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Knee Extensor-Focused Biomechanical Intervention For Pain, Posture, and Disability in Non-Specific Low Back Pain: A Randomized Controlled Trial

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Contents

CHAPTER I

INTRODUCTION

1. Introduction to the chapter

The following chapter will provide a concise background on low back pain especially nonspecific low back pain (NLBP), including its prevalence and impact. Additionally, it will clarify the relationship between the spinal column and the lower extremities, discussing how they are considered a single entity. Furthermore, this chapter will outline the research problem, aim, significance, objectives, research questions, and hypotheses.

1.1- Background

Low back pain is defined as pain in the back of the body that is severe enough to prevent the individuals from engaging in daily activities for more than a day, extending from the lower edge of the twelfth ribs to the lower gluteal folds, with or without pain in the lower extremities (Hayden et al.,2019). It lasts for at least a day and spreads from below the costal margin to the gluteal folds, with or without referred pain in one or both legs (Elmannan et al., 2021). Pain in the lumbar region, sacral spine, or S1 to sacrococcygeal junction region is referred to as axial lumbosacral back pain. Due to nerve or dorsal root ganglion compressions, radicular leg pain spreads along the dermatomal distribution to the lower extremity. In contrast, referred pain is felt in a location separate from its source, following a non-dermatomal route (Urits et al., 2019).

LBP is a common musculoskeletal problem worldwide. Between 1990 and 2017, the number of people with LBP increased from 377.5 million to 577 million. In 2017, LBP remained the primary cause of disability worldwide (Wu et al., 2020). Approximately 619 million individuals worldwide were impacted by LBP in 2020 (with a 95% uncertainty interval of 554–694 million), and projections estimate 843 million (ranging from 759 to 933 million) cases by 2050 (Ferreira et al., 2023).

Most individuals who experience LBP are diagnosed with NLBP which is considered a diagnosis of exclusion. This term encompasses diverse symptoms and presentations that cannot be attributed to a specific, recognizable pathology, such as fractures, rheumatoid arthritis, infections, neoplasms, or metastases (Hayden et al., 2019).

The prevalence of LBP ranged from 63.8% to 89% in Saudi Arabia. Approximately 80% to 90% of all cases of low back pain are NLBP, which most likely results from the interplay of biological, psychological, and social variables (Aldera et al., 2020). The prevalence and complexity of LBP can affect any age which included young children, teenagers, and adults (World Health Organization, 2023). Age-related changes in both the structure and physiology of the body contribute to high disability rates among those with NLBP (Özsoy & İlçin, 2021) geriatric adults who aged 80 years and above. It was discovered that females were more likely than males to have LBP and was observed to increase with age. Women are more prone than men to LBP, with peak rates between the ages of 50 and 55 years (Vos et al., 2019).

Several modifiable risk factors are associated with NLBP, particularly occupationnal hazard such as prolonged standing and manual labor involving lifting heavy weights (Chiarotto & Koes, 2022). For instance, a study in Saudi Arabia reported a high prevalence (46.3%) of physical disability related to NSLBP among male soldiers (Sidiq et al., 2021). Similarly, 65.6% nurses in Qassim, Saudi Arabia reported experiencing NSLBP (Elmannan et al., 2021). Physiotherapists were the most prevalent healthcare professionals with LBP (89%), whereas teachers were the least prevalent (63.8%) (Aldera et al., 2020). Additional adjustable variables were sedentary lifestyle (including obesity), psychological variables (including depression and anxiety), and previous LBP episodes (Chiarotto & Koes, 2022).

Earlier literature indicated that patients with NLBP frequently have problems in social life, prefer to avoid employment, which ultimately impacts their quality of life (QOL) (Keeley et al., 2008; Zou et al., 2019). Nieminen et al. (2021) noted that untreated NLBP may lead to bad prognosis and disability.

Moreover, LBP may cause considerable economic losses. The treatment costs, as well as other expenditures on LBP in healthcare, are very high. In a study by Al Amer (2020), 15.3% of Saudi Arabian LBP workers missed work, 29.2% of them reported limited work activity, and 24.1% reported a reduced working hours. The consequences of LBP for health workers include limited social, leisure, and daily activities, as well as requesting medical care, and even surgical intervention (Aseri et al., 2019). Previous studies have demonstrated a strong correlation between recurrent LBP and a higher likelihood of leaving salaried employment for health-related reasons (Kim et al., 2019). Additionally, LBP can lead to several psychological and physical issues as well as affect the healthcare system, especially concerning increased healthcare expenses and work absences (Kim et al., 2019). So, early detection and treatment of nonspecific LBP can greatly lower medical expenses and employee absenteeism.

Rehabilitation of LBP depends mainly on exercise and behavioral interventions with medication coming as the second option for intervention (Chiarotto & Koes, 2022). However, there was no single exercise that was shown to be more effective than another in decreasing the symptoms and recurrent episodes of LBP (Essman & Lin, 2022). In systematic reviews (N> 200 randomized trials) reported that most exercises had helpful effects on relieving pain and developing functioning (Hayden et al, 2021).

Common interventions for LBP include walking, aerobic exercise, yoga, and Pilates. However, no single exercise modality has demonstrated superior effectiveness in reducing symptoms or preventing recurrence of LBP (Essman & Lin, 2022). Walking has been explored as a cost-effective alternative to structured trunk muscle exercise programs for managing low back pain (LBP), with studies reporting no significant differences in pain and disability outcomes between the two approaches (Vanti et al., 2019). Variations in walking duration or modality may influence outcomes, suggesting the need for further research.

Aerobic exercise prescriptions for individual with LBP specifically engage weight-bearing, low-impact, moderate-intensity activities- defined as 40%–60% of heart rate reserve, performed 5 to 7 days per week. For those with low baseline activity levels, shorter sessions of 10 to 15 minutes may be initiated, with gradual progression toward the recommended 150 minutes per week. In the case where weight-bearing exercise is contraindicated or poorly tolerance, aquatic exercises including swimming have demonstrated effectiveness in managing chronic pain. It is essential to evaluate the individualized’ s baseline fitness to appropriately tailor exercises intensity and duration (Pocovi et al, 2022).

1.2 Statement of the Problem

Most rehabilitation protocols for NLBP primarily focus on the axial body, which includes the spine, shoulder girdle, and pelvic girdle (Kwok et al, 2021). Most of the NLBP studies focus on lumbar stabilization, core stabilizer or hip musculature, with limited exploration of distal kinetic chain elements like the knee extensors training (Li et al, 2023).

With reference to the biomechanical linkage between the knee and lumbar spine, the distal joints of the lower limb play a critical role in maintaining mechanical balance and functional alignment of proximal joints and the spine (Escamilla et al., 2010; Youdas et al., 2024). While open kinetic chain (OKC) and closed kinetic chain (CKC) exercises are widely compared in orthopedic and sports rehabilitation, few studies have analyzed their differential effects on kinetic chain function in populations with NLBP (Sadeghi et al., 2024).

