Journal Pre-proof

Evaluation of deep oscillation therapy for the treatment of lumbar pain syndrome using motion capture systems: A systematic review

Fernando Villalba-Meneses, Karla Chaglla-Monge, Diego Almeida-Galárraga, Carolina Cadena-Morejón, Alejandro Moreno-Calvo, Javier Marín, José J. Marín

PII: S1360-8592(24)00025-1

DOI: https://doi.org/10.1016/j.jbmt.2024.01.010

Reference: YJBMT 2756

To appear in: *Journal of Bodywork & Movement Therapies*

Received Date: 3 August 2022

Revised Date: 17 June 2023

Accepted Date: 13 January 2024

August 2, 2022

CREDIT AUTHOR STATEMENT

Fernando Villalba-Meneses: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition. **Karla Chaglla-Monge**: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization. **Diego Almeida-Galárraga**: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization. **Carolina Cadena-Morejón**: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization. **Alejandro Moreno-Calvo**: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization. **Javier Marín**: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization. **José J. Marín**: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition.

Sincerely,

Fernando Villalba
Universidad de Zaragoza – Spain

Evaluation of deep oscillation therapy for the treatment of lumbar pain syndrome using motion capture systems: A systematic Review

Fernando Villalba-Meneses[a, b]*, Karla Chaglla-Monge[b], Diego Almeida-Galárraga[b], Carolina Cadena-Morejón[c], Alejandro Moreno-Calvo[a], Javier Marín[a,d,e], and José J. Marín[a,d,e]

[a] *Universidad de Zaragoza, Zaragoza, 50018, Spain;*

[b] *School of Biological Sciences & Engineering, Universidad Yachay Tech, Urcuquí, 100650, Ecuador,*

[c] *School of Mathematical and Computer Sciences, Universidad Yachay Tech, Urcuquí, 100650, Ecuador,*

[d] *IDERGO (Research and Development in Ergonomics), I3A (Instituto de Investigación en Ingeniería de Aragón), University of Zaragoza, C/Mariano Esquillor s/n, 50018 Zaragoza, Spain,*

[e] *Departamento de Ingeniería de Diseño y Fabricación, Universidad de Zaragoza, C/Mariano Esquillor s/n, 50018 Zaragoza, Spain*

Fernando Villalba-Meneses*

762301@unizar.es*

Word count:

Abstract: 248

Main Text: 5496

ABSTRACT

Low back pain is a painful disorder that prevents normal mobilization, increases muscle tension and whose first-line treatment is usually non-steroidal anti-inflammatory drugs, together with non-invasive manual therapies, such as deep oscillation therapy. This systematic review aims to investigate and examine the scientific evidence of the effectiveness of deep oscillation therapy in reducing pain and clinical symptomatology in patients with low back pain, through the use of motion capture technology. To carry out this systematic review, the guidelines of the PRISMA guide were followed. A literature search was performed from 2013 to March 2022 in the PubMed, Elsevier, Science Director, Cochrane Library, and Springer Link databases to collect information on low back pain, deep oscillation, and motion capture. The risk of bias of the articles was assessed using the Cochrane risk of bias tool. Finally, they were included 16 articles and 5 clinical trials which met the eligibility criteria. These articles discussed the effectiveness of deep oscillation therapy in reducing pain, eliminating inflammation, and increasing lumbar range of motion, as well as analyzing the use of motion capture systems in the analysis, diagnosis, and evaluation of a patient with low back pain before, during and after medical treatment. There is no strong scientific evidence that demonstrates the high effectiveness of deep oscillation therapy in patients with low back pain, using motion capture systems. This review outlines the background for future research directed at the use of deep oscillation therapy as a treatment for other types of musculoskeletal injuries.

Keywords: Low back pain, deep oscillation therapy, motion capture, inertial sensor, range of motion.

1. INTRODUCTION

Low back pain (LBP) is considered one of the most common causes of physical activity limitation and work disability worldwide (Hoy et al., 2014; Traeger et al., 2017), caused as a result of exposure to excessive efforts, unbalanced weight lifting, forced postures, demanding physical activities, etc. (Sánchez-Pinilla, 2020; Vlaeyen et al., 2018). Studies found that approximately 84% of the world's adult population will suffer from low back pain at least once in their lives (Abdollahi et al., 2020). LBP is a muscle pain located from the twelfth rib area to the folds of the lower buttocks (Celletti et al., 2020; Kahere et al., 2022). This painful disorder is usually treated considering certain aspects such as the duration of symptoms, sources of pain (Urits et al., 2019), the potential cause of the pathology, and root symptoms (Qaseem et al., 2017). The treatments used for the management of LBP include manual, physical, pharmacological, psychological therapies and surgical interventions (Parthan et al., 2006). Deep Oscillation (DO) is a patented manual therapy that produces mechanical vibrations in the skin and deep tissues (Vladeva et al., 2021). This device uses repeated electrostatic oscillations to relieve the pain and swelling (Zehtindjieva et al., 2013) of a specific area by moving the swelling through the lymphatic system (Hausmann et al., 2019; Kraft et al., 2013). DO therapy builds up a pulsating electrostatic field of low intensity (Kraft et al., 2013)(100-400 V; 150 µA) and low frequency (5-250 Hz) between the hand applicator and the affected tissue (Aliyev, 2009; Stengel et al., 2018). Its low-frequency electrostatic field produces a throbbing effect in the underlying tissues that improve the wound healing and anti-inflammatory effects (Brien et al., 2016; Vladeva et al., 2021), stimulates lymphatic flow (Jahr et al., 2008), stimulates collagen production, cell regeneration (Gao et al., 2015), and ensures more blood reaches the affected area (Hausmann et al., 2019). Both, the patient and the physical therapist are connected to the deep oscillation device, which serve as a source of tension with high internal resistance (Jahr et al., 2008). The impulse of the voltage produces an electrostatic attraction on the tissue and rhythmic frictions are generated when massaging the edema (Jahr et al., 2008; Kraft et al., 2013). These rhythmic frictions result in oscillations of the local tissue (skin, conductive tissue, subcutaneous adipose tissue, muscles, blood, and lymphatic vessels) and increase the vascular circulation of the area concerned (Aliyev, 2014; Kraft et al., 2013). Each session of deep oscillation therapy follows a rigorous clinical protocol. In most medical trials, therapy begins with 15 minutes of conventional manual lymphatic drainage (Jahr et al., 2008). Later the equipment of DO is used for 10 minutes at 200 -250 Hz (Brien et al., 2016) in the area to be treated, and to finish is administered oscillations of 85Hz for 10 minutes (Boisnic & Branchet, 2013; Brien et al., 2016). The physiological effects of deep oscillation therapy in the treatment of low back pain will depend on the frequency and intensity applied (Mratskova, 2020). Clinical studies have reported that DO therapy restores mobility between fibers, repairs affected tissue (Aliyev, 2014; Jahr et al., 2008), anti-inflammatory effect, reduces edema (Winkelmann et al., 2018), improves drainage channels, and accelerates wound healing (Aliyev, 2014; Kraft et al., 2013; Winkelmann et al., 2018).

Deep oscillation therapy has gained strength in recent years as a treatment for musculoskeletal injuries. The available information and the number of clinical studies of this therapy as a treatment for low back pain is scarce. Despite this limitation, there are scientific articles and clinical studies that highlight the use of alternative therapies to deep oscillation therapy, which have a similar function. Pulsed electromagnetic field therapy is a non-invasive therapy. It increases the vasodilatation of blood vessels by accelerating circulation (Özdemir et al., 2021), also modulates cyclic adenosine, which is the monophosphate (cAMP) signaling pathway, which is related to pain (Ross et al., 2022) .

Such as pulsed electromagnetic field therapy is a non-invasive therapy, it increases the vasodilatation of blood vessels by accelerating circulation (Özdemir et al., 2021) and also modulates cyclic adenosine, which is the monophosphate (cAMP) signaling pathway. , a pathway that is related to pain (Ross et al., 2022).

The lumbar spine has 6 degrees of freedom of movement: three rotational movements and three translational movements (Wilke & Volkheimer, 2018). The normal thoracolumbar range of motion (RoM) of a person without LBP is typically 90° of forward flexion, 30° of back extension, and ~ 15.3° of axial rotation and 25° of lateral flexion (Urits et al., 2019). People with LBP have limited lumbar RoM, low lumbar movement speed, reduced proprioception, slow movements (Kuligowski & Sipko, 2021; Laird et al., 2016, 2019; Mjøsund et al., 2017), and decreased accuracy of trunk repositioning during flexion (Edwards et al., 2020; Šarabon et al., 2021) compared to people without LBP. Fingertip to Floor Test, Schober´s Test, and inclinometers are some of the non-invasive methods used to assess spinal mobility. One of the disadvantages of their use is that they only allow measuring the lumbar movement of the patient in a static position (Mjøsund et al., 2017).

