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Clinical and gait profile of patients with lumbar disc herniation manifested as acute sciatica versus healthy controls: a case-control study

Dissertação de Mestrado em
Fisioterapia em
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Relatório de Investigação

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Relatório de Investigação apresentado para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Fisioterapia em Condições Músculo-Esqueléticas realizada sob a orientação científica da Professora Doutora Rita Fernandes e do Doutor Nuno Cristino.

Declaro que este Relatório de Investigação é o Resultado da minha investigação pessoal e independente. O seu conteúdo é original e todas as fontes consultadas estão devidamente mencionadas no texto, nas notas e na bibliografia.

O candidato,

Lisboa, 2 de dezembro de 2025

Declaro que este Relatório de Investigação se encontra em condições de ser apresentado a provas públicas.

A orientadora,

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Resumo

Perfil clínico e de marcha em pacientes com hérnia discal lombar manifestada como ciática aguda *versus* indivíduos saudáveis: um estudo de caso-controlo

Emily Pedroso, Rita Fernandes, Nuno Cristino

Introdução: A hérnia discal é o diagnóstico mais comum entre as alterações degenerativas da coluna lombar. Em aproximadamente 85–90% dos casos a hérnia discal causa ciática aguda. Tais alterações degenerativas apresentam padrões específicos de deterioração da marcha. Informação acerca de parâmetros da marcha reporta a existência de aumentos nos parâmetros temporais e diminuições nos parâmetros espaciais quando comparados com indivíduos saudáveis. **Objetivo:** Caracterizar variáveis clínicas e características biomecânicas dos parâmetros da marcha em pacientes com hérnias discal manifestada como ciática aguda e comparar os parâmetros de marcha com os de indivíduos saudáveis. Também, determinar como estas variáveis se correlacionam com *outcomes* clínicos. **Metodologia:** Foi realizado um estudo de caso-controlo com uma amostra de 19 indivíduos com hérnia discal lombar e 17 indivíduos saudáveis. *Outcomes* clínicos e parâmetros espaciotemporais da marcha foram avaliados. Parâmetros de marcha foram avaliados presencialmente com recurso a IMUs e avaliação de *outcomes* clínicos através de questionários. **Resultados:** Diferenças significativas entre os grupos foram encontradas nos parâmetros da marcha. Valores superiores no grupo de hérnia discal foram encontrados nos parâmetros espaciotemporais *stride, step* e *stance time*, *swing time* (lado sintomático), *double support* e *single support time* (lado não sintomático). Valores superiores no grupo saudável foram encontrados nos parâmetros *speed, cadence*, *stride* e *step length*. Índice de massa corporal ajustado como covariável influenciou o parâmetro *double support time,* que deixou de apresentar diferença entre grupos. Correlações significativas foram encontradas entre resultados da ODI, EQ-5D-3L, NPRS basal e pico do membro inferior e parâmetros espaciotemporais. Uma correlação forte foi encontrada entre a ODI e *stance time* (lado não sintomático). Intensidade da dor "pico" do membro inferior foi significativamente diferente entre o grupo severo e não severo da hérnia discal, com valores superiores no grupo severo. **Conclusão:** Pacientes com hérnia discal manifestada como ciática aguda apresentam alterações de marcha caracterizadas por diminuições nos parâmetros espaciais e aumentos nos parâmetros temporais quando comparados com indivíduos saudáveis. Apresentam variabilidade na intensidade da dor axial e valores altos de dor no membro inferior afetado. Estas alterações correlacionam-se com maior incapacidade, menor qualidade de vida e maior intensidade da dor. **Palavras-chave:** Hérnia discal lombar, ciática, parâmetros espaciotemporais, dor, incapacidade, qualidade de vida relacionada com a saúde.

ABSTRACT

Clinical and gait profile of patients with lumbar disc herniation manifested as acute sciatica versus healthy controls: a case-control study

Emily Pedroso, Rita Fernandes, Nuno Cristino

Introduction: Lumbar disc herniation (LDH) is the most common diagnosis among the degenerative abnormalities of the lumbar spine. In approximately 85–90% of cases, a herniated disc causes acute sciatica. Degenerative diseases such as LDH have unique patterns of gait deterioration. Information on gait parameters reports alterations including increases in temporal parameters and decreases in spatial parameters when compared to healthy controls. **Aim:** To characterize clinical and biomechanical gait characteristics in patients with LDH manifested as acute sciatica and compare gait variables parameters with healthy individuals. Also, to determine how these variables correlate with clinical outcomes. **Methodology:** A case-control study was carried out with a sample of 19 LDH patients and 17 healthy individuals. Clinical outcomes and spatiotemporal gait parameters were assessed. Gait parameters were assessed via onsite gait analysis with IMU's and clinical outcomes via clinical questionnaires. **Results:** Significant differences were found in gait parameters when comparing the LDH group with the healthy group, higher values in spatiotemporal gait parameters were found in the LDH group for stride time, step time, stance time, swing time (symptomatic side), double support time (non-symptomatic side) and single support time (non-symptomatic side). Higher values in spatiotemporal gait parameters were found in the healthy group for speed, cadence, stride length and step length. Body mass index adjusted as a covariate influenced double support time which no longer was different between groups. Significant correlations were found between ODI scores, EQ-5D-3L index values, baseline and peak NPRS leg pain scores and spatiotemporal parameters. A strong correlation was found between ODI and stance time (non-symptomatic side). Pain scores of lower limb peak pain differed significantly between severe and non-severe LDH, with higher scores in severe patients. **Conclusion:** Patients with LDH manifested as acute sciatica exhibit gait alterations characterized by decreases in spatial parameters and increases in temporal parameters when compared to healthy individuals. They present a variability of axial pain scores and high levels of pain scores in the affected lower leg. These alterations correlate with higher pain intensity, greater disability levels and lower health-related quality of life**.** **Keywords:** Lumbar disc herniation, sciatica, spatiotemporal gait parameters, pain, disability, health-related quality of life.

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Abbreviation list

LBP – Low back pain

NSLBP - Non-specific low back pain

SLBP – Specific low back pain

CT - Conventional Computed Tomography CT

MRI - Magnetic Resonance Imaging

LDH - Lumbar disc herniation manifested as acute sciatica

IMUs – Inertial measurement units

ODI – Oswestry Disability Index

NPRS – Numerical pai rating scale

BMI – Body mass index

Std – Standard deviation

IQR – Inter Quartile Range

SF-36 -Short Form 36

QOL – Quality of life

DoF – Degrees of freedom

Introduction

When it comes to musculoskeletal disorders, low back pain (LBP) ranks as the leading issue, distinguished by its high prevalence and as the most common cause of years lived with disability worldwide (Cruz et al., 2020; GBD 2021 Low Back Pain Collaborators, 2023; Konstantinou et al., 2018).

Low back pain covers a spectrum of different phenotypes of pain (nociceptive, neuropathic and nociplastic) that frequently overlap and is usually defined as pain, muscle tension, or stiffness localized below the costal margin and above the inferior gluteal folds, with or without leg pain (Koes et al., 2006; Knezevic et al., 2021). This heath problem, present in all developed countries, is most commonly treated in primary health care settings and has as its main symptoms pain and has a large impact on disability, perceived health and quality of life for the individual (Cruz et al., 2020; Koes et al., 2006).

When diagnosing LBP, management guidelines endorse the triage of patients with specific or non-specific low back pain (NSLBP). Non-specific low back pain is the most widespread form of LBP representing around 90% of patients with these symptoms, in essence, it is diagnosed based on the exclusion of specific serious pathology and therefore defined as symptoms without a clear cause (Koes et al., 2006). Specific low back pain (SLBP), defined as LBP with symptoms caused by a specific medically serious pathology, (infection, osteoporosis, rheumatoid arthritis, fracture, tumor or herniated discs) represents less common cases of LBP that require diagnostic work-up or specialist referral, or both (Maher et al, 2017; Koes et al., 2006). The triage includes the fundamental identification or exclusion of red flags as indicators of possible underlying serious pathology. Only in these cases, where red flags are identified, might imaging be indicated (Maher et al, 2017; Koes et al., 2006). Lumbar disc herniation (LDH) and lumbar stenosis are both degenerative lumbar spine diseases which present with a range of symptoms such as lumbar pain, sciatica and neurogenic intermittent claudication (Natarajan et al., 2022). Regarding LDH specifically, which falls into the category of SLBP, it is the most common diagnosis among the degenerative abnormalities of the lumbar spine with its typical clinical picture including initial lumbar pain, followed by sciatica and is the principal cause of spinal surgery among the adult population (Vialle et al., 2015). More than 90% of disc herniations occur at the L4-L5 or L5-S1 disc space in the lumbar spine, subsequently compressing the L4, L5 or S1 nerve roots and resulting in sciatica (Al Mulhim et al., 2023). Radiculopathy, per se, refers

to inflammation, injury, or compression of the spinal nerve roots, and can present itself as pain, weakness, or numbness with a myotome or dermatome distribution, representing a true neurological deficit and as mentioned above may be caused by LDH (Rogerson et al., 2019; Schmid et al., 2023; Zaina et al., 2023). Sciatica is the term most used in literature to describe study populations presenting radiating leg pain or symptoms associated with back pain (Davis et al., 2022; Liu et al., 2023). It is relevant to note that sciatica is specific to the pain that is a direct result of sciatic nerve or sciatic nerve root pathology, yet the term is not clearly defined and frequently any LBP and/or radicular leg pain is incorrectly labeled as sciatica (Davis et al., 2022; Lin et al., 2014). Other terms are used such as nerve root pain, pseudo radicular pain, neural mechanosensitivity, radicular pain, somatic referred pain, lumbar radiculopathy, and LDH associated with radiculopathy, which may have distinct entities and different symptoms (El Melhat et al., 2024; Lin et al., 2014; Schmid et al., 2023).

Lumbar disc herniation manifested as acute sciatica is largely a clinical diagnosis based on the person's symptoms and findings on examination (Jensen et al., 2019; Vialle et al., 2015). No specific test exists for the diagnosis of sciatica, although clinical presentation and a combination of positive findings on examination increases its likelihood (Jensen et al., 2019). Besides clinical imaging, a positive neural tension test with provocation of pain in the affected leg should be present with possible neurological deficit associated with the involved nerve root (muscle weakness/ absence of tendon reflexes/sensory deficit) (Davis et al., 2022; Jensen et al., 2019). Imaging examinations are often used in patients with LBP and/or leg pain to assess the compression of a nerve root caused by LDH (Divi et al., 2021). Conventional Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) are studied to be best exams to perform for the diagnosis of LDH and lumbar stenosis, with MRI being the imaging modality of choice, given its relatively high sensitivity (75%) (Divi et al., 2021; Huang et al., 2023; Kim et al., 2018; Koes et al., 2006).

Approximately 5–15% of patients that present with SLBP suffer from LDH manifested as acute sciatica (Davis et al., 2022; Kim et al., 2018; Liu et al., 2023; Pojskic et al., 2024; Rogerson et al., 2019). In approximately 85-90% of cases, a herniated disc causes lumbar nerve root compression at the recess and/or intervertebral foramina of the lumbar spinal canal causing perineural inflammatory reaction and irritation of the sciatic nerve leading to acute sciatica disease (Davis et al., 2022; Kim et al., 2018; Liu et al., 2023; Rogerson et al., 2019).

Sciatica is a heterogeneous condition likely caused by differing mechanisms in individual patients (Fourré et al., 2023; Schmid et al., 2023). Low back pain that radiates to the leg is not always related to a lesion or a disease of the nervous system. In sciatica patients, some may experience a main clinical picture of neuropathic pain and others may experience a main clinical picture of nociceptive pain (Fourré et al., 2023; Konstantinou et al., 2018; Schmid et al., 2023). Many cases are a combination of both neuropathic and nociceptive pain, with one of these being the predominant mechanism (Fourré et al., 2023). The most common cause of neuropathic pain in LBP patients is the compression of neural structures such as sciatica due to LDH, being clinically important as the prognosis of a patient with predominant neuropathic pain is worse, with increased suffering and disability, when compared with a patient with nociceptive pain (Fourré et al., 2023; Schmid et al., 2023).

Lumbar disc herniation manifested as acute sciatica is associated with worse overall outcomes compared to LBP alone (Schimd et al., 2023; Konstantinou et al., 2018). Several studies have shown a favorable natural history of sciatica due to LDH with most patients having symptoms that substantially resolved 4 to 8 weeks (Jensen et al., 2019; Konstantinou et al., 2018). Despite its favorable clinical course, at least a third of patients develop persistent sciatica symptoms such as pain and disability lasting a year or longer (Schimd et al., 2023; Rogerson et al., 2019). In more severe cases or cases where the neurologic deficit is present, the patient may have a more prolonged recovery course (Davis et al., 2022; Fairag et al., 2022). Other studies have proven furthermore a good prognosis for LDH manifested as acute sciatica with approximately 75% of the patients recovering after 3 months. Further literature found success rates of 80% for surgically treated patients and 56% for non-surgically treated patients at 1 year post onset, with additional studies presenting results that approximately 80% of surgically treated patients and 60% of non-surgically treated patients reported major improvement after 1 and 2 years of follow-up (Haugen et al., 2012).

Lack of prognostic factors poses a disadvantage as it impairs the prediction of recovery of pain and function in this population, early identification of patients at risk of developing persistent symptoms as well as identifying and developing the best course of treatment for acute sciatica symptoms (Jensen et al., 2019; Schmid et al., 2023).