In past exercise programs, trunk and core muscle activities have not frequently incorporated lower limb involvement to overall movement synergy and load distribution (Grooten et al., 2022). Furthermore, the transfer effects of lower limb training on trunk control are not well understood, and little evidence is available on the potential impact of strengthening the knee extensors, especially in the context of different kinetic chains, on posture, pelvic control, or lumbar spine stability of individuals with NLBP (Lindblom et al., 2023; Escamilla et al., 2010).

The knee extensor muscles, like the quadriceps, contribute to the upright posture, body weight support, and ground reaction force absorption (Escamilla et al., 2010). Compensatory loading patterns in the lumbar spine can result from dysfunctional lower limb biomechanics. Investigating the impact of interventions, including corrective exercises to enhance the knee position, can be helpful to clinicians to understand the factors of LBP management and prevention strategy of chronicity and recurrent LBP (Abbasi et al., 2024). Thus, with no clinical comparisons between OKC and CKC training being conducted in the NLBP setting, the present study design was intended to investigate how two alternative approaches might affect the intensity of pain, lumbar posture and quality of life (QOL) of patients with NLBP. The study is committed to offer important insights and knowledge that can support the designing of future interventions of this population. It is worth considering the knee during NSLBP rehabilitation since it will help to maximize the alignment of the kinetic chain, reduce lumbar strain, and improve overall movement patterns.

1.3. Research Objectives

1.3.1 General objective

To examine the impacts of open kinetic chain (OKC) and closed kinetic chain (CKC) knee extensor strengthening activities on pain, postural control, lumbar lordosis and core stabilizer, as well as functional disability in adults with NLBP.

1.3.2 Secondary objectives

1.3.1 To contrast the outcomes of open and closed kinetic chain knee extensor strengthening training with conventional training (lumbar stabilization training) on pain, lumbar curvature, postural control, and disability in patients with non-specific low back pain.

1.3.2. To compare the effects of open kinetic chain knee extensor strengthening on pain, lumbar curvature, postural control, and disability compared to closed kinetic chain exercises in individuals with non-specific low back pain?

1.3.3 To compare the effects of open kinetic chain knee extensor strengthening on pain, lumbar curvature, postural control, and disability compared to conventional lumbar muscle exercises in individuals with non-specific low back pain?

1.3.4 To compare the effects of closed kinetic chain knee extensor strengthening on pain, lumbar curvature, postural control, and disability compared to conventional lumbar muscle exercises in individuals with non-specific low back pain?

1.3.5 To investigate the effects of open kinetic chain knee extensor strengthening on pain, lumbar curvature, postural control, and disability in individuals with non-specific low back pain?

1.3.6 To investigate the effects of closed kinetic chain knee extensor strengthening on pain, lumbar curvature, postural control, and disability in individuals with non-specific low back pain?

1.3.7 To investigate the effects of conventional lumbar extensor strengthening on pain, lumbar curvature, postural control, and disability in individuals with non-specific low back pain?

1.4 Research Questions

1.4.1 What are the comparative effects of open and closed kinetic chain knee extensor strengthening exercises versus lumbar stabilization exercises on lumbar curvature, postural control, and disability in individuals with non-specific low back pain?

1.4.2. How does open kinetic chain knee extensor strengthening affect pain, functional capacity, and lumbar spine stability compared to closed kinetic chain exercises in individuals with non-specific low back pain?

1.4.3 What is the effect of open kinetic chain knee extensor strengthening on pain, functional capacity, and lumbar spine stability compared to conventional lumbar muscle exercises in individuals with non-specific low back pain?

1.4.4 What is the effect of closed kinetic chain knee extensor strengthening on pain, functional capacity, and lumbar spine stability compared to conventional lumbar muscle exercises in individuals with non-specific low back pain?

1.4.5 What is the effect of post open kinetic chain knee extensor strengthening on pain, functional capacity, and lumbar spine stability in individuals with non-specific low back pain?

1.4.6 What is the effect of post close kinetic chain knee extensor strengthening on pain, functional capacity, and lumbar spine stability in individuals with non-specific low back pain?

1.4.7 What is the effect of post conventional lumbar extensor strengthening on pain, functional capacity, and lumbar spine stability in individuals with non-specific low back pain?

1.5 Research Hypotheses

1.5.1. H_0: There are no significant differences in lumbar curvature, postural control, or disability outcomes among individuals with non-specific low back pain following closed kinetic chain, open kinetic chain, or lumbar stabilization exercises.

H_1: There will be significant differences in lumbar curvature, postural control, or disability outcomes among individuals with non-specific low back pain following closed kinetic chain, open kinetic chain, or lumbar stabilization exercises.

1.5.2- H_0: Open kinetic chain knee extensor strengthening does not lead to greater improvements in lumbar curvature, postural control, and disability compared to close kinetic chain or lumbar stabilization exercises in individuals with non-specific low back pain

H_1: Open kinetic chain knee extensor strengthening will lead to greater improvements in lumbar curvature, postural control, or disability compared to close kinetic chain or lumbar stabilization exercises in individuals with non-specific low back pain

1.5.3- H_0: Open kinetic chain knee extensor strengthening does not lead to greater improvements in lumbar curvature, postural control, and disability compared to conventional lumbar muscle exercises in individuals with non-specific low back pain

H_1: Open kinetic chain knee extensor strengthening will lead to greater improvements in lumbar curvature, postural control, or disability compared to conventional lumbar muscle exercises in individuals with non-specific low back pain

1.5.4- H_0: Closed kinetic chain knee extensor strengthening does not lead to greater improvements in lumbar curvature, postural control, and disability compared to conventional lumbar muscle exercises in individuals with non-specific low back pain

H_1: Closed kinetic chain knee extensor strengthening will lead to greater improvements in lumbar curvature, postural control, or disability compared to conventional lumbar muscle exercises in individuals with non-specific low back pain

1.5.5- H_0: There are no significant improvements in lumbar curvature, postural control, and disability post open kinetic chain knee extensor strengthening in individuals with non-specific low back pain

H_1: There are significant improvements in lumbar curvature, postural control, and disability post open kinetic chain knee extensor strengthening exercises in individuals with non-specific low back pain

1.5.6 H_0: There are no significant improvements in lumbar curvature, postural control, and disability post close kinetic chain knee extensor strengthening in individuals with non-specific low back pain

H_1: There are significant improvements in lumbar curvature, postural control, and disability post close kinetic chain knee extensor strengthening exercises in individuals with non-specific low back pain

1.5.7 H_0: There are no significant improvements in lumbar curvature, postural control, and disability post conventional lumbar muscle exercises in individuals with non-specific low back pain

H_1: There are significant improvements in lumbar curvature, postural control, and disability post conventional lumbar muscle exercises in individuals with non-specific low back pain

1.6 Research Significance

1.6.1 New knowledge

Previous research often treats spine and lower limb problems as separate entities, but emerging models (e.g., “knee–spine syndrome”) suggest an integrated biomechanical relationship. This present study's finding helps to bridge this gap by investigating how open vs closed kinetic chain knee exercises affect lumbar alignment. Exploring the neuromuscular and postural linkage between the knee extensors and lumbopelvic control. Hence, it contributes novel insights into kinetic chain rehabilitation, which is underexplored in NLBP populations. It evaluates a novel, functional intervention with potentially wide clinical applicability.