Technological advances have created new opportunities in clinical and rehabilitation environments for the investigation of pathologies related to lumbar mobility, through the use of inertial measurement unit sensors (IMU) (Beange et al., 2019; Laird et al., 2016). Some of its advantages are: 1) portable devices, 2) inexpensive, and 3) do not require a controlled laboratory to use them.(Ha et al., 2013). Motion capture technology makes it possible to monitor, quantify and measure the 3D position and movement of the lumbar spine (Cai et al., 2021) during dynamic conditions. This technology also makes it possible to identify lumbar movement patterns in people with low back pain and compare them with those of healthy people.

Inertial motion sensors based on accelerometers, gyroscopes, magnetometers, and algorithms (Al-amri et al., 2018; Laird et al., 2019) provide information on the kinematic parameters of a person's movement, such as range and speed of movement and inclination angles (Laird et al., 2019). MoCap systems are not only used in the diagnosis and evaluation of certain physical injuries or musculoskeletal pathologies, but are also used to monitor the effectiveness of manual and physical rehabilitation treatments (Fitzgerald et al., 2008) recommended for patients with musculoskeletal pain.

Despite the fact that low back pain is a musculoskeletal disorder that represents great economic losses for governments, efforts to research and develop new rehabilitation treatments are scarce. This systematic review aims to investigate and collect scientific information to determine the effectiveness of deep oscillation therapy or, alternatively, therapies that work under a modality similar to low-frequency pulsed magnetic fields for the treatment of low back pain. All of this, makes it possible to compile the potentialities and limitations of these treatments and their evaluation using MoCap technology, essential for future studies in the clinical and rehabilitation fields.

2. METHODS

2.1. Study design

This systematic review followed the guidelines and criteria established in the PRISMA 2020 Checklist. The protocol was registered in the PROSPERO database (https://www.crd.york.ac.uk/prospero/) with registration number CRD42023407401.

2.2. Eligibility criteria

This systematic review includes research articles and clinical trials with certain characteristics 1) articles evaluating the use of deep oscillation therapy or therapies related to Low-intensity and extremely low-frequency electrostatic fields as a treatment for low back pain; 2) articles highlighting the importance and use of motion capture systems (MoCap) as a tool for diagnosis and evaluation of medical therapies for people with low back pain; 3) articles in English and with full text availability; 4) studies conducted from January 2013 until February 2022. Systematic reviews or meta-analyses were excluded.

2.3. Information sources

A comprehensive search of the existing literature was conducted from January 2013 to February 2022 in the following databases: Google Scholar, PubMed, Elsevier, Science Director, Cochrane Library, and Springer Link. The descriptors used for the search in the databases included a mixture of titles and keywords related to deep oscillation therapy (DO), low back pain (LBP), motion capture system (MoCap), inertial sensors, range of motion, low-intensity and extremely low-frequency electrostatic fields. The reference lists of the selected studies were searched to find articles that met the inclusion requirements and that could be selected for the development of the systematic review.

2.4. Selection of studies

Initially the studies were filtered and selected according to the importance and relevance of their abstracts. Then, the full text of the selected articles was evaluated, in order to identify if they met the inclusion criteria.

2.5. Data collection process

In the beginning, the literature search was focused on evaluating the effectiveness of deep oscillation therapy as a treatment for low back pain, using motion capture. However, the information collected in the metasearch was scarce, so the research was divided into two parts: 1) evaluation of low back pain through the use of inertial sensors/motion capture and 2) low-intensity and low-frequency electrostatic field therapy for low back pain. The information found about deep oscillation therapy as a treatment for low back pain was limited, so the literature search range was broadened to topics such as low intensity and low-frequency electrostatic fields, and pulsed electromagnetic field.

2.6. Risk of bias

For the evaluation of the risk of bias of the selected articles and clinical trials, an evaluation based on Cochrane domains was considered. Several criteria were analyzed: 1) experimental design; 2) randomized controlled trial; 3) sample characteristics, 4) inclusion/exclusion criteria of the participants; 5) control group included. These criteria were evaluated on a scale from 0 to 2, being equivalent to 0= low level of risk of bias (the article broadly describes and provides information on the analyzed domain), 1= medium level of risk of bias (the article does not describe the domain evaluated clearly), 2= high level of risk of bias (the article does not analyze or provide information on the corresponding domain).

In this systematic review, two reviewers independently reviewed, evaluated, and scored selected research articles and clinical studies. It is important to mention that when there were different scores in some of the domains analyzed, a third evaluator intervened to establish the final total bias risk score.

3. RESULTS

3.1. Study selection

From the literary search in the different databases, 150 titles were obtained. Afterwards, this number of studies was reduced by eliminating duplicate articles (n= 50). After this first selection filter, n= 56 studies not found within the range of the search deadline were excluded. In the third filter, a total of 23 studies were excluded as they did not meet the inclusion criteria that were set out at the beginning of this systematic review. Finally, the literature search identified 16 research articles related to motion capture systems and 5 clinical trials related to the use of electromagnetic field therapies for the treatment of lumbar pain (see Figure 1), who met the selection. requirements.

3.2. <u>Method quality</u>

Table 1 shows the methodological quality of the trials analyzed in this systematic review through a final score. The following results were reached: 17 of the 21 selected trials presented a final score between one and four points. Research articles with a final score between 1 and 3 can be considered to have a low risk of bias. The domain that presented the highest risk of bias was the randomized controlled trial, considering that most of the papers that obtained a score equal to 2 (high risk of bias) correspond to articles that analyzed the use of motion capture systems for the medical evaluation of patients with low back pain.

PLACE HERE TABLE 1

3.3. <u>Evaluation questionnaires.</u>

Several questionnaires were used as complementary tools for the evaluation and analysis of disability related to LBP. Oswestry Disability Index (ODI) was used to measure the impact of LBP on patients (Krammer et al., 2015).

Gombatto et al., (2015b), and Wildenbeest et al., (2021b) in their articles used the ODI to measure the functional limitation and disability of the patient about lumbar pain, representing 100% of the total score at maximum disability. Further, the Fear Avoidance Based Questionnaire (FABQ) is included to measure the degree to which a person with some pathology performs limited physical activity due to fear of pain (Gombatto et al., 2015). On the other hand, Wildenbeest et al., (2021b) use the numerical rating scale (NRS) to evaluate the intensity of pain that the patient may feel during the physical evaluation. The scale was evaluated from 0 to 10, where 0 equals no pain and 10 equals maximum pain (Wildenbeest et al., 2021). Other studies used a 24 question Roland Morris Disability Questionnaire (RMDQ-24), where 100% equals to a maximum limitation of activity (Laird et al., 2019).

3.4. Study characteristics

The most significant characteristics of the selected trials are summarized in Tables 1-2.

Pulsed electromagnetic fields - low back pain

A total of 347 patients were included in the five selected randomized controlled clinical trials (Table 2). N= 65 participants received pulsed electromagnetic field therapy, while the remaining N= 282 patients received low-frequency magnetic field therapy. Only one of these five clinical trials had a control group (N=25) within its experimental phase.

The main objective of the selected papers is to evaluate the effectiveness of low-frequency pulsed magnetic or electromagnetic fields therapies combined with manual and physical therapies in the treatment of LBP (Abdulla et al., 2019; Alzayed & Alsaadi, 2020). The studies were designed as double-blind randomized placebo-controlled trials, i.e., participants were randomly assigned to the control or experimental groups, using a blind research assistant (Abdelhalim & Samhan, 2018; Elshiwi et al., 2018). Participants were excluded from the study if they had previous back surgery, cardiopulmonary diseases (Elshiwi et al., 2018), pregnancy or lactating (Abdulla et al., 2019), spinal fracture, heart pacemaker (Alzayed & Alsaadi, 2020), and tumors (Krammer et al., 2015). To validate the effectiveness of electromagnetic field therapy in the treatment of LBP, researchers such as Abdulla et al. (2019) evaluate the progress of the rehabilitation process of patients in three phases: first at the beginning of therapy, second at the end of the third week of rehabilitation and finally during the sixth week of the rehabilitation sessions. Before starting treatment, the range of mobility, degree of flexion, rotation, and lateralization of the trunk was evaluated with the help of an inclinometer bubble, while the degree of lumbar pain was measured using the visual analog scale (VAS)(Abdelhalim & Samhan, 2018).

It is important to mention that in the papers analyzed, both the experimental group and the control group, in addition to receiving low-frequency and low-intensity magnetic/electromagnetic field therapy or placebo, they use of hot compresses (Abdulla et al., 2019) and conventional physiotherapy exercise (Alzayed & Alsaadi, 2020; Elshiwi et al., 2018) as additional tools to the recovery of patients with LBP, whether acute or chronic.

