



# Effectiveness of Hydrotherapy in Lumbar Radiculopathy: A Literature Review

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## Abstract

## Introduction

Hydrotherapy, an aquatic-based therapeutic approach, has been widely utilized for musculoskeletal rehabilitation. However, its efficacy in managing lumbar radiculopathy remains underexplored. Lumbar radiculopathy, a condition caused by nerve root compression, leads to significant pain and functional limitations. This literature review aims to evaluate hydrotherapy's effectiveness in alleviating symptoms, improving mobility, and enhancing the quality of life in individuals with lumbar radiculopathy.

## Materials and Methods

A comprehensive search was conducted across databases such as PubMed, Google Scholar, and ResearchGate for studies published until 2024. Inclusion criteria focused on studies evaluating hydrotherapy's impact on lumbar radiculopathy and its comparison with land-based rehabilitation approaches. A total of 75 articles were reviewed, with a subset of 15 specifically analyzing hydrotherapy's efficacy in lumbar radiculopathy.

## Results

Findings revealed that hydrotherapy offers significant benefits in pain reduction, functional improvement, and quality of life enhancement. Studies comparing hydrotherapy to land-based exercises showed varied results, with some demonstrating superior outcomes in hydrotherapy groups, while others found no statistically significant differences. Hydrotherapy's therapeutic mechanisms, including buoyancy, hydrostatic pressure, and thermal effects, contribute to its effectiveness.

## Discussion and Conclusion

Hydrotherapy presents a promising, non-invasive intervention for managing lumbar radiculopathy. Despite its benefits, variations in treatment protocols and study methodologies indicate the need for standardized guidelines. Future research should focus on optimizing hydrotherapy protocols and assessing long-term outcomes to establish its role as a primary treatment modality for lumbar radiculopathy.

## Keywords

Lumbar Radiculopathy, Hydrotherapy, Aquatic Therapy, Low back pain

## Introduction:

Hydrotherapy uses water to facilitate 'established' therapies – stretching, strengthening, joint mobilization, gait training, etc.- using multi-depth immersion pools or tanks.<sup>[1]</sup> Hydrotherapy dates back to 2400 BC by the Proto-Indian culture and gained popularity in the USA by spas' development in the 18<sup>th</sup> century. <sup>[2]</sup> Hydrotherapy's therapeutic benefits stem from the unique properties of water. Firstly, the temperature promotes vasodilatation, which increases capillary blood flow and eliminates chemical substances from the circulation, which causes a reduction of muscle spasms and elicits decreased pain. <sup>[3,4,5]</sup> It has the effect of breaking down a vicious circle of “pain-spasm-more pain- more spasm”. Secondly, the buoyancy effects of water can decrease joint stress, reduce pressure on intervertebral discs, and lessen pain intensity. <sup>[3]</sup> Finally, viscosity and hydrostatic pressure strengthen the spine and lower abdomen muscles, alleviating the suppression of the intervertebral disc and reducing the degree of discomfort, enhancing joint range of motion, and reducing functional limitations. <sup>[3,6]</sup> Moreover, the warmth and fluidity of water can hinder nociceptors by influencing thermal and mechanoreceptors, positively impacting spinal segments. <sup>[7]</sup> Cold showers have been attributed to antidepressive effects in the presence of a high density of cold receptors in the skin. <sup>[8]</sup>

Research also showed that immersion in cold water decreases motor nerve conduction.<sup>[9]</sup> Hydrotherapy has also been used as a cryo effect to reduce edema and inflammatory reactions.<sup>[10]</sup> Several techniques to consider for spinal involvement include Halliwick, Ai Chi and Bad Ragaz method.<sup>[11]</sup> Dr. Knupfer developed the Bad Ragaz technique in Germany and later brought to Bad Ragaz in Switzerland by Nele Ipsen. It requires cervical collars to exercise in water. The modern Bad Ragaz method includes movement techniques in straight plane and diagonal patterns with resistance and stabilization provided by the therapist. The Halliwick method was introduced by James McMillan in 1949 at Halliwick School, London. This is recreational and focuses on the goal of individual independence in water. It emphasizes the abilities of patients in water and not their disabilities on land. A study by Mirmoezzi et al. (2021) concluded that the non-specific low back pain symptom was improved concerning pain, disability, and Straight leg raise test after 10 sessions of a hydrotherapy program developed based on McKenzie and Williams therapy.<sup>[12]</sup>