1.6.2 Clinical Relevance

This present study targets a non-spinal intervention (knee training) to address a spinal condition (NLBP)—which is novel and clinically relevant. The finding of present study may inform that knee chain extensor training improves lumbar lordosis and postural control, it offers a non-invasive, low-cost alternative or adjunct to conventional back-focused therapies. Results may inform whether CKC or OKC is more beneficial for improving functional outcomes. The clinicians could better tailor lower limb strengthening interventions that may indirectly affect spinal posture and improve functional disability and QOL.

1.6.3 Future research

This study highlights the need for long-term kinetic chain effects and cross-joint rehabilitation strategies in larger multicentre trials.

1.7 Scope of the study

This clinical trial will be conducted among adult male participants aged 40 to 60 years diagnosed with NSLBP, in the western region of Saudi Arabia, specifically in Taif. The primary objective is to investigate the effect of incorporating knee extensor strengthening exercises into the rehabilitation program for adult patients with non-specific low back pain (NSLBP). The intervention will utilize knee chain training and conventional lumbar muscle training techniques targeting the knee extensors to determine the most effective approach for improving the aforementioned outcomes. The study will focus on the following outcome measures: lumbar spine posture, assessed via X-ray using the Cobb angle method, pain intensity, measured using the Numerical Pain Rating Scale (NPRS); quality of life (QOL) evaluated using the validated Arabic version of the Oswestry Disability Index (ODI); and lastly isometric knee extensor strength, measured using a handheld dynamometer.

1.8 Definition of terms

1.8.1 Non-specific low back pain: Back pain without a distinct nociceptive reason, with or without leg pain (Hayden et al., 2019).

1.8.2 Isometric strength: Isometric contractions are performed without joint motion and the muscle length remains constant (Dunleavy & Slowik, 2019)

1.8.3 Cobb angle for lumbar lordosis:

A line is drawn through the first lumbar vertebra's superior endplate on a lateral lumbar radiograph, followed by a second line parallel to the fifth lumbar vertebra's inferior endplate. Perpendicular lines are then created, and the angle formed at their intersection is measured (Furlanetto et al., 2018).

1.8.4 Ten repetition maximum: the greatest load for which 10 consecutive repetitions could be completed (Monteiro et al. 2019).

1.8.5 Functional disability: refers to limitations or impairments in a person’s ability to perform everyday activities that are essential for independent living (Baradaran et al., 2020).

1.8.6 Quality of life: the individual's overall well-being, encompassing physical, psychological, and social aspects of their life (Cieza et al., 2021).

1.8.7 Lumbar extensor exercises: strength-training or rehabilitation movements that specifically target the lumbar extensor muscles to improve spinal stability and function (Raza et al., 2021).

1.8.8 Core stabilizer training: exercises aimed at activating and strengthening the deep muscles of the trunk, such as the transversus abdominis and multifidus, to enhance spinal control (Akuthota & Ferreiro, 2020).

1.8.9 Closed kinetic chain exercise: are movements where the distal segment (e.g., foot or hand) is fixed, and multiple joints move simultaneously. These exercises promote joint stability and functional movement (Nagai et al., 2020).

1.8.10 Open kinetic chain exercise: are those in which the distal segment is free to move, typically targeting a specific muscle group in non-weight-bearing positions (Delgado-Payán et al., 2019).

1.8.11 Knee extensor training: Knee extensor training is a set of exercises that helps to strengthen the quadriceps, which is crucial in the process of knee extension and lower limb function (Krupa et al., 2023).

1.9 Summary

This chapter briefly introduces the purpose of the current study, which is to incorporate knee extensor training as a new intervention in the rehabilitation program for adult patients with NLBP. It also emphasises the need to incorporate lower limb training in spinal rehabilitation. Emergent models (e.g. "knee-spine syndrome") imply a biomechanical interaction.

The research design focuses on a biomechanical connection that has been ignored in the conventional management of back pain. It fills an existing evidence gap about the importance of knee extensor kinetic chain training on enhancing spinal outcomes.

CHAPTER 2

LITERATURE REVIEW

2. Introduction to chapter

This chapter will lay the theoretical groundwork for the current project by addressing all necessary aspects to support the study's concept and aid in completing the practical component. It will review previous research that has examined fundamental topics related to the current study. Key subjects to be discussed include the lumbar spine, LBP, the interaction between the lower limbs and the spine, mechanical alterations in the knee joint of patients with LBP, and protocols for strengthening knee extensors.

2.1 Lumbar Spine

The lumbar spine is an important part of the human body, which includes both active and passive components to support a person in maintaining a posture, allowing motion, and carrying significant loads during the daily routine. Active structures, primarily muscles, regulate movement and coordination, whereas passive features, including bones, ligaments, and intervertebral discs, provide stability to the spine, limit ROM, and protect the neural structures within the spinal canal (Widmer et al., 2020).

Its strong structure helps withstand huge mechanical loads, such as frequent blows of walking, jumping, and lifting (Desmoulin et al., 2020). It undergoes great stresses and strains when performing heavy load activities, such as carrying heavy things (Frost et al., 2019). In addition, it provides stability needed without functional mobility loss, particularly in the trunk and in the pelvic region.

The lumbar spine is practically held accountable to support the weight transmitted by the upper body and adapt to various postural and dynamic loads (Frost et al., 2019). It provides a maximum flexion-extension range of over 50 degrees, and each of its vertebral segments provides about 7°–7.5° of rotational motion (Pourahmadi et al., 2021; Haughton et al., 2002). This type of biomechanical feature ensures the spinal cord security and mobility in different physical activities.

2.1.1 IVD and facet joints

The human spine is composed of a series of anatomical structures that make it both stable and mobile. The most important of these are the intervertebral discs (IVDs) that exist between the vertebral bodies and a system of supporting ligaments. Important spinal ligaments are the anterior longitudinal ligament connecting the anterior surfaces of the vertebral bodies, the posterior longitudinal ligament connecting with the posterior vertebral cortex and the ligamentum flavum that connects the laminae of the adjacent vertebrae. Other stabilizing structures are the intertransverse ligaments, which connect the transverse processes, interspinous and supraspinous ligaments, which are found along the dorsal spinous processes.

