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Physical therapies after surgery for lumbar disc herniation- evidence synthesis from 55 randomized controlled trials (RCTs) and a total of 4,311 patients

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ABSTRACT

Introduction: The role of physical therapy after lumbar disc herniation surgery is unclear.
Research question: To determine the impact of physical therapy following LDH surgery (Q1), investigate the effects of activity limitations (Q2), the best time to start physical therapy (Q3), the significance of supervised physical rehabilitation (Q4), the types of physical therapies used (Q5), and the role of additional approaches, such as education, manipulation, and acupuncture, in enhancing the effectiveness of rehabilitation (Q6).
Material and methods: This systematic review searched three databases from inception to May 2024. Independent reviewers screened studies, assessed and extracted data, and critically appraised the quality of the available evidence.
Results: This systematic review included 55 randomized controlled trials with 4311 patients. We demonstrated that physical therapy after lumbar disc surgery is effective in alleviating pain and improving function and quality of life after surgery for lumbar disc herniation. Exercise regimens aimed at enhancing the endurance, flexibility, and strength of the back musculature are generally efficacious, with the exception of exercises involving neural mobilization. Imposing limitations on physical activity does not yield substantial advantages; however, the occurrence rate of potential complications, the optimal timing for initiating activity and the cost-effectiveness of supervised exercise remain subjects of ongoing discourse. Concurrent application of manual therapy, acupuncture, educational interventions, and behavioral and occupational therapy has the potential to augment outcomes.
Discussion and conclusion: Physical therapy improves functional outcomes after lumbar disc surgery. Further studies should address its safety, and cost-effectiveness, and provide dissemination and applicability tools.

1. Introduction

Lumbar disc herniation (LDH) is a prevalent spinal condition characterized by the protrusion of the soft inner core of a vertebral disc in the lower back (lumbar spine) through the outer layer of the disc (El Melhat et al., 2024; Zhang et al., 2023). The primary cause of LDH is degenerative progression, although spinal trauma can also be a contributing factor (El Melhat et al., 2024; Zhang et al., 2023). Common symptoms of LDH include back pain, leg pain, numbness, decreased reflexes, and muscle weakness, while in severe cases it presents with cauda equina syndrome (El Melhat et al., 2024). All symptoms are attributable to the compression resulting from the disc herniation (El Melhat et al., 2024; Zhang et al., 2023).

The management of LDH typically commences with conservative interventions, such as rest, physical therapy, anti-inflammatory medications, and epidural steroid injections aimed at alleviating pain and reducing inflammation (El Melhat et al., 2024; Zhang et al., 2023; Benzakour et al., 2019). The non-surgical treatment also includes patient education and self-management, manipulation, traction, exercise, ultrasound and laser therapy, and epidural steroid injections (El Melhat et al., 2024; Zhang et al., 2023). In rare cases symptoms from the bladder

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Abbreviations

ADL	activities in daily living
BDI	Beck Depression Inventory
BDS	Beck Depression Scale
BQ	Bournemouth Questionnaire
DPQ	Dalla Pain Questionnaire
EQ-5D	EuroQol Group 5 item questionnaire
FABQ	fear avoidance belief questionnaire
FASTER	Function After Spinal Treatment, Exercise, and Rehabilitation trial
GPE	Global Perceived Effect
HADS	hospital anxiety and depression scale
IBLF	interbody lumbar fusion
JOA	Japanese Orthopedic Association scale
LBPQ	low back pain questionnaire
LBPRS	Low Back Pain Rating Scale
LDH	lumbar disc herniations
LM	lumbar multifidus
mBST	model-based system testing
MDI	Million disability indexes
MST	Modified Schober Test
NHP	Nottingham Health Profile
NPRS	Numeric pain rating scale
NRS	numerical rating scale
ODI	Oswesrty Disability Index
PASS	Pain anxiety symptoms scale
PELD	percutaneous endoscopic discectomy
PILE	Progressive Isoinertial Lifting Evaluation
RCT	randomised controlled study
RMDQ	Rolland-Morris disability questionnaire
RMDI	Rolland Morris Disability Index
SES	Self-efficacy scale
SF-12	Short Form 12
SF-36	Short-Form 36
TFT	Testing Experience and Functional Test
US	ultrasound
VAS	visual analogue scale
WBMF	whole-body magnetic field

and bowel necessitate urgent management (El Melhat et al., 2024). In cases where conservative measures prove ineffective or when the symptoms are severe and significantly impair daily functioning, surgical intervention may be warranted (El Melhat et al., 2024; Zhang et al., 2023). The most prevalent surgical procedure for disc herniation is a discectomy, involving the removal of the portion of the disc exerting pressure on the nerve (El Melhat et al., 2024; Zhang et al., 2023). Various discectomy techniques are available, and in certain instances, spine fusion may be advised, with the choice guided by the underlying pathology, the patient's symptomatic presentation, imaging findings, and the surgical team's expertise (El Melhat et al., 2024; Zhang et al., 2023; Liu et al., 2023). Surgery for LDH has been found to be superior than conservative management in terms of pain control, function preservation, and cost effectiveness in LDH (Glennie et al., 2022; Bailey et al., 2020; Rickers et al., 2021).

However, the role of physical therapy after lumbar disc herniation remains unclear. The current study aims primarily to identify the role of physical therapies after surgery for LDH (Q1). The secondary aims were to study the role of activity restriction (Q2), the optimal timing of physical therapy initiation (Q3), the role of training, education, behavioural management, and rehabilitation in physical therapies (Q4), the nature of the implemented physical therapies (Q5), and the role of adjuncts, such as education, manipulation, acupuncture, in promoting the efficacy of rehabilitation (Q6). The research questions are summarized in terms of PICOT format in Supplementary Table 1.

2. Methodology

We performed a systematic literature review using an electronic search in compliance with the PRISMA checklist (Page et al., 2021). The study did not include any human subjects and was registered in Prospero (CRD42023434839). This research is independent and not based on any prior systematic review or meta-analysis. The approach we utilized to identify studies in our systematic review is transparently reported in the Electronic Supplementary Material.

2.1. Search strategy - information sources

Our current meta-analysis focused on two main concepts: "physical therapies" and "lumbar discectomy". Initially, AK and AB searched Medical Subjects Headings/National Library of Medicine, Google Scholar, and Wikipedia to identify relevant keywords. Subsequently, both TS and AB conducted independent searches of electronic databases (PubMed, Scopus, and the Web of Science) using every possible combination of keywords. The search strings for each database are presented in Table 1. Additionally, we searched the reference lists of the collected articles to find additional relevant studies. We conducted a comprehensive literature search on March 9th, 2024, and then repeated the search on May 5th, 2024.

2.2. Eligibility criteria - study selection

Two review authors (AK and AB) searched for randomized controlled trials (RCTs) in English involving adults aged 18 and older who underwent physical therapy after lumbar disc herniation surgery. We were specifically not interested in surgery for lumbar spine stenosis, spondylolisthesis, or failed back surgery syndrome. There were no restrictions on the comparator, registered outcome, or study duration. However, we excluded studies not written in English and those not designed as RCTs. We uploaded the metadata from all three databases to Rayyan to select the relevant studies (Ouzzani et al., 2016). Initially, we removed all duplicate studies from the three databases. In cases where multiple studies were based on the same study population, only the most recent article was considered. Two review authors (AK and AB) then screened the articles based on the relevance of the title and abstract. We excluded studies based on their study design, such as observational studies, laboratory studies, case series and reports, reviews, editorials, letters to the editor, and the population under study (including children, patients with low back pain only, with stenosis). Finally, we also excluded studies that did not contain extractable data. Any disagreements between the two review authors were discussed with the senior authors (KNF and AKD).

Table 1
Search string of our literature review in PubMed, WoS, and Scopus.

Database	Search string
PubMed	((rehabilitation) OR (physical therapy)) AND (((lumbar disc surgery) OR (lumbar discectomy)) OR (lumbar microdiscectomy)))
WoS	https://www.webofscience.com/wos/woscc/summary/021123f4-7ef1-4091-8b9b-f3fe8b889a93-e86d9477/relevance/1
Scopus	(TITLE-ABS-KEY ("lumbar disc surgery" OR "lumbar discectomy" OR "lumbar microdiscectomy")) AND (TITLE-ABS-KEY ("physical therapy" OR "rehabilitation"))

2.3. Data collection process

The studies were identified by the first author's name and the year of publication. Two review authors (AK and AB) independently collected the data from each eligible study, including study design, sample characteristics, sociodemographic data, intervention and comparison group details, outcomes of interest, and follow-up duration.

2.4. Evidence synthesis and appraisal

In anticipation of significant clinical diversity, we presented the available evidence for each research question in a narrative review. Two review authors (AK and AB) used the Risk of Bias Tool for RCTs, RoB-2, to assess the risk of reporting bias in our study (Sterne et al., 2016, 2019).

3. Results

3.1. Literature search

The literature search identified 660 articles, of which 177 duplicate studies were removed. Upon careful review of the collected articles' titles, abstracts, and full text, a total of 290 articles were excluded based on their titles and abstracts and 145 articles were excluded after a full-text assessment. Seven additional articles were included after reading the citations of the eligible studies. The resulting 55 studies with 4311 patients formed the basis of our systematic review (Fig. 1).

3.2. The role of physical therapies after surgery for LDH (Q1)

Ten studies with 794 patients, as depicted in Table 2, aimed to study the efficacy of physical therapies after therapies (Alaranta et al., 1986; Donceel and Du Bois, 1999; Dolan et al., 2000; Danielsen et al., 2000; Filiz et al., 2005; Erdogmus et al., 2007; Ebenbichler et al., 2015; Rushton et al., 2015, 2016, 2017; Jentoft et al., 2020; Aldemir and Gurkan, 2021). A randomized control study by Alaranta et al., focused on the safety and of rehabilitation (Alaranta et al., 1986). The authors compared a group of patients undergoing a rehabilitation program to a control group without rehabilitation after lumbar disc surgery in terms of postoperative handicap (Alaranta et al., 1986). The rehabilitation program was not responsible for additional handicaps one year after surgery (Alaranta et al., 1986). As a matter of fact, postoperative handicap, in both groups, was clearly associated with the patient's preoperative functional status (Alaranta et al., 1986). Ten studies provided overwhelming evidence that physical therapy improves back and leg pain control after lumbar disc surgery, irrespective of the pain assessment tool (Dolan et al., 2000; Danielsen et al., 2000; Filiz et al., 2005; Erdogmus et al., 2007; Ebenbichler et al., 2015; Rushton et al., 2015, 2016, 2017; Jentoft et al., 2020; Aldemir and Gurkan, 2021; Mannion et al., 2007). Equally important, physical therapy improves back-related disability (Dolan et al., 2000; Danielsen et al., 2000; Filiz et al., 2005; Erdogmus et al., 2007; Ebenbichler et al., 2015; Jentoft et al., 2020; Aldemir and Gurkan, 2021; Mannion et al., 2007) and overall quality of life (Danielsen et al., 2000; Erdogmus et al., 2007; Aldemir and Gurkan, 2021) while decreasing anxiety and depression levels, including fear avoidance behavior (Filiz et al., 2005; Erdogmus et al., 2007; Jentoft et al., 2020). In their study, Dolan et al. demonstrated that implementing a 4-week exercise program led to notable enhancements in back muscle endurance capacity and hip and lumbar mobility, along with a reduction in back muscle fatigability (Dolan et al., 2000). Furthermore, Donceel et al. demonstrated that a multidisciplinary rehabilitation program increased the probability of returning to work after lumbar disc surgery (Donceel and Du Bois, 1999). Most of the studies have some concerns regarding bias, with only three demonstrating a low risk of bias.