A group of neuropathic problems referred to as "radiculopathy" are brought on by compression of spinal nerves at or close to the level of the nerve root.<sup>[13]</sup> Radiculopathy and radicular pain are two distinct conditions. When radicular pain happens, there is no neurological damage and the pain travels down along the nerve root.<sup>[14]</sup> However, radiculopathy inhibits conduction along a spinal nerve or its root and also results in dermatome-dispersed numbness that degrades sensory fibers; on the other hand, motor fiber blockage causes myotomal weakening.<sup>[15]</sup> The distribution of pain in lumbar radiculopathy originates in the lower back and extends to the gluteal and sacroiliac areas, as well as into the back of the thigh beyond the knee.<sup>[16]</sup> Lumbar disc herniation, lumbar spinal stenosis, trauma, osteoarthritis, inflammation, infection, neoplasm, and diabetes are the most frequent causes of lumbar radiculopathy.<sup>[17]</sup> The source of this pain stems from the irritation of a specific nerve, which can happen at various locations along its path and is frequently caused by pressure. This pressure might arise within the thecal sac, as the nerve emerges from it in the lateral recess, as it passes through the neural foramina, or even after it has exited the foramina.<sup>[18]</sup> As reported by individuals experiencing it, the nature of the pain can vary, described as sharp, dull, aching, burning, or throbbing.<sup>[17]</sup> Lumbar radiculopathy affects about 3-5% of the population, with an even distribution among both genders.<sup>[17]</sup> Activities like sitting, coughing, bending forward, and straining tend to exacerbate discomfort when radiculopathy is linked to disc herniation; however, lying down or occasionally taking a walk may help to relieve the pain.<sup>[19]</sup> Research suggests that non-surgical approaches should be considered for managing lumbar radiculopathy unless there are signs of deteriorating neurological function.<sup>[20]</sup> The initial assessment

should involve a thorough review of medical history and a physical examination, including tests like manual muscle assessment, sensory evaluation, checking deep tendon reflexes, and performing Lasegue's sign. <sup>[18]</sup> The management of pain in lumbar radiculopathy can be effectively achieved through a variety of conservative care methods, hydrotherapy is one of those.

While hydrotherapy is well-recognized for its benefits in treating musculoskeletal disorders, its specific impact on lumbar radiculopathy has been less thoroughly investigated. By analyzing existing evidence, this review seeks to uncover the therapeutic mechanisms of hydrotherapy, assess its efficacy in alleviating pain and enhancing function, and address any inconsistencies or gaps in the literature. The findings will offer clinicians and researchers valuable insights into hydrotherapy's potential role in managing this condition.

### **Aim:**

This review aimed to evaluate the available evidence to find the effectiveness of hydrotherapy in managing lumbar radiculopathy, a condition marked by pain and functional impairments resulting from nerve compression in the lumbar spine. The objectives of this review include, evaluate the efficacy of hydrotherapy in reducing pain, improving mobility, and enhancing the quality of life in individuals with lumbar radiculopathy, analyze the therapeutic mechanisms of hydrotherapy, including its biomechanical and physiological benefits, such as buoyancy, hydrostatic pressure, and thermal effects, comparing hydrotherapy with other conservative management approaches for lumbar radiculopathy, highlighting its advantages and limitations, identifying variations treatment protocols and their impact on outcomes, including session duration, frequency, and specific exercises utilized in hydrotherapy, also exploring the contraindications and challenges during the use of hydrotherapy for lumbar radiculopathy and suggest the evidence-based modifications to optimize patient outcomes and recommend future research directions to address gaps in the evidence and standardize protocols for hydrotherapy in lumbar radiculopathy management.