Functionally, the spinal motion segment (known as the articular triad or three-joint complex) consists of an intervertebral disc and two facet (zygapophyseal) joints. This three dimensional articulation forms the basis of biomechanical versatility of the spine. The IVD, which is surrounded by cartilaginous end plates, gives segmental mechanical stability, limits movement between the vertebrae, and maintains facet joint alignment (Mohd Isa et al., 2022a). The facet joints, which are created by the articular cartilage and are surrounded by fibrous capsules, provide passive mechanical resistance and limit excessive movement, especially during axial rotation and extension (Widmer et al., 2020). The combination of the disc and facet joints allows the physiological movement of the spine, reduces the likelihood of mechanical injury and helps to protect against low back pain (Han et al., 2023).

All passive spinal structures of ligaments, discs, and joints have a particular part in maintaining a stable spine, determined by their anatomy and biomechanical characteristics. Nevertheless, long-term mechanical stress and aging are identified as the causes of progressive wear and tear of these components, weakening their performance and frequently causing dislocation or pain (Widmer et al., 2020). It is important to note that IVD degeneration, which is a major cause of low back pain in 26-42% of patients, is associated with decreased nucleus pulposus (NP) progenitor cell and impaired intrinsic regenerative ability (Mohd Isa et al., 2022b). The degenerative changes, including the loss of disc height, may change the transmission of axial loads and cause the inferior articular process to compress the adjacent structures during extension, which entraps the capsule and results in pain (Inoue et al., 2020). Furthermore, facet joint degeneration, which often progresses concurrently with disc degeneration, is implicated in conditions such as degenerative spondylolisthesis and contributes to facet osteoarthritis through biomechanical dysfunction (Inoue et al., 2020).

2.2 Lumbar Spine and Lower Limb

The spine takes the shape of an inverted pendulum, with the weight of the upper body resting upon a slender, standing-up column. Stability in this analogy is attained with a moving base of support, just like balancing a pencil on a fingertip when the pencil (the spine) starts to lean, stability is gained by moving the fingertip (representing the lower limbs) to place the center of gravity back on the base (Zeinali et al., 2008). Applying this model to human biomechanics, the hip, knee, and ankle joints act together in providing stability to the posture by modifying in the sagittal and multiplanar directions, especially during functional activities. This neuromechanical interaction is an effective model to explain compensatory processes and disturbed movement patterns in persons with low back pain (LBP) (McGregor & Hukins, 2009).

In addition to this interdependence, Jean Felix Dubousset has proposed a cone of economy model that explains a dynamic balance, where the skeletal system holds an upright position with a minimum muscular force when the line of gravity lies within a narrow cone of movement (Hasegawa and Dubousset, 2022). This cone is increased in musculoskeletal dysfunctional patients due to compensatory muscular recruitment, which denotes the unstable posture that predisposes the risk of pain and functional constraints (Shu et al., 2020).

The sagittal plane of posture position is particularly vulnerable to alterations of the center of gravity. The anterior shift of the gravity line can result in the following compensatory changes: the reduction of thoracic kyphosis, back pelvic tilt, hip extension, and knee flexion (resulting in LBP) (Takahashi et al., 2021). With sagittal global malalignment, individuals can also respond by flexion of the lower extremity, reduction of lumbar lordosis, and rearward rotation of the pelvis (Yagi et al., 2017).

A significant association occurs between lower lumbar lordosis (<30°) and limited extension of the knee. Patients with >5° knee-extension limit are susceptible to significant lumbar curvature reductions (Shimizu et al., 2020; Teraguchi et al., 2021). These alterations are age-dependent, implying a biomechanical connection between degenerative alterations in knee joints and spinal positioning, known as the “knee-spine syndrome” (Shimizu et al., 2020).

Upon surpassing the capacity for establishing pelvic retroversion as a compensatory mechanism, the additional compensatory mechanisms include more hip extension and knee flexion. This is found to be negatively correlated with lumbar lordosis, a fact that underscores the inter-relationship between lower limb and spinal biomechanics (Obeid et al., 2011).

Coordinated muscular activation between the lower limbs and the trunk affects the lumbopelvic stability as one of the determinants of spinal health. The successful transfer of force along the chain of movements depends on hip strength, neuromuscular control, and lower limb joint mobility (De Sousa et al., 2019; Nelson et al., 2008). Disruptions in this system (lumbar spine, pelvis, hips, or knees) may cause changes in the load distribution and mechanical instability (De Sousa et al., 2019).

Both mechanical and functional impairments of individuals with LBP have been attributed to abnormal lower limb mechanics. These results confirm the hypothesis that spinal and lower limb pathomechanics are not independent, but related (Farahpour et al., 2018; Madabi et al., 2020). Moreover, a lack of mobility or lower extremity weakness can enhance lumbar compensatory movement, which can aggravate or cause LBP.

The etiology behind low back pain cannot be viewed as spinal condition, but rather it results from a local interdependence between the spine, pelvis and lower extremities (McGregor and Hukins, 2009). This becomes particularly applicable considering the fact that around 90% of LBP cases are non-specific with no concrete structural pathology by definition (Han et al., 2023).

2.3 Relationship Between Hip, Knee Function, and Low Back Pain (LBP)

There is emerging evidence of a biomechanical and functional interdependence between the knee and hip joints and the presence or maintenance of low back pain (LBP). Whilst high-quality studies are scarce, a few studies indicate that there is a significant relationship between lower limb joint alignment and LBP (Abbasi et al., 2024). Rahimi et al. (2020) established that LBP individuals have exhibited decreased knee flexion at the late stance phase of gait, which reflect changes in lower limb kinematics. Knee posture and alignment abnormalities can also cause muscle imbalances in the lower extremities and spinal muscles, which contributes to increasing LBP risks (Hira et al., 2021).

Restricted knee range of motion (ROM) and quadriceps weakness have also been shown to be associated with LBP (Kato et al., 2021). The strength of knee extensors is also always reduced among patients with LBP compared to healthy people (De Sousa et al., 2019; Jimenez-del-Barrio et al., 2020). It was also found that knee extensor strengthening results in more sagittal plane positioning and improves pelvic position, which in turn also has the potential to decrease the loads on the lumbar spine (Takahashi et al., 2021).

It has also been reported that a decrease in both abdominal and knee extensor muscle strength occurs concurrently in the LBP populations, thereby implying that core and lower-limb muscle deficits can interact synergistically to the detriment of trunk-lower-limb coordination (Kato et al., 2021). This interrelationship is further supported by the inverse correlation between pain intensity and quadriceps and abdominal strength. As a result, lower-limb muscle strengthening interventions, especially quadriceps, can potentially improve posture in LBP groups and reduce symptoms (De Sousa et al., 2019).

In athletes, especially runners with chronic LBP (CLBP), literature indicates a lowering of knee extensor strength that affects the eccentric action of the contraction of the quadriceps muscle during the initial ground contact. Such a deficit decreases shock-absorption capacity, thus making it easier to transfer more ground-reaction forces to the lumbar spine (Cai and Kong, 2015). Repeated loading may increase the load stress on the spine and worsen the pain related to this kind of load redistribution.