3.3. The role of activity restriction after LDH (Q2)

Three separate studies involving a total of 252 patients, as shown in Table 3, with 126 in the intervention group and 126 in the control group, were conducted to investigate the impact of activity restriction following LHD (Zoia et al., 2018; Bono et al., 2017; Yao et al., 2018). Zoia et al. conducted a study on the impact of corset adoption following single-level lumbar discectomy (Zoia et al., 2018). The findings indicated that the utilization of corsets did not lead to improvements in either short- or long-term outcomes (Zoia et al., 2018). In a similar article, Yao et al., conducted a comparative study involving 44 patients with lumbar degenerative disc disease who underwent lumbar transforaminal interbody fusion along with bracing, juxtaposed with 46 comparable patients who did not utilize bracing (Yao et al., 2018). The study's findings suggested that the postoperative use of a brace did not yield improvements in functional outcomes, nor was it correlated with an increased fusion rate or a reduction in complications (Yao et al., 2018). Finally, in a study conducted by Bono et al., a comparison was made between two groups of patients: one undergoing a short-term period of 2 weeks of activity restriction and the other undergoing 6 weeks of long-term activity restriction (Bono et al., 2017). The findings indicated that there was no significant association(Qvarfordh et al.,

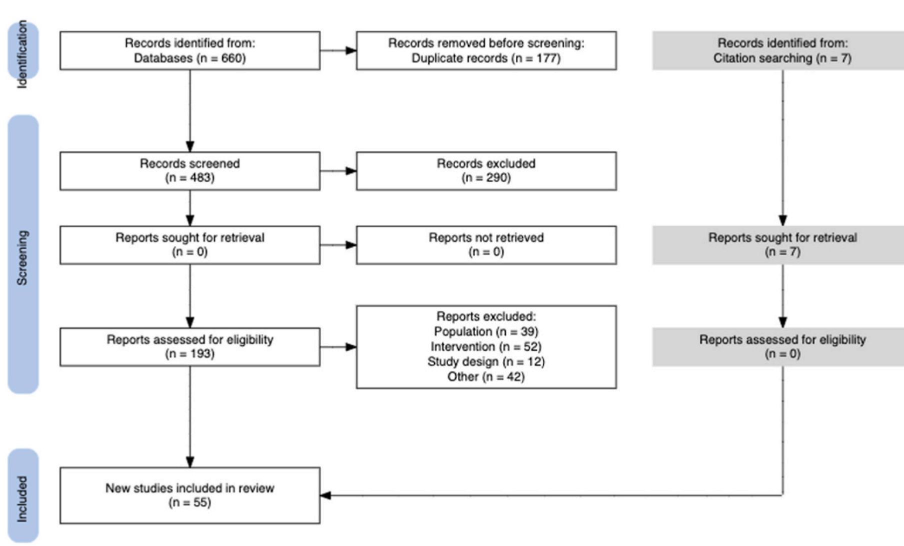

Fig. 1. Flow chart of our study. From a total of 66o, we included 55 studies based on eligibility criteria.

Table 2
Summary of basic study characteristics on research question 1 (Q1).

Author (Year)	Patients	Intervention	Comparator	Outcomes	Time	Summary	Risk of bias
Alaranta et al. (1986) (Alaranta et al., 1986)	Surgery for LDH	Rehabilitation (N = 106)	Control group (N = 106)	Subjective results and return to work	1 year	Rehabilitation after LDH surgery did not increase the back-related handicap	Some concerns
Donceel et al. (1999) (Donceel and Du Bois, 1999)	Surgery for LDH	Early mobilization by professionals (N = 30)	Mobilization as usual (N = 30)	Return to work	52 weeks	A rehabilitation program increases the probability of returning to work after surgery for LDH	Some concerns
Dolan et al. (2000) (Dolan et al., 2000)	Lumbar microdiscectomy	Exercise (N = 9)	Control group (N = 11)	Pain (VAS), disability (LBPQ), back muscle endurance capacity, and hip and lumbar mobility	52 weeks	A 4-week postoperative exercise program can enhance pain, disability, and spinal function in patients after microdiscectomy	Low risk of bias
Danielsen et al. (2000) (Danielsen et al., 2000)	Arcotomy or microsurgical lumbar disc herniation	Training group (N = 39)	Control (N = 24)	Pain (VAS), disability (RMDQ), sick leave, participation in daily activities, and overall health	12 months	Intense physical exercise therapy, initiated four weeks after the surgical procedure for lumbar disc herniation, resulted in a decrease in post-surgery pain and disability	Some concerns
Filiz et al. (2005) (Filiz et al., 2005)	Lumbar discectomy	Intensive exercise (N = 20)	Classical exercise (N = 20), No exercise (N = 20)	Pain (VAS), back-related disability (ODI), physical exercise, return to work, and psychometric tests (DBI)	NR	It appears that engaging in vigorous exercise is more effective in reducing pain and disability	Some concerns
Erdogmus et al. (2007) (Erdogmus et al., 2007)	Surgery for LDH	Physiotherapy (N = 35)	Sham (N = 32), No therapy (N = 32)	Pain (LPRS), back-related disability (ODI), psychometric properties, and activity of daily living	18 months	Physiotherapy following initial disc herniation surgery is more effective than no therapy in the short term	Low risk of bias
Ebenbichler et al. (2015) (Ebenbichler et al., 2015)	Surgery for LDH	Physiotherapy (N = 29)	Sham (N = 22), No therapy (N = 23)	Pain (VAS), back-related disability (ODI), and recurrence	12 years	Participating in a comprehensive physiotherapy program following lumbar disc surgery may be linked to better long-term health benefits compared to receiving no intervention	Some concerns
Rushton et al. (2017) (Rushton et al., 2017)	Surgery for LDH	Physiotherapy plus leaflet education (N = 29)	Leaflet education (N = 30)	Questionnaires on patients' and physiotherapists perceptions about physiotherapy rehabilitation	NR	Post-surgical rehabilitation preferences were driven by patients' individual priorities, including the need for a swift return to work	Some concerns
Jentoft et al. (2020) (Jentoft et al., 2020)	Surgery for LDH	Exercise and information (N = 33)	Information (N = 37)	Back and leg pain (NPRS), back-related disability (ODI), fear avoidance behaviour (TSK-13 and FABQ)	12 months	Engaging in physical exercise along with receiving relevant information resulted in a reduction of leg pain and improvement in function	Some concerns
Aldemir et al. (2021) (Aldemir and Gurkan, 2021)	Surgery for LDH	Walking group (N = 33)	Control group (N = 34)	Pain (McGill Pain Questionnaire), disability (ODI), and quality of life (SF-36)	3 months	Engaging in walks following surgery for a herniated disc has been shown to reduce pain and disability while enhancing overall quality of life	Low risk of bias

LDH, lumbar disc herniation; VAS, visual analogue scale; LBPQ, low back pain questionnaire; RMDQ, Rolland-Morris disability questionnaire; ODI, Oswestry disability questionnaire; NPRS, numeric pain rating scale; FABQ, fear avoidance belief questionnaire; SF-36, Short-Form 36; BDI, Beck Depression Inventory.

Table 3
Summary of basic study characteristics on research question 2 (Q2).

Author (Year)	Patients	Intervention	Comparator	Outcomes	Time	Summary	Risk of Bias
Zoia et al. (2018) (Zoia et al., 2018)	Lumbar discectomy	Use lumbar corset (N = 29)	No lumbar corset (N = 25)	Pain (VAS), back-related disability (ODI and RMDQ), and complications	6 months	The adoption of a corset does not lead to improvements in the short-term and midterm outcomes of patients following single-level lumbar discectomy	High risk of bias
Bono et al. (2017) (Bono et al., 2017)	Surgery for LDH	Short (2 weeks) activity restrictions (N = 53)	Long (6 weeks) activity restrictions (N = 55)	Back and leg pain (VAS), back-related disability (ODI), and reoperation rate	1 year	The clinical outcomes of LDH surgery are irrelevant to the length of activity restrictions	High risk of bias
Yao et al. (2018) (Yao et al., 2018)	Transforaminal lumbar interbody fusion	Brace (N = 44)	No brace (N = 46)	Pain (VAS), back-related disability (ODI), fusion rate, reoperation rate, and complications	12 months	The use of a postoperative brace doesn't seem to affect the rate of fusion or cause any complications or reoperation	Some concerns

ODI, Oswesrty Disability Index; RMDQ, Rolland-Morris disability questionairre; VAS, visual analogue scale.

2014)between the duration of activity restriction and functional outcomes or the time required to return to work (Bono et al., 2017). Among these studies, only one has some concerns about bias, while the other two have a high risk of bias.

3.4. The optimal timing of physical exercise initiation after surgery (Q3)

Eleven studies with 419 patients in the intervention groups and 531 in the control groups, as shown in Table 4, focused on the optimal timing to start physical therapies in association with surgery for LDH with contradictory evidence (Qvarfordh et al., 2014; Kjellby-Wendt and Styf, 1998; Kjellby-Wendt et al., 2001, 2002; Oosterhuis et al., 2013, 2017; Abbott et al., 2010; Newsome et al., 2009; Ozkara et al., 2015; Uysal et al., 2023; Oestergaard et al., 2013a; Lindbäck et al., 2018; Chen et al., 2015). The evidence is frequently contradictory with evidence showing that early mobilization offers some to no advantage in rehabilitation outcomes. According to the risk of bias assessment, there was a range from low to high risk among the studies.

Based on one study, Lindback et al., demonstrated that physiotherapy **initiated before surgery** reduces pain, lowers the risk of avoiding activities, prevents deterioration of mental well-being, enhances the quality of life, and increases physical activity levels compared to those on the waiting list (Lindbäck et al., 2018).

Four studies reported on **immediate intervention after surgery**. Newsome et al., documented that encouraging patients to start moving as early as 2 h after surgery can result in a reduced hospital stay and faster return to work, without impacting their reported pain and overall recovery (Newsome et al., 2009). Chen et al., compared a group of patients after lumbar decompression surgery undergoing in-hospital rehabilitation to a group without in-hospital mobilization. The authors reported improvement in pain intensity but failed to demonstrate any lasting benefit in the functional outcomes (Chen et al., 2015). Moreover, Qvarfordh et al., showed that it may even be safe and feasible to mobilize patients shortly after lumbar disc surgery, as there were no signs of an increased number of postoperative complications (Qvarfordh et al., 2014). Likewise, Ozkara et al., provided evidence that a 12-week postoperative exercise program starting immediately after surgery has the potential to improve pain management, reduce disability, and enhance spinal function in individuals who have undergone microdiscectomy (Ozkara et al., 2015).