International guidelines for the management of sciatica recommend a stepwise model approach starting with conservative management (non-steroidal anti-inflammatory drugs and physical therapy with opioid analgesics recommended for severe pain that does not

improve with over-the-counter painkillers) escalating to steroid injections (Liu et al., 2023; Schmid et al., 2023). Second-line treatments for individuals whose symptoms have persisted for at least 4 to 6 weeks and who are not responding to conservative care include translaminar epidural injections and selective nerve root blocks (Awadalla et al., 2023). When these non-surgical interventions fail and if radiological findings are consistent with symptoms or when major radicular weakness is present, surgery is considered (Liu et al., 2023; Schmid et al., 2023).

Regarding LDH manifested as acute sciatica's clinical presentation, it represents a debilitating condition characterized mainly by pain, numbness and/or paresthesia within the sciatic nerve distribution (pain most commonly radiating posteriorly at the leg and below the knee) (Davis et al., 2022; Jensen et al., 2019). It is associated with higher levels of pain, disability, poorer quality of life and increased use of health resources compared with LBP alone. Additionally, leg pain is usually worse than the pain in the back, and patients may describe the affected leg as "feeling heavy" (Davis et al., 2022; Lee et al., 2021; Schmid et al., 2023).

Gait is a clinically important biomarker for the identification, assessment and evolution of different pathologies, such as sciatica. Existing and frequently used tests such as the 10-Meter Walk Test, the 6-Minute Walk Test and the Timed Up and Go test are used to assess gait. These tests, besides not specifying which gait parameters differ from healthy individuals, also focus on a single quantitative parameter of gait, overseeing the quality of gait (Natarajan et al., 2022). Patients with LBP often report difficulties with walking, and usually walk slower than their healthy peers, furthermore, gait coordination is changed in these patients (Huang et al., 2011). The degeneration of the intervertebral disc, in addition to back pain, potentially causes gait kinetic and kinematic variations as well as postural changes (Krekoukias et al., 2021). Walking and running patterns are frequently assessed in individuals with acute and persistent LBP, with previous work highlighting biomechanical differences in individuals with persistent LBP compared to pain-free controls (Natarajan et al., 2022; Smith et al., 2022). Evidence supports that individuals with persistent LBP tend to walk significantly slower and present shorter spatial parameters such as stride length. Such work is lacking in the LDH population (Natarajan et al., 2022; Smith et al., 2022).

Although varying in symptoms and severity, degenerative lumbar diseases like LDH are theorized to be associated with biomechanical impairments of spinal muscles resulting

in energy-inefficient gait patterns and subsequently a deterioration of gait quality and capacity (Natarajan et al., 2022). Existing literature on the subject suggests degenerative diseases of the lumbar spine have unique patterns of gait deterioration, although until now, only few studies have tried to detail the precise variables affected in the walking pattern of LDH (Lee et al., 2021; Natarajan et al., 2022).

A study identified that gait instability in patients with LDH may occur due to an increase in pain, displaying a positive correlation between the characteristic of the stance phase, swing phase, single support and lumbar pain (assessed by the numeric pain rating scale), suggesting that LDH leads to a more asymmetrical gait pattern, with increased pain correlating with greater temporal imbalance between the affected and unaffected lower limb (Lee et al., 2021). Additional literature provides more precise information on gait parameters, reporting that altered variables in LDH include increases in temporal parameters (gait cycle duration, double-limb support and swing duration) and decreases in spatial parameters (gait cycle length, gait velocity and cadence) when compared to healthy controls, portrayed as typical gait alterations in these patients (Natarajan et al., 2022).

Gait evaluation performed preoperatively in LDH patients submitted to microdiscectomy revealed significantly longer step duration, longer gait cycle duration, longer double stance duration and longer swing duration, shorter step length, shorter gait cycle length, slower velocity and less in cadence when compared with healthy controls (Bonab et al., 2023). Postoperatively, significant differences between the preoperative and postoperative gait assessment were found in all spatial and temporal gait parameters. In this phase, 15 days post-op, patients presented with shorter temporal parameters and longer spatial parameters (step duration, gait cycle duration, double stance duration, swing duration, step length, gait cycle length, velocity and cadence) (Bonab et al., 2023). When comparing the spatiotemporal parameters of healthy subjects with those of the post-operative group, temporal parameters were found to be resembling and with no statistically significant difference between both groups (step duration, gait cycle duration, double stance duration, swing duration. Spatial parameters (step length and gait cycle length, velocity and cadence), on the other hand, were statistically different. Although these parameters improved from pre-op to post-op, they remained decreased when compared to the healthy subjects, suggesting that these parameters take longer to recover post-surgery (Bonab et al., 2023). Comparing gait parameters in the affected versus non-affected leg in LDH patients, revealed that

spatiotemporal parameters, such as single-step time, showed significant differences between both sides, whereas, in the same study, no notable gait differences were found between the left and right legs in healthy subjects (Wang et al., 2023). Findings from a 2024 case report corroborate with findings of previous studies, exhibiting that parameters such as speed, stride length, and cadence were lower in patients with a herniated disc when compared with a control group in a preoperative period (Santos et al., 2024).

Besides observing that LDH patients had significantly longer step duration, gait cycle duration, swing duration, shorter step length, gait cycle length, slower walking speed and less cadence when compared to a healthy control group, a 2020 study also revealed a strong correlation between pain intensity and temporal gait parameters (Bonab et al., 2020). While in other studies information regarding correlation between pain and gait parameters is scarce, this study found a considerable negative correlation between pain intensity and spatial gait parameters such as step length, stride length, cadence and velocity. (Bonab et al., 2020). They also obtained significantly positive correlations between pain intensity and temporal parameters such as step duration, swing duration and double stance duration (Bonab et al., 2020).

A study focusing on gait instability via a gait symmetry index found a positive correlation between lumbar pain intensity and gait instability in LDH patients, increases in pain were correlated with greater gait instability during the stance phase, swing phase and single support phase (Lee et al.,2021). Although the findings suggest pain impacts gait stability, these findings do not provide clear insight into specific spatiotemporal changes.

The existing literature suggests a correlation between disease severity and changes in gait spatiotemporal parameters, though further investigation of these alterations across different severity grades is still needed.

Previous studies have revealed significantly positive correlations between pain intensity (assessed via the visual analogue scale) and gait parameters such as bilateral step duration, bilateral gait cycle duration and bilateral swing duration. This work highlighted a significantly strong positive correlation between pain intensity and bilateral double stance duration. They also reported strong negative correlations between pain intensity and parameters such as bilateral step length and bilateral gait cycle length. They highlight a significant strong negative correlation between pain intensity and speed as well as cadence (Bonab et al., 2020) the authors of this work later emphasize these correlations of posterior

work regarding the comparison of gait parameters in LDH patients when compared to healthy individuals (Bonab et al., 2023).

To summarize, studies differentiate severity of LDH manifested as acute sciatica primarily through pain intensity, neurological deficits, functional impairment, and sometimes the anatomic level of herniation, rather than just the radiological size (Costa et al., 2024; Parwani et al., 2025). Severe cases typically present high pain scores, loss of motor function, and significantly limited daily activity and are more likely to be treated surgically. Less, or, non-severe cases, with milder symptoms are managed primarily with conservative treatment (Costa et al., 2024; Kreiner et al., 2014; Parwani et al., 2025; Zhang et al., 2022). Furthermore, current evidence also suggests a correlation between disease severity and changes in gait spatiotemporal parameters, however, only a limited number of studies have explored this association across the different severity grades (Parwani et al., 2025; Kreiner et al., 2014; Zhang et al., 2022; Bonab et al., 2023; Bonab et al., 2020). Apart from the limited existing number of studies, they also present some limitations, they mention limitations such as small sample sizes with heterogeneous patient populations, a lack of standardized protocols for evaluating LDH severity and sparse and less advanced motion caption technology to assess gait with conclusions are based only on basic laboratory based gait measurements which they mention might not fully reflect real life biomechanics (Parwani et al., 2025; Kreiner et al., 2014;; Zhang et al., 2022; Bonab et al., 2023; Bonab et al., 2020).

Single-point wearable inertial sensors such as inertial measurement units (IMUs) have recently been introduced into clinical practice as a relatively lower costing alternative for gait analysis, currently used in the assessment of gait in lumbar degenerative diseases (Natarajan et al., 2022). They have been proven to be valuable and feasible for supervised kinematic analysis (Brognara et al., 2019; Caldas et al., 2017).

The review of patient's specific movement patterns and possible altered biomechanics is considered paramount to better characterize patients at baseline assessment and for predicting outcomes, identifying the possible risk of complications, recurrent injury or even symptom resolution (Campos et al., 2022; Waghe et al., 2024). As several questions regarding LDH manifested as acute sciatica remain unanswered with the existing literature, studies to provide a more detailed assessment of the characteristic gait pattern of these patients is essential. A clinical and kinematic characterization of this population to define

which variables better represent the disease severity, could enable further studies to identify, at an earlier stage, the hallmarks of LDH manifested as acute sciatica and better predict treatment outcomes. The objective of the present study is to characterize the gait spatiotemporal patterns of patients with LDH manifested as acute sciatica, and to correlate them with pain intensity, disability and health related quality of life. Additionally, it aims to compare gait spatiotemporal parameters between patients with LDH manifested as acute sciatica and healthy individuals and between severe and non-severe patients with LDH manifested as acute sciatica. The identification of biomechanical markers associated with worst symptoms may enable further studies to investigate how these parameters change with disease progression, allowing a more standardized approach to conservative treatment versus surgical planning with better transition for minimal invasive procedures, reduced risks, lower costs, and maximized clinical outcomes.

Methodology

Type of Study

In light of the study's objective, an observational analytic case-control study was conducted with a sample of 19 patients with a diagnosis of lumbar disc herniation manifested as acute sciatica and 17 healthy individuals.

Sample

Patients were recruited at the outpatient clinic of the Neurosurgery Department of Hospital da Luz Setúbal and healthy individuals were recruited both at the Neurosurgery Department of Hospital da Luz Setúbal and at the Clínica Luísa Todi of the Hospital da Luz Setúbal (primary centers). Main criteria for recruitment of patients were the diagnosis of LDH manifested as acute sciatica and for recruitment of healthy individuals was the absence of current and previous history and symptoms of LDH manifested as acute sciatica.

Inclusion and exclusion criteria

To be included in the study, patients had to follow the defined inclusion criteria: **(1)** age between 18 and 65 years; **(2)** established diagnosis of LDH by clinical criteria and magnetic resonance imaging (protrusion, extrusion, or sequestered fragment); **(3)** evidence of sciatic nerve-root irritation with a positive nerve-root tension sign (positive straight leg raise) or a corresponding neurologic deficit (asymmetrical depressed reflex, decreased sensation in a dermatomal distribution, or weakness in a myotomal distribution); **(4)** less than 2 months of symptom duration; **(5)** ability to give informed consent; **(6)** ability to read and fluently speak Portuguese (Weinstein et al., 2006; Lee et al; 2021). Patients were excluded if they presented any of the following exclusion criteria: **(1)** previous spine surgery; **(2)** isthmic spondylolisthesis; **(3)** cauda-equina syndrome; **(4)** neurological disease that might interfere with walking; **(5)** known orthopedic conditions that significantly cause gait impairment as per investigator judgement; **(6)** severe comorbidity; **(7)** vertebral fractures; **(8)** spine infection or tumor; **(9)** pregnancy; **(10)** dementia or developmental disorders with low intelligence quotient or any other form of cognitive impairment; **(11)** inability to give informed consent (Peul et al., 2008; Lequin et al., 2013).

Healthy individuals had to follow the defined inclusion criteria: **(1)** age between 18 and 65 years; **(2)** no symptoms of LDH manifested as acute sciatica; **(3)** no previous history of LDH manifested as acute sciatica; **(4)** ability to give informed consent; **(5)** ability to read

and fluently speak Portuguese; **(6)** previous history of low back pain did not excluded the healthy control, as long as there was no acute pain at the time of evaluation (Weinstein et al., 2006; Lee et al; 2021; Zhang et al., 2022; Bonab at al., 2023). Healthy individuals were excluded if they presented any of the following exclusion criteria: **(1)** previous spine surgery; **(2)** isthmic spondylolisthesis; **(3)** cauda-equina syndrome; **(4)** neurological disease that might interfere with walking; **(5)** known orthopedic conditions that significantly cause gait impairment as per investigator judgement; **(6)** severe comorbidity; **(7)** vertebral fractures; **(8)** spine infection or tumor; **(9)** pregnancy**; (10)** dementia or developmental disorders with low intelligence quotient or any other form of cognitive impairment; **(11)** inability to give informed consent (Peul et al., 2008; Lequin et al., 2013; Zhang et al., 2022).

Recruitment

Patients assessed at a neurosurgery appointment in the Neurosurgery Department of Hospital da Luz Setúbal, who presented with eligible symptoms, a confirmed diagnosis of LDH and who met all inclusion criteria, were invited to participate in the study by the attending neurosurgeon. Healthy individuals were recruited both at the Clínica Luísa Todi of the Hospital da Luz Setúbal and the Hospital da Luz Setúbal whenever they were evaluated for non-lumbar disease related routine follow-up medical appointments.

Ethical Considerations

Those who agreed to participate remained at the hospital or clinic after their consultation to receive a detailed explanation of the study, including its aims and procedures, also to provide written informed consent. After confirming eligibility and obtaining consent, each participant was assigned an individual study ID to ensure total anonymity. The study protocol was submitted to and approved by the Grupo Luz Saúde Research Committee and the Hospital da Luz Ethics Committee to ensure that all procedures adhered to ethical standards and complied with national and international guidelines for human research, including the Declaration of Helsinki (World Medical Association, 2024).