Besides, the frequency with which the treatment is applied to patients with LBP is different in each experimental article and can range from 12 sessions for one month to 39 sessions for 3 months. It all depends on the severity of the musculoskeletal disorder, that is, if the low back pain is chronic or acute, and the value of the frequency and intensity with which the pulsed electromagnetic field therapy is being applied. All the characteristics of the clinical trials that were previously described are further detailed in Table 2. All of the clinical studies reviewed reported the effectiveness of low-frequency and low-intensity magnetic/electromagnetic field therapy in patients with low back pain, reducing low back pain and swelling, as well as increasing their lumbar range of motion.

PLACE TABLE 2

MoCap and low back pain

Lumbar RoM was evaluated in a total of 929 people using different motion capture systems. A total of n= 8 research articles evaluated the RoM of patients with LBP. While n= 3 articles evaluated the pathology of NSCLBP (Non-Specific Chronic Low Back Pain), and n= 4 articles evaluated CLBP (Chronic Low Back Pain). Only one of the selected research articles evaluated the lumbar lordosis of their patients. The studies included control groups of people without low back pain (Abdollahi et al., 2020; Ashouri et al., 2017; Bacon et al., 2020b; Gombatto et al., 2015b; Hemming et al., 2018; Wildenbeest et al., 2021b) to compare lumbar RoM with the group of people with LBP. Exclusion criteria were also established, such as presenting acute trauma (Bauer et al., 2016), pregnancy (Celletti et al., 2020), people with medical condition affecting the spine (Gombatto et al., 2015), previous back surgery (Graham et al., 2020), spine fractures (Laird et al., 2016), tumors, vertebral infections, and musculoskeletal injury.

Some articles took into account the demographic and anthropometric characteristics of the participants such as age, gender, weight, height, and body mass index (BMI) (Abdollahi et al., 2020; Ashouri et al., 2017; Davoudi et al., 2020; Gombatto et al., 2015; Hemming et al., 2018; Mjøsund et al., 2017; Shin & Yoo, 2019; Wildenbeest et al., 2021; Zhang et al., 2020) in order to recommend an adequate therapy according to the physical characteristics of the patients. Also, anthropometric analysis is important to identify the lumbar area where the motion capture systems (sensors) should be placed, to record the lumbar RoM before and after treatment.

Sensor systems characteristics

Different MoCap systems were used to measure lumbar RoM, for example Vison-Based System (Vicon), Inertial Measurement Unit (ViMove), and Marker-Based System. Each of them is made up of essential components such as cameras, markers, triaxial accelerometers, triaxial gyroscopes and triaxial magnetometers (Table 3-4).

PLACE TABLES 3 AND 4 HERE

Table 3 describes sixteen movement capture systems, which allow detecting and measuring lumbar-pelvic movements like flexion, extension, lateral flexion, and rotation (Zhang et al., 2020). Each of these systems locates the sensors in different body segments. E-Skin system locates the sensors in the T3-T7 and L1-L3 regions. In the case of Vicon systems, a series of markers are placed on the lumbar, cervical, and thoracic (T8) regions (Hemming et al., 2018; Wildenbeest et al., 2021). While, MTw2 trackers (Xsens Technologies) were placed on C7, L2, and L4 vertebrae (Bacon et al., 2020), to record the angle of each lumbar movement. On the other hand, the Vicon system (512 and 612) depending on the model uses different amounts of cameras ranging from 4 to 9 cameras (Hemming et al., 2018). This system is mainly used to measure the kinematics of the lumbar spine and pelvis during movements and exercises such as walking (Gombatto et al., 2015). Several sensors are composed of an accelerometer, gyroscope, and triaxial magnetometer (Abdollahi et al., 2020; Ashouri et al., 2017; Celletti et al., 2020) which makes them inertial systems. In addition, these systems allow evaluating the balance and mobility of the participants (Celletti et al., 2020).

Softwares like Matlab (Abdollahi et al., 2020) and Nixus Vicon (Hemming et al., 2018) were used for data processing and analysis. Then, data were exported to the Visual 3D (C-Motion) software to evaluate the gait of the participant (Gombatto et al., 2015). For data storage, the E-Skin system collects information wirelessly using a smart system, this application also allows the control of data transmission and storage (Zhang et al., 2020).

3.5. Synthesis of the study results

Pulsed electromagnetic field treatment in patients with nonspecific low back pain had positive effects on the low back recovery of the patients. Elshiwi et al. (2019a) through their investigations found that both the control group and the study group increased their RoM in flexion and extension after applying conventional physical therapy exercises and simulated magnetic field therapy, respectively. The study group after receiving pulsed electromagnetic field therapy experienced RoM-flexion from 3.20 ± .67 to 4.8 ±0.14 while ROM-extension increased in value from 1.53 ± .51 to 1.9 ±0.12 (Elshiwi et al., 2018). Abdelhalim & Samhan (2018) used a Low-Frequency Magnetic Field therapy in people with low back pain. Both, experimental group "A" and control group "B" increased their lumbar RoM after treatment. Thus, before treatment, group A had a forward trunk flexion value equivalent to 20.55 ±6.25, and after treatment, this value increased to 54.95±20.17. The same happened for the case of right and left lateral flexions of the trunk (Abdelhalim & Samhan, 2018).

To assess the degree of recovery of patients with LBP and evaluate the efficacy of pulsed electromagnetic field or Low-Frequency Magnetic Field rehabilitation therapies, evaluations and questionnaires were applied to the participants. In the case of Elshiwi (2019), he used a visual rating scale for the patient to locate the presence/absence of pain on a scale (0= no pain, 10= presence of pain), and also used the Owestry disability index and evaluated lumbar range of motion. In contrast, researchers such as Abdulla et al. (2019) used analysis of covariance to assess the effect of low-frequency pulsed magnetic field therapy in patients with CLBP.

In addition, motion capture systems described in the Tables 3-4, allowed to identify the differences in the movement patterns during flexion, extension, and rotation of the individuals with LBP compared to the healthy group. The Vicon 512 system reported that the group of people with NSCLBP showed more kyphotic thoracic-lumbar postures than the healthy group, which may explain the reason LBP occurs (Hemming et al., 2018). After performing the motion capture, it was possible to identify 1) people with LBP exhibited 5.48° less lumbar flexion than people without LBP 2) people with LBP exhibited 4.18° less anterior pelvic tilt than people without LBP ($p < 0.05$) 3) people with LBP perform a greater degree of rotation (1.7°) to the left in the lower lumbar region than people with low back pain (0.1; $p < 0.05$) 4) people with LBP show less rotation (3.3 ± 0.3°) than people without low back pain (4.3 ± 0.3) 5) people with LBP show 1.58° less superior lumbar rotation than people without LBP (Gombatto et al., 2015).

The use of motion capture systems allows classifying low back pain patients into clinical subgroups, to offer personalized exercise rehabilitation programs (Bacon et al., 2020). Regarding the analysis of the effectiveness of pulsed electromagnetic field therapy in patients with LBP, it was possible to identify that after applying this treatment, a significant difference was evidenced in the percentage of pain, functional disability, and flexion range between the control and experimental groups- (Elshiwi et al., 2018). The patients who underwent the low-frequency magnetic field treatment showed 1) a significant decrease in pain after finishing the treatment ($p < 0.05$ compared with pre-treatment) 2) a significant increase in the degree of flexion and extension of the trunk when end treatment ($p < 0.05$ compared with pre-treatment) (Abdelhalim & Samhan, 2018).

4. DISCUSSION

The main objective of this systematic review was to examine the scientific articles and clinical trials that demonstrate the effectiveness of deep oscillation therapy in the treatment of low back pain and the use of motion capture systems as an evaluation tool. However, the 5 clinical trials discussed in this systematic review use treatments that work in a similar way to deep oscillation therapy. Therefore, it is important to clarify the similarities and differences between these therapies. Pulsed low-frequency magnetic field therapy has an anti-inflammatory effect (Abdulla et al., 2019) just like DO therapy.

Each clinical trial selected for this review followed a specific protocol for the administration of low-intensity and extremely low-frequency electrostatic fields therapy.

The included clinical trials, whose characteristics are summarized in Table 2, found some similarities. For example, in the majority of studies, pulsed magnetic/electromagnetic field treatments were carried out in adult populations with a history of low back pain that has been clinically evaluated. However, the number of sessions of pulsed electromagnetic field therapy and their duration varies between clinical trials. On average, most clinical trials conducted 3 sessions per week for two to three weeks. However, Alzayed & Alsaadi (2020) in their study reports the performance of 39 sessions of 20 minutes for 3 months. The number of sessions of low frequency pulsed magnetic field therapy is higher than the rest of the clinical trials.

In assessing the disability of patients with low back pain, each clinical trial applies a different assessment method such as the Oswestry Disability Index and the Visual Analogue Scale (VAS). With the similarity that each scale and index allow verifying the improvements of patients with low back pain after receiving pulsed electromagnetic field therapy.