In a multicenter randomized controlled trial, Oosterhuis et al. compared **early** referral to exercise therapy versus no referral after lumbar discectomy. The study assessed pain control, back-related disability, and cost-effectiveness. The authors failed to demonstrate the effectiveness or cost-effectiveness of early rehabilitation following lumbar disc surgery over no referral in this study (Oosterhuis et al., 2013, 2017). Abbott et al., demonstrated that an early rehabilitation program offers optimized outcomes even after lumbar fusion for lumbar disc herniation (Abbott et al., 2010). Kernc et al., supported that strength training is safe as early as three weeks after lumbar spine fusion and facilitates prompt functional recovery (Kernc et al., 2018). Notably, Oestergaard et al., reported that early rehabilitation programs initiated 6 weeks after LDH surgery, including lumbar fusion, were not superior to delayed rehabilitation programs (12 weeks) in terms of patient functionality and work absenteeism (Oestergaard et al., 2013a, 2013b). Similarly, Uysal et al., suggested that early exercise rehabilitation accelerates recovery, enhances quality of life, and preserves patients' working capacity, without precluding later initiation of exercise (Uysal et al., 2023). Kjellby-Wendt, Carlsson, and Styf showed that an early rehabilitation program was safe and effective, resulting in an improvement in pain control and functional outcome, without any further burden on the re-operation rate (Kjellby-Wendt and Styf, 1998; Kjellby-Wendt et al., 2001, 2002).

3.5. The role of training, education, behavioural management, and rehabilitation in physical therapies (Q4)

Seven studies with 568 patients equally divided into an intervention and control arm, shown in Table 5, focused on the role of supervision in postoperative rehabilitation after LDH with conflicting evidence, despite stratifying the results according to the index procedure (Soegaard et al., 2006; Donaldson et al., 2006; Johansson et al., 2009; Paulsen et al., 2020a; Oestergaard et al., 2020; Saha and Goktas, 2021; Shaygan et al., 2023). Johansson et al., showed that clinic-based supervised physiotherapy is more effective in reducing back pain, improving quality of life, increasing activity levels, and patient satisfaction than a home-based programing patients undergoing lumbar discectomy (Johansson et al., 2009). In another study, Soegaard et al., showed that low-cost biopsychological interventions, such as supervised group exercise and cafe meetings, could help reduce primary healthcare utilization and associated costs after lumbar fusion for degenerative disorders (Soegaard et al., 2006). Equally important, Shaygan et al. demonstrated that in-person training is not only effective in reducing post-operative pain levels but also in improving functional outcomes and decreasing post-operative anxiety (Shaygan et al., 2023). However, the later study failed to defined the index procedure.

On the other hand, Donaldson found no added benefit in pain reduction, back-related disability, and overall functional outcome from adopting a 6-month supervised non-aggravating, gym-based exercise program one year after lumbar discectomy (Donaldson et al., 2006). Likewise, Paulsen et al., showed that referring patients to municipal physical rehabilitation services after primary lumbar discectomy does not yield a significant difference in postoperative outcomes compared to non-referral, and it is not a cost-effective measure for improving patient return to work (Paulsen et al., 2020a, 2020b). Saha and Goktas demonstrated that the implementation of a computer-based lumbar disc surgery discharge training program, along with a CD containing the training content, had a positive impact on enhancing patient independence in their daily activities (Saha and Goktas, 2021). Finally, Oestergaard et al. reported no significant impact of using a one-to-one case manager-assisted rehabilitation after lumbar fusion on the back-related functional outcome (Oestergaard et al., 2020). However, they found that the measure was not cost-effective (Oestergaard et al., 2020). The majority of the studies have some concerns about bias, while only one has a low risk of bias.

3.6. The optimal type of physical rehabilitation exercise (Q5)

Seventeen studies with 1044 patients tried to identify the optimal exercise therapy for managing patients after LDH surgery (Table 6). Substantial evidence arising from sic studies showed that dynamic exercise increasing the force-generating capacity of trunk muscles is superior to regular exercise or no exercise at all (Manniche et al., 1993; Kulig et al., 2009; Beneck et al., 2014; Choi et al., 2005; Yílmaz et al., 2003; Demir et al., 2014; Ju et al., 2012). Similarly, functional exercise with flexion and extension of the lower limbs, trunk and neck reduces pain and improves functional outcomes after lumbar disc surgery, but it seems that extension exercises are more effective (Zhang et al., 2018; Abdi et al., 2023). Bahceli and Karabulut compared 50 and 47 patients receiving progressive relaxation exercise and usual care postoperatively (Bahçeli and Karabulut, 2021). The authors reported that nursing-led relation exercise helped, not only in reducing pain and anxiety but also improved sleep quality (Bahçeli and Karabulut, 2021). Two articles studied the role of aquatic exercise after LDH surgery (Yolgösteren and Külekçioğlu, 2021; Kim et al., 2010). Yolgostren et al., highlighted that aquatic exercises were significantly better than those in the non-aquatic exercise group, while Kim, Park and Shim indicated that the aquatic backward locomotion exercise is equally effective as progressive resistance exercise in enhancing lumbar extension strength in patients following lumbar discectomy surgery (Yolgösteren and Külekçioğlu,

Table 4
Summary of basic study characteristics on research question 3 (Q3).

Initiation	Author (Year)	Patients	Intervention	Comparator	Outcomes	Time	Summary	Risk of Bias
Before surgery								
	Lindbäck et al. (2018) (Lindbäck et al., 2018)	Surgery for LDH	PREPARE physiotherapy (N = 99)	Waiting list (N = 98)	Back-related disability (ODI), back pain (VAS), quality of life (EQ-5D), EQ-VAS, psychometric parameters (FABQ, SES, HADS), activity level	1 year	Presurgery physiotherapy decreases pain, risk of avoidance behaviour, and worsening of psychological well-being, and improves quality of life and physical activity levels before surgery compared with waiting-list controls	Some concerns
Immediate								
	Newsome et al. (2009) (Newsome et al., 2009)	Lumbar microdiscectomy	Exercise within 2 h after surgery (N = 15)	Exercise on the 1st postoperative day (N = 15)	Time to independent mobilization, postoperative pain and disability, and return to work	3 months	Ultra-early mobilization of patients can lead to a shorter hospital stay and earlier return to work, without any adverse effect on patient-reported pain and functional outcome	Some concerns
	Chen et al. (2015) (Chen et al., 2015)	Decompression surgery for lumbar stenosis	Perioperative rehabilitation (N = 29)	Regural control group (N = 31)	Pain (VAS), back-related functional capacity (RMDQ), and overall functional capacity (SF-36)	6 months	A rehabilitation program during the hospital stay seems to offer no additional benefit on the functional performance	Some concerns
	Qvarfordh et al. (2014) (Qvarfordh et al., 2014)	Surgery for LDH	Walk from surgery bed (N = 11)	Transportation in beds (N = 11)	Pain and nausea (NRS), back-related discomfort (BQ),	3 weeks	It may be safe and feasible to mobilize patients shortly after lumbar disc surgery, as there were no signs of an increased number of postoperative complications	Some concerns
	Ozkara et al. (2015) (Ozkara et al., 2015)	Lumbar microdiscectomy	Exercise group (N = 15)	Control group (N = 15)	Leg and back pain (VAS), back-related disability (ODI), functional tests, quality of life (SF-36), return to work, and psychometric tests (BDS)	12 weeks	A postoperative exercise regimen lasting 12 weeks and commencing immediately after surgery has the potential to enhance pain management, reduce disability, and improve spinal function in individuals who have undergone microdiscectomy.	Low risk of bias
Early								
	Oosterhuis et al. (2017) (Oosterhuis et al., 2017)	Surgery for LDH	Early rehabilitation (N = 82)	No rehabilitation (N = 71)	Functional status (ODI), pain (VAS), global perceived recovery (Likert), general health (SF-12), and cost analysis	26 weeks	Receiving early rehabilitation after lumbar disc surgery did not prove to be more effective or cost-effective compared to not receiving a referral	Low risk of bias
	Abbott et al. (2010) (Abbott et al., 2010)	Lumbar fusion with or without decompression	Rehabilitation exercise (N = 54)	Psychomotor therapy (N = 53)	Leg and back pain (VAS), disability (ODI), US of LM	3 years	It is safe to initiate post-surgery recovery measures after lumbar fusion. including psychological and motor functions for optimal results	Some concerns
	Oestergaard et al. (2013) (Oestergaard et al., 2013b)	Surgery for LDH	Early rehabilitation (6 weeks, N = 34)	Late rehabilitation (12 weeks, N = 34)	Pain (DPQ, LBRS), back-related disability (ODI), and work absenteeism	1 year	No difference was found in the effect of initiating rehabilitation either 6 or 12 weeks after LSF on the patients' physical performance in terms of fitness and walking distance	Some concerns
	Kernc et al. (2018) (Kernc et al., 2018)	Lumbar fusion	Early strength training group (N = 14)	No exercise group (N = 13)	Pain (VAS), back-related disability (ODI), physical performance tests, satisfaction	18 months	Strength training is safe just three weeks after lumbar spine fusion and facilitates prompt functional recovery	Some concerns
	Uysal et al. (2023) (Uysal et al., 2023)	Surgery for LDH	Group a (The 2nd-week walking group, N = 40)	Group b (1st-month walking group, N = 39), Group c (2nd-week waist exercise, N = 42), Group d (1st-month waist	Pain (VAS), back-related disability (ODI)	12 months	Early implementation of exercises is ideal, but even if initiated later, standard back exercises can still expedite rehabilitation	High risk of bias

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Table 4 (*continued*)

Initiation	Author (Year)	Patients	Intervention	Comparator	Outcomes	Time	Summary	Risk of Bias
				exercise, N = 42), Group e (No exercise, N = 41)				
	Kjellby-Wendt et al. (2002) (Kjellby-Wendt et al., 2002)	Lumbar discectomy	Active exercise program (N = 26)	Less active program (N = 26)	Pain, functional outcomes, and psychometric tests (BDI)	5–7 years	Active exercise does not seem to affect the reoperation rate	High risk of bias

BDI, Back Depression Inventory; ODI, Oswesrty Disability Index; VAS, visual analogue scale; RMDQ, Rolland-Morris disability questionnaire; SF-36, Short-Form 36; LDH, Lumbar Disc Herniation; DPQ, Dalla Pain Questionnaire; LBPRS, Low Back Pain Rating Scale; LSF, Lumbar Spinal Fusion; NRS, numerical rating scale; BQ, Bournemouth Questionnaire; BDS, Beck Depression Scale; SF-12, Short Form 12; EQ-5D, EuroQol Group 5 item questionnaire; FABQ, fear avoidance belief questionnaire; SES,Self-Efficacy Scale; HADS, Hospital Anxiety and Depression Scale; US, ultrasound; LM, lumbar multifidus.

Table 5
Summary of basic study characteristics on research question 4 (Q4).