### **Materials and Methods:**

We searched and analyzed articles published till 2024 using Google Scholar, PubMed, and Research Gate. The selection was based on specific criteria, including the requirement that the articles be written in English and address topics such as the relationship between low back pain (LBP) and hydrotherapy, postural deficiencies, herniated disc syndrome, hydrotherapy for lumbar radiculopathy, the mechanisms of radiculopathy, effectiveness, and the principles of hydrotherapy. Articles that did not focus on hydrotherapy's

effectiveness, those published before 1970, or those unavailable in their full versions were excluded. Initially, 95 articles were found, but after applying the exclusion criteria, 75 articles were evaluated and reviewed.

## Results:

From 75 articles, 15 studies focused on lumbar radiculopathy. These studies showed that the difference between radiating pain and radiculopathy also explained the common causes, nature, and aggravating factors of radiculopathy. Various types of conservative management were found to be effective for LBP with radiating and non-radiating pain. Ten studies focused on concepts, principles, and different modalities of hydrotherapy. The other ten studies showed how hydrotherapy works in lumbar radiculopathy. Five studies showed that hydrotherapy was more effective than land-based exercise. We also analyzed that some studies showed that there were no statistical differences between hydrotherapy and land-based exercises. Ten studies also showed that hydrotherapy was not only effective for reducing pain but also for improving quality of life. Fifteen studies also focused on the effectiveness of hydrotherapy in various conditions like Parkinson's, multiple sclerosis, and stroke. Only one study focused on the effect of hydrotherapy on both athletes and non-athletes. The overall result showed a positive effect of hydrotherapy on radiculopathy.

Table 1. Main characteristics of the included studies

| Author                       | Number of Participants   | Intervention                                                         | Outcomes                                                                                                                                                                                                                                                                                                                          |
|------------------------------|--------------------------|----------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Sawant et al. <sup>[7]</sup> | 30<br>GrA= 15<br>GrB= 15 | Experimental study<br>GrA= Conventional therapy<br>GrB= Hydrotherapy | A significant difference was observed in post-intervention VAS values ( $p = 0.0182$ ), while no notable differences were found in other parameters such as ROM and MMT. Nevertheless, it was established that participants undergoing hydrotherapy treatment demonstrated a faster rate of improvement compared to other groups. |

|                        |                                                            |                                                                                         |                                                                                                                                                                                                                                                                                                                                                               |
|------------------------|------------------------------------------------------------|-----------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Costantino et al. [21] | 56<br><br>GrA=28<br><br>GrB=28                             | 12 weeks, 2×1hr/week<br><br>GrA= Back Schools<br><br>GrB=Hydrotherapy programme         | There was no discernible difference between the two groups.                                                                                                                                                                                                                                                                                                   |
| Bello et al. [22]      | 16<br><br>GrA=8<br><br>GrB=8<br><br>Age; 32-70 years       | 6 weeks, 2×1hr/week<br><br>GrA= Hydrotherapy<br><br>GrB= Land- Based Exercises.         | The t-test results indicated no significant differences in pre- and post-intervention values for VAS ( $p<0.05$ ) and MSFT ( $p<0.05$ ). However, the hydrotherapy group showed a higher MSET ( $p<0.05$ ) score compared to the land-based exercise group. This demonstrates that hydrotherapy is more effective than land-based exercises in managing CLBP. |
| Dundar et al. [23]     | 69<br><br>GrA= 33<br><br>GrB = 33<br><br>Age; 20-50 years. | 20 sessions, 5×1hr/week.<br><br>GrA = Aquatic Therapy<br><br>GrB = Land Based Exercise. | The findings revealed significant improvements in social functioning ( $p<0.001$ ), VAS ( $p<0.001$ ), and bodily pain ( $p<0.001$ ) within the aquatic therapy group.                                                                                                                                                                                        |
| Khanjari et al. [24]   | 20<br><br>GrA= 10<br><br>GrB= 10                           | 8 weeks.<br><br>GrA = Hydrotherapy exercise group<br><br>GrB = Control group            | In the pre-test, no significant difference was observed in the mean RMDQ scores between the two groups ( $p = 0.425$ ). However, the post-test revealed a notable difference in the mean RMDQ                                                                                                                                                                 |