Patients with CLBP received pulsed magnetic field therapy at a frequency of 30 Hz for 30 ms, as in Abdulla et al. (2019). Different to Abdelhalim & Samhan (2018) who administered a magnetic field therapy in a frequency range of 1 to 100 Hz (low frequency) to patients with chronic or acute LBP. The frequency of the electrostatic field therapy is estimated for each participant (Mjøsund et al., 2017), and its physiological effects depend on the frequency value with which the treatment is applied (Mratskova, 2020). For example, frequencies of 80 to 250 Hz work like anti-inflammatory and analgesic, 25 to 80 Hz repair the tissues and improve the venous flow, and finally, 5-25 Hz improves muscle functionality (Mratskova, 2020).

Abdelhalim & Samhan (2018) and Elshiwi et al. (2018) reported positive results from magnetic field therapy reflecting a decrease in low back pain, and an increase in the trunk and spinal RoM in people with LBP.

Not all the clinical trials showed positive results of the long-term effectiveness of pulsed electromagnetic field therapy in the treatment of low back pain (Andrade et al., 2016; Paolucci et al., 2020). Authors such as Alzayed & Alsaadi (2020) and Krammer et al. (2015) agree that both pulsed Low-Frequency Magnetic Field Therapy and Pulsed Electromagnetic therapy have no beneficial effect in the treatment of low back pain. Alzayed & Alsaadi (2020) and Krammer et al. (2015) mention that the aforementioned therapies are not superior to the results obtained when applying conventional exercise therapies to the control group. This means that exercise sessions are optimal candidates and with better results in the treatment of people with LBP. Krammer et al. (2015) demonstrated that the experimental group that received pulsed electromagnetic therapy showed no improvement in ODI scores.

Regarding the limitations of the studies, Elshiwi et al. (2018) mention that one limitation in their research was not evaluating the long-term efficacy of pulsed electromagnetic field therapy. Unlike Abdulla et al. (2019), who at the beginning of their research plan to evaluate both the efficacy such as the safety of long-term low-frequency pulsed magnetic field therapy.

In general, the results presented by the five clinical trials that have been analyzed in this systematic review do not demonstrate 100% effectiveness of low frequency magnetic field therapy compared to other therapies that already exist on the market and to exercises traditional of physiotherapy.

Different MoCap systems are used to evaluate and quantify RoM dysfunction associated with low back pain (Bauer et al., 2016; Ha et al., 2013). Each research article locates the motion capture systems (vision-based systems and IMU-based systems) (Zhang et al., 2020) in different anatomical parts of the spine, for which reference points are used throughout long and in the lower part of the back spine. The orientation of these sensors is essential to avoid errors in the RoM measurement. Table 4 shows in more detail the components of the motion capture systems that were used in each research article, as well as briefly summarizes the results reached by the authors.

Zhang et al. (2020) through their research demonstrated that the E-Skin sensor is a sensitive, flexible sensor that allows detecting and recording the angles of the spine, when the patient executes repetitive movements of flexion, extension, pelvic tilt, lateral flexion, and rotation. On the contrary, in the investigation by Hemming et al. (2018), the patients did not perform the mechanical movements of flexion, extension and rotation of the lumbar region. In contrast, the patients performed exercises that simulate the activities that people carry out in our daily lives. Such as going up, down, lifting a box, etc. In the case of Celletti et al. (2020), the patients performed the exercises sitting in a standard chair, got up, walked 3m away, went around an object and returned to the chair.

Celletti et al. (2020) informed that the IMU system automatically provides data on spinal angle of flexion, range of motion, and rate of gyration. These parameters allow determining the improvement in patients with low back pain, after receiving back school therapy. On the contrary, Bacon et al. (2020), with their research, demonstrated that the IMU MTw2 motion capture system is a useful tool for the health area, to classify patients with low back pain into clinical subgroups, in order to establish exercise routines. and physiotherapy specialized in the needs of each patient (Bacon et al., 2020). This system is based on data analysis of the angles of sway, obtained when the patient performed exercises of flexion, lateralization, squats, sitting and standing. In summary, Bacon et al. (2020) demonstrates the effectiveness of IMU systems in the diagnosis of lumbar pathologies. Similarly, Abdollahi et al. (2020) demonstrated the effectiveness of IMU movement sensors (9DOF Razor IMU) in the categorization of patients with non-specific low back pain. Davoudi et al. (2020) in their research also examined inertial sensors as a useful tool for the classification of non-specific low back pain disorders in clinical settings.

The IMU sensors of Abdollahi et al. (2020) recorded the data of linear acceleration and angular velocity, in 2 directions X,Y,Z while the participants performed trunk flexion and extension movements (Abdollahi et al., 2020). In the case of the IMU system by Ashouri et al. (2017), the sensors record the information of 6 signals that represent the angular velocities and accelerations in 3D, data that allows the detection of lumbar disorders.

Zhang et al. (2020) demonstrated that the E-Skin motion capture system has a much faster response to movement changes compared to IMU systems. On the other hand, Mjøsund et al. (2017) conducted a comparison between the inertial motion sensor system (ViMove) and the Vicon system, in terms of their potential in assessing range of motion during tilting of the lower back. This latest investigation showed that different values of the angle of inclination are obtained when using one of these two systems. The ViMove system being the most suitable candidate.

Celletti et al. (2020) assessed patients before and after receiving physiotherapy treatment with the Oswestry Disability Index (ODI), Performance Oriented Mobility Assessment Scale (POMA), and Numerical Rating Scale (NRS) (Celleti et al.., 2020)

In this way, this systematic review highlights the importance of LBP treatment, and the relevance of motion capture as an evaluation tool in real time to assess the condition of LBP patients before, during and after receiving therapies and rehabilitation treatments. In this way, the potentialities and limitations outlined here can be a starting point for future research on the use of deep oscillation therapy as an effective treatment for musculoskeletal disorders in general. Through this literature review, researchers can develop studies that directly evaluate the use of deep oscillation therapy as LBP therapy. As well as evaluating the effectiveness of this therapy using motion capture systems before and after applying the treatment.

5. CONCLUSION

Pulsed electromagnetic field rehabilitation therapy appears to be highly effective in relieving and decreasing low back pain, eliminating swelling and inflammation, and increasing lumbar RoM. The rapid anti-inflammatory and analgesic effect of this therapy contributes to obtaining better results in reducing motor limitation in patients with LBP. However, definitive conclusions about the effectiveness of deep oscillation therapy in the treatment of low back pain cannot be established due to the scarce bibliographic information, despite this, the effectiveness of alternative therapies that have a concept of operation similar to that of the deep oscillation therapy. Motion capture systems and sensor systems enable a kinematic analysis of the lumbar spine and identify abnormalities in movement patterns. Portable motion capture systems noninvasively assess the effectiveness of a medical therapy by measuring the patient's RoM in real time in three stages: 1) before, 2) during and 3) after treatment.

Clinical Relevance

The results presented in this systematic review article serve as a tool for health professionals in the rehabilitation of patients with acute or chronic / specific and non-specific low back pain. Deep oscillation therapy seems to be a useful tool for the treatment of patients with low back pain and mobility, since after applying this therapy, patients experience positive changes both physiologically and biomechanically, for example, reduced inflammation, increased range of motion and locomotion, etc. On the other hand, emphasis should be placed on the importance of using motion capture systems as a tool for diagnosing lumbar pathologies and evaluating the effectiveness of different lumbar rehabilitation treatments, such as deep oscillation therapy.

Disclosure statement

The corresponding author of the manuscript "Evaluation of deep oscillation therapy for the treatment of lumbar pain syndrome using motion capture systems: A systematic Review", on behalf of himself and all authors, declares that there is no conflict of interest.

And that there are no financial and personal relationships with other persons or organizations that could inappropriately influence (bias) our work.

<u>Prospero Registration number</u>

CRD42023407401

REFERENCES

Abdelhalim, N. M., & Samhan, A. F. (2018). Long Term Effects of Low-Frequency Magnetic Field Therapy in TreatmentPatients with Low Back Pain. *International Journal of Medical Research & Health Sciences*, *7*(4), 108–113.