	Author (Year)	Patients	Intervention	Comparator	Outcomes	Time	Summary	Risk of Bias
Training and patient education	Donaldson et al. (2006) (Donaldson et al., 2006)	Lumbar discectomy	Gym-based exercise (N = 47)	Surgery advice (N = 46)	Pain (VAS), back-related disability (ODI and RMDQ), quality of life (SF-36), working ability	3 years	The gym-based program added no improvement to the surgery advice	Low risk of bias
	Soegaard et al. (2006) (Soegaard et al., 2006)	Lumbar fusion	Training group (exercise therapy, N = 30)	Video group (one-time video instruction, N = 28), Cafe group (video presentation and regular group meetings, N = 30)	Cost analysis	2 years	A rehabilitation program covering biological, psychological, and social factors has been found to be cost-effective in reducing primary healthcare service utilization when compared to the standard regimen and a workout program	Some concerns
	Saha and Goktas (2021) (Saha and Goktas, 2021)	Lumbar disc surgery	Computer-based training (N = 30)	Control group (N = 30)	Modified Barthel Index and Exercise and Self-Care Scale	12 months	The discharge training program on computers led to participants being more independent when carrying out daily tasks	High risk of bias
Behavioural management	Johansson et al. (2009) (Johansson et al., 2009)	Lumbar microdiscectomy	Clinic-based physiotherapy training and behavioral management (N = 28)	Home-based training (N = 29)	Back-related disability (ODI), physical activity level, kinesiophobia, coping, pain, quality of life, and patient satisfaction	12 months	Clinic-based physiotherapy is more effective in reducing back pain, improving quality of life, increasing activity levels, and patient satisfaction	Some concerns
Rehabilitation	Paulsen et al. (2020) (Paulsen et al., 2020b)	Lumbar discectomy	Municipal rehabilitation program (N = 73)	Home rehabilitation program (N = 73)	Back and leg pain (VAS), back-related disability (ODI), quality of life (EuroQol)	24 months	Referring patients to physical rehabilitation provided by the municipality does not result in a significant difference in postoperative outcomes compared to not referring them, it is not cost-effective and does not improve the patient's return to work	Some concerns
	Oestergaard et al. (2020) (Oestergaard et al., 2020)	Lumbar fusion	Usual physical rehabilitation (N = 41)	Case manager assisted rehabilitation (N = 41)	Back-related disability (ODI), quality of life (EuroQol), cost analysis	2 years	This case manager-assisted rehabilitation programme was unlikely to be cost-effective.	Some concerns
	Shaygan et al. (2023) (Shaygan et al., 2023)	Lumbar surgery	Personal rehabilitation program (N = 35)	Control group (N = 35)	Pain (NPRS), back-related disability (ODI), anxiety (PASS)	3 months	Physical and psychological pain management education was shown to be effective in decreasing pain intensity, anxiety, and disability	High risk of bias

VAS, visual analogue scale; ODI, Oswesrty Disability Index; RMDQ, Rolland-Morris disability questionnaire; SF-36, Short-Form 36; NPRS, Numeric pain rating scale; PASS, Pain anxiety symptoms scale.

Table 6
Summary of basic study characteristics on research question 5 (Q5).

Author (Year)	Patients	Intervention	Comparator	Outcomes	Time	Summary	Risk of Bias
Manniche et al. (1993) (Manniche et al., 1993)	Lumbar discectomy	Intensive exercise program (N = 42)	Traditional exercise program (N = 40)	Back pain, leg pain, back-related disability, physical impairment, change to a less heavy job, convalescence, long-term sick leave, and work disability pension	12 months	An intensive exercise program increases the functional and working capacity of the patient	Some concerns
Scrimshaw and Maher (2001) (Scrimshaw and Maher, 2001)	Lumbar disc surgery	Neural mobilisation exercise (N = 38)	Standard care (N = 38)	Global perceived effect (7-point scale), pain (VAS and McGill Pain Questionnaire, and disability (Quebec Disability Scale)	12 months	The neural mobilization protocol evaluated in this study did not provide an additional benefit to standard postoperative care for patients undergoing spinal surgery	Some concerns
Yílmaz et al. (2003) (Yílmaz et al., 2003)	Lumbar microdiscectomy	Dynamic exercise (N = 14)	Home-based exercise (N = 14), No exercise (N = 14)	Pain (VAS), back-related disability (ODI, functional tests, and depression (BDS)	8 weeks	Dynamic lumbar stabilization exercises are an efficient and useful technique in the rehabilitation of patients who have undergone microdiscectomy, as they relieve pain, improve functional parameters, and strengthen trunk, abdominal, and low back muscles	Some concerns
Hakkinen et al. (2004) (Hakkinen et al., 2007)	Surgery for LDH	Combined strengthening and stretching group (N = 61)	Control group (N = 65)	Pain (VAS), back-related disability (ODI and MDI), physical parameters	12 months	At the 12-month follow-up, a combined strengthening and stretching program does not seem to alter the physical function, pain, or disability measures between the groups	Low risk of bias
Choi et al. (2005) (Choi et al., 2005)	Surgery for lumbar disc herniation	Exercise (N = 35)	Control (N = 40)	Lumbar extensor power, lumbar multifidus cross-sectional area, pain (VAS), back-related disability (ODI), and return to work	12 weeks	The postoperative early lumbar extension muscle-strengthening program has positive effects on pain, return to work, and back muscle strength in patients after herniated lumbar disc surgery	Low risk of bias
Kulig et al. (2009) (Kulig et al., 2009)	Lumbar microdiscectomy	Education plus exercise (N = 43)	Education (N = 14) and Usual physical therapy (N = 20)	Back-related function (ODI) and several tests including walking distance	12 months	Patients who have undergone a single-level lumbar microdiscectomy can benefit from a comprehensive exercise program along with education, as it can help reduce disability and enhance their overall functionality	Some concerns
Kim et al. (2010) (Kim et al., 2010)	Lumbar discectomy	Progressive extension exercise (N = 10)	Aquatic backward exercise (N = 10), Control group (N = 10)	Lumbar muscle strength	18 weeks	The results obtained suggested that the aquatic backward locomotion exercise is as beneficial as progressive resistance exercise for improving lumbar extension strength in patients after lumbar discectomy surgery	Some concerns
Ju et al. (2012) (Ju et al., 2012)	Surgery for LDH	Extension exercise program (N = 7)	Control group (N = 7)	Lumbar muscle extension strength, pain (VAS)	12 weeks	A strengthening program after lumbar disc herniation surgery was successful in strengthening the muscles in the lower back and decreasing discomfort.	Low risk of bias
Demir et al. (2014) (Demir et al., 2014)	Lumbar microdiscectomy	Dynamic lumbar stabilization exercise (N = 22)	Homed based exercise (N = 22)	Pain (VAS), back-related disability (ODI), overall patient functioning (NHP), spinal mobility, psychometric test (FABQ), and return to work	6 months	DLS exercises seem beneficial in reducing pain, increasing spinal mobility, and ensuring faster return to work periods	Low risk of bias
Beneck et al. (2014) (Beneck et al., 2014)	Lumbar microdiscectomy	Exercise and education (N = 45)	Education (N = 32)	SF-36	6 months	An intensive, progressive exercise program combined with education increases the quality of life in patients who have recently undergone lumbar microdiscectomy	Some concerns
Hebert et al. (2015) (Hebert et al., 2015)	Lumbar discectomy	Specific trunk exercise (N = 29)	General exercise (N = 32)	Leg and back pain (VAS), disability (ODI), US of LM	6 months	Both specific and general trunk exercises included in multimodal rehabilitation programs demonstrate comparable effects on muscle	High risk of bias

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Table 6 (*continued*)

Author (Year)	Patients	Intervention	Comparator	Outcomes	Time	Summary	Risk of Bias
						function outcomes and clinical results	
Zhang et al. (2018) (Zhang et al., 2018)	PELD	Functional exercise (N = 46)	Control group (N = 46)	Pain, radiological parameters, functional parameters	3 years	Early rehabilitation exercises involving passive and autonomic activities can enhance the postoperative quality of life for individuals with lumbar disc herniation	Low risk of bias
Bahceli and Karabulut (2020) (Bahçeli and Karabulut, 2021)	Lumbar microdiscectomy	Relaxation exercise program (N = 47)	Control group (N = 50)	Pain (VAS), sleep, and anxiety	1 month	Progressive relaxation exercises, as a nursing intervention, reduce pain and anxiety and increase sleep quality	High risk of bias
Lyu et al. (2021) (Lyu et al., 2021)	Lateral approach single-segment PELD	Staged program with lumbar-pelvic-leg kinetic chain exercise (N = 25)	Regular exercise (N = 26)	Pain (VAS), back-related disability (ODI and JOA), overall patient functioning (SF-36), gait analysis, LM cross-sectional area on MRI	24 weeks	Lumbar kinetic chain training was found to be more effective than regular low back muscle exercise in the staged rehabilitation program for LDH after PELD	Low risk of bias
Reyes et al. (2021) (Reyes et al., 2021)	Lumbar disc surgery	Standard rehabilitation plusNeural mobilisation exercise (N = 12)	Standard rehabilitation (N = 12)	Pain (VAS), disability (ODI), overall functionality (SF-36)	NR	Neural stabilization exercise offered no additional benefit to rehabilitation as usual	High risk of bias
Yolgösteren and Kulekcioglu (2021) (Yolgösteren and Külekçioğlu, 2021)	Surgery for lumbar disc herniation	Aquatic exercise (N = 20)	Non-aquatic exercise (N = 20)	Pain (VAS), back-related disability (LDS, RMDI), functional tests (MST, Finger-to-Floor Distance, Sorensen Test, PILE), and psychometric tests (BDI, NHP, and SF-36 Health Survey)	6 months	Aquatic exercise group showed significantly better changes in pain control and functional outcomes compared to the non-aquatic exercise group.	Some concerns
Abdi et al. (2023) (Abdi et al., 2023)	Surgery for LDH	Repeated flexion exercise (N = 30)	Extension-based exercise (N = 30), Control group (N = 30)	Pain (VAS), back-related disability (ODI), back and trunk muscle endurance (mBST and TEFT), and return to work	8 weeks	Both flexion- and extension-based exercise improved the functional outcomes and reduced pain, but the effect of extension-based exercise was more profound	Some concers

VAS, visual analogue scale; ODI, Oswesrty Disability Index; BDS, Beck Depression Scale; MDI, Million disability indexes; FABQ, fear avoidance belief questionnaire; NHP, Nottingham Health Profile; SF-36, Short-Form 36; US, UltraSound; LM, lumbar multifidus; PELD, percutaneous endoscopic discectomy; JOA, Japanese Orthopedic Association scale; SF-36, Short-Form 36; LDH, Lumbar Disc Herniation; RMDI, Rolland Morris Disability Index; BDI, Beck Depression Inventory; NHP, Nottingham Health Profile; SF-36, Short-Form 36; mBST, model-based system testing; TFT, Testing Experience and Functional Test; MST, Modified Schober Test; PILE, Progressive Isoinertial Lifting Evaluation.

2021; Kim et al., 2010). A study comparing the combination of strengthening and stretching exercises (N = 61) to stretching and stabilization exercises only (N = 65) regarding pain control, disability, and several physical parameters showed that the combination program added no further improvement to the stretching-only regiment (Häkkinen et al., 2005). In their study, Lyu et al. demonstrated that lumbar kinetic chain training yielded superior results compared to regular low back muscle exercises in the staged rehabilitation program for LDH following percutaneous endoscopic lumbar discectomy (Lyu et al., 2021). Conversely, Hebert et al. reported no discernible disparity in clinical and muscle function outcomes when contrasting the effects of specific trunk exercises with general trunk exercises after lumbar discectomy (Hebert et al., 2015). Lastly, there is consistent evidence that neural mobilization exercise, including passive movements and active exercises designed to mobilize the lumbosacral nerve roots and sciatic tract, provide an additional benefit to standard postoperative care for patients undergoing spinal surgery (Scrimshaw and Maher, 2001; Reyes et al., 2021). Concerning the risk of bias, we have studies in all three categories: low risk, high risk, and some concerns.