|                                  |                                                                 |                                                                                          |                                                                                                                                                                                                                                                                        |
|----------------------------------|-----------------------------------------------------------------|------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                  |                                                                 |                                                                                          | scores between the groups ( $p = 0.010$ ). The results indicate that hydrotherapy has a more substantial impact on CLBP compared to the control groups.                                                                                                                |
| Bayraktar et al. <sup>[25]</sup> | 31<br><br>GrA= 17<br><br>GrB= 14<br><br>Age; 18-65 years old    | 8 weeks, 3×1hr/week<br><br>GrA = Land-Based exercise<br><br>GrB = Water specific therapy | No notable differences were identified between the two treatment groups regarding pain levels ( $p<0.05$ ), functional status ( $p<0.05$ ), and health-related quality of life ( $p<0.05$ ).                                                                           |
| Irandoost et al. <sup>[26]</sup> | 32<br><br>GrA= 16<br><br>GrB= 16<br><br>Age; over 65 years old. | 12 weeks,<br><br>3×1hr/week.<br><br>GrA= Aquatic training<br><br>GrB = Control Group     | The results indicated an improvement in trunk muscles ( $p<0.005$ ) and a reduction in low back pain ( $p<0.005$ ). After 12 weeks of aquatic training, trunk muscle strength increased by up to 4.1%.                                                                 |
| Abadi et al. <sup>[27]</sup>     | 39<br><br>GrA = 19<br><br>GrB = 20                              | 12 weeks,<br><br>2×1hr/week<br><br>GrA = Aquatic therapy<br><br>GrB = Control group      | The Bonferroni test results showed a significant improvement in pain intensity ( $p<0.022$ ), standing ability ( $p<0.006$ ), sleep quality ( $p<0.020$ ), and total disability score ( $p<0.020$ ) in the aquatic group after 12 weeks compared to the control group. |
| Peng et al. <sup>[28]</sup>      | 113<br><br>GrA = 56<br><br>GrB = 57                             | 12 weeks,<br><br>2×1hr/week<br><br>GrA = Therapeutic aquatic exercise                    | The results also demonstrated that therapeutic aquatic exercise was more effective than physical therapy                                                                                                                                                               |

|                                      |                                                            |                                                                                                        |                                                                                                                                                                              |
|--------------------------------------|------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                      |                                                            | GrB = Physical therapy modalities                                                                      | modalities in reducing pain intensity on the NPRS scale ( $p<0.001$ ).                                                                                                       |
| Nasar et al. <sup>[29]</sup>         | 60<br><br>GrA = 30<br><br>GrB = 30<br><br>Age; 25-40 years | 4 weeks<br><br>GrA = land-based exercise program.<br><br>GrB = Aquatic exercise program.               | Following four weeks of intervention, all outcome measures showed a statistically significant improvement favoring the water exercises group ( $p<0.001$ ).                  |
| Dogan et al. <sup>[30]</sup>         | 60<br><br>GrA = 35<br><br>GrB = 25                         | 3 weeks,<br><br>5×20min/week<br><br>GrA = Balneotherapy and physiotherapy.<br><br>GrB = Physiotherapy  | The results indicated that combining physiotherapy with balneotherapy was more effective in managing CLBP.                                                                   |
| Cuesta-Vargas et al. <sup>[31]</sup> | 49<br><br>GrA = 25<br><br>GrB = 24                         | 15 weeks, (3×1hr<br>MMP+ 20 min<br>DWR/week)                                                           | Both treatment groups showed similar significant improvements.                                                                                                               |
| Simmerman et al. <sup>[32]</sup>     | 60<br><br>GrA = 30<br><br>GrB = 30                         | GrA = Land-based exercise<br><br>GrB = Aquatic<br><br>Vertical traction<br><br>15 minutes of exercises | The results indicated that following the application of aquatic vertical traction, pain intensity was significantly reduced, and there was centralization of other symptoms. |
| McIlveen et al. <sup>[33]</sup>      | 109<br><br>GrA = 56<br><br>GrB = 53                        | 4 weeks, 2×1hr/week<br><br>GrA = Hydrotherapy group<br><br>GrB = Control group                         | The results revealed that only the hydrotherapy group showed a significant improvement in function, while other outcomes remained similar to those in the control group.     |



VAS = Visual Analog Scale, MMT = Manual Muscle Testing, ROM = Range of Motion, CLBP= Chronic

Low Back Pain, RMDQ = Modified Roland – Morris Disability Questionnaire, NPRS = Numeric Pain Rating

