs with an MFS of 4 or 5 when medical treatment proves ineffective (Ragetly et Ragetly, 2013; Nelson et Couto, 2014). Age and activity also play a role in decision-making. For instance, ambulatory dogs may respond well to medical management, while surgical intervention may be warranted for young and active dogs experiencing recurrent events or with multiple mineralized discs (Olby et al., 2022, 2020). In veterinary literature, there is few scientific evidence supporting surgical over conservative approaches. A systematic review of Olby and colleagues (2022) has grouped the results of several articles to create a table (Table 2) comparing medical and surgical outcome according to injury severity. It highlights better outcomes for surgical approach than medical. However, most clinical trials are retrospective, and there are no randomized double-blind trials comparing outcomes between the two different approaches (Langerhuus et Miles, 2017; Moore et al., 2020).

Table 2: Medical and surgical outcomes in dogs with TL – IVDE. Table adapted from (Olby et al., 2022).

Injury severity	Medical outcome	Surgical outcome
Spinal pain only and ambulatory paraparesis	80.0 %	98.5 %
Non-ambulatory paraparesis	81.0 %	93.0 %
Paraplegia with deep pain positive	60.0 %	93.0 %
Paraplegia with deep pain negative	21.0 %	61.0 %

Nevertheless, neither medical nor surgical management aims to repair the damaged intervertebral disc itself (Lewis, Granger et Jeffery, 2020). Physiotherapy serves as a rehabilitation therapy aimed at providing supportive care and preserving tissue strength and function, ultimately leading to shorter recovery times and protecting animals from complications such as ankylosis, muscle atrophy and pressure ulcers (Bruno et al., 2020). The selection of physiotherapy techniques for this pathology depends on the severity of the injury, the temperament of the animal, and the preferences of the tutor. These techniques are broadly categorized into manual and instrumental approaches. Manual techniques include cryotherapy, massages, passive and active exercises, and hydrotherapy. Instrumental techniques include electrostimulation, pulsed electromagnetic field, laser therapy and ultrasound (Dragone, 2010). Through these physiotherapy techniques, it is possible to effectively manage pain, reduce edema and inflammation of affected tissues, stimulate blood and lymphatic circulation, promote brain plasticity, improve coordination and proprioception, prevent muscle atrophy, maintain a muscle tone, and preserve joint mobility, thus improving the overall recovery prognosis (Le Bleis, 2022).

3. MANUAL TECHNIQUES OF PHYSIOTHERAPY IN THORACOLUMBAR DISK EXTRUSION IN DOGS

3.1. CRYOTHERAPY

3.1.1. Definition and benefits

One of the oldest physiotherapy techniques is cryotherapy, the application of cold. The principal effects of cryotherapy include vasoconstriction of the blood vessels which reduces the blood flow in the treated area, decreased edema, reduced cellular metabolism and permeability, induces local analgesia, decreases sensory and motor nerve conduction velocities, and reduced muscle spasm (Rivière et al., 2005). During the inflammatory phase of tissue healing, there is an increase in the permeability of microvasculature, resulting in the release of histamine and bradykinin release. These chemical mediators cause vasodilation, increased blood flow and cause edema formation. The primary role of cryotherapy in this phase is to reduce the metabolic rate of the injured tissue, resulting in decreased metabolite production and metabolic heat.

Analgesia and the concomitant reduction of reflex muscle spasms are due to the decreased nerve conduction velocity that occurs when nerves are cooled. This phenomenon is referred to as the Q10 effect, indicating that nerve conduction velocity is comparable until 10 °C, below which it is reduced. Cryotherapy also induces the Hunting response 20 to 40 minutes after application. This reaction, first described by Lewis in 1930, refers to the cyclical temperature oscillation of 2 °C to 6 °C every 8 to 15 minutes, representing alternating vasoconstriction and vasodilatation (Millis, Levine et Taylor, 2013; Baltzer, 2020).

3.1.2. Applications

Cryotherapy is used during the acute phase of injury and subsequent healing process to mitigate the effects and potential complications of tissue damage. Additionally, it is applied following passive or active exercise as part of the rehabilitation protocol to mitigate adverse secondary inflammatory responses (Millis, Levine et Taylor, 2013).

In cases of TL – IVDE, cryotherapy is recommended during the post-operative period near the thoracolumbar incision site, immediately following surgery and after passive and active exercises as part of the rehabilitation process (Spinella et al., 2022). Various methods are available for applying cryotherapy, including ice packs, ice bath immersion, cryomassage, and vapor coolant spray (Le Bleis, 2022). Ice packs are commonly employed in TL – IVDE cases (Gordon-Evans et al., 2019; Zidan et al., 2018a; Bennaim et al., 2017). They allow for targeted application to a specific area without the risk of contamination of the incision site, as seen with ice bath immersion.

As generally reported, cryotherapy begins immediately after surgery and typically involves cold application for 10 to 20 minutes, two to three times a day during the first 48 hours post-surgery (Millis, Levine et Taylor, 2013; Le Bleis, 2022; Brockstahler, Levine et Millis, 2004; Dragone, 2010; Olby et al., 2022; Zidan et al., 2018a,b; Bennaim et al., 2017; Gordon-Evans et al., 2019; Hodgson et al., 2017; Baltzer, 2020; Bockstahler et al., 2019).

3.1.3. Precautions

Cryotherapy also has some contraindications, as it can induce cold injury and cellular damage. To prevent this, it is crucial to carefully observe the skin at the end of the application. The skin may normally appear erythematous. Pale or white skin is an indication that cold may have caused tissue damage (Millis, Levine et Taylor, 2013; Sardar et al., 2016). Moreover, cryotherapy should be avoided in dogs who are cold-sensitive or exhibit responses such as cold urticaria (wheals formation due to histamine liberation), those with circulatory problems or those with open wounds in close proximity (Brockstahler, Levine et Millis, 2004; Bockstahler et al., 2019).

3.2. MASSOTHERAPY

3.2.1. Definition and benefits

Massotherapy involves the mobilization of soft tissue, ranging from superficial to deep layers, including the skin, connective tissue, fascia, muscles, and tendons. During locomotor examination in physiotherapy, palpation is utilized to identify abnormalities, such as areas of abnormal temperature, dysfunction, tension points, pain or tissue remodeling. As a result, massages are often the initial treatment used to prepare tissues for passive and active exercises, relieve spasms and contractures, and induce relaxation in the animal. Additionally, massages are beneficial following passive and active exercises to promote drainage and toxin elimination (Le Bleis, 2022; Dybczyńska et al., 2022). Massotherapy is used to enhance blood flow, facilitating oxygen delivery and waste product removal, while also contributing to alleviation. Furthermore, massages stimulate release of endorphins, natural substances within the body contributing to pain relief. Moreover, massage therapy accelerates muscle recovery, increases venous and lymphatic return, improves cutaneous perception or somatesthesia, and promotes mental and physical relaxation (Brockstahler, Levine et Millis, 2004; Bockstahler et al., 2019).