3.7. *Improving outcomes in physical therapy (Q6)*

Seven studies with 305 and 458 patients in intervention and control groups, as depicted in Table 7, focused on additional methods to improve the outcomes of physical therapies after surgery for LDH (Kim et al., 2015, 2016, 2017; Ostelo et al., 2003, 2004; Kulikov et al., 2018; McGregor et al., 2010, 2011, 2012; Zhao et al., 2008; He et al., 2021; Oestergaard et al., 2012). Kim et al., in a small group study, demonstrated that manipulative therapy is safe and feasible after surgery for LDH (Kim et al., 2015, 2016, 2017). Similarly, there is evidence that acupuncture and whole-body magnetic field therapy may improve functional outcomes after surgery for lumbar disc prolapse (Kulikov et al., 2018; Zhao et al., 2008). The utilization of the semi structured Canadian Occupational Performance Measure interview appears to be beneficial in identifying and subsequently addressing challenges related to activities of daily living utilizing occupational therapy (Oestergaard et al., 2012). The implementation of behavioral therapy, utilizing graded activity and positive reinforcement to promote healthy behavior and alleviate pain, did not yield a reduction in fear avoidance behaviors or catastrophizing pain. Moreover, this approach did not lead to improved functional outcomes (Ostelo et al., 2003, 2004). There is conflicting evidence regarding the benefit of education in the rehabilitation after surgery for LDH. The prize-winning Function after Spinal Treatment, Exercise, and Rehabilitation (FASTER) trial by McGregor et al., studied the use of booklet education and rehabilitation in patients undergoing discectomy (McGregor et al., 2011). The trial reported no effect on long-term pain and functional outcomes. On the contrary, He et al. showed that a continuous nursing-led educational program could result in improved functional outcomes, particularly by facilitating patient compliance (He et al., 2021). An equal number of studies have

Table 7
Summary of basic study characteristics on research question 6 (Q6).

Author (Year)	Patients	Intervention	Comparator	Outcomes	Time	Summary	Risk of Bias
Ostelo et al. (2003) (Ostelo et al., 2003)	Lumbar discectomy	Behavioral graded activity (N = 52)	Usual care (N = 53)	Pain (VAS), back-related disability (RMDQ), emotions, satisfaction (GPE), range of motion, activities of daily living (SF-36 and ADL), and reoperation rate	3 months	Activity after first-time lumbar disc surgery is safe	Some concerns
McGregor et al. (2011) (McGregor et al., 2011)	Surgery for LDH	Booklet plus rehabilitation (N = 91)	Rehabilitation (N = 86), Booklet (N = 70), NS Usual care (N = 91)	Pain (VAS) and disability (ODI), psychometric tests (FABQ and HADS), and quality of life (EQ-5D)	12 months	Both interventions did not have a significant impact on long-term outcomes	Low risk of bias
Oestergaard et al. (2012) (Oestergaard et al., 2012)	Lumbar fusion	Occupation therapy (N = 28)	Control (N = 32)	Survey	3 years	The utilization of the COPM while in the hospital proved beneficial in identifying a greater number of ADL challenges experienced by patients in the initial three months following discharge	Some concerns
Kim et al. (2017) (Kim et al., 2017)	Lumbar open laser microdiscectomy	Manipulation rehabilitation (N = 14)	Active rehabilitation (N = 7)	Pain (VAS) and disability (RMDQ)	2 years	The study verified the feasibility of manipulation therapy after LDH surgery	High risk of bias
Kulikov et al. (2018) (Kulikov et al., 2018)	Lumbar discectomy	Magnetic field therapy (N = 37)	Control (N = 36)	Pain (VAS) and infrared thermography	NR	WBMF therapy combined with rehabilitation seemed to be effective in reducing lumbar pain, temperature, and, possibly, inflammation	Some concerns
Zhang et al. (2018) (Zhao et al., 2008)	Lumbar disc surgery	Acupuncture plus rehabilitation (N = 36)	Rehabilitation (N = 35)	Back-related function JOA)	1 year	Acupuncture seems to promote functional recovery	Low risk of bias
He et al. (2021) (He et al., 2021)	Lumbar discectomy	Nursing education (N = 47)	Control group (N = 48)	Quality of life (SF-36), back-related disability (ODI and JOA), and compliance	3 months	A continuous nursing-led program improves the compliance of the patients	Low risk of bias

VAS, visual analogue scale; RMDQ, Rolland-Morris disability questionnaire; GPE, Global Perceived Effect; SF-36, Short-Form 36; ADL, activities in daily living; FABQ, fear avoidance belief questionnaire; HADS, hospital anxiety and depression scale; EQ-5D, EuroQol Group 5 item questionnaire; WBMF, whole-body magnetic field; JOA, Japanese Orthopedic Association scale; ODI, Oswesrty Disability Index.

some concerns and low risk of bias, though only one has a high risk of bias.

4. Discussion

4.1. Summary of the evidence

In our present systematic review, our objective was to investigate the efficacy of physical therapy following surgery for lumbar disc herniation (LDH) through a series of predetermined inquiries. Initially, we endeavored to pinpoint high-quality studies that addressed these inquiries. Subsequently, we sought to succinctly present the existing evidence in a narrative format from a critical standpoint. Our findings suggest that physical therapy is a safe and effective intervention, particularly in the improvement of back and leg pain control, reduction of back-related disability, and overall enhancement of quality of life following LDH surgery, in spite of some controversies. Furthermore, it is evident that physical rehabilitation positively influences back muscle function and mitigates feelings of depression and anxiety. Most exercise programs targeting the improvement of endurance, mobility, and strength of the back musculature demonstrate effectiveness, except for neural mobilization exercises. As previously postulated, activity restriction does not offer substantial advantages to the patient, such as the avoidance of recurrence and reoperation. However, the optimal timing for commencing activity and the cost-effectiveness of supervised exercise remain topics of ongoing debate. It seems that patient education and training, behavioural management, and rehabilitation programs are useful in improving outcomes and are usually cost-effective. Enhanced outcomes may also be achievable through concomitant manual therapy, acupuncture, educational interventions, and behavioral and occupational therapy. Nevertheless, there is still an absence of robust and undougthed evidence in any of the above statements.

4.2. Main obstacles in the literature review

The main research question is as follows: What is the role of physical therapies following surgery for LDH? In reviewing the literature on physical therapy and LDH surgery, it becomes evident that there is significant clinical diversity among studies. This diversity is not only limited to the type of physical therapy and the comparison group chosen but also extends to the outcome measures and assessment tools used, as well as the specific time points at which the assessments are conducted. The spectrum of surgical treatments for lumbar disc herniation, spanning from percutaneous endoscopic discectomy (PELD) to open discectomy and interbody lumbar fusion (IBLF), presented a significant source of procedural heterogeneity across the included studies. The frequent absence of detailed surgical procedure specifications, likely a consequence of this variability, acted as a confounding factor, impeding the precise analysis and interpretation of the aggregate study results. Pain levels can be measured using the visual analogue scale (VAS), the numeric pain rating scale (NPRS), or the Dallas Pain Questionnaire (DPQ), while back-related disability can be assessed using the Oswestry Disability Index (ODI), the Rolland-Morris Disability Questionnaire (RMDQ), or the Japanese Orthopedic Association (JOA) scale. Adding to the complexity, the outcomes are measured at various intervals, ranging from two weeks to 12 years after surgery. The main challenge with this diversity is that it makes direct comparisons between studies difficult, hindering the identification of the optimal therapy. In the absence of homogeneous data regarding patient selection, intervention, comparator, outcome, and timing, we concluded that a quantitative evidence synthesis, including a network meta-analysis, is not appropriate. Therefore, we identified the main research questions in the gathered literature and seven research questions which were dictated by the gathered evidence. We made every effort to be as inclusive as possible for the completeness of our Systematic Review.

4.3. Comparison with the existing knowledge

Throughout the years, several high-quality reviews have been published, but none of them has tried to answer the spectrum of questions set in our study (Oosterhuis et al., 2014; Ruffilli et al., 2024; Yu et al., 2024; Atsidakou et al., 2021; Dupeyron et al., 2021; Özden, 2022). Despite these obstacles, Ruffilli et al., tried to identify the optimal timing of physical therapy initiation after lumbar disc surgery through a systematic review and a meta-analysis (Ruffilli et al., 2024). The meta-analysis was limited to the postoperative pain control and the complication occurrence and was stratified to the 12 weeks and 12 months' time points (Ruffilli et al., 2024). The authors included 14 studies in their systematic review and three to five studies in their meta-analysis (Ruffilli et al., 2024). The results showed a notable contrast between early and standard physical therapy in relation to low back pain at 12–18 months, with no significant variances in complications for both discectomy and arthrodesis (Ruffilli et al., 2024). The findings from the study by Ruffilli et al., seem to differ from our findings, particularly due to the adopted methodology (Ruffilli et al., 2024).

In a systematic review conducted by Yu et al., similar challenges were encountered in assessing the effectiveness of postoperative rehabilitation following lumbar disc surgery (Yu et al., 2024). The literature search yielded 20,531 citations, from which only 25 articles met the eligibility criteria. The authors evaluated various rehabilitation interventions, including pregabalin, education, and behavioral therapy as part of physical therapies (Yu et al., 2024). The review's findings were categorized based on outcomes including function, pain, quality of life, self-recovery, and adverse events (Yu et al., 2024). Ultimately, the authors concluded that evidence supporting effective and safe post-surgical rehabilitation interventions is limited (Yu et al., 2024). They identified two interventions with potential short-term benefits, namely Pilates exercises and whole-body magnetic therapy, while acknowledging unclear safety profiles for these interventions (Yu et al., 2024). In contrast to the systematic review by Yu et al., based on a much larger pool of studies, we demonstrated that postoperative physical therapy is safe and effective, with some concerns about the optimal time and its cost-effectiveness (Yu et al., 2024).

In a systematic review by Atsidakou et al., the focus was on the outcomes of exercise programs after lumbar discectomy (Atsidakou et al., 2021). The literature search identified seven RCTs meeting the study's eligibility criteria. After reviewing the literature, the authors suggested that there is evidence indicating that exercise either improves or does not affect pain intensity levels, functional outcome, quality of life, muscle performance, and return to work. Most of the evidence came from "moderate" quality studies. Interestingly, the authors did not find many studies reporting on the complications associated with exercise therapy after lumbar discectomy. Our current systematic review indicated that the evidence favoring the use of exercise after discectomy in terms of functional outcomes outweighs the limited concerns against it. Moreover, our review was based on a larger pool of eligible studies.