Following the necessary requirements such as participant eligibility criteria, recruitment procedures, informed consent, study explanatory letter and confidentiality measures, the study was formally authorized to be conducted. All participants received a detailed explanatory letter (Annex 1) outlining the study's aims and procedures and were given the opportunity to ask questions before providing their written informed consent (Annex 2). Participation in the study was fully voluntary with the option to withdraw at any

time. The listed procedures ensured that the study was in full accordance with the required ethical norms governing research with human participants (Vanclay et al., 2013). Each participant was assigned an individual study ID to ensure anonymity and compliance with data protection guidelines of the hospital. Data was anonymized under the responsibility of the research team leader. All the databases were also declared to the Grupo Luz Saúde Data Protection Officer and Hospital da Luz Setúbal Ethics Committee for approval.

Procedures

The inclusion and exclusion criteria were identified by the neurosurgeon during the appointment when undergoing a standard clinical assessment (including image assessment) at baseline. Baseline data was defined as data collected no later than two weeks before selected treatment started. Posteriorly, participants were instructed to fill in a questionnaire to assess health-related quality of life, the EQ-5D-3L (Annex 3), and a questionnaire to assess level of disability due to their symptoms, the Oswestry Disability Index (Annex 4). These forms could be filled out in the waiting room or in a private room. Forms were then reviewed by the assistant nurse or physiotherapist to grant the full filling in of the whole form. Following, participants were interviewed by the assistant nurse regarding demographic and clinical data for both hospital informatic registration and study purposes. The responsible physiotherapist conducted on-site quantitative gait analysis using a 3D full-body kinematics analysis system based on inertial sensors (Xsens, Technologies B.V. Enschede, Netherlands). Fifteen inertial measurement units (40Hz) were placed and secured using elasticated velcro straps in the protocolled body segments (first on head, second on thorax, third and fourth on each upper arm, fifth and sixth on each forearm, seventh and eighth on each hand, ninth on sacrum, tenth and eleventh on each thigh, twelfth and thirteenth on each shank and fourteenth and fifteenth on each foot as shown in instructions) (Alberto et al., 2021) (Figure 3 - Appendix 1).

Once sensors were placed, all 15 detected and calibrated by the software, the individual to be assessed would be instructed to walk an established 10-meter corridor at a comfortable, self-selected walking speed, enabling the capture of natural walking cycles (Figure 4 - Appendix 2). The instruction was to walk the corridor 3 times, have a 2-minute rest, walk the corridor 2 times, have another 2-minute break and walk the corridor 1 last time, giving that pain levels allowed so that the person was able to do so safely. All individuals tried to complete all 3 registers (3 walks, 2 walks, 1 walk) of the gait analysis. In

cases where severe pain was present, the test was interrupted, avoiding exacerbation of the patients' symptoms and data would be partially recorded. Removal of sensors and inspection to guarantee patient safety was conducted, and data collection and storage was then completed. Raw data files were saved immediately after acquisition to prevent data loss. Each gait cycle was saved into a file and classified as "T_(timing of evaluation) _Ciclo_(number of the walking cycle)". Raw data files were uploaded onto the Kinetikos Health platform for a posterior gait analysis report and generation of spatiotemporal parameter data. Only data from the highest completed register of each patient was used for the analysis. Therefore, for patients who successfully completed all 3 corridor walks, only data from this corresponding cycle – the 3rd - was used (as for patients who only successfully completed 2 corridor walks and 1 corridor walk).

All the health personnel had previous skill training on how to apply the equipment, conduct the test and register the collected data. The skill training was indispensable and key points such as the correct placement of sensors, well and tight fit of the velcro straps for no sensor movement, correct sensor calibration and raw data saving were emphasized. Participants would then proceed to scheduling their next appointment and receive treatment accordingly with usual standard care without any influence from the investigators. The study procedures did not influence the usual decision-making process by the neurosurgeon and assessments were performed at normal scheduled visits to the outpatient clinic.

Research instruments and clinical assessment

Sociodemographic and clinical characterization was done via questioning by the assistant nurse, following the usual questioning conducted during the neurosurgeons' consultations. This characterization included demographic data such as age, gender, and exercise habits. Clinical characterization included height, mass, calculation of body mass index (BMI), previous surgeries, comorbidities, detailed description of symptoms and past and present medication.

Pain level was assessed at axial (lumbar) and irradiated level (lower limb) using the numeric pain rating scale (NPRS) (Annex 5). The left-most end of this scale classifies patients pain level as with "no pain" and the right-most end with "worst pain imaginable", numbers from 0 to 10 are spaced evenly across the page representing pain level (Correll.,2011). Patients are instructed to circle the number that represents the amount of pain (axial and irradiated) at baseline and peak levels (Correll., 2011). Its fast and ease of

use is an advantage for pain assessment. High test–retest reliability has been observed in both literate and illiterate patients (r = 0.96 and 0.95) (Ferraz et al., 1990). The NPRS was shown to be highly correlated with the visual analogue scale with correlations range from 0.86 to 0.95 (Ferraz et al., 1990). Disadvantages of the NPRS exist. One notable disadvantage is its ceiling effect, if a patient reports a pain level of "10" at one time point and the pain later worsens, the scale provides no way to capture this change, since "10" remains the maximum score (Correll, 2011).

Oswestry Disability Index (ODI) was used to quantify disability. It is a scale used for NSLBP and SLBP to measure the level of disability caused by the symptoms, assessing pain intensity and how the leg and back pain affect nine daily activities (Fairbank & Pynsent., 2000). The ODI is a reliable and valid scale suitable for measuring disability in patients with LBP (Lee et al., 2017). This validated questionnaire was first published by Fairbank et al (980) and the current version is now registered with the International Consortium for Health Outcomes Measurement as a standard outcome measure (Bielewicz et al., 2022). The ODI is easy to administer and score, objectifies clients' complaints, and monitors effects of therapy.

The Portuguese version of the ODI demonstrates having excellent psychometric properties, reliable in its translated form and for its targeted population (Martins., 2002; Pereira., 2003). Furthermore, the adapted questionnaire shows excellent internal consistency (Cronbach's α=0,95) and very high test-retest reliability (r=0.90). The adapted questionnaire also shows strong construct validity (r between -0.59 to -0.75), assessed using correlations with the Short Form 36 (SF-36) health measurement, indicating that higher disability scores correspond to lower quality of life. Additionally, the ODI can effectively discriminate between different patterns of pain location, including no irradiation, proximal irradiation, and distal irradiation (Martins., 2002; Pereira., 2003). Additionally, it shows a standardized response mean of 0.93 (assessed before and after 4 weeks of physiotherapy), demonstrating good sensitivity to detect clinically relevant changes over time (Martins et al., 2002; Pereira et al., 2003).

The original version of the ODI demonstrates having excellent psychometric properties with good internal consistency (Cronbach's α=0,85), with very high test-retest reliability with values ranging from 0.83 to 0.99 depending on the time interval between measurements. Comparison with other condition-specific outcome measures such as the

Roland-Morris Disability Questionnaire and the Quebec Back Pain Disability Scale, as well as comparison with general health questionnaire such as the SF-36, yields comparable results in terms of validity, reliability, and responsiveness (Saltychev et al., 2017; Vianin, 2008).

The EQ-5D-3L (EuroQol Group) is a concise, generic measure of self-reported health which evaluates the generic quality of life (QOL), developed in Europe and widely used (Balestroni & Bertolotti., 2012). It's a questionnaire developed to be brief, minimize the burden of extensive data collection, and to be used in a spectrum of health care sectors (Garratt et al., 2024; Devlin & Brooks., 2017). The '5D' refers to its use of 5 dimensions for describing health states, being them mobility, usual activities, self-care, pain & discomfort and anxiety & depression (Devlin & Brooks., 2017). Being generic rather than specific in focus, this questionnaire includes a health profile applicable in different health conditions and complements more narrowly focused, disease-specific patient reported outcomes (Garratt et al., 2024; Devlin & Brooks., 2017).

In the same manner as the ODI, a Portuguese adaptation of the instrument was used. The Portuguese version of the EQ-5D-3L was finalized in 1998, based on orientation by the EuroQol group (Ferreira et al., 2013) who found that the Portuguese version of the EQ-5D has good acceptability, reliability, and validity in measuring the health status of its users.

The adapted questionnaire shows acceptable internal consistency (Cronbach's α=0.716) and strong test-retest reliability, confirmed with moderate Cohen's k values in the dimensions of 'self-care' (k = 0.586) and 'pain/discomfort' (k = 0.555) and as for the questionnaires remaining dimensions, good Cohen's k values (mobility: k = 0.647; usual activities: k = 0.308; anxiety/depression: k = 0.633). Validity of the adapted questionnaire was supported by positive associations of low EQ-5D scores with increasing age and presence of illness, plus correlations with dimensions of the SF-36v2 (Ferreira et al., 2013). The original version of the EQ-5D-3L questionnaires shows an acceptable internal consistency (Cronbach's ~ 0.70), good test-retest reliability (ICC $\geq$0.70). The original version's validity has been supported primarily in comparison to the EQ-5D-5L as well as established physical, mental, and self-perceived health measures commonly used in health research (CASP quality of life scale, EURO-D scale for depression and anxiety) (Buchholz et al., 2022; Michalowsky et al., 2022; Tai et al., 2025). Also, findings in literature support the construct validity of the EQ-5D-3L for use in patients with LBP scheduled for total disc replacement. Scores from the EQ-5D-3L showed moderate to high correlations with the ODI,

Visual Analogue Scale and the Hopkins Symptom Checklist-25, reflecting expected relationships between generic health status and disease-specific or symptom-based measures (Garratt et al., 2020).

Quantitative gait analysis using a 3D full-body kinematics analysis system based on inertial sensors was performed for the objective assessment of participants gait pattern. The use of inertial measurement units shows strong evidence in reliability and validity in spatiotemporal parameters and joint kinematics (Kobsar et al., 2020; Yin et al., 2025). Inertial measurement units have demonstrated high validity and reliability for assessing spatiotemporal gait parameters. Combined data from previous studies showed excellent agreement with gold-standard measurements for speed, cadence, step/stride time, and step/stride length (ICCs ≥0.954) (Yin et al., 2025).Test-retest reliability was also high, with walking speed, cadence, step/stride time, stance/swing time, and step/stride length showing excellent reliability (summary ICCs ≥0.941), while variability measures such as swing/stance time, step time variability, and stride time variability exhibited good to moderate reliability (summary ICCs 0.501–0.757) (Yin et al., 2025).

Data processing

Data was processed by KinetikosOS CE-marked cloud-based platform (Kinetikos, Coimbra, Portugal) and then used to reconstruct participants' full-body motion using a 3D kinematic computer model of the skeletal system, including the head, trunk, upper and lower limbs, totaling 26 degrees of freedom (DoF). IMU orientation data, along with inertial and angular velocity measurements, were recorded through the Kinetikos application.

In the KinetikosOS CE-marked cloud-based platform inverse kinematics was applied to estimate joint angles at each time frame by minimizing the error between experimental IMU orientations and model-defined IMU frames through a global optimization procedure. From the reconstructed joint angles and detected gait events, spatiotemporal gait parameters were calculated.

Data Analysis

Data analysis and statistical processing were performed using the Statistical Package for the Social Sciences (SPSS) software for Windows, version 30.0.

The data analysis was centered on the study of the sociodemographic characterization of the groups as well as the study of the spatiotemporal variables. Nominal variables included sex, exercise habits (yes/no) and leg pain laterality (left leg pain/right leg pain). Quantitative

variables included age, height, mass, and BMI, gait parameters, pain scores, EQ-5D-3L scores, and ODI scores.

Descriptive analysis was used to systematize information regarding the characterization of the study groups, and descriptive statistics were calculated to analyze measures such as mean, median, standard deviation and interquartile range (IQR) for gait parameters, ODI scores, EQ-5D-3L index scores, and pain scores.

A significance level of $p \leq 0.05$ was adopted. Data normality was tested using the Shapiro–Wilk test. As data normality was not met for all variables in either the LDH group nor the Healthy group, the Mann–Whitney U test was used for quantitative variables and the Fishers Exact test for categorical variables to compare groups in sociodemographic variables.

Comparison of sociodemographic variables between the LDH group and healthy group was conducted to check for significant differences between both groups. Posteriorly, descriptive statistics were calculated to analyze measures such as median and interquartile range for spatiotemporal parameters. These descriptive statistics were calculated for gait parameters prior to the Mann–Whitney U test for analysis of differences of gait parameters between the LDH and healthy group. The non-parametric Mann Whitney U test was used on all gait parameters when comparing these groups. Spatial gait parameters analyzed were speed (m/s), cadence (steps/min), step length symptomatic and non-symptomatic side (cm), stride length (cm) and step width (cm). Temporal gait parameters analyzed were step time symptomatic and non-symptomatic side (s), stride time (s), stance time symptomatic and non-symptomatic side (s), swing time symptomatic and non-symptomatic side (s), double support time symptomatic and non-symptomatic side (s), single support time symptomatic and non-symptomatic side (s).

Number of gait cycles for each group was taken into consideration (LDH group: lowest - left 12 / right 13 cycles, highest – left 63 / right 62 cycles, mean left = 52,89 / mean right = 52,47; healthy group: lowest - left 15 / right 17 cycles, highest – left 95 / right 98 cycles, mean left = 51,35 / mean right = 51,53).