3.2.2. Applications

In the case of TL – IVDE, in cases of TL – IVDE, massages are frequently incorporated into the rehabilitation protocol, as evidenced by numerous articles (Martins et al., 2021a; Henea et al., 2023). These massages typically involve five-minute sessions on the pelvic limbs, are performed twice a day (Hodgson et al., 2017; Gordon-Evans et al., 2019) or even three to four times daily (Mojarradi et al., 2021). Similar protocol recommendations can be found in specialized literature (Le Bleis, 2022; Millis, Levine et Taylor, 2013; Brockstahler, Levine et Millis, 2004; Dragone, 2010; Bockstahler et al., 2019; McGowan, 2016). Various types of massages are utilized, each with distinct effects:

- Stroking (superficial effleurage): this massage technique promotes relaxation of the animal at the beginning and at the end of a session, or between deeper massages. Superficial slow movements are applied along the direction of the dog's hair.
- Circular pressure: this massage aims at target a specific area for drainage, particularly beneficial for reducing edema.
- Kneading (petrissage): alternating pressure and release are applied in this technique, effective for addressing muscle spasm, tension, and tissue congestion.

- Rubbing (friction): this massage is always used after other massage techniques, rubbing helps to reduce fibrous adhesions.
- Shaking (vibration): this technique induces relaxation in muscles and deep tissues, extending to the articulations.
- Percussion (clapping, hacking): Light, rhythmic strikes are delivered with gradually increasing force, stimulating circulation and tissue relaxation (Le Bleis, 2022).

Therefore, massages play a crucial role in managing acute TL – IVDE. Indeed, poor posture caused by back pain and neurological deficits caused by TL – IVDE often lead to muscle tensions. Thus, massage therapy is important in alleviating stress in animals' post-surgery, promoting relaxation, reducing pain, alleviating muscle contracture and aiding in the drainage of potential edema (Brockstahler, Levine et Millis, 2004; Baltzer, 2020; Le Bleis, 2022; Millis, Levine et Taylor, 2013; Sardar et al., 2016).

3.3. PASSIVE AND ACTIVE EXERCISE

3.3.1. Definition and benefits

Therapeutic exercises are a vital component of post-surgery physiotherapy and during the rehabilitation period. The duration and intensity of the physiotherapy program are adapted according to each individual animal, considering factors such as neurological deficits and pain levels. Additionally, the continuation of physiotherapy sessions is determined by the tutors' decision (Dragone, 2010; Sardar et al., 2016). During therapeutic sessions, signs of improvement in the animal's health serve as indicators for modifying the treatment, including adjustment to type, intensity, duration and/or frequency of exercises. It is recommended to adapt exercises based on the animal's evolving condition, either increasing or decreasing them as needed (Henea et al., 2023). The goal of these exercises is to enhance arterial, venous and lymphatic flow, stimulate the cardiorespiratory system, sensibility, and voluntary movements, and promote a broader range of motion (ROM), a better muscle strength and movements coordination. Additionally, they aim to enhance stability, proprioception and prevent joint stiffness (Dragone, 2010; McGowan, 2016).

Therapeutic exercises (Figure 3) are categorized into three categories: passive exercise, active-assisted exercise and active exercise. Passive exercises include passive range of motion (PROM), stretching, and flexor reflex stimulation. PROM consist of using an external force to move the joint, incorporating slow movements of flexion, extension, abduction, and adduction, or bicycling movements (Sardar et al., 2016). This technique is beneficial for joint flexibility, promoting blood circulation and lymphatic drainage. It is recommended to perform passive mobilization 10 to 15 times consecutively, one to three time a day. Each series can be followed by stretching, which involves maintaining flexion and extension at its maximum amplitude during 10 to 15 seconds. This technique allows to gain joint amplitude, muscular and joint flexibility and prevents adhesions between soft tissue and bone (Le Bleis, 2022). The goal of flexor reflex stimulation is to enhance muscle contraction, limit muscle atrophy and improve muscle tone by pinching the pads and phalanges with fingers. It is recommended to perform three to five repetitions, two to four times a day. Therapeutic exercises should ideally initiate with passive movements at least 48 to 72 hours post-surgery to avoid impeding the natural inflammatory phase essential for healing (Dragone, 2010; Dybczyńska et al., 2022). Subsequently, therapeutic exercises should continue for 10 days to six weeks, or until ambulation or normal mobility is restored (up to one year in some case) (Olby et al., 2022). Active assisted exercise is initiated as soon as the animal is capable, facilitating enhanced muscular engagement while still requiring assistance. This regimen encompasses various activities such as assisted standing exercises, employment of rollers (such as a peanut ball) and engaging in balancing movements. Standing exercises serve as a fundamental phase in rehabilitation dogs with neurological deficits, such as paralysis (Le Bleis, 2022). To facilitate this, the dog may necessitate support through the use of a sling or manual assistance positioned around the abdominal region, just anterior to the hindlimbs. The ability to stand is essential for walking developing, and the dog must be motivated and encouraged to move even slowly and as independently as possible (Henea et al., 2023). Additionally, integrating rollers into the regimen proves beneficial, and allows dogs with neurological deficit to exercise that enhance tactile stimulation, proper limb placement and proprioception awareness. Incorporating balancing movements into the regimen involves gently guiding the dog’s hip from side to side facilitating balance enhancement and tone while in a standing position. Dogs with posterior deficits often exhibit a weight shift towards the anterior region, a phenomenon discernible with tools like the Stance Analyzer, which illuminates weight distribution and identifies affected limbs. Correcting this imbalance can be achieved by placing the hands on the front of the dog’s thighs and gently pulsing them backward. These exercises can also be performed by gradually removing one support from the animal, further challenging balance and promoting stability (Le Bleis, 2022; Sardar et al., 2016; Dybczyńska et al., 2022).

Active exercises are crucial components of canine rehabilitation, including a range of movements standing exercises, sit-to-stand transitions, walking, fast walking, and specialized proprioceptive exercises such as those involving proprioceptive tablets, Cavaletti rails, climbing or descending steps and physio balls (Le Bleis, 2022). Proprioception exercises hold particular importance as they serve to reinforce the dog’s innate motor patterns, restoring normal movement and function.