Abdollahi, M., Ashouri, S., Abedi, M., Azadeh-fard, N., Parnianpour, M., Khalaf, K., & Rashedi, E. (2020). *Using a Motion Sensor to Categorize Nonspecific Low*. https://doi.org/10.3390/s20123600

Abdulla, F. A., Alsaadi, S., Sadat-Ali, M. I. R., Alkhamis, F., Alkawaja, H., & Lo, S. (2019). Effects of pulsed low-frequency magnetic field therapy on pain intensity in patients with musculoskeletal chronic low back pain: Study protocol for a randomised double-blind placebo-controlled trial. *BMJ Open*, *9*(6), 1–9. https://doi.org/10.1136/bmjopen-2018-024650

Al-amri, M., Nicholas, K., Button, K., Sheeran, L., & Davies, J. L. (2018). *Inertial Measurement Units for Clinical Movement Analysis : Reliability and Concurrent Validity*. 1–29. https://doi.org/10.3390/s18030719

Aliyev, R. (2009). Klinische wirksamkeit des therapieverfahrens tiefenoszillation bei sportverletzungen. *Sportverletzung-Sportschaden*, *23*(1), 31–34. https://doi.org/10.1055/s-0028-1109216

Aliyev, R. (2014). *Additive E ff ekte von Tiefenoszillation in der Rehabilitation nach Vorderer-Kreuzband-Plastik Additive E ff ects of Deep Oscillation in Rehabilitation after Anterior Cruciate*. 183–190. https://doi.org/10.1055/s-0034-

1382036

Alzayed, K. A., & Alsaadi, S. M. (2020). Efficacy of pulsed low-frequency magnetic field therapy on patients with chronic low back pain: A randomized double-blind placebo-controlled trial. *Asian Spine Journal*, *14*(1), 33–42. https://doi.org/10.31616/ASJ.2019.0043

Andrade, R., Duarte, H., Pereira, R., Lopes, I., Pereira, H., Rocha, R., & Espregueira-Mendes, J. (2016). Pulsed electromagnetic field therapy effectiveness in low back pain: A systematic review of randomized controlled trials. *Porto Biomedical Journal*, *1*(5), 156–163. https://doi.org/10.1016/j.pbj.2016.09.001

Ashouri, S., Abedi, M., Abdollahi, M., Dehghan Manshadi, F., Parnianpour, M., & Khalaf, K. (2017). A novel approach to spinal 3-D kinematic assessment using inertial sensors: Towards effective quantitative evaluation of low back pain in clinical settings. *Computers in Biology and Medicine*, *89*(June), 144–149. https://doi.org/10.1016/j.compbiomed.2017.08.002

Bacon, Z., Hicks, Y., Al-Amri, M., & Sheeran, L. (2020). Automatic low back pain classification using inertial measurement units: A preliminary analysis. *Procedia Computer Science*, *176*, 2822–2831. https://doi.org/10.1016/j.procs.2020.09.272

Bauer, C. M., Heimgartner, M., Rast, F. M., Ernst, M. J., Oetiker, S., & Kool, J. (2016). Reliability of lumbar movement dysfunction tests for chronic low back pain patients. *Manual Therapy*, *24*, 81–84. https://doi.org/10.1016/j.math.2016.02.013

Beange, K. H. E., Chan, A. D. C., Beaudette, S. M., & Graham, R. B. (2019). Concurrent validity of a wearable IMU for objective assessments of functional movement quality and control of the lumbar spine. *Journal of Biomechanics*, *97*, 109356. https://doi.org/10.1016/j.jbiomech.2019.109356

Boisnic, S., & Branchet, M.-C. (2013). Anti-inflammatory and draining effect of the Deep Oscillation ® device tested clinically and on a model of human skin maintained in survival condition. *European Journal of Dermatology*, *23*(February), 59–63. https://doi.org/10.1684/ejd.2012.1904

Brien, O., Med, J. S., Stud, D., Cp, O. B., & Watson, A. (2016). *Journal of Sports Medicine & Doping Studies Deep Oscillation ® Therapy in the Treatment of Lateral Epicondylalgia : A Pilot Randomized Control Trial*. *6*(3). https://doi.org/10.4172/2161-0673.1000

Cai, L., Liu, D., & Ma, Y. (2021). Placement recommendations for single kinect-based motion capture system in unilateral dynamic motion analysis. *Healthcare (Switzerland)*, *9*(8), 1–15. https://doi.org/10.3390/healthcare9081076

Celletti, C., Mollica, R., Ferrario, C., Galli, M., & Camerota, F. (2020). Functional evaluation using inertial measurement of back school therapy in lower back pain. *Sensors (Switzerland)*, *20*(2), 1–7. https://doi.org/10.3390/s20020531

Davoudi, M., Shokouhyan, S. M., Abedi, M., Meftahi, N., Rahimi, A., Rashedi, E., Hoviattalab, M., Narimani, R., Parnianpour, M., & Khalaf, K. (2020). A Practical Sensor-Based Methodology for the Quantitative Assessment and Classification of. *Sesnors*, *20*.

Edwards, N., Dickin, C., & Wang, H. (2020). Low back pain and golf: A review of biomechanical risk factors. *Sports Medicine and Health Science*, *2*(1), 10–18. https://doi.org/10.1016/j.smhs.2020.03.002

Elshiwi, A. M., Hamada, H. A., Mosaad, D., Ragab, I. M. A., Koura, G. M., & Alrawaili, S. M. (2018). Effect of pulsed electromagnetic field on nonspecific low back pain patients: a randomized controlled trial. *Brazilian Journal of Physical*

Therapy, *23*(3), 244–249. https://doi.org/10.1016/j.bjpt.2018.08.004

Fitzgerald, D., Kelly, D., Ward, T., Markham, C., & Caulfied, B. (2008). *Usability Evaluation of E-Motion: A Virtual Rehabilitation System Designed to Demostrate, Instruct and Monior a Therapeutic Exercise Programme*.

Gao, Y., Peng, C., & Peng, R. Y. (2015). *A long term chronic fibrotic adhesion of elbow muscles alleviated by applying hivamat 200 deep oscillation therapy*. *2*(1), 286–289.

Gombatto, S. P., Brock, T., DeLork, A., Jones, G., Madden, E., & Rinere, C. (2015). Lumbar spine kinematics during walking in people with and people without low back pain. *Gait and Posture*, *42*(4), 539–544. https://doi.org/10.1016/j.gaitpost.2015.08.010

Graham, R. B., Dupeyron, A., & van Dieën, J. H. (2020). Between-day reliability of IMU-derived spine control metrics in patients with low back pain. *Journal of Biomechanics*, *113*, 110080. https://doi.org/10.1016/j.jbiomech.2020.110080

Ha, T., Saber-Sheikh, K., Moore, A. P., & Jones, M. P. (2013). Measurement of lumbar spine range of movement and coupled motion using inertial sensors – A protocol validity study. *Manual Therapy*, *18*(1), 87–91. https://doi.org/10.1016/j.math.2012.04.003

Hausmann, M., Ober, J., & Lepley, A. S. (2019). *The Effectiveness of Deep Oscillation Therapy on Reducing Swelling and Pain in Athletes With Acute Lateral Ankle Sprains*. 902–905.

Hemming, R., Sheeran, L., van Deursen, R., & Sparkes, V. (2018). Non-specific chronic low back pain: differences in spinal kinematics in subgroups during functional tasks. *European Spine Journal*, *27*(1), 163–170. https://doi.org/10.1007/s00586-017-5217-1

Hoy, D., March, L., Brooks, P., Blyth, F., Woolf, A., Bain, C., Williams, G., Smith, E., Vos, T., Barendregt, J., Murray, C., Burstein, R., & Buchbinder, R. (2014). The global burden of low back pain: Estimates from the Global Burden of Disease 2010 study. *Annals of the Rheumatic Diseases*, *73*(6), 968–974. https://doi.org/10.1136/annrheumdis-2013-204428

Jahr, S., Schoppe, B., & Reisshauer, A. (2008). *ORIGINAL REPORT EFFECT OF TREATMENT WITH LOW-INTENSITY AND EXTREMELY LOW- FREQUENCY ELECTROSTATIC FIELDS (DEEP OSCILLATION ®) ON BREAST TISSUE AND PAIN IN PATIENTS WITH SECONDARY BREAST LYMPHOEDEMA*. *8*, 645–650. https://doi.org/10.2340/16501977-0225

Kahere, M., Hlongwa, M., & Ginindza, T. G. (2022). A Scoping Review on the Epidemiology of Chronic Low Back Pain among Adults in Sub-Saharan Africa. *International Journal of Environmental Research and Public Health*, *19*(5), 1–22. https://doi.org/10.3390/ijerph19052964

Kraft, K., Kanter, S., & Janik, H. (2013). *Safety and Effectiveness of Vibration Massage by Deep Oscillations : A Prospective Observational Study*. *2013*.