Scale, MMP = Multimodal Program, DWR = Deep Water Running

## Discussion:

There is no particular hydrotherapeutic protocol available for lumbar radiculopathy. However, researchers have implemented a variety of approaches in their studies to attain the best possible outcomes for managing low back pain through hydrotherapy. The hydrotherapeutic unit's temperature ranges from 30 to 33 degrees Celsius during aquatic exercise. <sup>[23,27,28,34]</sup> According to Dundar et al., more intensive aquatic exercise regimens, involving higher frequency and longer session durations, can improve disability, functional capacity, and quality of life for individuals with chronic low back pain. <sup>[23]</sup> Treatment protocols generally span 12 weeks, lasting approximately 60 minutes. <sup>[23,27,28,34]</sup> Each session is structured into three distinct phases. The first phase involves a 10-minute warm-up and a 40-minute main exercise program, and concludes with a 10-minute cool-down period. <sup>[26,28,34]</sup> During the warm-up, participants spend 2 minutes walking forward, backward, and sideways in the pool. <sup>[28]</sup> This phase combines an active range of motion exercises, water walking, and relaxation techniques. <sup>[23,26]</sup> The main exercise segment is divided into two components: stretching and strengthening. The stretching portion targets the lower back muscles, lateral trunk rotators, hamstrings, gastrocnemius, hip adductors, and neck muscles. <sup>[22,23,28]</sup> The strengthening component focuses on the transverse abdominis, lower back muscles, gluteal muscles, lateral trunk rotators, and muscles of the lower and upper limbs. <sup>[23,28]</sup> Lower limb exercises include squats, lunges, toe raises, one-leg balance, kickboard oblique movements, hip flexion, abduction, extension, calf lifts, bicycle kicks, and knee curls. <sup>[23,26,28]</sup> Upper limb strengthening incorporates kickboard pushes, shoulder flexion, extension, abduction, adduction, upper back glides, chest-back presses, behind-the-back presses, and pivoted shoulder presses. <sup>[26,28]</sup> The cool-down phase consists of 2 minutes of pool walking in various directions, slow walking, squats, standing exercises, deep breathing, and relaxation techniques. <sup>[27,28]</sup>

An effective warm-up routine can enhance overall performance, minimize muscle soreness, and help prevent injuries. <sup>[35]</sup> Additional advantages include improved aerobic capacity, reduced lactate accumulation, faster muscle contractions, more efficient neural impulse transmission, better movement efficiency, enhanced oxygen delivery, and increased cardiac output and blood circulation. <sup>[35]</sup>

Muscle strength and flexibility are vital in stabilizing the body's muscles.<sup>[36]</sup> During spinal flexion, the initial 50-60 degrees predominantly involve the lower lumbar spine, while additional flexion requires forward pelvic tilting.<sup>[37]</sup> The posterior hip muscles control this forward tilt as the spine flexes.<sup>[37]</sup> However, in individuals with low back pain, there is decreased activation of the multifidus and erector spinae muscles, along with weakness in the transverse abdominis and gluteal muscles, leading to increased posterior tilt.<sup>[38]</sup> To address this, improving posterior tilt and enhancing the flexibility of these muscles through stretching is essential. The pelvis is crucial for maintaining proper spinal alignment in an upright posture, and its tilt affects postural muscle activity by influencing the static load on the spine.<sup>[39]</sup> Weak abdominal and gluteal muscles fail to support the pelvis's normal inclination, which can increase lumbar spine lordosis.<sup>[36]</sup> Research suggests that reduced abdominal muscle strength contributes to low back pain.<sup>[26]</sup> Therefore, strengthening the abdominal and gluteal muscles is necessary to manage low back pain effectively.