The physio ball can be used, offering versatility with various shapes for different exercises, making them invaluable tools in canine rehabilitation. For example, dogs can place their front paws on the ball while keeping the back paws on the ground, gently moving the ball back and forth. Alternatively, exercises can involve both front and back paws on the ground, using textured little pads or smooth balance discs or textured balance discs for stability. It's recommended to slightly deflate the balls for optimal use (Le Bleis, 2022). Proprioceptive tablets like the Freeman tablet or the Imoove® system allow for 360° swinging movements of the animal (Henea et al., 2023). Cavaletti rails are useful for promoting alternate limb movement and joint mobility, with poles spaced one body length apart and set at or just below the level of the tarsi (Hodgson et al., 2017). All these active exercises provide several benefits, including stimulating the cartilaginous metabolism, facilitating metabolite diffusion, improving ROM, enhancing muscle tone and strength, reducing fat mass, and triggering the release of endogenous opioids, which can alleviate pain (Dragone, 2010).

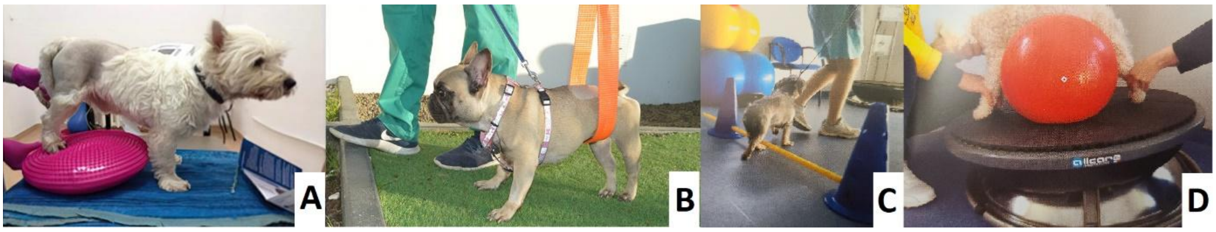

Figure 3: Postoperative physiotherapy in dogs with TL – IVDE. Balancing movement on disc with picot **(A)**, gait stimulation with support **(B)**, Cavaletti rails **(C)**, and changing the center of gravity with rollers and proprioceptive tablet **(D)** (Martins et al., 2021b; Henea et al., 2023; Le Bleis, 2022).

3.3.2. Applications

These therapeutic have been extensively studied to demonstrate their effectiveness in rehabilitation protocols following hemilaminectomy in cases of TL – IVDE (Table 3) (Millis, Levine et Taylor, 2013). In a study conducted by A. Gallucci and colleagues, in 2017, all patients diagnosed with thoracolumbar spinal lesion (TL-IVDE 66 % or trauma 34 %) underwent Magnetic Resonance Imaging and computed tomography scans. The dogs presented with paraplegic without pain perception. The study implemented a physiotherapy protocol consisting of five main categories of exercises: passive range of motion exercises, stimulation of flexor reflexes and crossed extensor reflexes, active-assisted exercises, electrostimulation, and hydrotherapy on an underwater treadmill (UWTM). The results showed that early intensive physiotherapy had a favorable outcome with 59 % of cases showing the development of unassisted involuntary gait. Additionally, the study showed that younger age (less than 60 months) was associated with better results (Gallucci et al., 2017).

In a contrasting study published in 2016 regarding the outcomes of paraplegic dogs with TL-IVDE (between T10 and L3) and without pain perception, no significant correlation with age was found (Jeffery et al., 2016; Castel et al., 2019). Another retrospective study, by IS. Jeong and colleagues in 2019, focused on physiotherapy intervention. Dogs with TL – IVDE (grades 2, 3 and 4) were treated with surgical decompression and were divided into rehabilitated and non-rehabilitated groups. The rehabilitated group received a comprehensive regimen including electrotherapy, standing training, deep tendon reflex work, infrared therapy and aquatic treadmill exercise. The non-rehabilitated group was only treated with surgical decompression. At the end, 86.46 % of dogs in the rehabilitated group had a successful neurological outcome, significantly higher than those in the non-rehabilitated group, emphasizing the efficacy of physiotherapy protocols, particularly locomotor training (Jeong et al., 2019). Furthermore, a 2021 study by A. Martins and colleagues, explored the potential intensive neurorehabilitation plasticity effects on postoperative paraplegic dog with severe acute TL-IVDE aiming to restore ambulatory status. Dogs in the intensive neurorehabilitation group underwent multimodal approaches, including intensive locomotor training, electrostimulation protocols and pharmacological management in cases of absent deep pain perception. In contrast, the control group received cage rest and basic physiotherapy consisting of PROM massages, supported standing position and neuromuscular electrical stimulation. The intensive neurorehabilitation protocol resulted in 99.4% recovery of ambulatory status in dogs with deep pain perception and 58.5 % in those without (significantly higher than the control group). Therefore, intensive neurorehabilitation may be a useful approach for these dogs. This study highlighted that passive and active exercises were useful in the rehabilitation process, particularly when combined with electrostimulation and intensive locomotor training (Martins et al., 2021a). Similarly, MM. Hodgson and colleagues (2017) demonstrated the positive impact of intensive rehabilitation in dogs with TL-IVDE. Their study compared dogs with TL – IVDE, treated with basic rehabilitation techniques (cryotherapy, massotherapy and PROM 10 min two to three times per day; photobiomodulation and UWTM once a day) with intensive rehabilitation (PROM, sling walking and standing exercises three to four times per day) at home, showing that more dogs returned to full neurological function with in-house rehabilitation. Therefore, showing and explaining correctly how to perform physiotherapy exercises to the tutor at home is essential to have better recovery (Hodgson et al., 2017).

In another study by ME. Henea and colleagues (2023), all patients diagnosed with paraplegia and urinary incontinence due to TL-IVDE or other causes gradually regained spinal walking ability, indicating potential for functional recovery (Henea et al., 2023).