Non-parametric ANCOVA test was conducted to adjust BMI as a covariate as this variable was significantly different between the LDH group and health group. For the analysis of the correlation between gait parameters and clinical outcomes (pain intensity: NPRS axial baseline pain, NPRS axial peak pain, NPRS baseline leg pain, NPRS

For the analysis of the subgroups (LDH severe versus LDH non-severe), the analysis procedure was conducted as described above for the comparison of the LDH group and healthy group. Analysis of the sociodemographic variables was conducted, as was the comparison of gait spatiotemporal parameters between the LDH severe and LDH non-severe group.

In this subgroup analysis, comparison of the clinical outcomes (ODI scores, EQ-5D-3L scores and pain intensity: NPRS axial baseline pain, NPRS axial peak pain, NPRS baseline leg pain, NPRS peak leg pain) was conducted via the Mann-Whitney U test to analyze differences in these variables between the subgroups.

Results

Sociodemographic characterization of groups (LDH versus Healthy)

The present study included a total of 36 participants, of which 19 individuals diagnosed with lumbar disc herniation manifested as acute sciatica (LDH) and 17 healthy individuals. Table 1 summarizes the sociodemographic characteristics of the participants, including age, mass, height, BMI, gender and exercise habits. The total sample consisted of 22 women (57.9%) and 14 men (36.8%). In the LDH group the mean age was 50.37 ± 13.45 and 41.47 ± 16.74 years in the healthy group. Both groups consisted predominantly of female participants (LDH 53%, Healthy 71%). The groups exhibited similar mean heights, with the LDH group presenting a mean height of 169.2 cm ± 9.29 cm and the healthy group a mean height of 168.06 cm ± 11.62 cm. The groups presented similarities regarding body mass (LDH group: median = 76 kg, IQR = 26 kg; healthy group: median = 68 kg, IQR = 16.5 kg). Body mass index was also calculated (LDH group: median = 27.25, IQR = 5.16; healthy group: median = 23.39, IQR = 5.10). Regarding physical activity, 19 participants reported engaging in regular exercise, while 16 did not (1 missing value). Within the LDH group, the majority of participants did not exercise (53%), whereas in the healthy group, most reported regular physical activity (65%).

There were no statistically significant differences between the groups in terms of age ($p = 0.086$) and height ($p = 0.745$). Body mass also did not differ significantly between groups ($p = 0.071$), however, statistically significant differences in BMI were present ($p = 0.023$). No statistically significant differences were observed for gender ($p = 0.322$) or exercise habits ($p = 0.326$). Overall, the LDH and healthy group were comparable across most sociodemographic characteristics, except for BMI, which was significantly higher in the LDH group.

Table 1 - Sociodemographic variables of participants.

Sociodemographic Variables	Total Participants (n=36)	Lumbar Disc Hernia Group (n=19)	Healthy Group (n=17)	*P* value	Lumbar Disc Hernia Group (n=19)		*P* value
					Non-severe (n=10)	Severe (n=9)	
Age (mean ± SD)	46,17 ± 15,54	50,37 ± 13,45	41,47 ± 16.74	0,116*	51,20 ± 14.16	49,44 ± 13.39	0,775**
Height cm (mean ± SD)	168,67 ± 10,32	169,21 ± 9,29	168,06 ± 11,62	0,727*	173,90 ± 8,12	164,00 ± 7,87	**0,018****
Mass Kg (Median; IQR)	70 (23)	76 (26)	68 (16,5)	0,071**	85 (24)	70 (23)	**0,050****
BMI (Median; IQR)	25,21 (5,65)	27,25 (5,16)	23,39 (5,10).	**0,023****	28,01 (6,44)	25,89 (5,07)	0,327**
Gender (n; %)	Female 21 (58%) Male 15 (42%)	Female 9 (53%) Male 10 (47%)	Female 12 (71%) Male 5 (29%)	0,322***	Female 3 (30%) Male 7 (70%)	Female 7 (78%) Male 2 (22%)	0,188***
Exercise (n; %)	Yes 19 (53%) No 16 (44%) MS 1 (3%)	Yes 8 (42%) No 10 (53%) MS 1 (5%)	Yes 11 (65%) No 6 (35%)	0,316***	Yes 6 60(%) No 4 (40%)	Yes 2 (22%) No 6 (67%) MS 1 (11%)	0,070***
Pain Laterality (n,%)	NA	Left side 10 (53%) Right side 9 (47%)	NA	NA	Left side 4 (40%) Right side 6 (60%)	Left side 6 (67%) Right side 3 (33%)	0,258**

*Independent T-test; **Mann-Whitney U test; ***Fisher's exact test; SD - Standard deviation: IQR - interquartile range; BMI - body mass index; cm – centimetres; kg – Kilograms; n – number; NA - Not applicable; MS – Missing Value

Sociodemographic characterization and comparison of subgroups (LDH severe vs LDH Non-severe)

Sociodemographic characterization of the subgroups is detailed in table 1. Both groups have similar age means (non-severe 51,20 ± 14.16 and severe 49,44 ± 13.39). The groups presented similarities in all variables except for height (non-severe: 173,90cm ± 8,12cm and severe: 164,0cm ± 7,87cm) and mass (non-severe: median = 85kg, IQR = 24kg and severe: median = 70kg, IQR = 23kg). Regarding exercise habits, in the non-severe group most patients answered "*yes*" when asked if they exercised regularly (60%) and in the severe group the majority answered "*no*" (67%). Overall, the groups were comparable, but significant differences were found in height ($p = 0,018$) and mass ($p = 0,050$), both of which were higher in the non-severe group.

Gait characterization and comparison of spatiotemporal parameters between groups (LDH vs Healthy)

Significant differences were found in various gait parameters when comparing the LDH group with the healthy group (table 2). Regarding the healthy group, gait parameters were compared between left and right lower limb, no statistically significant differences were found in any spatiotemporal parameters between both limbs in this group (table 3 - Appendix 3). Concerning the significant differences found in the spatiotemporal gait parameters, higher median values were found in the LDH group for: stride time (median = 1.19s, IQR = 0.12s, p = 0,001), step time symptomatic side and non-symptomatic side (median = 0.60s, IQR = 0.07s p < 0,001; median = 0.60s, IQR = 0.06s p = 0,003, respectively), stance time symptomatic side and non-symptomatic side (median = 0.79s, IQR = 0.09s, p = 0,005; median = 0.82s, IQR = 0.12s, p < 0,001, respectively), swing time symptomatic leg (median = 0.40s, IQR = 0.05s , p = 0,001), double support time non-symptomatic side (median = 0.21s, IQR = 0.05s, p = 0,009), double support time (median = 0.43s, IQR = 0.07s, p = 0,025) and single support time non-symptomatic side (median = 0.39s, IQR = 0.05s, p < 0,001). Spatiotemporal gait parameters with significant differences between groups and higher median values in the healthy group were speed (median = 0.97m/s, IQR = 0.25m/s, p = 0,003), cadence (median = 110.55 steps/min, IQR = 11.32 steps/min, p = 0,001), stride length (median = 103.7cm, IQR = 19.34cm, p = 0,012) and step length, which in the LDH group had a lower median value in the symptomatic side (LDH group: median = 41.59cm, IQR = 7.95cm; healthy group: median = 49.77, IQR =13.68cm, p < 0,001).

As mentioned, BMI was significantly higher in the LDH group. Adjustment for this variable as a covariable altered the group comparison results in only one gait parameter, which no longer reached statistical significance (double support time, p = 0,025 to p = 0,061). All other spatiotemporal gair parameters maintained their initial significance. For the parameter which lost significance (double support time), BMI was found to have a significant effect on that parameter (p = 0,041) and only in one other gait parameter (double support time non-symptomatic side, p = 0,043). Although in this last parameter no change was found after adjusting BMI as a covariate.

Table 2: Descriptives of spatiotemporal gait parameters.

Gait Spatiotemporal Parameters		Lumbar Disc Hernia Group (median; IQR)	Healthy Group (median; IQR)	*P* value	
				Mann-Whitney – before adjustment for BMI	ANCOVA - after adjustment for BMI
Speed (m/s)		0.75 (0.21)	0.97 (0.25)	**0,003**	**0,004**
Cadence (steps/min)		100.38 (10.95)	110.55 (11.32)	**0,001**	**0,001**
Stride Time (s)		1.19 (0.12)	0.5411 (0.0621)	**0,001***	**0,001**
Stride Length (cm)		89.76 (16.98)	103.07 (19.34)	**0,012**	**0,019**
Step Width (cm)		15.56 (0.66)	49.77 (13.68)	>0,05	>0,05
Step Time	Symptomatic side (s)	0,60 (0,07)	0.54 (0.06)	**<0,001***	**<0,001**
	Non-Symptomatic side (s)	0.60 (0,06)	0.55 (0.07)	**0,003***	**0,004**
Step Length	Symptomatic side (cm)	41.59 (7.95)	49.77 (13.68)	**<0,001**	**<0,001**
	Non-Symptomatic side (cm)	47.21 (9.40)	49.44 (10.14)	>0,05	>0,05
Stance Time	Symptomatic side (s)	0.79 (0.09)	0.74 (0.08)	**0,005***	**0,009**
	Non-Symptomatic side (s)	0.82 (0.12)	0.73 (0.07)	**<0,001***	**<0,001**
Swing Time	Symptomatic side (s)	0.40 (0.05)	0.35 (0.05)	**0,001***	**<0,001**
	Non-Symptomatic side (s)	0.39 (0.04)	0.37 (0.06)	>0,05	>0,05
Double Support Time	Symptomatic side (s)	0.21 (0.04)	0.19 (0.03)	>0,05	>0,05
	Non-Symptomatic side (s)	0.21 (0.05)	0.18 (0.04)	**0,009***	**0,020**
Double Support Time (s)		0.43 (0.07)	0.38 (0.06)	**0,025***	>0,05
Single Support Time	Symptomatic side (s)	0.39 (0.04)	0.37 (0.05)	>0,05	>0,05
	Non-Symptomatic side (s)	0.40 (0.05)	0.36 (0.04)	**<0,001***	**<0,001**

m/s – meters per second; steps/min – steps per minute; cm – centimetres; s – seconds; IQR - interquartile range; *Higher gait parameter values in lumbar disc hernia manifested as acute sciatica patients; No "*" - higher gait parameter values in healthy group

Gait characterization and comparison of spatiotemporal parameters between groups (severe vs non-severe)

Spatiotemporal gait parameter characterization of the non-severe group and the severe group were analyzed, compared and summarized in table 7 (Appendix 4). No statistically significant differences were found when comparing spatiotemporal gait parameters between the subgroups.

Clinical characterization of LDH group and subgroups

The clinical outcomes of the 19 patients of the LDH group are summarized in table 3 (pain intensity: NPRS axial baseline pain, NPRS axial peak pain, NPRS leg baseline pain and NPRS leg peak pain, the EQ-5D-3L scores and ODI total scores). Lumbar disc hernia manifested as acute sciatica patients reported lower levels of axial baseline pain when compared to the baseline pain reported in the symptomatic lower limb (NPRS axial baseline pain: median = 0, IQR = 3; NPRS leg baseline pain: median = 5, IQR = 4). The median ODI score was 24.0 (IQR = 9), corresponding to percentage score of 48%, which is indicative of a moderate to severe level of functional limitation. In this group, health related quality of life assessed with the EQ-5D-3L showed a median index of 0.516 (IQR = 0.532). This index score is considerably lower than normative values for the Portuguese population thus presenting a moderate reduction in health-related quality of life.

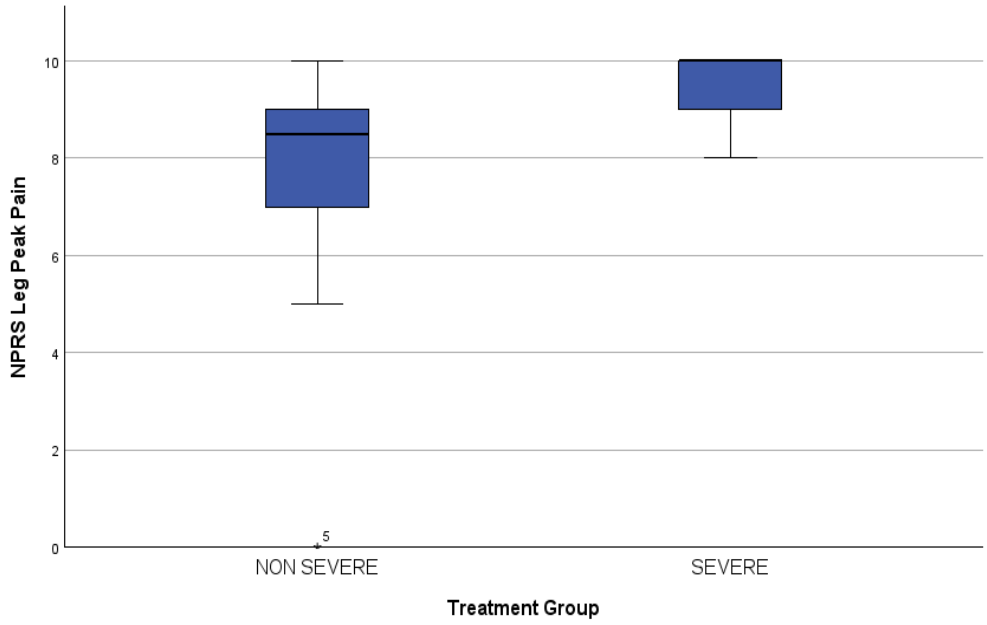
The subgroups consisted of the 19 LDH patients which were separated into severe (*n* = 9) vs non-severe (*n* = 10) depending on if these patients were scheduled for surgery (severe) or conservative treatment (non-severe). When comparing the clinical variables between the groups, analysis showed that the two groups were comparable in terms of clinical outcomes, apart from a statistically significant difference found in the NPRS leg peak pain score (p = 0,038) with this score being higher in the severe group (Figure 1). Despite this, both groups showed similar dispersion in the NPRS leg peak pain scores given the interquartile range found in each group (non-severe group: NPRS leg peak pain, IQR = 3; severe group: NPRS leg peak pain, IQR = 2)

Table 2: Clinical outcomes of LDH group and sub-groups.