In their systematic review, Ozden et al. evaluated the efficacy of exercise following lumbar decompression surgery on various outcome measures including pain, function, motor sensory symptoms, and psychosocial parameters (Özden, 2022). Their review included a total of fourteen studies selected from 1219 accessed articles (Özden, 2022). The findings indicated that exercises such as strengthening, stabilization, and aerobic exercises offer additional benefits compared to receiving only education or clinical advice post-surgery (Özden, 2022). Additionally, the importance of relaxation, stretching, and mobilization training was underscored by the studies (Özden, 2022). The review concluded that exercise training resulted in improved disability scores at six to twelve weeks follow-up with high-degree evidence, while demonstrating lower efficacy in reducing pain scores (Özden, 2022). Furthermore, the review highlighted the moderate degree of effectiveness of exercise training on physical function, bodily pain, and social function based on Short Form-36 pooling at the 12-week follow-up (Özden, 2022). Overall, these results emphasize the significance of exercise training, particularly focusing on strengthening, in the post-lumbar decompression surgery recovery period (Özden, 2022).

The French Society of Physical Medicine and Rehabilitation recently published the French recommendation on rehabilitation after lumbar surgery, excluding stenosis and spondylolisthesis restoration (Dupeyron et al., 2021). The guidelines were established through a comprehensive three-step process, which involved question formulation, a thorough literature review, and the finalization of recommendations (Dupeyron et al., 2021). The question formulation stage resulted in eight primary questions, while the literature review uncovered 66 articles of various designs, including randomized controlled trials, observational studies, case reports, systematic reviews, and surveys (Dupeyron et al., 2021). One of the key consensuses reached through the Delphi method was that prehabilitation in the form of 150 min per week of physical conditioning and education can significantly enhance function, time-to-recovery, and patient satisfaction (Dupeyron et al., 2021). Furthermore, it was recommended that patients should aim to resume most activities of daily living within two weeks after discectomy, and rehabilitation should be initiated based on the patient's status from 3 weeks after surgery, but no later than six weeks, especially after lumbar fusion where the recovery period is longer (Dupeyron et al., 2021). The consensus also emphasized the importance of intense and dynamic exercises as the first-line choice, advising against less effective isometric or isolated stretching exercises, with a clear recommendation to avoid repetitive flexion exercises (Dupeyron et al., 2021). It was suggested that exercise programs initially be supervised and then transition to independent sessions (Dupeyron et al., 2021). Additionally, structured information, discussion forums, and educational cafes were highlighted as potential integral components of the rehabilitation program (Dupeyron et al., 2021). The use of corsets and belts should be minimized and considered on a case-by-case basis (Dupeyron et al., 2021).

4.4. Future considerations

This literature review highlighted four important fields requiring future attention. To start with, no more poor-quality studies are required to study the effect of physical therapy against no physical therapy in terms of pain control, back-related disability, and quality of life. It should be stressed, however, that the evidence on particular safety parameters is underreported. Future studies need to consistently record and publish the occurrence rate of potential complications associated with physical therapy, including recurrence and reintervention rates. Secondly, a widely accepted tool to register and establish the cost-effectiveness of physical therapy is mandatory. In an era of constrained resources, it is imperative to allocate resources judiciously. Thirdly, there is an imperative need to translate the existing evidence into clinical recommendations, disseminate them across relevant disciplines, and create tools to enhance their applicability.

4.5. Limitations

It is pertinent to acknowledge that our study is subject to certain limitations that necessitate consideration when interpreting the findings. Our deliberate restriction of the search to RCTs was aimed at ensuring the inclusion of high-quality data. However, this method resulted in a reduced pool of eligible studies for some of our inquiries. Nevertheless, a substantial volume of data was available, facilitating evidence synthesis from 56 RCTs and encompassing a total of 4381 patients. Solely studies published in the English language were encompassed in our analysis. A singular literature search was conducted to address multiple queries, and the identified studies exhibited a noteworthy degree of heterogeneity in outcome reporting. Finally, it is imperative to underscore that a qualitative review of the findings was conducted, and a quantitative analysis to summarize the results was not pursued.

5. Conclusions

Our current systematic review focused on the efficacy of physical therapy following surgery for lumbar disc herniation (LDH). The findings indicate that physical therapy is a safe and effective intervention for improving back and leg pain control, reducing back-related disability, and enhancing overall quality of life post-surgery. Additionally, physical rehabilitation positively influences back muscle function and helps alleviate feelings of depression and anxiety. Most exercise programs targeting endurance, mobility, and strength of the back musculature are effective, with the exception of neural mobilization exercises. Activity restriction does not offer substantial advantages, but the optimal timing for commencing activity and the cost-effectiveness of supervised exercise remain topics of ongoing debate. Concomitant manual therapy, acupuncture, educational interventions, and behavioral and occupational therapy may enhance outcomes.

Declaration of competing interests

The authors declare no competing interests.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bas.2025.104238.

References

Abbott, A., Tyni-Lenné, R., Hedlund, R., 2010. Early Rehabilitation Targeting Cognition, Behavior, and Motor Function after Lumbar Fusion: a Randomized Controlled Trial, vol. 35. Spine, pp. 848–857 [Internet] Available from: https://pubmed.ncbi.nlm.nih.gov/20354468/.

Abdi, A., Bagheri, S., Shekarbeigi, Z., Usefvand, S., Alimohammadi, E., 2023. The effect of repeated flexion-based exercises versus extension-based exercises on the clinical outcomes of patients with lumbar disk herniation surgery: a randomized clinical trial. Neurol Res [Internet] 45, 28–40. Available from: https://pubmed.ncbi.nlm.nih.gov/36039973/.

Alaranta, H., Hurme, M., Einola, S., Kallio, V., Knuts, L., Törmä, T., 1986. Rehabilitation after surgery for lumbar disc herniation: results of a randomized clinical trial. Int J Rehabil Res Int Z Rehabil Rev Int Rech Readaptation [Internet] 9, 247–257. Available from: https://pubmed.ncbi.nlm.nih.gov/3536770/.

Aldemir, K., Gurkan, A., 2021. The effect of pedometer-supported walking and telemonitoring after disc hernia surgery on pain and disability levels and quality of life. Int. J. Nurs. Pract. 27.

Atsidakou, N., Matsi, A.E., Christakou, A., 2021. The effectiveness of exercise program after lumbar discectomy surgery. J Clin Orthop Trauma [Internet] 16, 99–105 [cited 2024 May 26] Available from: https://linkinghub.elsevier.com/retrieve/pii/S0976566220305932.

Bahçeli, A., Karabulut, N., 2021. The effects of progressive relaxation exercises following lumbar surgery: a randomized controlled trial. Complement Med Res [Internet] 28, 114–122. Available from: https://pubmed.ncbi.nlm.nih.gov/32882693/.

Bailey, Chris S., Parham, Rasoulinejad, David, Taylor, Keith, Sequeira, Miller, Thomas, Jim, Watson, et al., 2020. Surgery versus conservative care for persistent sciatica lasting 4 to 12 months. N. Engl. J. Med. 382, 1093–1102 [Internet] [cited 2024 May 27] Available from: https://www.nejm.org/doi/full/10.1056/NEJMoa1912658.

Beneck, G., Popovich, J.M.J., Selkowitz, D., Azen, S., Kulig, K., 2014. Intensive, progressive exercise improves quality of life following lumbar microdiskectomy: a randomized controlled trial. Clin Rehabil [Internet] 28, 892–901. Available from: https://pubmed.ncbi.nlm.nih.gov/24572139/.

Benzakour, T., Igoumenou, V., Mavrogenis, A.F., Benzakour, A., 2019. Current concepts for lumbar disc herniation. Int. Orthop. 43, 841–851.

Bono, C., Leonard, D., Cha, T., Schwab, J., Wood, K., Harris, M., et al., 2017. The effect of short (2-weeks) versus long (6-weeks) post-operative restrictions following lumbar discectomy: a prospective randomized control trial. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc [Internet] 26, 905–912. Available from: https://pubmed.ncbi.nlm.nih.gov/27807771/.

Chen, C., Chang, C., Lee, S., Chen, Y., Tang, S., Cheng, C., et al., 2015. Is rehabilitation intervention during hospitalization enough for functional improvements in patients undergoing lumbar decompression surgery? A prospective randomized controlled study. Clin Neurol Neurosurg [Internet] 129, S41–S46. Available from: https://pubmed.ncbi.nlm.nih.gov/25683312/.

Choi, G., Raiturker, P., Kim, M., Chung, D., Chae, Y., Lee, S., 2005. The effect of early isolated lumbar extension exercise program for patients with herniated disc undergoing lumbar discectomy. Neurosurgery 57, 764–772 [Internet] discussion 764-72. Available from: https://pubmed.ncbi.nlm.nih.gov/16239890/.

Danielsen, J., Johnsen, R., Kibsgaard, S., Hellevik, E., 2000. Early Aggressive Exercise for Postoperative Rehabilitation after Discectomy, vol. 25. Spine, pp. 1015–1020 [Internet] Available from: https://pubmed.ncbi.nlm.nih.gov/10767815/.

Demir, S., Dulgeroglu, D., Cakci, A., 2014. Effects of dynamic lumbar stabilization exercises following lumbar microdiscectomy on pain, mobility and return to work. Randomized controlled trial. Eur J Phys Rehabil Med [Internet] 50, 627–640. Available from: https://pubmed.ncbi.nlm.nih.gov/25201615/.

Dolan, P., Greenfield, K., Nelson, R., Nelson, I., 2000. Can exercise therapy improve the outcome of microdiscectomy? Spine 25, 1523–1532 [Internet] Available from: https://pubmed.ncbi.nlm.nih.gov/10851101/.

Donaldson, B., Shipton, E., Inglis, G., Rivett, D., Frampton, C., 2006. Comparison of usual surgical advice versus a nonaggravating six-month gym-based exercise rehabilitation program post-lumbar discectomy: results at one-year follow-up. Spine J Off J North Am Spine Soc [Internet] 6, 357–363. Available from: https://pubmed.ncbi.nlm.nih.gov/16825039/.

Donceel, P., Du Bois, M., 1999. Predictors for work incapacity continuing after disc surgery. Scand. J. Work. Environ. Health 25, 264–271.

Dupeyron, A., Ribinik, P., Rannou, F., Kabani, S., Demoulin, C., Dufour, X., et al., 2021. Rehabilitation and lumbar surgery: the French recommendations for clinical practice. Ann Phys Rehabil Med 64, 101548 [Internet] [cited 2024 May 26] Available from: https://linkinghub.elsevier.com/retrieve/pii/S187706572100066X.

Ebenbichler, G., Inschlag, S., Pflüger, V., Stemberger, R., Wiesinger, G., Novak, K., et al., 2015. Twelve-year follow-up of a randomized controlled trial of comprehensive physiotherapy following disc herniation operation. Clin. Rehabil. 29, 548–560 [Internet] Available from: https://pubmed.ncbi.nlm.nih.gov/25288048/.

El Melhat, A.M., Youssef, A.S.A., Zebdawi, M.R., Hafez, M.A., Khalil, L.H., Harrison, D.E., 2024. Non-surgical approaches to the management of lumbar disc herniation associated with radiculopathy: a narrative review. J. Clin. Med. 13, 974.