Beyond muscular weakness, patients with NSLBP often exhibit neuromuscular deficits such as delayed trunk muscle recruitment, impaired lumbar proprioception, and reduced lower-limb activation—factors that compromise balance and postural control (Berenshteyn et al., 2019). Quadriceps strength shows an inverse relationship with pain severity (Kocaman et al., 2023).

Isokinetic studies provide quantitative support: LBP patients demonstrate significantly lower knee flexor and extensor strength than controls at 60–120°/s, with extensor torque deficits of 0.31 Nm/kg (De Sousa et al., 2019). Similar reductions in peak torque have been reported in limbs of older adults (Genc & Demircioglu, 2024) and in elderly women with LBP (Kato et al., 2023). Moreover, erector spinae fatigue has been linked to quadriceps inhibition in golfers with poor spinal endurance, underscoring the functional interdependence of spinal and lower-limb systems (Edwards et al., 2020).

2.4 Assessment for LBP

2.4.1 Low Back Pain (LBP) Intensity

The Numerical Pain Rating Scale (NPRS) accounts for a valid, reliable, and acceptable tool used in measuring the severity of LBP. It can be utilized in clinical and research contexts owing to its simplicity and sensitivity to changes. The NPRS is a 11 point scale, with 0 (no pain) to 10 (worst imaginable pain). The patients are requested to rate the intensity of their pain on it (Ostelo et al., 2005).

The NPRS shows strong construct validity through positive correlations with other pain measures (Von Korff et al., 2000) and responsiveness to meaningful changes, with a minimum clinically important difference of 2 points (Childs et al., 2005). Additionally, NPRS scores have demonstrated predictive value in determining the extent of disability that comes with LBP (Shafshak et al., 2021).

2.4.2 Lumbar Posture

2.4.2.1 Lumbar Lordosis Assessment

Lumbar lordosis is one of the most important postural parameters and is commonly measured as a part of measuring spinal positioning and mechanical activity. The lumbar curvature should be measured accurately, both clinically and in research. Cobb angle between L1 and L5 radiographs is considered the gold standard of all available methods (Dreischarf et al., 2016). Healthy populations have normal L1-L5 Cobb angles, which are between 38.1° and 45.6°, but these values do not necessarily remain constant across age, sex, and ethnicity (Furlanetto et al., 2018; Dimitrijevic et al., 2022). Less invasive methods of lumbar lordosis can be provided by non-radiographic equipment like inclinometer or flexicurves, but might not be as accurate as other radiographic methods.

2.4.2.2 Pelvic Alignment

Digital Inclinometers/Goniometers: To assess anterior/posterior pelvic tilt angles.

Pelvic tilt should be assessed correctly in order to examine lumbopelvic alignment and its role in postural control, lower back pain, and functional mobility. Digital inclinometers and goniometers are commonly used because of their portability, easy to use and find application in both clinical and research settings. These instruments give a quantitative measure of both anterior and posterior tilt of the pelvis in the sagittal plane, which offers useful information on pelvic positioning in the standing and actively engaged positions. According to Yudas et al. (1996), inclinometers are able to distinguish different degrees of pelvic tilt, with a high degree of precision, among asymptomatic individuals, creating the possibility to establish numeric reference values. Levine and Whittle (1996) showed that the tilt of the pelvis has a significant effect on the positioning of the lumbar spine, which makes it necessary to have valid measuring tools. Moreside and McGill (2011) validated digital inclinometers can be used to identify clinically significant changes in pelvic angle after hip intervention to record subtle compensatory changes that are often not visually obvious. Owing to their precision, the digital inclinometers and goniometers have been confirmed as reliable tools to measure pelvic tilt in healthy subjects and patients with musculoskeletal disorders such as NLBP.

2.4.3 Muscle Strength

2.4.3.1 Knee Muscle Strength Using Hand-Held Dynamometer (HHD)

The hand-held dynamometer (HHD) makes up a practical and economical instrument to assess knee extensor strength. It has been shown to have reliability, validity, and responsiveness, even when compared with more sophisticated electromechanical devices (Kittelson et al., 2020). It is a particularly beneficial measure for monitoring quadriceps strength before and after total knee arthroplasty in clinical studies.

According to Baron et al. (2024), the HHD is considered to be a valid technique for measuring the knee strength during various joint positions in healthy individuals. Measurement accuracy is increased with the use of the mean of two repeated trials. Pinto et al. (year) showed that the HHD is clinically useful in testing Knee extension strength and should be included in musculoskeletal assessment protocols.

2.4.3.2 Lumbar Muscle Strength Using Hand-Held Dynamometer (HHD)

Measuring the lumbar muscles' strength is the most important technique for assessing spinal stability, functional ability and rehabilitation progress. Recently, hand-held dynamometers (HHDs) have become an easily administered, inexpensive, and portable alternative to isokinetic devices for the assessment of isometric lumbar flexor and extensor strength in clinical and research settings. Studies have shown that HHDs are both reliable and valid: Tanveer et al. (2021) found high intra- and inter-rater reliability (ICC = 0.94--0.97) in healthy adults and have, thus, confirmed its usefulness for baseline and follow-up testing. Althobaiti and Falla (2023) found good to excellent test-retest reliability (ICC = 0.73-0.93) in patients with CLBP and healthy volunteers, while their correlations to isokinetic dynamometry were moderate to high (r = 0.56-0.78), which established their criterion validity.

Concerning responsiveness, HHDs have demonstrated usefulness in identifying the changes in lumbar strength over time. Althobaiti et al. (2025) conducted a follow-up to determine how responsive HHD was after six weeks of an exercise program in chronic LBP patients. he authors indicated moderate to large internal responsiveness, with effect sizes (ES) of between 0.40 and 0.85 and standardized response means (SRM) of between 0.60 and 0.74. Nonetheless, the external responsiveness, which is measured by the association of the changes in the strength with the changes in the functional outcomes, was low (r = 0.22 -0.26), meaning that the changes in the strength might not necessarily relate directly to the perceived clinical improvement.

HHDs also have been examined in athletic populations. Juan-Recio et al. (2024) examined the consistency of HHDs when testing the strength of seated trunk flexion and extension among female amateur athletes. Their results showed moderate to high reliability (ICC = 0.65 -0.87), and moderate correlations (r = 0.42 -0.47) between the HHD and the isokinetic testing. Nevertheless, the authors warned against the interchangeability of HHD and isokinetic devices because they have fundamental differences in the application of resistance and stabilization needs. Collectively, these results imply that HHDs are a valid and reliable technique in the measurement of lumbar muscle strength within different communities. Although they might not completely substitute laboratory-quality apparatus in sophisticated strength profiling, they can provide a workable, reproducible, and responsive instrument in clinical use and research, especially in the areas where sophisticated equipment is inaccessible.