Clinical Outcomes	Lumbar Disc Hernia Total (N=19) (median; IQR)	Lumbar Disc Hernia Non-Severe (N=10) (median; IQR)	Lumbar Disc Hernia Severe (N=9) (median; IQR)	*P* value
NPRS axial baseline pain (0-10)	0 (3)	0 (3)	0 (2)	0,792*
NPRS axial peak pain (0-10)	0 (9)	0 (7)	0 (4)	0,428*
NPRS leg baseline pain (0-10)	5 (4)	5 (7)	6 (4)	0,198*
NPRS leg peak pain (0-10)	9 (2)	8.5 (3)	10 (2)	**0,038***
ODI (0-50)	24,00 (9)	23.5 (10)	24 (7)	0,366*
EQ-5D-3L (–0.594 to 1.000)	0,516 (0,532)	0.516 (0.210)	0.516 (0.619)	0,166*

IQR - interquartile range; NPRS – Numerical pain rating scale; ODI – Oswestry disability index; *Mann-Whitney U test

Figure 1 - NPRS Leg Peak Pain by treatment group

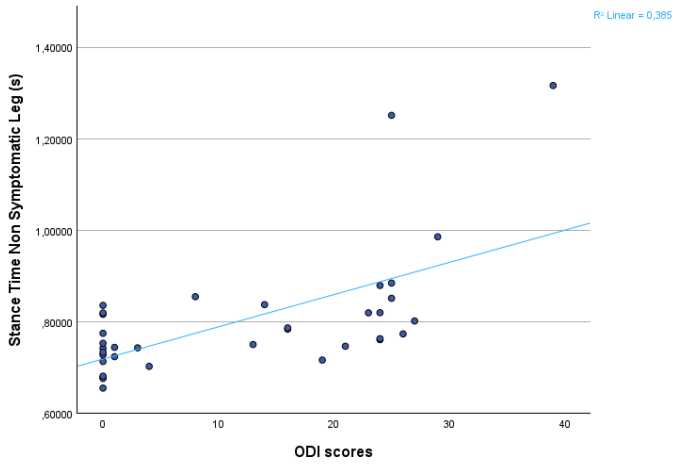


Simple Boxplot comparing Leg Peak Pain between treatment severe and non-severe groups; NPRS – Numerical pain rating scale

Correlation analysis (spatiotemporal parameters and clinical outcome measures)

Results of the correlation analysis between gait spatiotemporal parameters and the clinical outcomes in the LDH group are summarized in table 4, 5 and 6. Significant correlations were found between ODI scores and spatiotemporal gait parameters, described in table 4. Negative significant correlations were found for speed, cadence, stride length and step length of the symptomatic side (moderate correlations). Positive significant correlations were found for stride time, double support time; step time (both sides), stance time and swing time in the symptomatic side; double support time and single support time in the non-symptomatic side (moderate correlations). Results also showed a weak correlation between ODI scores and double support time in the symptomatic side (r_s = 0,381, p = 0,022) and a strong correlation between ODI and stance time in non-symptomatic side (r_s = 0,630, p <0,001) (Figure 2).

Figure 2 – Correlation ODI scores and Stance time non symptomatic side



Scatterplot of correlation between ODI and stance time in non-symptomatic side in LDH group.
ODI – Oswestry disability index; LDH – Lumbar disc hernia

There were also significant correlations found between the EQ-5D-3L index scores and spatiotemporal gait parameters, described in table 5. Only positive correlations were found. Moderate correlations were found for speed, stride length, swing time non-symptomatic side and single support time symptomatic side. Significant correlations were found between NPRS baseline and peak leg pain scores and spatiotemporal gait parameters, described in table 6. In both pain scores, baseline and peak pain, negative correlations were found for speed, cadence, step length symptomatic side (moderate correlations) and stride length (moderate correlation with NPRS baseline leg pain, r_s = -0,424, p = 0,010 and weak correlation with NPRS peak leg pain; r_s = -0,390, p = 0,019). Only in the NPRS baseline leg pain score was a significant negative correlation found for step length non-symptomatic side (weak correlation). In both pain scores, baseline and peak pain, positive correlations were found for stride time, step time and swing time of the symptomatic side; step time, stance time and single support time of the non-symptomatic side (moderate correlations); double support time non-symptomatic side (weak correlations). Stance time on the symptomatic side showed a positive moderate correlation with the NPRS **baseline** leg pain scores (r_s = 0,407, p =0,014) and a positive weak correlation with NPRS **peak** leg pain scores (r_s = 0,399, p =0,016).

Table 4 – Spearman's correlations between spatiotemporal gait parameters and ODI results

Gait Spatiotemporal Parameters		Correlation Coeficient (r_s) ODI	*P* value
Speed (m/s)		-0,579	**<0,001**
Cadence (steps/min)		-0,534	**<0,001**
Stride Time (s)		0,523	**0,001**
Stride Length (cm)		-0,532	**<0,001**
Step Time	Symptomatic Side (s)	0,533	**<0,001**
	Non-Symptomatic Side (s)	0,519	**0,001**
Step Length	Symptomatic Side (cm)	-0,581	**<0,001**
	Non-symptomatic Side (cm)	-0,318	0,059
Stance Time	Symptomatic Side (s)	0,499	**0,002**
	Non-Symptomatic Side (s)	0,630	**<0,001**
Swing Time	Symptomatic Side (s)	0,567	**<0,001**
	Non Symptomatic Side (s)	0,024	0,891
Double Support Time (s)		0,475	**0,003**
Double Support Time	Symptomatic Side (s)	0,381	**0,022**
	Non-Symptomatic Side (s)	0,536	**<0,001**
Single Support Time	Non-Symptomatic Side (s)	0,578	**<0,001**
	Symptomatic Side (s)	0,062	0,720

ODI – Oswestry Disability Index scores; r_s – Spearman's rho.

Table 5 – Spearman's correlations between spatiotemporal gait parameters and EQ-5D-3L index scores

Gait Spatiotemporal Parameters		Correlation Coeficient (r_s) EQ-5D-3L	*P* value
Speed (m/s)		0,463	**0,046**
Stride Length (cm)		0,551	**0,015**
Swing Time	Non-Symptomatic Side (s)	0,472	**0,042**
	Symptomatic Side (s)	-0,155	0,526
Single Support Time	Symptomatic Side (s)	0,484	**0,036**
	Non-Symptomatic Side (s)	-0,109	0,657

r_s – Spearman's rho.

Table 6: Spearman'scorrelations between spatiotemporal gait parameters and results of NPRS Baseline Leg Pain and NPRS Peak Leg Pain

Gait Spatiotemporal Parameters		Correlation Coeficient (r_s) NPRS Baseline Leg Pain	Correlation Coeficient (r_s) NPRS Peak Leg Pain	*P* value	
				NPRS Baseline Leg Pain	NPRS Peak Leg Pain
Speed (m/s)		-0,491	-0,462	**0,002**	**0,005**
Cadence (steps/min)		-0,441	-0,435	**0,007**	**0,008**
Stride Time (s)		0,431	0,434	**0,009**	**0,008**
Stride Length (cm)		-0,424	-0,390	**0,010**	**0,019**
Step Time	Symptomatic Side (s)	0,426	0,439	**0,010**	**0,007**
	Non-Symptomatic Side (s)	0,452	0,442	**0,006**	**0,007**
Step Length	Symptomatic Side (cm)	-0,431	-0,470	**0,009**	**0,004**
	Non-Symptomatic Side (cm)	-0,342	-0,270	**0,041**	0,111
Stance Time	Symptomatic Side (s)	0,407	0,399	**0,014**	**0,016**
	Non-Symptomatic Side (s)	0,504	0,498	**0,002**	**0,002**
Swing Time	Symptomatic Side (s)	0,513	0,517	**0,001**	**0,001**
	Non-Symptomatic Side (s)	0,141	0,182	0,412	0,289
Double Support Time	Non-Symptomatic Side (s)	0,381	0,357	**0,022**	**0,032**
	Symptomatic Side (s)	0,226	0,203	0,184	0,234
Single Support Time	Non-Symptomatic Side (s)	0,527	0,538	**<0,001**	**<0,001**
	Symptomatic Side (s)	0,169	0,220	0,324	0,198

r_s – Spearman's rho; NPRS Baseline Leg Pain – Leg pain intensity "pain at its best"; NPRS Peak Leg Pain – Leg pain intensity "pain at its worst"; "-"– No significant correlation found.

Discussion

This study's aim was to characterize the spatiotemporal gait parameters in patients diagnosed with LDH manifested as acute sciatica and to compare these parameters with healthy individuals. Additionally, to explore the relationships between gait parameters and clinical outcomes such as pain, health related quality of life and disability. Spatiotemporal gait parameters were obtained via an on-site gait analysis with IMU's. The assessment of clinical outcomes allowed the further characterization of this sample and their correlation with the analyzed gait parameters. As a secondary aim, subgroup analysis was performed, characterizing the spatiotemporal gait parameters in severe and non-severe LDH patients.

Both groups had mostly female participants (LDH group 53% and healthy group 71%) which differs from most studies on the subject. LDH manifested as acute sciatica is a pathology which tends to include a higher proportion of male participants, reflecting the overall higher incidence of LDH in males. A male-to-female ratio of 2:1 is the prevalence of this pathology and especially in the 30-to-50-year age group (Chen et al., 2024; Strömqvist et al., 2016; Tabesh et al., 2015). Despite this, some recent studies regarding the analysis of spatiotemporal parameters in this pathology do report a higher number of female participants, as is the case of a 2020 study by Bonab et al. Regarding the age of the participants, mean age of the total group was 46 years, within the expected age spectrum and was studied in previous work (Bonab et al., 2023; Natarajan et al., 2022; Strömqvist et al., 2016; Tabesh et al., 2015).

Considering the existing literature, LDH patients were expected to present a deterioration of gait quality and capacity and, overall, demonstrate increases in temporal parameters and decreases in spatial parameters (Bonab et al., 2020; Bonab et al., 2023; Natarajan et al., 2022). These results were observed in this study as temporal gait parameters were significantly increased in the LDH group when compared to the heathy individuals. Parameters such as stride time, step time (symptomatic and non-symptomatic side), stance time (symptomatic and non-symptomatic side), swing time (symptomatic side), double support time (non-symptomatic side) and single support time (non-symptomatic side) showed higher values in the LDH group. These findings are supported by the existing literature as the evidence in these shows that, in this population, gait alterations are characterized by increased temporal parameters such as longer step time, stride time, stance time, swing time, and double support time when compared healthy individuals (Bonab et al.,

2023; Bonab et al., 2020; Natarajan et al., 2022). In addition to this, also in accordance with previous literature, a decrease in spatial parameters was observed in the LDH group, decreased values were found in parameters such as speed, cadence, stride length and step length (lower in symptomatic leg in LDH group). These findings for gait parameters indicate shorter and slower steps, consistent with compensatory adaptations to pain and neuromuscular impairments in this pathology and consistent with findings in previous work (Bonab et al., 2023; Bonab et al., 2020; Lee et al., 2021; Natarajan et al., 2022).

The differences in spatiotemporal gait parameters between the symptomatic side in the LDH group and the healthy group, which was the case of step time, step length, stance time and swing time are also in concordance with what previous literature has found. In previous work which compared the affected side of LDH patients with healthy subjects, all gait parameters exhibited significant differences between groups (cadence, stride time, stance phase, swing phase), indicating that pain significantly impairs gait on the symptomatic side (Wang et al., 2023). Addressing the non-symptomatic side, as the present study also shows, significant differences were also found between the non-symptomatic side in the LDH group and healthy individuals. This is also in accordance with previous work which found significant differences in spatiotemporal parameters between the non-symptomatic side of LDH patients and healthy individuals. These findings suggest that both the symptomatic and non-symptomatic side present gait alterations when compared to healthy individuals (Wang et al., 2023).

Authors have attributed gait alterations in the non-specific low back pain population to joint rigidity, muscle stiffness, muscle weakness, and poor neuromuscular function (altered timing of muscle activation and muscular incoordination), with these factors potentially leading to asymmetrical or abnormal mechanical loading of the lumbar spine (Bonab et al., 2023; Farra et al., 2024). Authors consider it plausible that pain-avoidance behaviors in NSLBP patients likely emerge in LDH patients due to overlapping symptoms and pain-related fears (Davis et al., 2022; Lee et al., 2021; Natarajan et al., 2022; Schmid et al., 2023). Overall gait differences observed between LDH patients and healthy individuals are recurrently attributed to pain levels with LDH patients often trying to adapt their gait patterns to alleviate the level of pain induced in different physical activities such as walking (Bonab et al., 2020). Authors have reported avoidance of wide trunk, pelvic and hip movements, restricted knee range of motion and refrainment from weight transfer between

left and right extremity to avoid exacerbation of the pain (Bonab et al., 2020). Other authors relate these differences specifically to pain in the affected lower limb as a result of sciatica, also reporting that these patients seek to limit hip and spine movement (Natarajan et al., 2022). Fear-avoidance behaviour, muscle weakness, numbness and neuromuscular impairment are also possible factors which may explain these gait alterations, as reported in other studies (Huang et al., 2011; Lee et al., 2021; Natarajan et al., 2022; Parwani et al., 2025). Patients with LDH, besides overall differences with gait in healthy subjects, also present a more asymmetrical gait pattern, with increased pain correlating with greater temporal imbalance between the symptomatic and non-symptomatic lower limb (Lee et al., 2021; Wang et al., 2023). Patients with LDH are more likely to develop neuromuscular impairments depending on the level and severity of disc herniation, leading to muscular and gait instability (Lee et al., 2021). Neuromuscular impairments are predominantly unilateral in this population with the symptomatic side presenting muscle weakness, altered activation patterns, sensory disturbances and increased pain levels which may explain more predominant changes in the affected sides single support time, step length and swing time (Davis et al., 2022; Lee et al., 2021; Wang et al., 2023). Differences in symptomatic side time for step length and swing time, along with differences in single support time and double support time in the non-symptomatic side found in this study, align with what previous literature suggests is the adaptations in this population where symptoms are predominantly unilateral but where pain levels may also impact the non-symptomatic side (Lee et al., 2021; Wang et al., 2023). These individuals spend more time in single and double support phases on the non-symptomatic lower limb to compensate and maintain stability during gait possibly reflecting an adaptive strategy to offload the painful limb with neuromuscular impairments also contributing to the differences and decrease in step length (Davis et al., 2022; Lee et al., 2021; Wang et al., 2023).