Erdogmus, C.B., Resch, K.-L., Sabitzer, R., Mueller, H., Nuhr, M., Schoeggl, A., et al., 2007. Physiotherapy-based rehabilitation following disc herniation operation -: results of a randomized clinical trial. Spine 32, 2041–2049.

Filiz, M., Cakmak, A., Ozcan, E., 2005. The effectiveness of exercise programmes after lumbar disc surgery: a randomized controlled study. Clin. Rehabil. 19, 4–11 [Internet] Available from: https://pubmed.ncbi.nlm.nih.gov/15704503/.

Glennie, R.A., Urquhart, J.C., Koto, P., Rasoulinejad, P., Taylor, D., Sequeira, K., et al., 2022. Microdiscectomy is more cost-effective than a 6-month nonsurgical care regimen for chronic radiculopathy. Clin. Orthop. 480, 574–584.

Häkkinen, A., Ylinen, J., Kautiainen, H., Tarvainen, U., Kiviranta, I., 2005. Effects of home strength training and stretching versus stretching alone after lumbar disk surgery: a randomized study with a 1-year follow-up. Arch Phys Med Rehabil [Internet] 86, 865–870. Available from: https://pubmed.ncbi.nlm.nih.gov/15895329/.

Hakkinen, A., Kautiainen, H., Jarvenpaa, S., Arkela-Kautiainen, M., Ylinen, J., 2007. Changes in the total Oswestry Index and its ten items in females and males pre- and post-surgery for lumbar disc herniation:: a 1-year follow-up. Eur. Spine J. 16, 347–352.

He, Q., Zhao, J., Fan, M., Wang, F., 2021. Effect of continuous nursing based on wechat platform on postoperative rehabilitation of patients with lumbar disc herniation. Jpn J Nurs Sci JJNS. 18, e12382.

Hebert, J., Fritz, J., Thackeray, A., Koppenhaver, S., Teyhen, D., 2015. Early multimodal rehabilitation following lumbar disc surgery: a randomised clinical trial comparing the effects of two exercise programmes on clinical outcome and lumbar multifidus muscle function. Br. J. Sports Med. 49, 100–106 [Internet] Available from: https://pubmed.ncbi.nlm.nih.gov/24029724/.

Jentoft, E.S., Kvale, A., Assmus, J., Moen, V.P., 2020. Effect of information and exercise programmes after lumbar disc surgery: a randomized controlled trial. Physiother. Res. Int. 25.

Johansson, A.-C., Linton, S.J., Bergkvist, L., Nilsson, O., Cornefjord, M., 2009. Clinic-based Training in Comparison to Home-Based Training after First-Time Lumbar Disc Surgery: a Randomised Controlled Trial, vol. 18. Eur Spine J [Internet]., pp. 398–409 [cited 2024 May 13] Available from: http://link.springer.com/10.1007/s00586-008-0826-3

Ju, S., Park, G., Kim, E., 2012. Effects of an exercise treatment program on lumbar extensor muscle strength and pain of rehabilitation patients recovering from lumbar disc herniation surgery. J Phys Ther Sci [Internet] 24, 515–518 [cited 2024 May 25] Available from: https://www.jstage.jst.go.jp/article/jpts/24/6/24_515/_article.

Kernc, D., Strojnik, V., Vengust, R., 2018. Early initiation of a strength training based rehabilitation after lumbar spine fusion improves core muscle strength: a randomized controlled trial. J. Orthop. Surg. 13, 151.

Kim, Y., Park, J., Shim, J., 2010. Effects of aquatic backward locomotion exercise and progressive resistance exercise on lumbar extension strength in patients who have undergone lumbar diskectomy. Arch Phys Med Rehabil [Internet] 91, 208–214. Available from: https://pubmed.ncbi.nlm.nih.gov/20159123/.

Kim, B.J., Ahn, J., Cho, H., Kim, D., Kim, T., Yoon, B., 2015. Rehabilitation with osteopathic manipulative treatment after lumbar disc surgery: a randomised, controlled pilot study. Int J Osteopath Med [Internet] 18, 181–188 [cited 2024 May 13] Available from: https://linkinghub.elsevier.com/retrieve/pii/S1746068914001205.

Kim, B.J., Ahn, J., Cho, H., Kim, D., Kim, T., Yoon, B., 2016. Early individualised manipulative rehabilitation following lumbar open laser microdiscectomy improves early post-operative functional disability: a randomized, controlled pilot study. J. Back Musculoskelet. Rehabil. 29, 23–29 [Internet] [cited 2024 May 13] Available