Krammer, A., Hons, B., & Mphty, S. H. (2015). Pulsed electromagnetic energy as an adjunct to physiotherapy for the treatment of acute low back pain: a randomised controlled trial. *New Zealand Journal of Physiotherapy*, *43*(1). https://doi.org/10.15619/nzjp/43.1.03

Kuligowski, T., & Sipko, T. (2021). Lumbopelvic biomechanics in patients with lumbar disc herniation—prospective cohort study. *Symmetry*, *13*(4).

https://doi.org/10.3390/sym13040602

Laird, R. A., Keating, J. L., Ussing, K., Li, P., & Kent, P. (2019). Does movement matter in people with back pain? Investigating “atypical” lumbo-pelvic kinematics in people with and without back pain using wireless movement sensors. *BMC Musculoskeletal Disorders*, *20*(1), 1–15. https://doi.org/10.1186/s12891-018-2387-x

Laird, R. A., Kent, P., & Keating, J. L. (2016). How consistent are lordosis , range of movement and lumbo-pelvic rhythm in people with and without back pain ? *BMC Musculoskeletal Disorders*. https://doi.org/10.1186/s12891-016-1250-1

Mjøsund, H. L., Boyle, E., Kjaer, P., Mieritz, R. M., Skallgård, T., & Kent, P. (2017). *Clinically acceptable agreement between the ViMove wireless motion sensor system and the Vicon motion capture system when measuring lumbar region inclination motion in the sagittal and coronal planes*. 1–9. https://doi.org/10.1186/s12891-017-1489-1

Özdemir, M., Yaşar, M. F., & Yakşi, E. (2021). Effect of pulsed electromagnetic field therapy in patients with supraspinatus tendon tear. *Revista Da Associação Médica Brasileira*, *67*(2), 282–286. https://doi.org/10.1590/1806-9282.67.02.20200730

Paolucci, T., Pezzi, L., Centra, A. M., Giannandrea, N., Bellomo, R. G., & Saggini, R. (2020). Electromagnetic field therapy: A rehabilitative perspective in the management of musculoskeletal pain – A systematic review. In *Journal of Pain Research* (Vol. 13, pp. 1385–1400). https://doi.org/10.2147/JPR.S231778

Parthan, A., Evans, C. J., & Le, K. (2006). Chronic low back pain: Epidemiology, economic burden and patient-reported outcomes in the USA. *Expert Review of Pharmacoeconomics and Outcomes Research*, *6*(3), 359–369.

https://doi.org/10.1586/14737167.6.3.359

Qaseem, A., Wilt, T. J., McLean, R. M., & Forciea, M. A. (2017). Noninvasive treatments for acute, subacute, and chronic low back pain: A clinical practice guideline from the American College of Physicians. *Annals of Internal Medicine*, *166*(7), 514–530. https://doi.org/10.7326/M16-2367

Ross, C., Overholt, T., Xu, R., Badlani, G., Evans, R. J., Matthews, C. A., & Walker, S. J. (2022). Pulsed electromagnetic field (PEMF) as an adjunct therapy for pain management in interstitial cystitis/bladder pain syndrome. *International Urogynecology Journal*, *33*(3), 487–491. https://doi.org/10.1007/s00192-021-04862-3

Sánchez-Pinilla, R. O. (2020). ¿Cuáles son los ejercicios indicados en la lumbalgia crónica y en la hernia discal? *FMC Formacion Medica Continuada En Atencion Primaria*, *27*(1), 34–46. https://doi.org/10.1016/j.fmc.2019.06.007

Šarabon, N., Vreček, N., Hofer, C., Löfler, S., Kozinc, Ž., & Kern, H. (2021). Physical abilities in low back pain patients: A cross-sectional study with exploratory comparison of patient subgroups. *Life*, *11*(3), 1–15. https://doi.org/10.3390/life11030226

Shin, S. shil, & Yoo, W. gyu. (2019). Inertial Measurement Unit-based Evaluation of Global and Regional Lumbar Spine and Pelvis Alignment in Standing Individuals With a Flat Lumbar Posture. *Journal of Manipulative and Physiological Therapeutics*, *42*(8), 594–600. https://doi.org/10.1016/j.jmpt.2019.05.004

Stengel, S. Von, Teschler, M., Weissenfels, A., Willert, S., & Kemmler, W. (2018). Journal of Exercise Science & Fitness Effect of deep oscillation as a recovery method after fatiguing soccer training : A randomized cross-over study. *Journal of*

Exercise Science & Fitness, *16*(3), 112–117. https://doi.org/10.1016/j.jesf.2018.10.004

Traeger, A., Buchbinder, R., Harris, I., & Maher, C. (2017). Diagnosis and management of low-back pain in primary care. *Cmaj*, *189*(45), E1386–E1395. https://doi.org/10.1503/cmaj.170527

Urits, I., Burshtein, A., Sharma, M., Testa, L., Gold, P. A., Orhurhu, V., Viswanath, O., Jones, M. R., Sidransky, M. A., Spektor, B., & Kaye, A. D. (2019). *Low Back Pain , a Comprehensive Review : Pathophysiology , Diagnosis , and Treatment*. 1–10.

Vladeva, E., Mihaylova, M., & Panayotova, L. (2021). *DEEP OSCILLATIONS-REDUCING EDEMA AND IMPROVING KINESIOLOGY IN THE EARLY STAGES AFTER KNEE JOINT ARTHROPLASTY*. *27*(1), 3577–3581.

Vlaeyen, J. W. S., Maher, C. G., Wiech, K., Van Zundert, J., Meloto, C. B., Diatchenko, L., Battié, M. C., Goossens, M., Koes, B., & Linton, S. J. (2018). Low back pain. *Nature Reviews Disease Primers*, *4*(1), 1–18. https://doi.org/10.1038/s41572-018-0052-1

Wildenbeest, M. H., Kiers, H., Tuijt, M., & van Dieën, J. H. (2021). Reliability of measures to characterize lumbar movement patterns, in repeated seated reaching, in a mixed group of participants with and without low-back pain: A test-retest, within- and between session. *Journal of Biomechanics*, *121*, 110435. https://doi.org/10.1016/j.jbiomech.2021.110435

Wilke, H. J., & Volkheimer, D. (2018). Basic biomechanics of the lumbar spine. In *Biomechanics of the Spine: Basic Concepts, Spinal Disorders and Treatments*. Elsevier Ltd. https://doi.org/10.1016/B978-0-12-812851-0.00004-5

Winkelmann, Z. K., Roberts, E. J., & Games, K. E. (2018). Acute effects and perceptions of deep oscillation therapy for improving hamstring flexibility. *Journal of Sport Rehabilitation*, *27*(6), 570–576. https://doi.org/10.1123/jsr.2017-0044

Zehtindjieva, M. G., Ioshinov, B. R., Andonov, D. R., & Ilkov, V. S. (2013). *DEEP OSCILLATION – A MODERN ADDITIONAL PHYSICAL MODALITY FOR ANALGESIA IN PATIENTS WITH BACK PAIN*. *29*, 85–90.

Zhang, Y., Haghighi, P. D., Burstein, F., Yap, L. W., Cheng, W., Yao, L., & Cicuttini, F. (2020). Electronic skin wearable sensors for detecting lumbar–pelvic movements. *Sensors (Switzerland)*, *20*(5). https://doi.org/10.3390/s20051510

Mratskova, G. (2020). USE OF DEEP OSCILLATION -THERAPY IN REHABILITATION PROGRAM FOR PATIENT AFTER DISTAL RADIUS FRACTURE WITH A COMPLEX REGIONAL PAIN SYNDROME : A CASE REPORT USE OF DEEP OSCILLATION - THERAPY IN REHABILITATION PROGRAM FOR PATIENT AFTER DISTAL RADIUS FRACTURE. *Trakia Journal of Sciences*, *18*(November), 187–193. https://doi.org/10.15547/tjs.2020.s.01.034

Figure 1. Flow diagram of search results and clinical trials included.