2.4.4 Functional Ability and Health-related Quality of Life

One of the most popular instruments that can be used to measure functional disability and health-related quality of life in people with LBP is the Oswestry Disability Index (ODI) (Garg et al., 2020; Omar et al., 2023). The ODI is a self-administered questionnaire consisting of 10 items, rated 0-5 each, with a total score being converted to a percentage (0 -100%). It can be interpreted as follows (El-Hady et al., 2023):

0–20%: Minimal disability; the patient can perform most daily activities.

21–40%: Moderate disability; difficulties in travel and social participation, but basic self-care and sleep are only partially affected.

41–60%: Severe disability; significant limitations in daily functioning due to pain.

61–80%: Crippling disability; pain affects all aspects of life.

81–100%: Bed-bound or possibly exaggerating symptoms.

ODI has been confirmed to be applicable to a wide range of populations, and it is responsive to variation induced by treatment, which makes it a useful scale in monitoring the progress of rehabilitation of LBP patients.

2.5 Exercise-Based Interventions for Non-Specific Low Back Pain (NLBP)

Exercise is recognized to be the most effective intervention for non-specific low back pain (NLBP) among other treatment modalities. There is solid evidence of the use of active therapy techniques, where patients are promoted to participate in progressive movement and functional activity. These are motor control training, resistance exercises, aerobic conditioning, and spinal stabilization exercises, which have shown clinically significant results in the reduction of pain and disability (Owen et al., 2020).

Dimitrijevic et al. (2022) conducted a meta-analysis to determine the effects of corrective exercise programs in patients with lumbar hyperlordosis and reported that there are moderate positive effects in reducing the excessive lumbar curvature. Such exercises are useful in hyperlordotic and normo-lordotic individuals to ensure alignment and functional changes.

Likewise, Kim et al. (2021) showed that corrective and resistance exercise programs were effective in increasing lumbar muscle cross-sectional area, improving lumbar lordosis angles, augmenting flexibility, and diminishing ODI scores. Notably, the researchers concluded that corrective exercises yielded a higher rate of improvement in lumbar position and functional impairment than resistance training and traditional physical therapy.

Also, integrated exercise regimens have better results. According to Woo and Kim (2016), a program combining lumbar stabilization and thoracic extension exercises proved more effective in the improvement of both the ODI and lumbar curvature than the program of lumbar stabilization. Likewise, Cho et al. (2015) established that lumbar stabilization exercises were superior in comparison to conservative treatment in terms of lumbar lordosis and functional disability scores.

Nevertheless, the relationship between lumbar stabilization and structural spinal changes is not always consistent in all studies. Ko et al. (2018) determined that lumbar stabilization exercises could positively affect lumbar lordosis angle, but they did not have a significant effect on lumbar lordosis functional and symptom management. All these studies point to the fact that even though exercise-based interventions are imperative in the management of NLBP, the type, intensity, and emphasis of exercise programs can also have a significant impact on the effects of spinal alignment and disability. Therefore, it is suggested that the prescription of exercises based on the individual needs of the muscle-function and spinal-position be applied in order to achieve the best therapeutic effects.

2.6 Knee extensor training (Open kinetic chain versus Closed kinetic chain)

Open kinetic chain (OKC) exercises refer to exercises where the distal segment such as the foot is free to move; examples include leg extensions and seated straight leg raises which allow for the selective activation of specific musculature especially the quadriceps muscle. In contrast, closed kinetic chain (CKC) exercises involve stabilisation of the distal segment against a surface, such as the ground, with exercises such as squats, lunges and step-ups involving multiple joints and muscle groups simultaneously (Diong et al., 2015).

Both OKC and CKC exercises have different biomechanical profiles, and therefore, both exercises play complementary roles in rehabilitation. A step-wise approach may be the best strategy: starting with OKC exercises to work on isolated strength in patients with high pain levels or poor stability followed by CKC exercises for improving neuromuscular coordination, functional strength, and postural control for daily and athletic activities. The integration of both OKC and CKC into individualized programs is particularly beneficial to patients with non-specific low back pain and lower limb involvement (optimizing functional outcomes).

Table 2.1 Summary of Key Differences Between CKC and OKC

Feature	**Closed Kinetic Chain (CKC)**	**Open Kinetic Chain (OKC)**
Distal Segment	Fixed	Free-moving
Muscle Activation	Co-contraction, multi-joint	Isolated muscle activity
Joint Loading	Higher (functional load)	Lower (reduced axial load)
Proprioception	Enhanced	Minimal
Suitability	Later-stage rehab, functional tasks	Early-stage rehab, pain-sensitive conditions
Example	Squats, lunges	Leg extension, straight leg raise

2.6.1 Neuromuscular and Functional Differences

CKC and OKC exercises: Neuromuscular activation and biomechanics are different for both exercises. CKC exercises stimulate the ability to co-contract the agonist and antagonist muscles, which, in turn, stimulates joint compression and stability that can be used to enhance the control of proprioception and lumbo-pelvic (Kim et al., 2018). They are also useful for stimulating the muscle spindles and joint receptors, which promotes better neuromuscular coordination and postural control (Cheon et al., 2020). In contrast, OKC exercises enable isolated muscle strengthening with low loading of the joint, making them more appropriate for early-stage rehabilitation, especially in patients with pain or instability, such as NLBP (Daskapan et al., 2013).

CKC vs OKC in neuromuscular and functional impacts

- The CKC exercises tend to promote stability and proprioception of the joints through co-contraction, which may promote lumbar-pelvic control.
- Isolated strengthening through OKC exercises with reduced axial load can be advantageous in painful cases of NLBP.

2.6.2 Functional Carryover

CKC exercises tend to have more functional relevance, as they are close to what would be done in real life (such as rising from a chair, stair climbing, and running). Accordingly, they are commonly prescribed for functional restoration in both lower limbs and spinal rehabilitation programs (Kim et al., 2018). In comparison, OKC exercises might be beneficial in controlled strengthening situations, specifically where there are impediments to performing CKC tasks due to pain, range limitation or poor stability. Thus, they are often used as part of early-phase rehabilitation before more functional CKC movements are undertaken (Owen et al., 2020).

2.6.3 Evidence Comparison

Although CKC and OKC exercises are commonly used for lower limb rehabilitation in patients with low back pain and knee pathology, there is still a lack of definitive evidence regarding the effectiveness of these exercises. Goh et al. (2019) noted that although it is common practice, there is no consensus on the effectiveness of one modality over the other for patients who have both knee and low back pain conditions. Some investigations support the use of OKC in relieving clinical symptoms specific to the joint in knee and hip disorders (Daskapan et al., 2013), while others report the superior proprioceptive and functional benefits of CKC (Kim et al. 2018). For example, Adegoke et al. (2019) found that both OKC and CKC improved quadriceps strength and reduced pain in patellofemoral pain syndrome, but CKC was more efficacious. Recent systematic reviews reflect this uncertainty: Pamboris et al. (2024) reported inconsistent results and low certainty evidence when comparing OKC and CKC in anterior cruciate ligament rehabilitation and Ozudogru and Gelecek (2023) reported no significant differences in quadriceps strength between OKC, CKC and combined exercises in grade II knee osteoarthritis. Overall, CKC is likely to be slightly better than open surgery with regards to functional outcome.