However, not all evidence supports the hypothesis that intensive physiotherapy enhances recovery in spinal cord injuries. Zidan et al. (2018b) conducted a blinded, randomized, prospective study comparing the outcomes of basic rehabilitation versus intensive rehabilitation protocol after TL-IVDE (T10-L3) surgery. While the intensive protocol was well tolerated, no statistical differences were between the two groups. It's worth noting that the study had a small sample size of just 30 dogs, predominantly with T13-L1 injuries, and larger studies might yield different results (Zidan et al., 2018b). In another study published in 2023 by ME. Henea and colleagues, all patients diagnosed with paraplegia and urinary incontinence caused by TL – IVDE (88.33 %) or fracture or luxation (11.67 %). Spinal walking (ability to develop an unassisted involuntary gait) was obtained progressively after 125-320 physiotherapy sessions (25 to 64 weeks). The rehabilitation protocol was composed by manuals methods, physical therapy (laser, ultrasound, electrostimulation), techniques for obtaining and maintaining the standing position, assistance in supporting body weight and adoption standing position, and techniques for proprioception and mobility. At the end of the study, 58.33 % of the animals successfully developed spinal walking without falling. Additionally, the research highlighted that excessive weight could complicate the recovery process. Therefore, during rehabilitation of dogs with TL – IVDE, incorporating a combination of active and passive exercises along with other physiotherapy techniques is crucial for promoting spinal walking and restoring deep pain perception (Henea et al., 2023).

Table 3: Conclusions regarding the utilization of physiotherapy protocols in TL – IVDE following hemilaminectomy.

Reference	**Groups**	**Conclusion**
(Hodgson et al., 2017)	248 dogs with TL – IVDE. A: Control group with basic rehabilitation (161 dogs). B: Basic and intensive rehabilitation at home (87 dogs).	-Significantly more dogs achieved full neurological function with in-house rehabilitation compared to standard care (33 % vs 9 %). -Conscious proprioception and ambulation returned earlier in the control group. -The Incidence of complications was higher in

		the control group (29 % vs 16 %).
(Gallucci et al., 2017)	81 acute paraplegic thoracolumbar dogs without pelvic limb pain perception (66 % TL – IVDE and 34 % trauma) with intensive physiotherapic protocol.	-Early intensive physiotherapic protocol increases the likehood of developing an unassisted involuntary gait by 59%. -Median time to achieve spinal walk is 75.5 days. -Young age correlates with better outcomes.
(Zidan et al., 2018b)	30 non-ambulatory paraparetic or paraplegic (with pain perception). <u>A</u>: Basic rehabilitation (15 dogs). <u>B</u>: Intensive rehabilitation (15 dogs).	-Intense rehabilitation is safe and well tolerated, yet it does not result in significant improvements in the rate or level of recovery.
(Jeong et al., 2019)	186 dogs with TL – IVDE (grades 2, 3 and 4). <u>A</u>: Rehabilitated group (96 dogs) with basic physiotherapy. <u>B</u>: Non-rehabilitated group (90 dogs).	-Improvement of neurological functions is significantly higher in the rehabilitated group compared to the non-rehabilitated group. -Success rates of all grades are significantly greater in the rehabilitated group than non-rehabilitated group.
(Martins et al., 2021a)	367 paraplegic dogs with TL – IVDE. <u>A</u>: Intensive neurorehabilitation (262 dogs). <u>B</u>: Control group with cage rest and basic physiotherapy (105 dogs).	-There exists a robust and significant difference regarding ambulation, higher in the intensive rehabilitated group, both for deep pain perception positive and negative cases.
(Henea et al., 2023)	60 paraplegic dogs without deep pain perception in the hindlimbs and urinary incontinence caused by TL – IVDE (88,33 %) or trauma (11,67 %) treated with basic physiotherapy.	-Chances of recovering Spinal walking are higher in dogs with lower weight (median of 6.83 kg). -Deep pain and tail mobility regained in all dogs after 30 sessions. -Spinal walking was obtained in 58.33 % dogs without deep pain perception after 125-320 physiotherapy sessions.

3.4. HYDROTHERAPY: USE OF UNDERWATER TREADMILL

3.4.1. Definition and benefits

The therapeutic use of water, known as hydrotherapy, is a widely practiced method in human medicine and is increasingly gaining popularity in veterinary medicine, especially for horses and dogs (Dragone, 2010; Dybczyńska et al., 2022; Skytte et Schmökel, 2018). Despite its associated challenges such as maintenance, space requirements, and cost, hydrotherapy remains a preferred method for dogs experiencing gait abnormalities following TL-IVD. Indeed, hydrotherapy is used to address issues like ataxy or hindlimbs paralysis, while promoting muscle strengthening. It improves strength, muscular endurance, cardiorespiratory function, ROM and overall physical well-being. Hydrotherapy sessions can be carried out in natural environment (river, lake), swimming pools or UWTM (Le Bleis, 2022). Floatability will reduce weight-bearing on the limbs facilitating active movements. During hydrotherapy, no constraints are placed on the limbs, reducing the risk of musculoskeletal and joints issues. Thanks to floatability, dogs with neurological deficits, such as those with TL-IVDE, can perform movements that may be impossible for them on the ground. Additionally, the hydrostatic pressure in water delivers a massaging and draining effect, beneficial for treating edema. Moreover, water facilitates neurosensory stimulation, helping dogs in becoming aware of their position in space and promoting the reactivation of dormant limbs (Millis, Levine et Taylor, 2013; Bockstahler et al., 2019). During hydrotherapy sessions, dogs are required to move their forelimbs to keep their heads above water. However, some dogs may not realize the necessity to move their hindlimbs and instead rely solely on their forelimbs, folding their hindlimbs under themselves and making minimal foot movements. In such cases, the use of UWTM is recommended to encourage walking movements in water rather than swimming (Le Bleis, 2022; Dybczyńska et al., 2022).