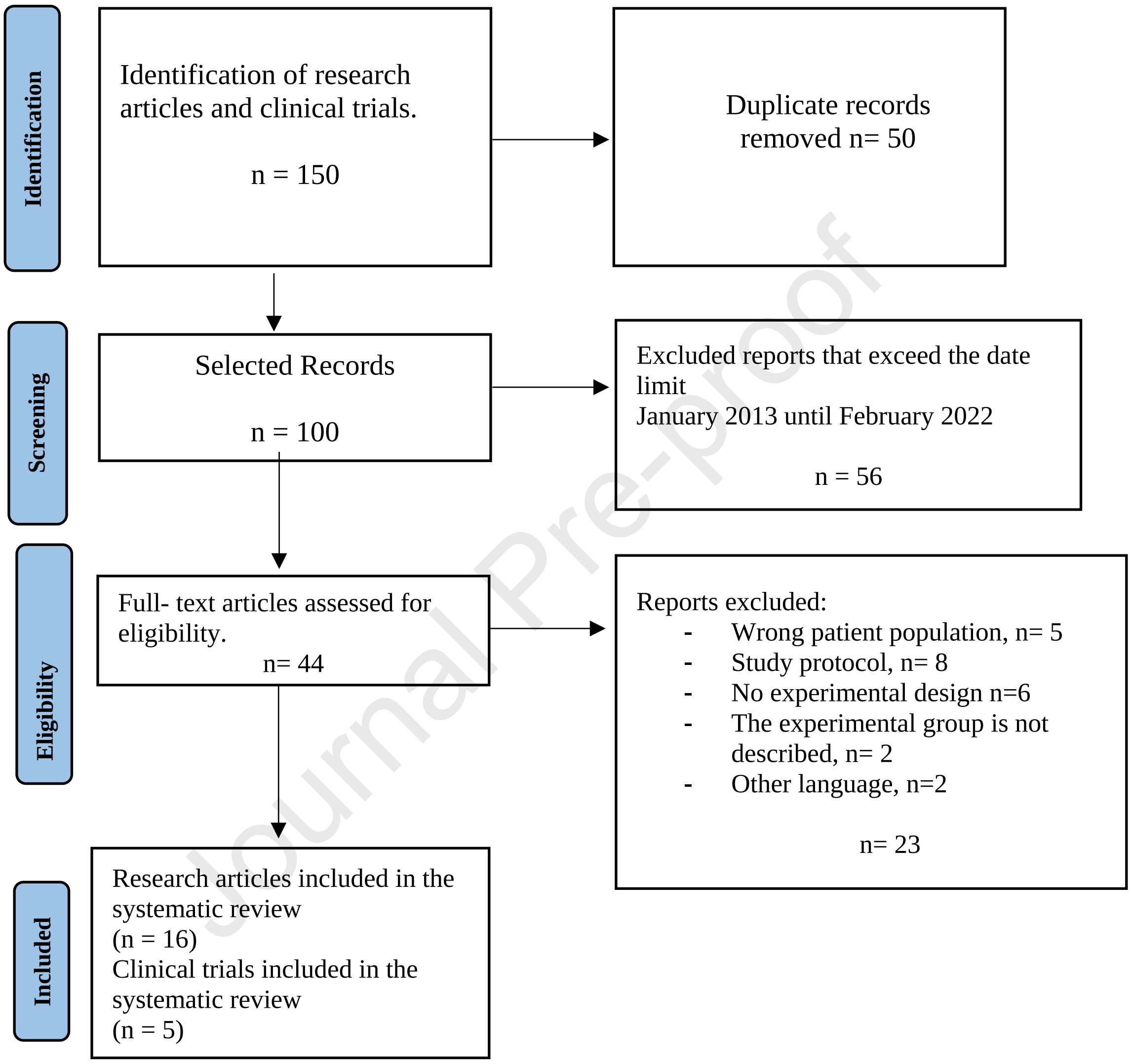

Table 1. Risk of bias score. Low risk level = 0, medium risk level = 1, high risk level = 2

Reference	Experimental design	Randomized controlled trial	Sample characteristics	Inclusion/exclusion criteria	Control group included	Final score
(Elshiwi et al., 2018)	0	0	0	1	0	1
(Abdulla et al., 2019)	0	0	0	0	1	1
(Krammer et al., 2015)	1	0	0	0	2	3
(Abdelhalim & Samhan, 2018)	0	0	0	1	1	2
(Alzayed & Alsaadi, 2020)	0	1	1	0	0	2
(Zhang et al., 2020)	0	2	0	2	2	6
(Hemming et al., 2018)	0	2	0	0	1	3
(Celletti et al., 2020)	0	2	0	0	2	4
(Gombatto et al., 2015)	0	2	0	0	0	2
(Wildenbeest et al., 2021)	0	2	0	0	1	3
(Bacon et al., 2020)	0	1	0	1	1	3
(Ashouri et al., 2017)	0	2	0	0	0	2
(Abdollahi et al., 2020)	0	1	0	0	2	3
(Davoudi et al., 2020)	0	1	0	0	2	3
(Shin & Yoo, 2019)	0	2	0	2	2	6
(Graham et al., 2020)	1	2	0	0	2	5
(Bauer et al., 2016)	1	1	0	0	2	4
(Mjøsund et al., 2017)	0	2	0	2	0	4
(Laird et al., 2019)	0	2	0	1	0	3
(Ha et al., 2013)	0	2	0	2	2	6
(Laird et al., 2016)	0	2	0	0	0	2

Table 2. Main characteristics from included studies using specific therapies to treat different types of low back pain (LBP).

Trial	Therapy	Participants	Frequency Value	Intensity Value	Time sessions	Outcome measures	Authors Results
(Elshiwi et al., 2018)	Pulsed electromagnetic field	N: 25 (experimental group) N: 25 (control group) Pathology: Chronic non-specific low back pain Age: 20-40 years	50 Hz	20 Gauss	12 sessions over 4 weeks	(1) pain intensity. (2) Oswestry Disability Index (ODI) (3) Spinal ROM	The experimental group showed a significant reduction in pain and disability, as well as an increase in the degree of lumbar flexion and extension after treatment.
(Abdulla et al., 2019)	Pulsed low-frequency magnetic field	N: 200 Pathology: Chronic low back pain Age: 18-60 years	30 Hz	14 uT	3 sessions for 6 weeks	Percentage of pain after and during treatment.	Reduction of low back pain after treatment
(Krammer et al., 2015)	Pulsed electromagnetic field	N: 40 Pathology: Non-specific low back pain Age: 18	27.12MHz	0.03 mT	Twice sessions per week for up to four weeks.	(1) Oswestry Disability Index (2) Numerical Pain Rating Scale	Pulsed electromagnetic energy provided no significant additional benefit over routine physiotherapy treatment for NSLBP.
(Abdelhalim & Samha	Low frequency magnetic field	N:40 F: 18 M:22 Pathology: Low back pain	1-100 Hz	100 Gauss	30 minutes three times per week	(1) Visual analogue scale (VAS) (2) Baseline bubble inclinometer.	Analysis of measures pre-treatment and post treatment showed a significant difference in visual analogue scale

n, 2018)		Age: 40-50 years					(pain) and trunk mobility, (p<0.05).
(Alzayed & Alsaadi, 2020)	Pulsed low-frequency magnetic field	N: 42 F: 20 M: 22 Age: 18-60 years	------	-------	39 sessions of 20 minutes (3 to 5 times a week) for 3 months	(1) Numerical Pain Rating Scale (2) Roland-Morris Disability Questionnaire	The results show a reduction in pain intensity and disability scores in the experimental group at week 3 (p <0.05), while the placebo group experienced an improvement at week 6

N: total number of participants; F: female; M: male; ROM: range of motion

Table 3. Main characteristics of included studies using motion (MoCap) capture systems to evaluate low back pain (LBP).

Authors	Patient's data	Patient´s pathology	Motion Capture system	N° of sensors	Sensors/ markers localization	Clinical Application
(Zhang et al., 2020)	N: 6 F: 4 M: 2 Age: 22-30 years Height: 159-183 cm Weight: 47-120 kg	LBP	Electronic-skin wearables (Created by: Monash University NanoBionics Group)	U	Lumbar Region: L1 – L5 Thoracic Region: T3 – T7	Measure the angle of anatomical joints and human body movements (lumbar-pelvic) that are not detected by MEMS-based sensors.
(Hemming et al., 2018)	N: 78 (28 healthy 50 with NSCLBP) F: ----- M: ---- Age: 18-65 years	NSC LBP	Vicon 512 Motion systems	-----	Spinous processes of the C7, T2, T4, T6, T8, T10, T12, L2 and L4 vertebrae. Manubrium stern (superior border). Anterior superior iliac spine. Posterior superior iliac spine. Iliac crest. Acromioclavicular joint. Ulna styloid process. 12^{th} thoracic spinous process. Lateral knee joint line. Lateral malleoli.	Investigate if there are kinematic differences between a person with NSC LPB and healthy individuals.

(Celletti et al., 2020)	N: 44 F: 34 M:10 Age: 70 ± 14.02 years	Low back pain	G-sensor (BTS SpA, Milan, Italy) IMU	U	At L5 vertebrae using an elastic belt.	Evaluate the participant's balance and mobility through the timed up and go test (TUG)
(Gombatto et al., 2015)	N:16 F: ----- M: ------ Age: 18-65 years	LBP	Vicon	----	4cm lateral to L1 and L4 Centered on L3- L5 Bilateral PSIS, ASIS Iliac crests	Measure kinematics of the upper and lower lumbar spine during walking. Measure kinematics of the pelvis during walking.
(Wildenbeest et al., 2021)	N: 36 (21 healthy and 15 with LBP) F: ---- M: --- Age: 35.8 years (mean) Height: 1.78 m (mean) Weight: 76.01 kg	CLBP	Vicon- 612, Oxford Metrics, UK	----	Two clusters of three markers were used. Clusters were fixed to the spinous processes of T8 and S1.	Assess lumbar motion
(Bacon et al., 2020)	N: 106 (85 NSLBP/21 healthy)	NSLPB	MTw2 trackers (Xsens Technologies)	----	On the spinus process of C2 vertebrae C7 vertebrae Spinous process of L2, L4. Sacral promontory	Classify non-specific LBP (NSLBP) into subgroups according to the symptoms that have been identified in the patient, which allows for personalized treatment and rehabilitation plans.
(Ashouri et al., 2017)	M: 24 healthy men M: 28 with LBP Age: 20-50 years	CLBP	Two inertial sensors: 9DOF Razor IMU,	2	Vertically on the xiphoid process.	Determine the optimal tasks for low back pain detection.