2.7 Conceptual framework

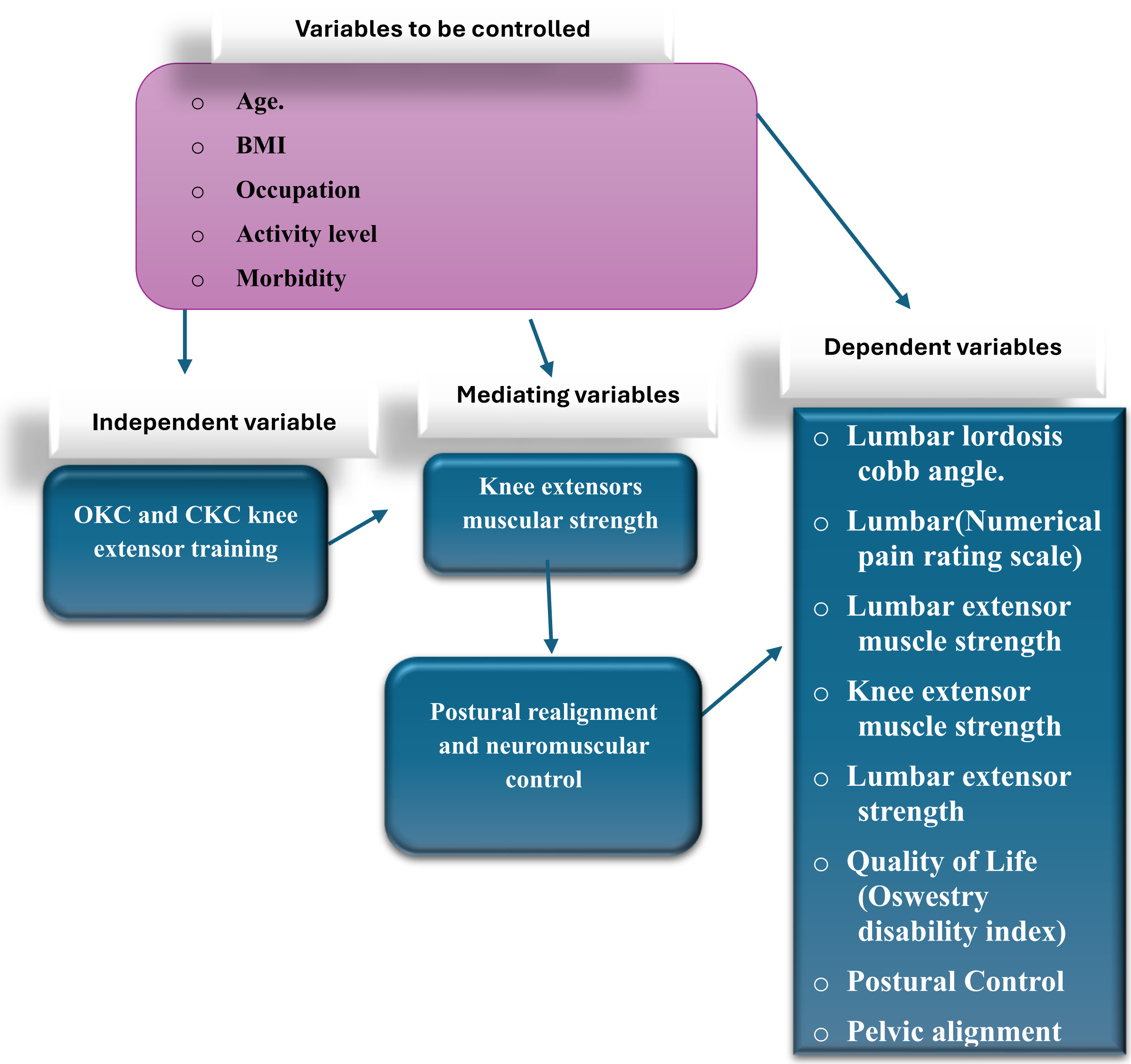


Figure 2.1 Conceptual framework of Knee Extensor Strength inrelation to NLBP

2.8 Summary of literature review

The management of non-specific low back pain (NLBP) increasingly incorporates lower limb-focused rehabilitation due to the biomechanical and neuromuscular interdependence between the lumbar spine, pelvis, hip, and knee joints. Among various approaches, Open Kinetic Chain (OKC) and Closed Kinetic Chain (CKC) exercises are two commonly applied strategies for knee extensor strengthening, each with distinct physiological and functional implications.

Evidence suggests that both OKC and CKC exercises can effectively improve muscle strength and reduce pain in individuals with lower limb or spinal disorders. However, CKC exercises are frequently preferred due to the superior effect of CKC exercises on neuromuscular control and functional performance. Nevertheless, the literature is still contradictory, as some studies found no significant difference between the two modalities regarding results of quadriceps strength or disability, especially in populations with knee osteoarthritis or patellofemoral pain syndrome.

The current literature is less clear regarding which kinetic chain approach provides a greater therapeutic benefit in patients with NLBP and the way in which lumbar stability, knee function, and global postural control influence each other. This shows a major gap in the literature and justifies the need for further research, especially in patient groups with combined lumbar and lower limb dysfunction. Further studies, especially prospective research, are needed to better understand these associations and to elucidate the causal pathways and mechanisms underlying LBP with special regard to the role of corrective exercises aimed at improving knee alignment in preventing chronic and recurrent cases.

CHAPTER 3

METHODOLOGY

3 Introduction

The methodology chapter describes the sequential steps of the empirical investigation, including a comprehensive plan of time on all research activities. It will discuss the methods and tools used for data collection, ensuring that their reliability and validity are demonstrated. In addition to describing the intervention in detail, the research design and the statistical analytical methods to be used are presented.

3.1 Research Design

An innovative therapeutic strategy of knee extensor training will be evaluated in a four-arm randomized controlled trial (RCT) for non-lumbar back pain (NLBP). We will use randomization to reduce the risk of bias and offer a valid way to study the cause-and-effect relationship between the intervention and the outcomes. This RCT will use a triple-blinded design in which the participants, outcome assessors, and statisticians will be blinded to the intervention assigned to each participant.

3.2 Research Setting

The research will be carried out in the Ministry of Health (MOH) hospitals of Taif, Kingdom of Saudi Arabia, for several strong reasons. First, the MOH hospitals in Taif represent a wide and mixed patient population, providing access to individuals representing a wide range of demographic, health status, and socioeconomic diversity. This diversity will increase the generalizability and applicability of study results to real-world clinical practice.