3.4.2. Applications

Using UWTM offers many benefits. It is possible to customize the water level treadmill speed, and to create a slope of up to 5 %. It is also possible to control the water temperature, typically set between 26 °C and 32 °C. This temperature range promotes myorelaxation, improving animal comfort and overall effectiveness (Martins et al., 2021a). Prior to initiating any protocol, such as those exposed in studies summarized in Table 4, it is recommended to do a complete physical examination (like the protocols that are to evaluate the benefit-risk ratio. Before initiating hydrotherapy, it is recommended to withhold food from the dog to prevent potential regurgitation or stomach dilatation and torsion syndromes. Additionally, allowing the dog walk beforehand facilitates defecation and urination. The first session is of great importance, as it sets the tone for subsequent sessions and builds animal's confidence. Thus, it is very important to stimulate and encourage the dog with toys or treats. If the dog exhibits signs of excessive stress, panic or an inability to relax, it may be necessary to stop the exercise (Le Bleis, 2022). Several authors emphasize the importance of UWTM in facilitating reflex pelvic limbs movements in paraplegic dogs, helping in the development of spinal walking (Martins et al., 2021b). A study Gallucci et al. (2017) showed that almost all dogs undergoing UWTM physiotherapy developed pelvic limbs movements several days earlier compared to those on a standard treadmill (Gallucci et al., 2017). The UWTM is used when the animal is capable of standing and walk. For dogs encountering difficulties specialized harnesses can be used, assisting the dog in water can help performing movements correctly. The exercise begins without slope, at a lower speed, and is gradually increased based on the dog's adaptation (Jeong et al., 2019). The optimal water level is recommended to be at the height of the greater trochanter of the femur (Bruno et al., 2020). It is recommended to incrementally increase slope, extend sessions durations, and reduce water level by 2.5 to 5 centimeters as the dog's strength, mobility, and stamina improve, increasing weight load and muscle strengthening (Hodgson et al., 2017). Several reviews support for initiating UWTM at low velocity such as two to three minutes per day (Bruno et al., 2020) or five minutes per day (Gordon-Evans et al., 2019; Martins et al., 2021a). Some other studies recommend gradually increasing this duration by two minutes per day until reaching an average of 25 to 30 minutes per session (Gordon-Evans et al., 2019; Le Bleis, 2022). Treadmill speed typically begins at 1 to 3.5 km/h and is gradually was increased based on the dog's comfort during walking (Gordon-Evans et al., 2019; Martins et al., 2021a; Henea et al., 2023). These parameters can be reduced, if necessary, particularly if the dog shows signs of weakness, struggles to perform movements correctly, or exhibits fatigue (Martins et al., 2021a). Movements execution can be monitored visually or using a gait analysis system (Sutton et al., 2016). A validated scoring system can be used for dogs with TL – IVDE on land treadmill or in an UWTM setting (Lewis, Thomovsky et Moore, 2023). Many studies begin UWTM sessions within two to seven days following surgery (Martins et al., 2021a). However, other reports recommend to begin 10 to 14 days post-surgery or upon suture removal once wound has healed (Zidan et al., 2018b; Mojarradi et al., 2021). Indeed, early hydrotherapy may potentially lead to postoperative complications such as surgical site infections and neurological deterioration due to further extrusion of calcified nucleus pulposus through the ruptured anulus fibrosus of the intervertebral disc involved in the surgical intervention (Mojarradi et al., 2021).

Table 4: Summary of the hydrotherapy protocols for TL -IVDE following hemilaminectomy.

Reference	Protocol UWTM
(Hodgson et al., 2017)	Frequency: twice daily. Duration: start at 5 min and increase by 5 min (based on the dog ability) until reaching 20 min. Speed: initially 0.16-0.64 km/h, progressing to 1.29 - 1.61 km/h. Water level: positioned at or near the greater trochanter, with adjustments of 2.54 - 5.08 cm as improvement is observed.
(Gallucci et al., 2017)	Frequency: twice daily. Duration: start at 5 min and increase (depending on dog ability) until reaching 15 min. Speed: set at 1.8 km/h.
(Bruno et al., 2020)	Duration: start at 2-3 min and gradually increase. Speed: begin with low velocity and gradually increase. Water level: set at the height of the greater the trochanter of the femur.
(Henea et al., 2023)	Frequency: once daily. Duration: 15 min for the first 40 sessions, 20 min from the 40th to the 80th session, and 30 to 45 min until the 125th session. If dogs require more than 125 sessions, the duration is extended to one hour. Speed: 0.8 km/h for the first 40 sessions, 1.5 to 1.8 km/h from the 40th to the 80th session, and 2.5 km/h until the 125th session. For sessions beyond the 125th sessions, the speed is set to 2.8 - 3 km/h, if dogs need more than.

4. INSTRUMENTAL TECHNIQUES OF PHYSIOTHERAPY IN THORACOLUMBAR DISK EXTRUSION IN DOGS

4.1. ELECTROSTIMULATION

4.1.1. Definition and benefits

Electrotherapy encompasses a range therapeutic method using electric currents to treat different pathologies. It facilitates increased muscle strength, muscle tone improvement, reduction of muscle spasm, enhanced ROM, correction of structural abnormalities, pain management, accelerated wound healing, edema reduction and improved transdermal administration of medication (Millis, Levine et Taylor, 2013; Dybczyńska et al., 2022). The terminology associated with electrostimulation lacked precision until 1990 when a committee within the electrophysiological section developed standards of electrotherapeutic terminology.

This technique is divided into two main categories: transcutaneous electrical neurostimulation (TENS) and Neuromuscular electrical stimulation (NMES) (Dragone, 2010). TENS is primarily used to manage both acute and chronic pain (Brockstahler, Levine et Millis, 2004; McGowan, 2016; Bockstahler et al., 2019). It involves the application of electrodes to areas of the body experiencing pain, which then deliver electrical currents. The intensity and frequency of these currents interfere with the normal pain signals emitted by sensitive cells in the affected region, thereby reducing the perceived sensation of pain by the patient (Henea et al., 2023). Electrical stimulation can be classified into two primary principles of action: high and low frequency. High frequency stimulation (80 - 100 Hz) induces the release of dynorphin and enkephalin (endogenous opioids), resulting in an immediate analgesic effect that has a short duration (dissipates quickly after the cessation of electrostimulation). Conversely, low frequency stimulation (2 - 4 Hz) allows the release of endogenous opioid substances, leading to an increase in the levels of endomorphins and their precursors in the cerebrospinal fluid. In this case, the analgesic effect is not immediate (requiring 15 - 30 minutes of electrostimulation) but remains effective for an extended period after termination of electrostimulation (Le Bleis, 2022).

4.1.2. Applications

In cases of TL – IVDE, is recommended for both acute and chronic pain, with electrodes placed cranially and caudally to the painful region (Brockstahler, Levine et Millis, 2004; Bockstahler et al., 2019). It is also used to stimulate a physiological motor neuron impulse, thereby stimulating individual or groups of muscles to prevent muscle atrophy. It also facilitates improved joint movement, enhanced blood flow, and acts as a tissular decongestant (Henea et al., 2023; Sardar et al., 2016; Boström et al., 2022). To achieve a complete muscular response, the stimulation intensity is gradually increased. Stimulation begins at the surface (large-caliber motoneuron at the muscular periphery), then will gradually propagate deeper (small diameter motor neuron) (Bockstahler et al., 2019). For dogs, recommended frequencies range from 1 and 3 Hz for mild contractures, 10 to 20 Hz for stimulating slow fibers (with massaging effect), and 50 to 70 Hz for complete tetanic contraction (Dragone, 2010). During voluntary movements, there is a complete asynchronous tetanus. In fact, the motor units do not all contract at the same time. However, during electromyostimulation, there will be a complete synchronous tetanus leading to increased muscle fatigue. Hence, adequate rest intervals are crucial (Bockstahler et al., 2019; McGowan, 2016). Pulse duration is also important as it determines the energy required for nerve and muscle fibers excitation and depolarization of. Typically, pulse duration ranges from 50 to 400 µs, depending on the dog's size and targeted muscle. Stimulation should not reach nociceptive fibers. Intensity is another important parameter, with a minimum intensity of 10 mA for frequencies of 10 to 20 Hz and 30 mA for frequencies of 50 to 70 Hz to obtain a muscular. During the first session, the intensity applied will be kept very low to acclimate the dog to the sensation (Le Bleis, 2022). NMES is recommended for muscle stimulation in all cases of TL - IVDE, including both dogs capable of independent walking and those that are paralyzed. Electrodes are placed on the skin, with an application gel adapted, to stimulate quadriceps and hamstrings (muscles most impacted during TL - IVDE) (Brockstahler, Levine et Millis, 2004; Bockstahler et al., 2019).