			Sparkfun®, Niwot, Colorado		On the left side of the iliac crest	
(Abdollahi et al., 2020)	Age: 19-40 years Height: 172, 6cm (mean) Weight: 79.5 kg (mean)	NSLBP	9DOF Razor IMU, Sparkfun®, Niwot, CO, USA. Wii Balance Board (Nintendo®, Kyoto, Japan)	2	Sternum	Track the linear acceleration and angular velocity. Calculate balance-related measures while the participants performing trunk flexion/ extension movements.
(Davoudi et al., 2020)	M: 100 Age: 20-50 years	LBP	9DOF SHARIF-HMIS	U	Vertically on the Xiphoid process	Classify patients based on kinematic data of the LBP
(Shin & Yoo, 2019)	N: 80 F: 55 M: 25 Age: 20	Lumbar lordosis	Wireless IMU systems	3	T10 L3 S2 spinous processes	Measure the global and regional lumbar lordosis
(Graham et al., 2020)	N: 30 F: 19 M: 11 Age: 44 years (mean)	LBP	HIKOB Fox inertial measurement unit (IMU) sensors	--	T8 S2spinus processes	Assess the between-day reliability of an IMU sensor (HIKOB FOX) in assessing functional movement quality in a population with chronic LBP.
(Bauer et al., 2016)	N: 23 Age: 18-65 years	CLBP	Valedo® (IMUs)	4	Right thigh Sacrum (S2) L1, T1	Measure the flexibility of the participant's spine to the end of active range through test of ROM. Evaluate the participant's ability to differentiate movement between

						two body segments, to stabilize their spine and to move smoothly.
(Mjøsund et al., 2017)	N: 34 Age: 19- 67 years	LBP	ViMove Vicon	2	Lumbar spine, S2, T12 (Upper sensor) Suprasternal notch Posterior superior iliac spines bilaterally. C7 and T5 spinous processes.	Measure and analyze the movements performed in the sagittal plane (flexion, extension) and coronal plane (lateral flexion).
(Laird et al., 2019)	N: 266	LBP	ViMove 5 system	2	T12, S2, L3	Measure and compare atypical kinematics parameters in people with and without LBP.
(Ha et al., 2013)	N: 26 F: 14 M: 12 Aged: 20-44 years	Back Pain	Xsens MTx 3Space FASTRAK	4	Spinus process of L1 and S1	Validate an inertial system used in the measurement of lumbar spinal ROM and coupled motion.
(Laird et al., 2016)	N: 60 Age: 18-60 years	CLBP	ViMove	2	T12 and S2 spinous processes.	Compare the lumbo-pelvic posture and range- pattern of motion in people with and without chronic LBP.

N: total number of participants; F: female; M: male; LBP: Low back pain; NSC LBP: Non-specific chronic low back pain; CLBP: Chronic low back pain, NSLBP: Non-specific low back pain.

Table 4. Main information from included studies for the evaluate of lumbar range of motion (ROM) using different types of motion capture.

Authors	Motion capture system	Components	Results
(Zhang et al., 2020)	E-Skin	------	The E-Skin sensor detects lumbar-pelvic movement in less time (approximately 1s) compared to the ViMove system
(Hemming et al., 2018)	Vicon 512 Motion Systems Ltd, Oxford, UK	Eight cameras. Spherical retro-reflective markers (10 mm).	Differences in the flexion pattern between the individuals with NSCLBP and the healthy group in the lower thoracic region when performing the activities of sitting, standing, crouching (Hemming et al., 2018).
(Celletti et al., 2020)	G- sensor (BTS SpA Milan, Italy) IMU	Triaxial accelerometer Triaxial magnetometer Triaxial gyroscope	The sensors evaluated the effectiveness of the Back school therapy for low back pain. Back school produces an improvement in the patient's motor functional limitations.
(Gombatto et al., 2015)	Vicon Visual 3D (C-Motion)	9- camera	1) People with LBP exhibited 5.48 ° less lumbar flexion than people without LBP. 2) People with LBP exhibited 4.18 ° less anterior pelvic tilt than people without LBP ($p < 0.05$) (18). 3) People with LBP perform a greater degree of rotation (1.7 °) to the left in the lower lumbar region than people with low back pain (0.1; $p < 0.05$). 4) People with LPB show less rotation (3.3 ± 0.3 °) than people without low back pain (4.3 ± 0.3). 5) People with LBP show 1.58 ° less superior lumbar rotation than people without LBP.
(Wildenbeest et al., 2021)	Vicon- 612, Oxford Metrics, UK	Vicon Bonita3 cameras.	MeanSD (spatial variability), CyclSD (temporal variability) and the LDE (dynamic stability) are reliable to assess lumbar movement patterns in single and multisession experiments.

		Two clusters of three markers	
(Bacon et al., 2020)	MTw2 trackers (Xsens Technologies)	Trackers	Different subgroups of NSLBP patients have different movement patterns. MTw2 IMU trackers were the most useful tool to classify NSLPB patients into subgroups.
(Ashouri et al., 2017)	9DOF Razor IMU, Sparkfun®, Niwot, Colorado	3-axis accelerometer 3-axis gyroscope	Using a single inertial sensor on the thorax with a simple test protocol, can identify LBP with an accuracy of 96%, a sensitivity of %100, and specificity of 92% (Ashouri et al., 2017).
(Abdollahi et al., 2020)	9DOF Razor IMU, Sparkfun®, Niwot, CO, USA Wii Balance Board (Nintendo®, Kyoto, Japan)	Accelerometer Gyroscope	Kinematic data obtained throughout the use of motion capture system could successfully be used to categorize patients into two main groups: high vs. low-medium risk low back pain.
(Davoudi et al., 2020)	9DOF SHARIF-HMIS [21]),	3-axis accelerometer 3-axis gyroscope 3-axis magnetometer	The acceleration at the moment of the trunk flexion was greater than during the extension, unlike the speed that was greater during the extension.
(Shin & Yoo, 2019)	Wireless IMU systems	3 transmitters 1 receiver 3 gyroscopes 3 accelerometers 3 magnetometers	The 80 asymptomatic participants were categorized into 3 Global Lumbar Lordosis angle groups: 1) T10-S2: <20°, 2) 20° ≤GLL < 30°, 3) 30°≤ GLL<40° Participants with GGG angle < 20° are representative of a flat lumbar posture.
(Graham et al., 2020)	HIKOB Fox inertial measurement unit (IMU) sensors	3D accelerometer Gyroscope Magnetometer	LDS (local dynamic stability) had greater between-day reliability than movement variability (MeanSD) when assessing spine movement using IMUs in patients with LBP

(Bauer et al., 2016)	Valedo® (IMUs)	Tri-axial gyroscope, magnetometer and accelerometer Wireless antenna and signal processing unit	ROM test were more reliable, compared to MCI (movement control impairments) and RE (reposition error) tests.
(Mjøsund et al., 2017)	ViMove Vicon	Accelerometer, magnetometer, gyroscope 8 MX-T20 8 MX-T40 2 Bonita digital cameras	Vicon and ViMove are two acceptable methods of measuring lumbar tilt movement in a person with or without low back pain.
(Laird et al., 2019)	ViMove 5 system	Triaxial accelerometer Triaxial gyroscope Triaxial magnetometer 2 wireless surface EMG sensors	Differences between flexion movement pattern in people with and without LBP. People with LBP show small ROM, slower movement, increased activity of the lumbar extensor muscles.
(Ha et al., 2013)	Xsens MTx 3Space FASTRAK	Triaxial gyroscopes, accelerometers and magnetometers.	The two-motion system are valid tools for 3D spinal range of movement measurements. The measurements obtained from the inertial measurement system and the electromagnetic tracking system are correlated.
(Laird et al., 2016)	ViMove	Triaxial accelerometer, gyroscope and magnetometer	Pelvic ROM in flexion: LBP 60.8°; NoLBP 54.8°, p =0.04 Lumbar ROM in right lateral flexion: LBP 22.2°; NoLBP 24.6°, p=0.04 ROM in right lateral flexion: LBP 28.4°; NoLBP 31.7°, p=0.02

DOF: degrees of freedom; IMU: Inertial measurement unit

August 2, 2022

CONFLICT OF INTEREST STATEMENT

The corresponding author of the manuscript "*Evaluation of deep oscillation therapy for the treatment of lumbar pain syndrome using motion capture systems: A systematic Review*", on behalf of himself and all authors, declares that there is no conflict of interest. And that there are no financial and personal relationships with other persons or organizations that could inappropriately influence (bias) our work.

Sincerely,

Fernando Villalba
Universidad de Zaragoza – Spain