Body mass index of the LDH group had a median of 27,2 with most participants' clustering between the overweight to obese range. In the healthy group median BMI was 23,39 with an IQR which relates to a healthy to overweight range. When BMI was adjusted as a covariate for the differences found in the spatiotemporal gait parameters, the parameter double support time no longer reached significance. Also, it was only in the double support time and double support time (non-symptomatic side) parameters where BMI demonstrated a significant influence (p = 0,041 and p = 0,043, respectively). This suggests the initial

difference found in double support time between LDH and healthy groups could be attributed to BMI rather than the influence of LDH. In the case of the parameter double support time (non-symptomatic side), significant difference between groups was maintained after adjustment, indicating that LDH affects this gait parameter independently of BMI.

Previous research has reported a significant correlation between BMI and spatiotemporal parameters, BMI has been positively correlated with temporal parameters such as step time, double support time and swing time (Bonab et al., 2020). This aligns with our findings were BMI significantly influences gait parameters, such as double support time, after adjustment as a covariate. Although showing consistent results with what previous studies have found, the comparison of these results is to be looked at with caution due to the lack of available literature specific to this population.

Regarding the clinical assessment and correlation with spatiotemporal parameters, previous work characterizes this population as a population with higher levels of pain, disability, poorer quality of life compared with populations presenting with LBP alone (Davis et al., 2022; Lee et al., 2021; Schmid et al., 2023). In this work, and with the characterization of the LDH group and their different pain assessments, it was found that most patients had mild or no baseline axial pain, while axial peak pain varied widely between patients with pain values going up to severe scores, although median was 0/10 (NPRS). Regarding leg pain, baseline scores present a median score of moderate leg pain (5/10 NPRS) with some variability between patients, while leg peak pain score were noticeably higher with a median score of 9/10 (NPRS) with most people presenting similarly severe peak leg pain. These results exhibit how LDH pain symptoms range widely in intensity with pain levels in the affected lower limb ranging from “no pain” to “worst pain possible”. This matches clinical observations described in previous work, where patients with LDH exhibit a wide spectrum of symptoms including mild to severe pain levels in both axial and leg pain, with the affected lower limb pain often described as severe, sharp and/or shooting pain extending down the leg (Bonab et al., 2023; Huang et al., 2011; Lee et al., 2021; Natarajan et al., 2022). Literature also describes how the severity of symptoms depends on the extent of nerve compression and varies significantly among patients, supporting the existence of different pain scores among patients (Parwani et al., 2025). The results also are aligned with what is stated in the literature regarding this specific group, which states that leg pain levels are expected to be worse than the axial pain levels (Davis et al., 2022; Lee et al., 2021;

Schmid et al., 2023).

Previous work has found that gait alterations are strongly correlated with pain intensity in LDH patients, and the current evidence suggests that higher pain scores lead to more pronounced changes such as decreased speed, shorter step length and stride length (Bonab et al., 2020). In the present work significant correlations between numerical pain rating scale leg pain scores (baseline and peak levels) and gait parameters were found. Negative significant correlations were found for speed, cadence and spatial parameters, such as step and stride length, and pain intensity. Although these results are consistent with results of previous work which reports strong correlations between pain scores and gait alterations in LDH patients (Bonab et al., 2020), the correlations found in this work were weak to moderate. Positive correlations were found for temporal parameters (such as stride time, step time and swing phase time) suggesting that participants with higher pain scores tended to have a slower, more cautious walking pattern, with more time of the gait cycle spent on the non-symptomatic leg.

In the LDH group the median raw score equated to 48%, describing severe disability, with homogeneity among the group. This reflects substantial limitations in daily living due to symptoms which is in accordance with current literature findings (Bonab et al., 2023). Previous work reports moderate to severe disability in LDH patients with pre-treatment scores of 47% to 54%, describing substantial functional limitation compared to healthy populations (Arfaaz et al., 2021; Saberi & Isfahani., 2008).

Correlations found between the ODI scores and spatiotemporal gait parameters in the LDH group in the present study suggest that functional impairment is correlated to gait alterations. The negative correlations between ODI scores and speed, cadence, step and stride length indicate that patients with greater disability tended to adopt a slower and restricted walking pattern. The positive correlations between ODI scores and parameters step, stride, stance, swing, double support and single support time also suggest that participants with greater disability scores tended to have a slower, apprehensive and pain avoidance walking pattern with more time spent on the non-symptomatic leg. These conclusions align with previous descriptions of protective gait strategies, fear and pain avoidance behaviour and possible neuromuscular impairments in this population (Bonab et al., 2023; Lee et al., 2021).

Health related quality of life, determined with the EQ-5D-3L index values, showed

a median index value of 0.516 (IQR = 0.532) in the LDH group. EQ-5D-3L population norms for the older European population with data from the Survey of Health, Ageing and Retirement in Europe, provide reference data with EQ-5D-3L index normative values ranging from 0.66 to 0.95 in the total male population, and from 0.54 to 0.91 in the total female population (Buchholz & Janssen 2023). These results demonstrated that this LDH sample had a relevant decline in health-related quality of life, with IQR of 0.532 reflecting heterogeneity in this outcome. In this group the highest index value was 0.760 and lowest value was -0.16. Preoperative EQ-5D-3L index scores ranging from 0 to 0.5 among surgical patients with sciatica caused by LDH have been reported in other countries, indicating a marked reduction in health-related quality of life before surgery (Lagerbäck et al., 2019). In the present study, despite index scores falling within the expected range for this population, the heterogeneity observed likely arises from variability in pain severity and the degree of disability each participant described.

Correlations found between the EQ-5D-3L index scores and spatiotemporal gait parameters in the LDH group suggest that overall health-related quality of life may be reflected in this sample gait characteristics. Positive significant correlations were found between the EQ-5D-3L index scores and parameters speed, stride length, swing time (non-symptomatic leg) and single support time (symptomatic side). These results reinforce the findings described above, emphasizing that patients with fewer functional limitations and better quality of life tend to maintain a gait pattern closer to the gait characteristics of healthy individuals.

The findings of this study suggest that patients with severe LDH, defined by the group scheduled for surgical intervention, reported significantly higher scores of leg peak pain with a median of 10 and IQR of 2. Prior studies have emphasized that the severity of LDH manifested as acute sciatica is primarily differentiated by pain intensity, neurological deficits, and functional limitation rather than radiological size alone (Costa et al., 2024; Kreiner et al., 2014; Parwani et al., 2025; Zhang et al., 2022). Therefore, results from this work reinforce that pain intensity remains an important key clinical marker of disease severity, with higher pain scores typically corresponding to higher disease severity with these cases being referred for surgical management (Costa et al., 2024; Kreiner et al., 2014; Parwani et al., 2025; Zhang et al., 2022).

Spatiotemporal gait parameters were compared between severe and non-severe

groups, with no significant differences found in any gait parameter. These results are in line with what some previous work has found, were the findings supported that spatiotemporal parameters such as speed, cadence, step length, and stance duration did not show significant variation across different severity degrees in this pathology (Wang et al., 2023). In contrast, other current evidence does suggest a correlation between disease severity and changes in spatiotemporal parameters, however, only a limited number of studies have explored this association across the different severity grades which is important to explain the lack of consistency in the results of overall existing evidence (Kreiner et al., 2014; Parwani et al., 2025; Zhang et al., 2022). Our findings may be explained by the small sample size of each subgroup and the fact that even in different severity levels of the pathology similar gait adaptations are possibly acquired as compensatory and fear avoidance strategies, despite symptom severity.

Results from this work reinforce that gait alterations remain a possible key clinical marker of LDH population. The results highlight the potential of onsite gait analysis of this population as a complementary outcome to assess these patients and to possibly monitor functional recovery following conservative or surgical treatment. Certain gait parameters may provide quantitative indicators of functional impairment besides currently used clinical outcome measures. Also, the early identification of prolonged temporal and decreased spatial parameters and impairment of the symptomatic leg may help tailor more specific rehabilitation programs to address these alterations. Also, this assessment may contribute to risk stratification, thus potentially detecting better or poor prognosis. The correlations between pain and gait parameters also bring to light the possible rehabilitation approaches in these patients with such approaches possibly benefiting from addressing movement quality and motor control, rather than focusing solely on pain relief. In addition to commonly used clinical assessment measures, gait assessment across different severity grades may provide valuable objective information to guide decision making regarding treatment options, particularly in distinguishing patients for surgical versus conservative treatment.

This study has relevant limitations to acknowledge. Firstly, the total sample size was modest in comparison to other studies, possibly limiting statistical power in analysing differences and correlations between the groups. This was a case control study only assessing gait parameters on a single time point (baseline assessment), nonetheless, this work suits as a possible base for future longitudinal studies following patients in different time points,

before and after selected treatment. Future research on this matter should include larger and more homogenous samples with larger subgroups, also, cohort studies could also determine how gait parameters evolve with clinical improvement and their potential role as prognostic indicators.

Conclusion

The results of this study show that patients with LDH manifested as acute sciatica present clear gait impairments when compared to healthy individuals. Such alterations are characterized by increased temporal parameters and decreased spatial parameters, affecting both the symptomatic and non-symptomatic side. This shows how impairments cause bilateral but asymmetrical gait alterations. These alterations correlate with higher pain intensity, greater disability levels and lower health related quality of life, which supports that gait may be a key marker of functional impairment. Overall, the findings suggest the potential of incorporating assessment of spatiotemporal gait parameters in the baseline assessment and eventual rehabilitation planning in this population.

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Appendixes

Appendix 1 – Scheme of 15 Inertial Measurement Unit (IMU) placement

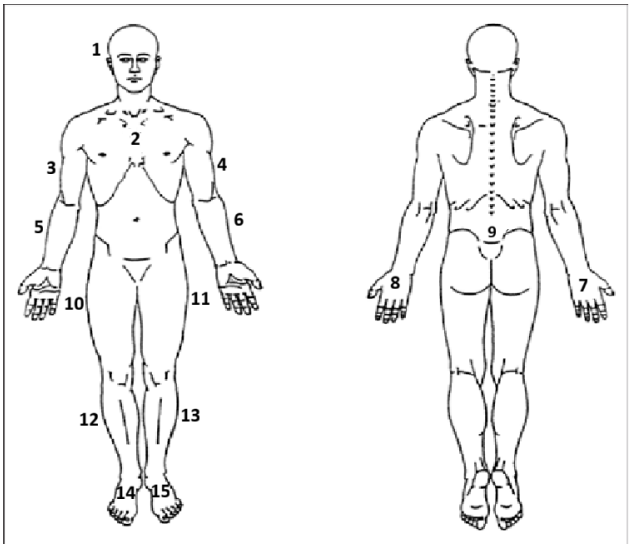


Figure 3 - **Inertial measurement unit placement:** (1) head, (2) thorax, (3) right arm, (4) left arm, (5) right forearm, (6) left forearm, (7) right hand, (8) left hand, (9) pelvis, (10) right thigh, (11) left thigh, (12) right shank, (13) left shank, (14) right foot and (15) left foot.

Appendix 2 – Scheme of corridor used for on-site gait analysis

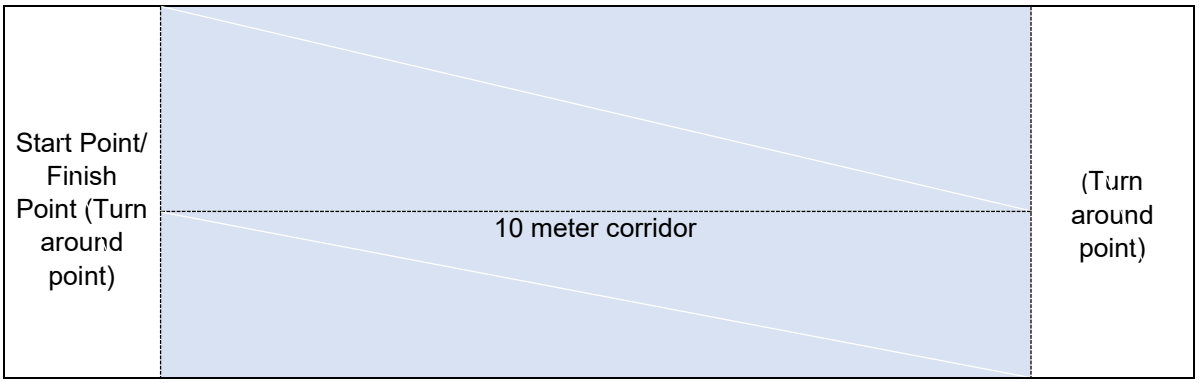


Figure 4 - Ten-meter-long corridor scheme used for on-site gait analysis.