Several reviews have incorporated electrostimulation into the rehabilitation programs for TL – IVDE post-hemilaminectomy. However, there is recently no recent review only analyzing the efficacy of electrostimulation. Examples of those protocols are summarized in Table 5 (Henea et al., 2023; Bennaim et al., 2017; Joaquim et al., 2010).

Table 5: Summary of the various electrostimulation protocols for dogs with TL – IVDE post-hemilaminectomy.

References	**Program**
(Henea et al., 2023)	Duration: starting at 15 minutes and progressing up to 40 min over multiple sessions. **For spasm reduction**: -Premod (interferencial): electrical current: continuous emission; frequency: 10 Hz; intensity: variable. **For muscle strengthening**: vibratory motor stimulation; electrical current: continuous emission; pulse: 200 µs; ramp: 2 s; frequency: 50 Hz and intensity: variable.
(Bennaim et al., 2017)	Localization: lateral recumbency for electrostimulation targeting the quadriceps, biceps femoris, semitendinous, and semimembranous muscles. Electrical current: symmetric biphase pulse (12 s on, 25 s off). Duration: once daily for 15 min. Frequency: 30-60 Hz. Pulse: 300 µs. Amplitude: increased until muscle contractions.

(Joaquim et al., 2010)	Electrical current: alternating current electrostimulation. Duration: Once weekly for 20 minutes over 1-6 months. Frequency: 2-15 Hz. Amplitude: incrementally increased until muscle contractions are observed.

4.2. PULSED ELECTROMAGNETIC FILED: USE OF DIATHERMY

4.2.1. Definition and benefits

Pulsed electromagnetic fields (PEMF) represents a non-invasive and non-thermal therapy with a long-standing history of use. PEMF technologies began in the 1930s, initially adapted a vacuum tube-based diathermy machine, traditionally employed to deliver deep tissue heat, to produce minimal no heat at all (Gaynor, Hagberg et Gurfein, 2018). Numerous clinical trials carried out on both humans and animals recommend the use of PEMF in diverse applications such as bone healing, osteoarthritis, inflammation, pain management, soft tissue wound healing, edema reduction, and neurological disorders. Each cell within the body has its unique frequency, which may undergo modification in the presence of pathology or dysfunction. The use of electromagnetic fields facilitates cell regeneration by aiding cells in returning to their initial frequency (Le Bleis, 2022; Sardar et al., 2016). There are different types of PEMF categorized based on the duration and frequency of treatment application, the waveform shape and strength of electromagnetic emission, as well as the size and geometry of antennas used. The two primary categories, approved by the U.S Food and Drug Administration, are non-invasive bone growth stimulators and nonthermal shortwave diathermy PEMF, encompassing targeted PEMF (Gaynor, Hagberg et Gurfein, 2018).

4.2.2. Applications

PEMF therapy is applicable in TL – IVDE post-surgery (Table 6). In a recent blinded, randomized prospective clinical trial, the effects of a targeted PEMF device (high frequency) therapy in dogs with TL – IVDE and acute paraplegia onset without pain perception (pelvic limb and tail) was evaluated. The dogs were divided into two groups: one with PEMF treatment and the other without. The group receiving targeted PEMF was treated for 15 minutes every two hours for two weeks, followed by twice daily sessions for four weeks. Gait, pain perception, and proprioceptive function were evaluated at two and six weeks. Plasma glial fibrillary acidic protein (GFAP) concentration was used as a biomarker for spinal cord injury, while mechanical sensory thresholds (MST) were quantified to evaluate post-operative pain. The study concluded that dogs receiving PEMF treatment experienced significant reductions in surgical incision site pain (as evidenced by increased MST), a decrease in inflammatory biomarker concentration, and an improvement in proprioceptive function compared to control group (Zidan et al., 2018a). Another study evaluated the impact of targeted pulsed electromagnetic field on dogs undergoing hemilaminectomy for TL – IVDE. The dogs were randomly assigned to receive either targeted PEMF therapy or a placebo treatment. The PEMF protocol was administered every six hours during hospitalization and then every 12 hours for seven days post-surgery. Wound healing was evaluated using a visual analog score and was significantly improved at six weeks in the targeted PEMF group. Pain medications (codeine) were administered less frequently in dogs treated with PEMF during the seven days following hemilaminectomy, making it a cost-effective option (Alvarez et al., 2019). Finally, a review that analyzed PEMF history and clinical studies of PEMF therapy highlighted that it is safe and non-invasive. Indeed, there were no reported side effects or significant adverse events associated with PEMF therapy. Therefore, PEMF emerges as a promising treatment to use alone or in combination with other treatments in veterinary medicine for TL – IVDE post-surgery (Gaynor, Hagberg et Gurfein, 2018).

Table 6: Clinical trial results on the use of PEMF in dogs with IVDE after hemilaminectomy.

Reference	**Number of animals**	**PEMF protocol**	**Conclusion**
(Alvarez et al., 2019)	53 dogs with nonambulatory paraparesis or paraplegia (grade 3 or more). Group A: PEMF on 27 dogs. Group B: Control without PEMF on 28 dogs.	During hospitalization: every 6 hours for 15min. After hospitalization: every 12 hours home therapy for 7 days following surgery.	-Wound healing was significantly improved at 6 weeks with targeted PEMF. -In dogs receiving PEMF, pain medications were administered less frequently during 7 days post-surgery -In the control group, codeine was administered 1.8 times more frequently.
(Zidan et al., 2018a)	16 dogs with paraplegia and no pain perception in either	15 minutes every 2 hours for 2 weeks then twice daily	-There was no significant difference in demographics or GFAP concentration between the 2 groups at trial entry. -Proprioceptive placing was significantly

	pelvic limb or the tail. Group A: PEMF on 8 dogs. Group B: control without PEMF on 8 dogs.	for 4 weeks.	better at 6 weeks. -GFAP concentrations were significantly lower at 2 weeks in the PEMF group. -MST were significantly higher in the PEMF group. → PEMF reduced incision-associated pain in dogs following surgery for IVDE and may reduce extent of spinal cord injury and enhance proprioceptive placing.