The cool-down phase helps the body gradually return to a relaxed state after physical activity, and when performed correctly, it can enhance the recovery process.<sup>[40]</sup> A well-structured cool-down routine aids in restoring heart rate and blood pressure to resting levels, providing an antiarrhythmic benefit and reducing the risk of cardiac incidents or hypotensive episodes.<sup>[41]</sup>

Borodulina et al.<sup>[42]</sup> demonstrated that a hydrogalvanic bath treats lumbosacral radiculopathy. They found that hydroelectric therapy significantly alleviated leg pain, lessened depressive symptoms, and enhanced patients' quality of life. Additionally, their research indicated that this therapy aids in improving sensory deficits associated with radiculopathy. Simmerman et al.<sup>[32]</sup> conducted an experimental study comparing land-based supine flexion with aquatic vertical traction for low back pain (LBP). They found that aquatic vertical traction was more effective in centralizing symptoms and reducing pain than land-based supine flexion. Gramatikova et al.<sup>[10]</sup> examined the effects of specialized magnetotherapy combined with underwater water jet massage on individuals with chronic lumbar pain, including both athletes and non-athletes. Their findings indicated that this therapy alleviates pain, enhances the neurodynamics of the sciatic nerve, increases hip joint mobility, and reduces the hypertonicity of paravertebral muscles in the lumbar area. Dundar et al.<sup>[23]</sup> conducted a study comparing water-based exercises to land-based exercises for chronic low back pain (CLBP). They discovered that water-based exercises improved disability and the physical aspect of quality of life. Additionally, balneotherapy is an effective treatment for CLBP.<sup>[30]</sup>

This paper examines hydrotherapy's impact on pain reduction and overall quality of life. McIlveen and Robertson's research indicated that hydrotherapy had no beneficial effect on pain, disability, or lumbar range of motion in individuals with low back pain or combined back and leg pain.<sup>[33]</sup> Costantino and Romiti compared a back-school program with hydrotherapy and found no significant difference between the two groups.<sup>[21]</sup> Additionally, some experimental studies have reported no notable differences in outcomes between group hydrotherapy and group land-based exercises for patients with chronic low back pain (CLBP).<sup>[20, 43]</sup>

Smith et al. conducted a pilot study examining the efficacy of hydrotherapy for chronic low back pain and observed a notable enhancement in thoracolumbar mobility.<sup>[44]</sup> Identical studies about the effectiveness of hydrotherapy in treating chronic low back pain were conducted by Sjogren et al.<sup>[20]</sup>, Rahmadhani et al.<sup>[45]</sup>, Irandoust et al.<sup>[26]</sup>, and Backhausen et al.<sup>[46]</sup>, with variations in the length of hydrotherapy administered. They all concluded that hydrotherapy plays a significant role in pain reduction. Furthermore, some studies demonstrated that hydrotherapy not only reduces pain but also diminishes functional disability and enhances the quality of life among patients with chronic low back pain.<sup>[43,47,48]</sup> Hydrotherapy has been shown in numerous medical situations to help lower pain and boost quality of life. Likewise, Volpe et al. demonstrated that hydrotherapy treatment improved balance in Parkinson's patients.<sup>[49]</sup> Additionally, some studies looked into the benefits of hydrotherapy for Parkinson's patients' quality of life in addition to their ability to balance.<sup>[50, 51]</sup> Patients with Multiple Sclerosis experienced considerable pain reduction after 40 sessions of the Ai Chi aquatic exercise program; also, fatigue spasms, depression, and quality of life were improved without any negative side effects.<sup>[52]</sup> Numerous studies have demonstrated that hydrotherapy significantly improves the quality of life for people with multiple sclerosis.<sup>[53, 54,55]</sup> Wang et al. investigated the effectiveness of hydrotherapy for stroke patients during four weeks.<sup>[56]</sup> Children with cerebral palsy benefit enormously from hydrotherapy in terms of enhanced gross motor abilities and a better standard of life.<sup>[57]</sup> Additionally, it has been reported that a 10-minute whirlpool significantly reduces anxiety.<sup>[58]</sup> While there is limited direct evidence of hydrotherapy specifically for lumbar radiculopathy, the collective body of research suggests that hydrotherapy is an effective therapeutic approach. It reduces pain intensity and facilitates the patient's return to normal daily functioning.

**Conclusion:**

Our review of the literature indicates that hydrotherapy is an effective treatment for reducing symptoms in lumbar radiculopathy. However, there is a limited number of studies specifically focusing on its impact on this condition. Further research is necessary to assess the long-term effectiveness of hydrotherapy in managing lumbar radiculopathy. This presents a valuable opportunity for future studies.

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