Appendix 3 - Table 3: Differences in gait parameters in left and right leg in healthy individuals

Table 3 – **Differences in gait parameters in left and right leg in healthy individuals**

Gait Spatiotemporal Parameters	Healthy Individuals *(P* value)
Step Time L and R (s)	0,931*
Step Length L and R (cm)	0,823*
Stance Time L and R (s)	0,642*
Swing Time L and R (s)	0,361*
Double Support Time L and R (s)	0,263*
Single Support Time L and R (s)	0,278*

L – Left leg; R – Right leg; s – seconds; m – meters; *Mann-Whitney U test

Appendix 4 - Table 7: Descriptives of spatiotemporal gait parameters (subgroups).

Table 7: Descriptives of spatiotemporal gait parameters (subgroups).

Gait Spatiotemporal Parameters		Lumbar Disc Hernia Severe (median; IQR)	Healthy Lumbar Disc Hernia Non-Severe (median; IQR)	*P* value
				Mann-Whitney
Speed (m/s)		0,69 (0,40)	0,78 (0,16)	>0,05
Cadence (steps/min)		93,72 (24,76)	100,63 (11,32)	>0,05
Stride Time (s)		1,27 (0,36)	1,19 (0,05)	>0,05
Stride Length (cm)		89,76 (25,39)	91,10 (18,18)	>0,05
Step Width (cm)		15,63 (0,85)	15,47 (0,44)	>0,05
Step Time	Symptomatic Leg (s)	0,643 (0,20)	0,60 (0,04)	>0,05
	Non-Symptomatic Leg (s)	0,64 (0,17)	0,60 (0,04)	>0,05
Step Length	Symptomatic Leg (cm)	41,60 (11,86)	40,03 (8,31)	>0,05
	Non-Symptomatic Leg (cm)	43,09 (16,02)	48,11 (10,64)	>0,05
Stance Time	Symptomatic Leg (s)	0,84 (0,29)	0,79 (0,09)	>0,05
	Non-Symptomatic Leg (S)	0,88 (0,37)	0,81 (0,06)	>0,05
Swing Time	Symptomatic Leg (s)	0,42 (0,07)	0,40 (0,04)	>0,05
	Non-Symptomatic Leg (s)	0,39 (0,07)	0,39 (0,03)	>0,05
Double Support Time	Symptomatic Leg (s)	0,20 (0,14)	0,21 (0,04)	>0,05
	Non-Symptomatic Leg (s)	0,24 (0,17)	0,21 (0,04)	>0,05
Double Support Time (s)		0,44 (0,31)	0,42 (0,06)	>0,05
Single Support Time	Symptomatic Leg (s)	0,39 (0,07)	0,39 (0,03)	>0,05
	Non-Symptomatic Leg (s)	0,42 (0,07)	0,40 (0,04)	>0,05

m/s – meters per second; steps/min – steps per minute; s – seconds; cm – centimetres; IQR - interquartile range.

Annexes

Annex 1 – Explanatory letter

HOSPITAL DA LUZ

Participação em Estudo/Ensaio Clínico

Nome do Estudo: Caracterização biomecânica da marcha em doentes com hérnia discal lombar

Centro do Estudo: Serviço de Neurocirurgia – H Luz Setúbal

Nome do Investigador Principal: Nuno Alexandre Remédio Cristino

INFORMAÇÃO AO DOENTE

Está a ser convidado/a a participar num estudo que está a decorrer no Serviço de Neurocirurgia do Hospital da Luz Setúbal.

Antes de decidir se quer participar, é importante que compreenda o motivo da realização deste estudo, o modo como a sua informação será utilizada, o que é que o estudo envolve e os possíveis benefícios, riscos e desconfortos. Por favor, leia atentamente esta informação e coloque todas as perguntas que entender. Poderá discutir este estudo com outras pessoas, como o seu médico de família e/ou a sua família, se o desejar. Tome o tempo que precisar.

A decisão de participar ou não neste estudo não afetará de modo nenhum o direito aos cuidados médicos que lhe são prestados, presentemente ou no futuro, nesta instituição.

QUAL É O OBJETIVO DESTE ESTUDO?

Os doentes com hérnia discal aguda apresentam apresentam uma dor irradiada pelo membro inferior e um padrão típico de marcha que ajuda no diagnóstico da doença, mas que até hoje não foi formalmente caracterizado. Este estudo pretende identificar componentes desta marcha, que permitam melhorar a compreensão das manifestações clinicas e o diagnóstico desta doença.

PORQUE ESTOU A SER CONVIDADO/A A PARTICIPAR NESTE ESTUDO?

Porque lhe foi diagnosticado uma hérnia discal e proposto tratamento no Serviço de Neurocirurgia do Hospital da Luz Setúbal.

TENHO DE PARTICIPAR NESTE ESTUDO?

Terá toda a liberdade para recusar-se a participar no estudo ou retirar o seu consentimento, suspendendo a participação em qualquer momento. A participação é voluntária e a sua recusa em participar não envolverá qualquer penalização ou perda de benefícios. A recusa ou abandono não colocarão, de modo algum, em risco o direito a receber tratamento ou assistência médica, presentemente ou no futuro, nesta instituição.

HOSPITAL DA LUZ

O QUE ENVOLVE A MINHA PARTICIPAÇÃO NESTE ESTUDO?

Realização de um exame de marcha no decorrer de algumas das suas consultas habituais e eventualmente a utilização de uma aplicação um telemóvel que irá analisar o seu movimento.

Adicionalmente será solicitada a autorização para recolha e análise de alguns dados clínicos através do preenchimento de questionários de saúde.

A participação neste estudo é voluntária e não irá interferir ou condicionar o seu tratamento, sendo o mesmo previamente definido pelo seu neurocirurgião, segundo os critérios clínicos habituais.

QUAIS SÃO OS POSSÍVEIS RISCOS E BENEFÍCIOS DE PARTICIPAR NESTE ESTUDO?

Riscos

Não está previsto qualquer risco decorrente da participação no estudo ou realização do exame solicitado.

Benefícios

Não existe qualquer benefício específico para o doente.

QUAIS SÃO OS CUSTOS POR PARTICIPAR NESTE ESTUDO?

Não terá custos acrescidos por participar neste estudo, no entanto também não haverá qualquer remuneração por participar neste estudo.

COMO SERÁ MANTIDA A MINHA CONFIDENCIALIDADE NESTE ESTUDO?

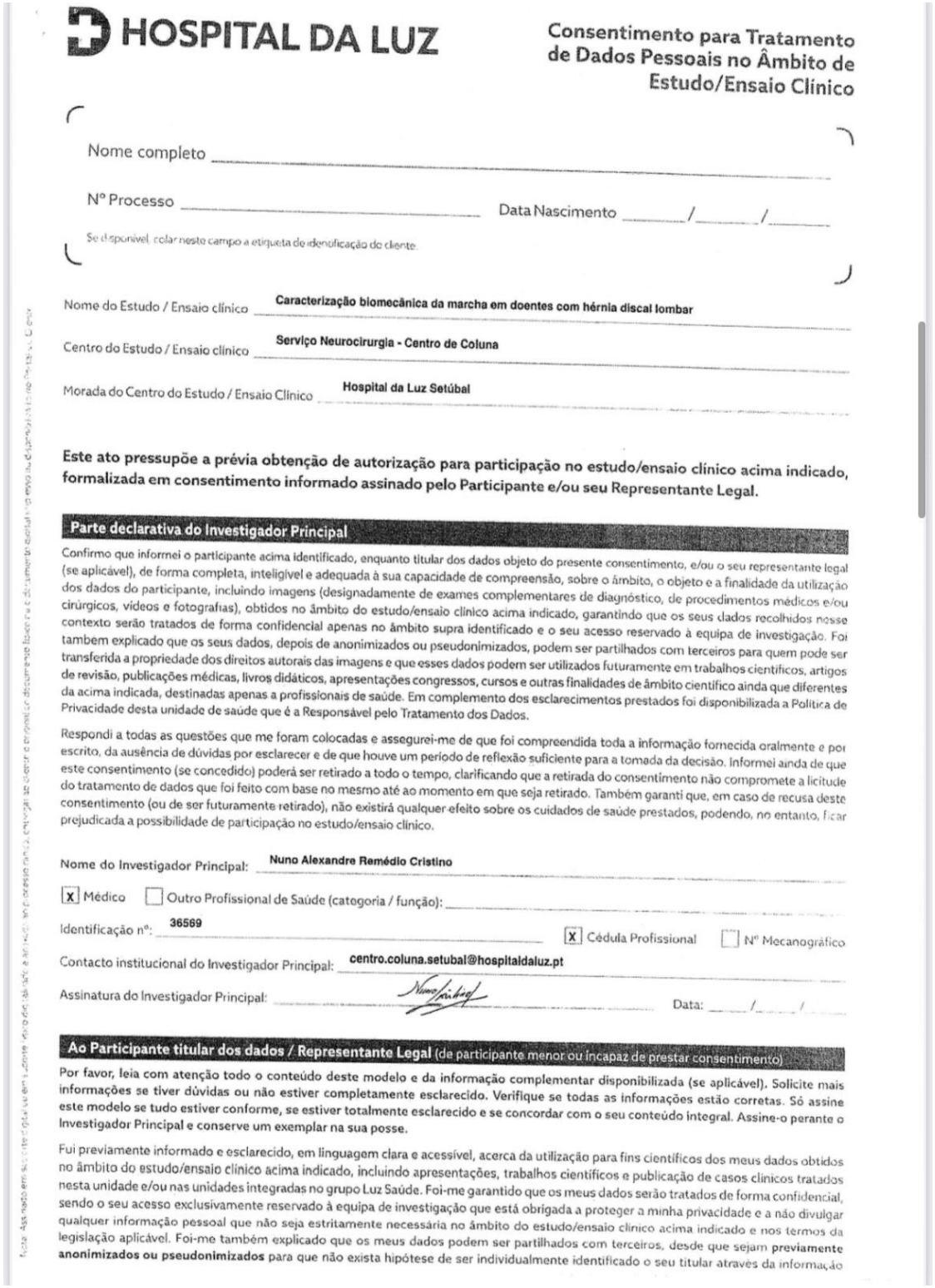
Os registos são confidenciais e da responsabilidade dos investigadores. Os doentes serão identificados por número de série, ficando a identidade dos clientes envolvidos e os dados recolhidos apenas na posse da equipa de investigação. O nome dos doentes não será identificado em nenhum relatório ou publicação decorrente deste estudo. A informação recolhida será analisada como parte deste estudo. Esta informação poderá ser analisada de forma anonimizada, por pessoas ou entidades autorizadas pelo investigador, pela Comissão de Ética deste hospital, pelas Autoridades de Saúde, sob supervisão do seu médico, ou com o objetivo de confirmar a veracidade dos dados do estudo. Estes dados poderão ser comunicados a Autoridades Regulamentares. Os dados serão guardados durante o tempo exigido por lei.

A QUEM DEVO COLOCAR QUESTÕES SOBRE O ESTUDO?

O Médico Investigador poderá esclarecer qualquer dúvida que tenha. Os contactos são:

E-mail: centro.coluna.setubal@hospitaldaluz.pt

Annex 2 – Informed Consent



HOSPITAL DA LUZ

Consentimento para Tratamento de Dados Pessoais no Âmbito de Estudo/Ensaio Clínico

Nome completo _____

Nº Processo _____ Data Nascimento ____/____/____

Se disponível, colar neste campo a etiqueta de identificação do cliente.

Nome do Estudo / Ensaio clínico **Caracterização biomecânica da marcha em doentes com hérnia discal lombar**

Centro do Estudo / Ensaio clínico **Serviço Neurocirurgia - Centro de Coluna**

Morada do Centro do Estudo / Ensaio Clínico **Hospital da Luz Setúbal**

Este ato pressupõe a prévia obtenção de autorização para participação no estudo/ensaio clínico acima indicado, formalizada em consentimento informado assinado pelo Participante e/ou seu Representante Legal.

Parte declarativa do Investigador Principal

Confirmo que informei o participante acima identificado, enquanto titular dos dados objeto do presente consentimento, e/ou o seu representante legal (se aplicável), de forma completa, inteligível e adequada à sua capacidade de compreensão, sobre o âmbito, o objeto e a finalidade da utilização dos dados do participante, incluindo imagens (designadamente de exames complementares de diagnóstico, de procedimentos médicos e/ou cirúrgicos, vídeos e fotografias), obtidos no âmbito do estudo/ensaio clínico acima indicado, garantindo que os seus dados recolhidos nesse contexto serão tratados de forma confidencial apenas no âmbito supra identificado e o seu acesso reservado à equipa de investigação. Foi tambem explicado que os seus dados, depois de anonimizados ou pseudonimizados, podem ser partilhados com terceiros para quem pode ser transferida a propriedade dos direitos autorais das imagens e que esses dados podem ser utilizados futuramente em trabalhos científicos, artigos de revisão, publicações médicas, livros didáticos, apresentações congressos, cursos e outras finalidades de âmbito científico ainda que diferentes da acima indicada, destinadas apenas a profissionais de saúde. Em complemento dos esclarecimentos prestados foi disponibilizada a Política de Privacidade desta unidade de saúde que é a Responsável pelo Tratamento dos Dados.