4.3. PHOTOBIOMODULATION

4.3.1. Definition and benefits

Photobiomodulation, also known as low-level laser therapy, employs red and near-infrared light (600 - 1200nm) to enhance cellular metabolism, thereby accelerating the healing process (Figure 4) (Wardlaw et al., 2019), while reducing pain and inflammation (Bockstahler et al., 2019). When light penetrates tissue, it undergoes scattering, reflection and absorption Light is absorbed by chromophores such as cytochrome C complex, opsin, flavins, flavoproteins and water. Among these, cytochrome C complex in oxidative phosphorylation is the most extensively studied mechanism of light absorption, located in the inner membrane of the mitochondria. Upon light absorption, cytochrome C is stimulated, leading to the increased ATP production. Additionally, laser stimulation produces reactive oxygen species and free nitric oxide. Nitric Oxides serves as a potent vasodilator and a crucial cellular signaling molecule. Vasodilatation improves microcirculation in damaged tissues, facilitating oxygen delivery and waste removal. Reactive oxygen species affect various vital signaling pathways involved in the inflammatory response, promoting the production of growth factors production and increasing cell proliferation (mitosis) and mobility (Hamblin, 2017; Wardlaw et al., 2019; Pryor et Millis, 2015). Photobiomodulation also induces the release of endorphins and serotonin, aiding in pain management, as well as facilitating axonal and nerve cell regeneration. These effects contribute to the recovery of spinal walking and the management of incontinence (Le Bleis, 2022; Sardar et al., 2016; Dybczyńska et al., 2022). There are several other mechanisms of action activated by Photobiomodulation to accelerate wound healing, reduce pain, and alleviate inflammation (Table 7) (Pryor et Millis, 2015).

Figure 4: Postoperative scar in a dog with TL – IVDE after 21 days without laser therapy **(A-B)** and with laser therapy **(C)** (Wardlaw et al., 2019).

Table 7: Summary of the processes occurring during photobiomodulation. Table adapted from (Pryor et Millis, 2015).

Pain	**Inflammation**	**Wound Healing**
-Increase in serotonin levels; -Elevation in beta endorphins which reduces the sensation of pain; -Reduction of bradykinins which induce pain sensation; -elevation in nitric oxide; -Normalization of ion channels; -Blocking of depolarization of C-fiber afferent nerves; -Elevation of nerve cell action potentials; -Improvement of axonal sprouting and nerve cell regeneration.	- Increased ATP production; -Stimulation of vasodilatation by inducting nitric oxide; -Stabilization of cellular membranes; -Reduction of interleukin-1; -Acceleration of leucocytes activity; -Enhancement of lymphocyte response; -Decrease in prostaglandin, synthesis; -Promotion of angiogenesis; -Regulation of superoxide dismutase levels.	-Enhanced leukocyte infiltration; -Increased macrophage activity; -Promotion of neovascularization; -Increased fibroblast proliferation; -Stimulated keratinocyte proliferation; -Facilitated early epithelialization; -Increased growth factors; -Improved wound tensile strength.

4.3.2. Precautions

However, several precautions must be taken int consideration. The use of protective eye wear for both dogs and clinicians are essential. This precaution is crucial due to the presence of chromophores, such as rhodopsin, which are abundant in retina. Additionally, it is recommended to avoid directing the laser directly into the eye, exercise caution when treating areas with dark hair or skin (as they absorb more light, leading to increased tissues heating), and cover examination tables or other metal surfaces to prevent light will reflection (Pryor et Millis, 2015).

Nowadays, lasers are classified into four categories depending on the power emitted radiation and associated risks. Class 1 lasers, emit low-power radiation (less than 0.5mW) and are considered safe without the need for eye protection. Conversely, class 4 lasers emit high-power radiation (greater than 500mW) with necessitate obligatory protective eyewear. Clinician must select the most suitable class of laser to deliver the adequate therapeutic dose (measured in $J.s^{-1}$) of light to the treated surface While many devices offer predefined treatment programs, they typically allow manual programming as well (Le Bleis, 2022).

4.3.3. Applications

Application of photobiomodulation for the treatment of acute TL – IVDE post-surgery has been investigated in several studies (Table 8). In a prospective study, dogs presenting with acute paraparesis or paraplegia due to acute IVDE with a Modified Frankel Score (MFS) of zero to three were evaluated. The authors compared two groups, one receiving low-level laser therapy after decompressive surgery, and the treatment was administered over five days or until reaching a MFS of four. The study concluded that the addition photobiomodulation to surgery decrease the time to recover ambulation in dogs with TL – IVDE (Draper et al., 2012). Another prospective study compared three groups of non-ambulatory dogs following hemilaminectomy for TL – IVDE. The first group received treatment with a laser without emission (placebo group), the second group was treated with physiotherapy along with non-therapeutic laser, and the last group received both physiotherapy and laser therapy. At the end, the authors did not find significative difference in the time taken to achieve autonomous standing position or walking among the groups. Additionally, there were no difference in postoperative opioid administration. These findings are in contradictions with those of a previous study by WE. Draper (Bennaim et al., 2017). A more recent study compared the time required for gait recovery post-surgery for TL – IVDE in two groups. The first group was treated with physiotherapy protocol alone, including massages, PROM, passive and active exercises (including balance exercises, Cavaletti rails, sit-to-stand, UWTM). The second group was treated with the same protocol of physiotherapy along with laser therapy. The conclusion drawn was that dogs treated with laser therapy demonstrated an improvement in neurological status (MFS higher). However, there is a trend towards a shorter time to regain ambulatory ability (MFS of four), although no significative difference was found between the two groups (Bruno et al., 2020). These studies indicate an improvement in recovery time for walking and neurological status with laser therapy, despite inconclusive results due to small sample sizes. Another study investigated the efficacy of laser therapy in wound healing after hemilaminectomy in dachshunds with TL – IVDE. Dogs were divided into two groups: one treated with laser therapy and the other without. Additional dogs were used to establish a scar score as a control test. Ultimately, scar scores were higher in laser group after 7 and 21 days, leading to the conclusion that laser therapy improved wound healing and cosmetic appearance (Wardlaw et al., 2019). Furthermore, other reviews include laser therapy into rehabilitation programs for its analgesic and anti-inflammatory effects, as well as its ability to accelerate healing and manage secondary issues such as urinary and fecal incontinence (Hodgson et al., 2017; Henea et al., 2023).