from: https://www.medra.org/servlet/aliasResolver?alias=iospress&doi=10.3233/BMR-150591.
Kim, B.J., Kim, T., Ahn, J., Cho, H., Kim, D., Yoon, B., 2017. Manipulative rehabilitation applied soon after lumbar disc surgery improves late post-operative functional disability: a preliminary 2-year follow-up study. J. Back Musculoskelet. Rehabil. 30, 999–1004 [Internet] [cited 2024 May 13] Available from: https://www.medra.org/servlet/aliasResolver?alias=iospress&doi=10.3233/BMR-169546.
Kjellby-Wendt, G., Styf, J., 1998. Early active training after lumbar discectomy. A prospective, randomized, and controlled study. Spine [Internet] 23, 2345–2351. Available from: https://pubmed.ncbi.nlm.nih.gov/9820916/.
Kjellby-Wendt, G., Styf, J., Carlsson, S., 2001. Early active rehabilitation after surgery for lumbar disc herniation: a prospective, randomized study of psychometric assessment in 50 patients. Acta Orthop Scand [Internet] 72, 518–524. Available from: https://pubmed.ncbi.nlm.nih.gov/11728081/.
Kjellby-Wendt, G., Carlsson, S.G., Styf, J., 2002. Results of early active rehabilitation 5–7 Years after surgical treatment for lumbar disc herniation. J. Spinal Disord. Tech. 15, 404–409 [Internet] [cited 2024 May 13] Available from: http://journals.lww.com/00024720-200210000-00010.
Kulig, K., Beneck, G.J., Selkowitz, D.M., Popovich, J.M., Ge, T.T., Flanagan, S.P., et al., 2009. An intensive, progressive exercise program reduces disability and improves functional performance in patients after single-level lumbar microdiskectomy. Phys Ther [Internet] 89, 1145–1157 [cited 2024 May 13] Available from: https://academic.oup.com/ptj/article/89/11/1145/2737705.
Kulikov, A., Voronina, D., Morozov, A., Zajceva, T., Ustinova, K., 2018. New approach for evaluating the effectiveness of whole-body magnetic field therapy in the rehabilitation of patients with lumbar discectomy. J Back Musculoskelet Rehabil [Internet] 31, 1065–1073. Available from: https://pubmed.ncbi.nlm.nih.gov/29991122/.
Lindbäck, Y., Tropp, H., Enthoven, P., Abbott, A., Öberg, B., 2018. PREPARE: presurgery physiotherapy for patients with degenerative lumbar spine disorder: a randomized controlled trial. Spine J Off J North Am Spine Soc [Internet] 18, 1347–1355. Available from: https://pubmed.ncbi.nlm.nih.gov/29253630/.
Liu, C., Ferreira, G.E., Abdel Shaheed, C., Chen, Q., Harris, I.A., Bailey, C.S., Peul, W.C., Koes, B., Lin, C.C., 2023 Apr 19. Surgical versus non-surgical treatment for sciatica: systematic review and meta-analysis of randomised controlled trials. BMJ 381, e070730. https://doi.org/10.1136/bmj-2022-070730. PMID: 37076169; PMCID: PMC10498296.
Lyu, Z., Bai, J., Chen, S., Liu, J., Yu, W., 2021. Efficacy of Lumbar Kinetic Chain Training for Staged Rehabilitation after Percutaneous Endoscopic Lumbar Discectomy, vol. 22. BMC Musculoskelet Disord [Internet], p. 793 [cited 2024 May 13] Available from: https://bmcmusculoskeletdisord.biomedcentral.com/articles/10.1186/s12891-021-04674-y.
Manniche, C., Asmussen, K., Lauritsen, B., Vinterberg, H., Karbo, H., S, A., et al., 1993. Intensive Dynamic Back Exercises with or without Hyperextension in Chronic Back Pain after Surgery for Lumbar Disc Protrusion. A Clinical Trial, vol. 18. Spine [Internet], pp. 560–567. Available from: https://pubmed.ncbi.nlm.nih.gov/8484146/.
Mannion, A.F., Denzler, R., Dvorak, J., Müntener, M., Grob, D., 2007. A Randomised Controlled Trial of Post-operative Rehabilitation after Surgical Decompression of the Lumbar Spine. Eur Spine J [Internet]. [cited 2024 May 13];16:1101–17. Available from: http://link.springer.com/10.1007/s00586-007-0399-6
McGregor, A., Doré, C., Morris, T., Morris, S., Jamrozik, K., 2010. Function after Spinal Treatment, Exercise and Rehabilitation (FASTER): Improving the Functional Outcome of Spinal Surgery, vol. 11. BMC Musculoskelet Disord [Internet], p. 17. Available from: https://pubmed.ncbi.nlm.nih.gov/20102625/.
McGregor, A.H., Dore, C.J., Morris, T.P., Morris, S., Jamrozik, K., Team, F., 2011. ISSLS prize winner: function after spinal treatment, exercise, and rehabilitation (faster) A factorial randomized trial to determine whether the functional outcome of spinal surgery can Be improved. Spine 36, 1711–1720.
McGregor, A.H., Henley, A., Morris, T.P., Dore, C.J., Team, F., 2012. An evaluation of a postoperative rehabilitation program after spinal surgery and its impact on outcome. Spine 37, E417–E422.
Newsome, R.J., May, S., Chiverton, N., Cole, A.A., 2009. A prospective, randomised trial of immediate exercise following lumbar microdiscectomy: a preliminary study. Physiotherapy [Internet] 95, 273–279 [cited 2024 May 13] Available from: https://linkinghub.elsevier.com/retrieve/pii/S0031940609000790.
Oestergaard, L.G., Maribo, T., Bünger, C.E., Christensen, F.B., 2012. The Canadian Occupational Performance Measure's semi-structured interview: its applicability to lumbar spinal fusion patients. A prospective randomized clinical study 21, 115–121. Eur Spine J [Internet] [cited 2024 May 13] Available from: http://link.springer.com/10.1007/s00586-011-1957-5.
Oestergaard, L., Christensen, F., Nielsen, C., Bünger, C., Fruensgaard, S., Sogaard, R., 2013a. Early versus Late Initiation of Rehabilitation after Lumbar Spinal Fusion: Economic Evaluation Alongside a Randomized Controlled Trial, vol. 38. Spine, pp. 1979–1985 [Internet] Available from: https://pubmed.ncbi.nlm.nih.gov/23928716/.
Oestergaard, L., Nielsen, C., Bünger, C., Svidt, K., Christensen, F., 2013b. The effect of timing of rehabilitation on physical performance after lumbar spinal fusion: a randomized clinical study. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc [Internet] 22, 1884–1890. Available from: https://pubmed.ncbi.nlm.nih.gov/23563500/.
Oestergaard, L., Christensen, F., Nielsen, C., Bünger, C., Holm, R., Helmig, P., et al., 2020. Case manager-assisted rehabilitation for lumbar spinal fusion patients: an economic evaluation alongside a randomized controlled trial with two-year follow-up. Clin. Rehabil. 34, 460–470 [Internet] Available from: https://pubmed.ncbi.nlm.nih.gov/31964164/.
Oosterhuis, T., Van Tulder, M., Peul, W., Bosmans, J., Vleggeert-Lankamp, C., Smakman, L., et al., 2013. Effectiveness and Cost-Effectiveness of Rehabilitation after Lumbar Disc Surgery (REALISE): Design of a Randomised Controlled Trial, vol. 14. BMC Musculoskelet Disord [Internet]. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84875825714&doi=10.1186%2f1471-2474-14-124&partnerID=40&md5=1a0454e91e95d8cbdb130d8727dbe48f.
Oosterhuis, T., Costa, L.O.P., Maher, C.G., de Vet, H.C.W., van Tulder, M.W., Ostelo, R.W.J.G., 2014. Rehabilitation after lumbar disc surgery. Cochrane Database Syst. Rev. 2014, CD003007.
Oosterhuis, T., Ostelo, R., van Dongen, J., Peul, W., de Boer, M., Bosmans, J., et al., 2017. Early rehabilitation after lumbar disc surgery is not effective or cost-effective compared to no referral: a randomised trial and economic evaluation. J. Physiother. 63, 144–153 [Internet] Available from: https://pubmed.ncbi.nlm.nih.gov/28668558/.
Ostelo, R.W.J.G., De Vet, H.C.W., Berfelo, M.W., Kerckhoffs, M.R., Vlaeyen, J.W.S., Wolters, P.M.J.C., et al., 2003. Effectiveness of Behavioral Graded Activity after First-Time Lumbar Disc Surgery: Short Term Results of a Randomized Controlled Trial, vol. 12. Eur Spine J [Internet], pp. 637–644 [cited 2024 May 13] Available from: http://link.springer.com/10.1007/s00586-003-0560-9.
Ostelo, R., Goossens, M., de Vet, H., Br van den, t, P., 2004. Economic evaluation of a behavioral-graded activity program compared to physical therapy for patients following lumbar disc surgery. Spine 29, 615–622.
Ouzzani, M., Hammady, H., Fedorowicz, Z., Elmagarmid, A., 2016. Rayyan—a web and mobile app for systematic reviews. Syst Rev 5, 210. https://doi.org/10.1186/s13643-016-0384-4 [cited 2024 May 28] Available from:
Özden, F., 2022. The effectiveness of physical exercise after lumbar fusion surgery: a systematic review and meta-analysis. World Neurosurg 163, e396–e412 [Internet] [cited 2024 May 26] Available from: https://www.sciencedirect.com/science/article/pii/S1878875022004375.
Ozkara, G., Ozgen, M., Ozkara, E., Armagan, O., Arslantas, A., Atasoy, M., 2015. Effectiveness of physical therapy and rehabilitation programs starting immediately after lumbar disc surgery. Turk Neurosurg 25, 372–379. Available from: https://pubmed.ncbi.nlm.nih.gov/26037176/.
Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., McGuinness, L.A., Stewart, L.A., Thomas, J., Tricco, A.C., Welch, V.A., Whiting, P., Moher, D., 2021 Mar 29. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372 (n71). https://doi.org/10.1136/bmj.n71. PMID: 33782057; PMCID: PMC8005924.
Paulsen, R.T., Carreon, L.Y., Andersen, M.Ø., 2020a. Patient-reported outcomes after surgery for lumbar disc herniation, a randomized controlled trial comparing the effects of referral to municipal physical rehabilitation versus No referral. Spine 45, 3–9 [cited 2024 May 13] Available from: https://journals.lww.com/10.1097/BRS.0000000000003221.
Paulsen, R.T., Sørensen, J., Carreon, L.Y., Andersen, M.Ø., 2020b. Cost-effectiveness of postoperative rehabilitation after surgery for lumbar disc herniation: an analysis based on a randomized controlled trial. J Neurosurg Spine 32, 733–740 [cited 2024 May 13] Available from: https://thejns.org/view/journals/j-neurosurg-spine/32/5/article-p733.xml.
Qvarfordh, P., Skovgaard, K., Bendix, T., Esbensen, B.A., 2014. Should patients walk from the postanesthesia care unit to the general ward after a lumbar discectomy? A randomized study. J Perianesth Nurs 29, 377–384.
Reyes, A., Aguilera, M.P., Torres, P., Reyes-Ferrada, W., Peñailillo, L., 2021. Effects of neural mobilization in patients after lumbar microdiscectomy due to intervertebral disc lesion. J Bodyw Mov Ther 25, 100–107. Available from: https://www.scopus.com/inward/record.uri?eid=2-s2.0-85098152008&doi=10.1016%2fj.jbmt.2020.10.023&partnerID=40&md5=416e4973df5704567895399935f4ce28.
Rickers, K.W., Pedersen, P.H., Tvedebrink, T., Eiskjær, S.P., 2021. Comparison of interventions for lumbar disc herniation: a systematic review with network meta-analysis. Spine J Off J North Am Spine Soc. 21, 1750–1762.
Ruffilli, A., Manzetti, M., Cargeli, A., Viroli, G., Ialuna, M., Traversari, M., et al., 2024. Unveiling timetable for physical therapy after single-level lumbar surgery for degenerative disc disease: insights from a systematic review and meta-analysis. J. Clin. Med. 13, 2553 [Internet] [cited 2024 May 26] Available from: https://www.mdpi.com/2077-0383/13/9/2553.
Rushton, A., Heneghan, N., Calvert, M., Heap, A., White, L., Goodwin, P., 2015. Physiotherapy post lumbar discectomy: prospective feasibility and pilot randomised controlled trial. PloS One 10, e0142013. Available from: https://pubmed.ncbi.nlm.nih.gov/26562660/.
Rushton, A., Calcutt, A., Heneghan, N., Heap, A., White, L., Calvert, M., et al., 2016. Descriptive analysis of a 1:1 physiotherapy outpatient intervention post primary lumbar discectomy: one arm of a small-scale parallel randomised controlled trial across two UK sites. BMJ Open 6, e012151 [Internet] Available from: https://pubmed.ncbi.nlm.nih.gov/28186932/.
Rushton, A., Heneghan, N.R., Heap, A., White, L., Calvert, M., Goodwin, P.C., 2017. Patient and physiotherapist perceptions of rehabilitation following primary lumbar discectomy: a qualitative focus group study embedded within an external pilot and feasibility trial. BMJ Open 7.
Saha, B., Goktas, S., 2021. The effect of computer-based training on self-care and daily living activities in patients with lumbar discectomy surgery: a randomized controlled study. Comput Inform Nurs CIN 40, 147–153. Available from: https://pubmed.ncbi.nlm.nih.gov/34508021/.
Scrimshaw, S., Maher, C., 2001. Randomized Controlled Trial of Neural Mobilization after Spinal Surgery, vol. 26. Spine [Internet], pp. 2647–2652. Available from: https://pubmed.ncbi.nlm.nih.gov/11740347/.

Shaygan, M., Zamani, M., Jaberi, A., Eghbal, K., Dehghani, A., 2023. The impact of physical and psychological pain management training on pain intensity, anxiety and disability in patients undergoing lumbar surgeries. Spine J Off J North Am Spine Soc 23, 656–664. Available from: https://pubmed.ncbi.nlm.nih.gov/36736739/.

Soegaard, R., Christensen, F.B., Lauersen, I., Bünger, C.E., 2006. Lumbar Spinal Fusion Patients' Demands to the Primary Health Sector: Evaluation of Three Rehabilitation Protocols. A Prospective Randomized Study, vol. 15. Eur Spine J [Internet]., pp. 648–656 [cited 2024 May 13] Available from: http://link.springer.com/10.1007/s00586-005-0884-8

Sterne, J.A., Hernán, M.A., Reeves, B.C., Savović, J., Berkman, N.D., Viswanathan, M., et al., 2016. ROBINS-I: a tool for assessing risk of bias in non-randomised studies of interventions. BMJ 355, i4919.

Sterne, J.A.C., Savović, J., Page, M.J., Elbers, R.G., Blencowe, N.S., Boutron, I., et al., 2019. RoB 2: a revised tool for assessing risk of bias in randomised trials. BMJ 366, l4898.

Uysal, E., Cine, H., Cetin, E., 2023. The necessity and timing of exercise after lumbar disc herniation surgery. Eur Rev Med Pharmacol Sci 27, 9521–9529. Available from: https://pubmed.ncbi.nlm.nih.gov/37916319/.

Yao, Y.C., Lin, H.H., Chang, M.C., 2018 Nov. Bracing Following Transforaminal Lumbar Interbody Fusion is not Necessary for Patients With Degenerative Lumbar Spine Disease: A Prospective, Randomized Trial. Clin Spine Surg. 31 (9), E441–E445. https://doi.org/10.1097/BSD.0000000000000697. PMID: 30024447.

Yílmaz, F., Yílmaz, A., Merdol, F., Parlar, D., Sahin, F., Kuran, B., 2003. Efficacy of dynamic lumbar stabilization exercise in lumbar microdiscectomy. J. Rehabil. Med. 35, 163–167 [Internet] Available from: https://pubmed.ncbi.nlm.nih.gov/12892241/.

Yolgösteren, E., Külekçioğlu, S., 2021. The effectiveness of balneotherapy and thermal aquatic exercise in postoperative persistent lumbar pain syndrome. Int J Biometeorol 65, 2137–2145 [cited 2024 May 13] Available from: https://link.springer.com/10.1007/s00484-021-02176-z.

Yu, H., Cancelliere, C., Mior, S., Pereira, P., Nordin, M., Brunton, G., et al., 2024. Effectiveness of postsurgical rehabilitation following lumbar disc herniation surgery: a systematic review. Brain Spine 4, 102806 [cited 2024 May 26] Available from: https://www.sciencedirect.com/science/article/pii/S2772529424000626.

Zhang, R., Zhang, S., Wang, X., 2018. Postoperative functional exercise for patients who underwent percutaneous transforaminal endoscopic discectomy for lumbar disc herniation. Eur. Rev. Med. Pharmacol. Sci. 22, 15–22 [Internet] [Internet] Available from: https://pubmed.ncbi.nlm.nih.gov/30004565/.

Zhang, A.S., Xu, A., Ansari, K., Hardacker, K., Anderson, G., Alsoof, D., et al., 2023. Lumbar disc herniation: diagnosis and management. Am. J. Med. 136, 645–651.

Zhao, B., Wang, K., Zhao, J., Wang, C., Huang, X., Shu-qiang, M., et al., 2008. Clinical effects of acupuncture after surgical operation in patients with prolapse of the lumbar intervertebral disc. J Tradit Chin Med Chung Tsa Chih Ying Wen Pan 28, 250–254 [Internet] Available from: https://pubmed.ncbi.nlm.nih.gov/19226891/.

Zoia, C., Bongetta, D., Alicino, C., Chimenti, M., Pugliese, R., Gaetani, P., 2018. Usefulness of corset adoption after single-level lumbar discectomy: a randomized controlled trial. J Neurosurg Spine 28, 481–485 [cited 2024 May 13] Available from: https://thejns.org/view/journals/j-neurosurg-spine/28/5/article-p481.xml.