Respondi a todas as questões que me foram colocadas e assegurei-me de que foi compreendida toda a informação fornecida oralmente e por escrito, da ausência de dúvidas por esclarecer e de que houve um período de reflexão suficiente para a tomada da decisão. Informei ainda de que este consentimento (se concedido) poderá ser retirado a todo o tempo, clarificando que a retirada do consentimento não compromete a licitude do tratamento de dados que foi feito com base no mesmo até ao momento em que seja retirado. Também garanti que, em caso de recusa deste consentimento (ou de ser futuramente retirado), não existirá qualquer efeito sobre os cuidados de saúde prestados, podendo, no entanto, ficar prejudicada a possibilidade de participação no estudo/ensaio clínico.

Nome do Investigador Principal: **Nuno Alexandre Remédio Cristino**

[X] Médico [ ] Outro Profissional de Saúde (categoria / função): _____

Identificação nº: **36569** [X] Cédula Profissional [ ] Nº Mecanográfico

Contacto institucional do Investigador Principal: **centro.coluna.setubal@hospitaldaluz.pt**

Assinatura do Investigador Principal: _____ Data: ____/____/____

Ao Participante titular dos dados / Representante Legal (de participante menor ou incapaz de prestar consentimento)

Por favor, leia com atenção todo o conteúdo deste modelo e da informação complementar disponibilizada (se aplicável). Solicite mais informações se tiver dúvidas ou não estiver completamente esclarecido. Verifique se todas as informações estão corretas. Só assine este modelo se tudo estiver conforme, se estiver totalmente esclarecido e se concordar com o seu conteúdo integral. Assine-o perante o Investigador Principal e conserve um exemplar na sua posse.

Fui previamente informado e esclarecido, em linguagem clara e acessível, acerca da utilização para fins científicos dos meus dados obtidos no âmbito do estudo/ensaio clínico acima indicado, incluindo apresentações, trabalhos científicos e publicação de casos clínicos tratados nesta unidade e/ou nas unidades integradas no grupo Luz Saúde. Foi-me garantido que os meus dados serão tratados de forma confidencial, sendo o seu acesso exclusivamente reservado à equipa de investigação que está obrigada a proteger a minha privacidade e a não divulgar qualquer informação pessoal que não seja estritamente necessária no âmbito do estudo/ensaio clínico acima indicado e nos termos da legislação aplicável. Foi-me também explicado que os meus dados podem ser partilhados com terceiros, desde que sejam **previamente anonimizados ou pseudonimizados** para que não exista hipótese de ser individualmente identificado o seu titular através da informação

contida nesses dados. Nessas circunstâncias, os referidos dados devidamente anonimizados ou pseudonimizados poderão ser utilizados futuramente em trabalhos científicos, artigos de revisão, publicações médicas, livros didáticos, apresentações, congressos, cursos e outras finalidades de âmbito científico ainda que diferentes do estudo/ensaio clínico acima indicado, destinadas apenas a médicos e a outros profissionais de saúde. Estes trabalhos científicos, apresentações e afins têm como objetivo divulgar informação que pode ser vir a ser útil à comunidade científica. Habitualmente, este tipo de trabalhos aborda casos que, pela sua originalidade ou raridade de apresentação, abordagem ou resultados atingidos, merecem ser divulgados, com a finalidade de contribuir para o desenvolvimento do conhecimento médico/científico e a melhoria dos cuidados de saúde prestados a outros clientes. Embora se procure garantir o total anonimato, fui alertado que pode haver algum risco (muito limitado) de que eu próprio ou outra(s) pessoa(s) possa(m) reconhecer-me.

Apreendi toda a informação que me foi disponibilizada oralmente e por escrito. Tive prévio conhecimento da Política de Privacidade da unidade, em conformidade com a legislação aplicável. Dessa forma estou perfeitamente informado sobre a identidade do Responsável pelo Tratamento e os termos do tratamento dos meus dados, incluindo o fundamento e a finalidade, bem como prazos de conservação, os contactos do Encarregado da Proteção de Dados e o modo como poderei exercer os meus direitos. Foi-me dada a oportunidade de fazer todas as perguntas sobre o assunto e para todas elas obter resposta esclarecedora, garantindo-me que não haverá prejuízo para os meus direitos assistenciais se recusar esta solicitação, apenas com a ressalva de que a recusa ou retirada deste consentimento poderá prejudicar a possibilidade de participar no estudo/ensaio clínico em referência. Concedo este consentimento, enquanto fundamento de legitimidade para o tratamento dos meus dados no âmbito do estudo/ensaio clínico acima indicado, como uma contribuição voluntária e gratuita no melhor interesse do desenvolvimento científico, da investigação médica e da formação e ensino, sem direito a qualquer retribuição ou compensação de qualquer espécie. Tive o tempo suficiente para refletir sobre a proposta e para tomar a decisão que aqui expresso de forma consciente, livre, informada e voluntária. Estou ciente de que poderei retirar o seu consentimento a todo o tempo, compreendendo que a retirada do consentimento não compromete a licitude do tratamento de dados que foi feito com base no mesmo até ser retirado.

Declaro que autorizo o tratamento dos meus dados obtidos no âmbito do estudo / ensaio clínico acima identificado. Concedo que os meus dados só sejam utilizados para qualquer outra finalidade nos termos acima indicados, se previamente anonimizados ou pseudonimizados.

Assinatura do Participante (com 16 anos ou mais e com discernimento):

_____ Data: _____ / _____ / _____

Representante Legal (de Participante menor de 18 anos ou com incapacidade de prestar este consentimento)

A decisão do Representante Legal deve refletir a vontade presumível do Participante titular dos dados.

Nome completo: _____

Contacto: _____

Tipo de Representação: ☐ Poder Paternal ou ☐ Tutor ou ☐ Curador ou ☐ Acompanhante nomeado pelo Tribunal

ou ☐ Procurador de Cuidados de Saúde, com poderes para praticar este ato

Identificação nº: _____ ☐ Cartão de Cidadão ☐ Bilhete de Identidade ☐ Passaporte

☐ Outro: _____

Assinatura do Representante Legal: _____ Data: _____ / _____ / _____

Annex 3 – EQ-5D-3L Questionnaire

EUROSPINE SPINE TANGO
CENTRO DE COLUNA (AVALIAÇÃO TODAS AS CONSULTAS)

HOSPITAL DA LUZ SETÚBAL

AVALIAÇÃO DE GANHOS EM SAÚDE

QUESTIONÁRIO EQ-5D

ND: _____Data_____

Assinale com uma cruz (assim X), um quadrado de cada um dos seguintes grupos, indicando qual das afirmações melhor descreve o seu **estado de saúde hoje!**

A. Mobilidade

0 Não tenho problemas em andar

1 Tenho alguns problemas em andar

2 Tenho de estar na cama

B. Cuidados pessoais (lavar, vestir, etc.)

0 Não tenho problemas com os meus cuidados pessoais

1 Tenho alguns problemas em lavar-me ou vestir-me

2 Sou incapaz de me lavar ou vestir sozinho/a

C. Actividades Habituais (ex. trabalho, estudos, actividades domésticas, actividades em família ou de lazer)

0 Não tenho problemas em desempenhar as minhas atividades habituais

1 Tenho alguns problemas em desempenhar as minhas atividades habituais

2 Sou incapaz de desempenhar as minhas atividades habituais

D. Dor / Mal-estar

0 Não tenho dores ou mal-estar

1 Tenho dores ou mal-estar moderados

2 Tenho dores ou mal-estar extremos

E. Ansiedade / Depressão

0 Não estou ansioso/a ou deprimido/a

1 Estou moderadamente ansioso/a ou deprimido/a

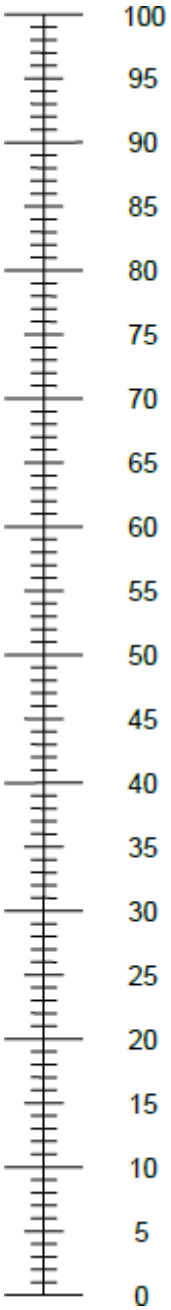
2 Estou extremamente ansioso/a ou deprimido/a

Gostaríamos de saber o quanto a sua saúde está boa ou má HOJE

- A escala está numerada de 0 a 100.
- 100 significa a melhor saúde que possa imaginar. 0 significa a pior saúde que possa imaginar.
- Coloque um X na escala de forma a demonstrar como a sua saúde se encontra HOJE.
- Agora, por favor, escreva o número que assinalou na escala no quadrado abaixo.

A SUA SAÚDE HOJE = ☐

A melhor saúde que pode imaginar



A pior saúde que possa imaginar

Muito obrigado por ter preenchido este questionário.

Annex 4 – Oswestry Disability Index (ODI)

COLUNA LOMBAR (AVALIAÇÃO TODAS AS CONSULTAS)

ODI – OSWESTRY DISABILITY INDEX

ND:_____Data_____

O questionário que se segue foi feito para nos dar informações de como o seu problema com as costas (ou perna) tem afectado a sua capacidade para viver o dia-a-dia. Por favor responda a todas as secções. Escolha apenas o quadrado em cada secção que **melhor o descreve hoje**.

A. Intensidade da dor

0 Neste momento não tenho dores

1 A dor é muito ligeira neste momento

2 A dor é moderada neste momento

3 A dor é um bocado forte neste momento

4 A dor é muito forte neste momento

5 A dor é o pior que se possa imaginar neste momento

B. Cuidados pessoais (lavar, vestir, etc.)

0 Consigo arranjar-me como antes sem ter mais dores

1 Consigo arranjar-me como antes mas tenho muitas dores

2 Tenho muitas dores quando me estou a arranjar e sou muito lento(a) e cuidadoso(a)

3 Preciso de alguma ajuda mas consigo arranjar-me quase todo(a) sozinho(a)

4 Preciso de ajuda todos os dias na maior parte dos meus cuidados pessoais

5 Não me visto, lavo-me com dificuldade, e fico na cama

C. Levantar pesos

0 Consigo levantar grandes pesos sem ter mais dores

1 Consigo levantar grandes pesos mas tenho mais dores

2 As dores não me deixam levantar grandes pesos do chão mas já consigo fazê-lo se estiverem num sítio que dê jeito, por exemplo, em cima duma mesa

3 As dores não me deixam levantar grandes pesos mas consigo levantar pesos leves ou médios se estiverem num sítio que dê jeito

4 Só consigo levantar pesos muito leves

5 Não consigo levantar ou carregar absolutamente nada

D. Andar

0 As dores não me impedem de andar qualquer distância

1 As dores não me deixam andar mais de 1,5 km

2 As dores não me deixam andar mais de 500 m

3 As dores não me deixam andar mais de 100 m

4 Só consigo andar com uma bengala ou com canadianas

5 Estou na cama a maior parte do tempo e tenho que me arrastar para ir a casa de banho

E. Estar sentado/a

0 Consigo estar sentado/a em qualquer cadeira o tempo que eu quiser

1 Consigo estar sentado/a na minha cadeira preferida o tempo que eu quiser

2 As dores não me deixam estar sentado/a mais de uma hora

3 As dores não me deixam estar sentado/a mais de meia hora

4 As dores não me deixam estar sentado/a mais de 10 minutos

5 As dores não me deixam estar sentado/a

F. Estar de pé

0 Consigo estar de pé o tempo que eu quiser sem ter mais dores

1 Consigo estar de pé o tempo que eu quiser mas tenho mais dores

2 As dores não me deixam estar de pé mais de uma hora

3 As dores não me deixam estar de pé mais de meia hora

4 As dores não me deixam estar de pé mais de 10 minutos

5 As dores não me deixam estar de pé

G. Dormir

0 O meu sono nunca é perturbado pelas dores

1 O meu sono é ocasionalmente perturbado pelas dores

2 Por causa das dores durmo menos de 6 horas

3 Por causa das dores durmo menos de 4 horas

4 Por causa das dores durmo menos de 2 horas

5 As dores não me deixam dormir

H. Vida sexual (se se aplicar)

0 A minha vida sexual é normal e não me causa mais dores

1 A minha vida sexual é normal mas causa-me mais dores

2 A minha vida sexual é quase normal mas causa-me muitas dores

3 A minha vida sexual é limitada pelas dores

4 Quase não tenho vida sexual por causa das dores

5 As dores não me deixam ter uma vida sexual

I. Vida social

0 A minha vida social é normal e não me causa mais dores

1 A minha vida social é normal mas aumenta a intensidade das dores

2 As dores não têm grande influência na minha vida social para além de limitaram as minhas atividades mais exigentes, por exemplo, desporto, etc

3 As dores limitaram a minha vida social e eu já não saio tanto

4 As dores confinaram a minha vida social à minha casa

5 Não tenho vida social por causa das dores

J. Viajar

0 Consigo viajar para qualquer lado sem dores

1 Consigo viajar para qualquer lado mas causa-me mais dores

2 As dores incomodam-me mas consigo fazer viagens de mais de 2 horas

3 As dores não me deixam fazer viagens de mais de 1 hora

4 As dores restringem-me a viagens necessárias e curtas, de menos de 30 minutos

5 As dores não me deixam viajar a não ser para fazer tratamento

Score Total: _____

Data e Hora do preenchimento:

_____

Annex 5 – Numerical Pain Rating Scale (NPRS)