Table 8: Summary of the studies employing photobiomodulation treatment in dogs with TL – IVDE post-hemilaminectomy.

Reference	**Group**	**Protocol**	**Conclusion**
(Bruno et al., 2020)	24 dogs diagnosed with TL – IVDE following hemilaminectomy were divided in two groups: Group A: consisting of 12 dogs receiving only physiotherapy. Group B: consisting of 12 dogs receiving physiotherapy in addition to laser therapy.	Once a day, prior to physiotherapy sessions. Laser: class IV Energy density: 4 J/cm^2	-MFS between the two groups was significantly different with higher scores observed in the laser group. -There was a shorter time to recover ambulation in laser group, although the results were not significantly significant.
(Wardlaw et al., 2019)	A total of 12 dogs underwent hemilaminectomy after TL – IVDE. Group A consisted of 3 dogs	Daily application for a duration of 7 days. Laser: class 3b Energy density: 8	Scar scores showed significant improvement at both day 7 and day 21 with the application of

	used to establish a standardized scare scale score. Group B consisted of dogs receiving laser therapy, and group C consisted of dogs serving as the control group without laser therapy.	J/cm^2	laser therapy.
(Bennaim et al., 2017)	There were 32 non-ambulatory dogs divided into group A received sham laser treatment only; Group B, underwent physiotherapy along with sham laser treatment and group C, underwent physiotherapy in addition laser therapy.	Daily application for up to 5 days or achieving a MFS of 4. Energy density: 2-8 J/cm^2	-There was no significant difference observed among the three groups in terms of time to recover ambulation or opioid administration.
(Draper et al., 2012)	A total of 35 dogs experiencing acute paraparesis/paraplegia due to acute TL - IVDE with Modified Frankel Score (MFS), ranging from, 0 to 3 after surgery, were divided in group A, consisted of 17 dogs receiving laser therapy and group B comprising 18 dogs as the control group without laser therapy.	Daily application for up to 5 days or until achieving a MFS of 4. <u>Energy density</u>: 2-8 J/cm^2	-The time taken to achieve a MFS of 4 was significantly shorter in the laser group (3-5 days) compared to the control group (14 days).

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4.4. ULTRASONOTHERAPY

4.4.1. Definition and benefits

Ultrasound therapy is increasingly is gaining popularity in human medicine but remains little used in veterinary medicine. However, it is a treatment of choice and is recommended for managing TL - IVDE in dogs (Le Bleis, 2022). Ultrasonotherapy uses acoustic vibration waves to generate either thermal effects (in continuous mode) or mechanical effects (in pulsed mode). The pulsed mode delivers ultrasound in intervals, allowing tissues to cool between each sequence. This mode typically offers three intensity levels: 10 %, 20 % and 50 % of the vibration time over one second (Le Bleis, 2022; Dragone, 2010; Verebová et Staničová, 2021; Boström et al., 2022). These techniques are beneficial for rehabilitating musculosqueletal conditions, including muscle spasm, contracture, pain management, wound healing, and improving ROM (Millis, Levine et Taylor, 2013; Bockstahler et al., 2019).

4.4.2. Applications

The device comprises an alternating current generator which options of 1MHz for treating deep areas and/or 3 MHz for superficial areas., This generator supplies a transmitter head housing a transducer (either a piezoelectric disk or quartz blade), converting electrical energy into mechanical energy, specifically acoustic vibration (Dragone, 2010). Probe heads are available in several diameters (1, 2, 5 or 10 centimeters) and are applied directly to the skin with contact gel. In case of irregular surface, remote application is possible but there will be a loss of emission (McGowan, 2016). Power is expressed in $W.cm^{-2}$. Recommended power levels include 1.5 to 2 $W.cm^{-2}$ for the posterior muscles (medium and large breeds), 1 to 1.5 $W.cm^{-}2$ for lumbar and quadriceps muscles (medium and large breeds), and 0 .5 to 1 $W.cm^{-}2$ for tendons and small breeds. The maximum application surface should not exceed four times the probe head. Each area should be treated for a maximum of four minutes per session (Le Bleis, 2022; Bockstahler et al., 2019).

The use of ultrasound for postoperative pain in paraplegic dogs with TL – IVDE was reported in a recent study. However, it was merely a part of the protocol and was not specifically investigated for its efficacity (Henea et al., 2023).

4.4.3. Precautions

To prevent potential complications, it is recommended to avoid using ultrasounds on the eyes, heart (due to potential modification of the action potential), during gestation, on growth cartilage, gonads and brain tissue. Caution should also be taken in cases of tumors, thrombosis, infections and diabetes (Le Bleis, 2022).

5. CONCLUSION

Intervertebral disk herniation is a common pathology frequently encountered in neurology consultations for dogs. While functional rehabilitation constitutes an essential part of treatment, it is not systematically used by all clinicians. Today, pet tutors increasingly favor non-invasive and non-toxic treatments. Functional rehabilitation corresponds well to these expectations. Indeed, when techniques are carried out correctly, no secondary risk has been reported.

Functional rehabilitation offers a range of therapeutic properties depending on the material and techniques used. For instance, it is possible to manage pain with the use of postoperative cryotherapy, massages, TENS, photobiomodulation, PEMF and ultrasound. Furthermore, functional rehabilitation also accelerates wound healing. Cryotherapy and massages facilitate tissue drainage and improve blood circulation. While photobiomodulation stimulates cell metabolism, promoting wound healing. Passive and active movements, electrostimulation (NMES), PEMF, photobiomodulation, hydrotherapy and ultrasound exert positive effects on joints (preventing joint stiffness), bones (fighting bone demineralization), ligaments (preventing fibrosis and ligament retraction), and muscles (preventing amyotrophy, fibrosis and ischemia). Additionally, these techniques aid in correct spatial position (proprioception) for the animal. While each of these techniques can be used individually, synergistic application yields superior outcomes. The exercises should ideally be carried out several times per week, or even multiple times daily. If the owners are motivated, a lot of exercises can be explained and carried out at home, enhancing the animal’s chances of recovery.

Numerous studies highlight the advantages of physiotherapy in managing TL-IVDE. However, the efficacy of these treatments often remains inconclusive due to limited sample sizes in many studies. Future research studies should prioritize larger sample sizes with the same characteristics such as breed, sex, age, hernia stage, and neurological deficit) and consistent treatments protocols for yielding more robust and definitive conclusions.

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