Second, these hospitals have standardized medical infrastructure and rehabilitation services, in particular, physical therapy departments staffed by licensed physiotherapists. This assures the availability of critical resources (assessment tools, therapeutic equipment and treatment facilities) necessary for safe and effective implementation of the study protocol.

Additional benefits arise from the institutional review boards at the hospitals and their experience with regulatory mechanisms for clinical research. These factors can support ethical approval processes, recruitment of participants and compliance with modern standards of research governance.

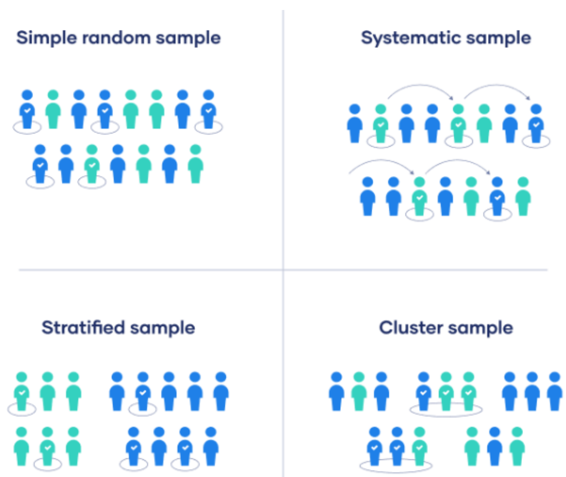
3.3 Research population and sampling techniques.

3.3.1 Research population

Saudi male adults aged 40-60 years suffering from NLBP can participate in the current study. The patient records in the Ministry of Health hospitals in Taif will be the source for patients' contact information.

3.3.2 Sampling technique

Probability of sampling with a simple random sample technique, as every member of a study has an equal chance of selection



3.3.3 Sample size

The G*Power software (Kang, 2021) was utilized to calculate the required sample size using the following parameters: F tests for MANOVA with repeated measures within and between interactions, specifying Pillai's trace of 0.16 an effect size of 0.3, an alpha error probability of 0.05, and a desired power of 0.85. The analysis involved eight groups and three measurement times (pre- after 4 weeks, and after 8 weeks of intervention), resulting in a determined sample size of 120 participants.

3.3.4 Randomization

A total of 128 participants will be enrolled and randomly assigned to one of eight study groups using a stratified randomization method. Randomization will be stratified by age to ensure equal distribution across intervention and control groups. Participants will first be categorized into two age strata:

- **Group A**: 40–49 years
- **Group B**: 50–59 years

Within each age stratum, participants will be randomly allocated to one of four intervention arms:

- Treatment Group I (lumbar strengthening exercise and knee OKC exercise)
- Treatment Group II (lumbar strengthening exercise and knee CKC exercise)
- Treatment Group III (lumbar strengthening exercise and knee OKC and CKC exercise)
- Control Group ((lumbar strengthening exercise)
-)

3.3.5 Blinding techniques

The double-blinding technique will be used during the study period, in which the participants, assessor, and statisticians will not know the assignment.

3.4 Selection criteria

3.4.1 Inclusion criteria:

Males aged 40 to 60 years, nonsmokers, with normal body mass index of Saudi nationality, office workers, suffering from chronic NLBP for 12 weeks or more with a moderate disability according to the Oswestry Disability Index (score of 21 - 40%) and moderate activity level according to the Arabic version of the International Physical Activity Questionnaire short form (Appendix III).

3.4.2 Exclusion criteria:

I. Previous spinal surgery, fracture, deformity, or disease.

II. Neurological deficit and Lower limb deformity or fracture, or disease.

III. Mental or psychological illness. The Arabic version of the Self-Reporting Questionnaire (SRQ-20) developed by the World Health Organization (WHO) to screen for common mental disorders such as depression and anxiety, uses a cut-off score to distinguish between individuals with and without significant psychological distress. A score of 7 or below is generally considered "normal", indicating no significant psychological distress (Al-Subaie et al., 1998).

IV. Systematic chronic illnesses such as hypertension, cardiac and respiratory disorders, and diabetes mellitus.

3.5. Data collection procedure

3.5.1 Recruitment

The sample of study will be selected from outpatient physical therapy and rehabilitation departments of Ministry of Health hospitals in Taif, Kingdom of Saudi Arabia. Two main methods will be used to identify and invite potential participants. Firstly, the subjects will be identified by conducting a systematic review of clinical databases and medical records in cooperation with hospital physiotherapists and attending physicians. Patients who were diagnosed with non-specific low back pain (NLBP) within the target age range (40-60 years) will be screened from records to identify those who meet the initial inclusion criteria. The identified subjects will then be contacted, by telephone or during clinic visits, to inform them of the study and invite them to take part. They will be given short and clear information about the purpose, procedures, potential benefits and their rights as research subjects. Second, to broaden recruitment and assure fair opportunity for participation, flyers, posters, and electronic advertisements will also be distributed on hospital waiting areas, rehabilitation units, and community health centers. These advertisements will contain a pithy study description, eligibility criteria, and contact information for the research team. Participants will be asked to voluntarily contact investigators. They will be screened initially by telephone or face-to-face pre-screening interview to establish eligibility.

3.5.2 Screening Process

All eligible participants, whether identified through clinical records or self-referred via advertisements, will be invited to attend a screening visit where informed consent will be obtained, and a detailed eligibility assessment will be conducted. Only those who meet the inclusion and exclusion criteria will be randomly allocated into one of the eight study groups, stratified by age and intervention type as described in the study design. Within each age stratum, participants will be randomly assigned to either the control group or one of three treatment groups (Group I, Group II, or Group III).

The assessor who is blind to group assignment (SAA) will conduct the baseline assessment, 4 weeks and at the end of eighth week intervention.

All potential participants will undergo a two-stage screening process. Stage I: an interview for age, BMI, medical history, occupation, other characters, low back pain intensity and Oswestry Disability Index and IPAQ-SF questionnaire. The interview will be conducted by a licensed physiotherapist to verify and questionnaire scores. Stage II : Physical measurement comprised of lumbar lordosis, postural control, lumbar instability and knee extensor isometric strength. The measurement will be conducted by a senior physiotherapist with over five years experience in managing musculoskeletal condition who will be blinded to group allocation where feasible.

Participants will attend prescheduled sessions for eight weeks. All exercise interventions will be delivered by licensed physical therapists with at least 5 years of clinical experience in musculoskeletal rehabilitation. Therapists will be trained in the study protocol and Intervention sessions will take place in the rehabilitation department of participating Ministry of Health hospitals and will follow standardized protocols for each exercise group, ensuring fidelity and consistency across all participants. The flow of the study is presented in Figure 3.1

3.6- Flow of the Study

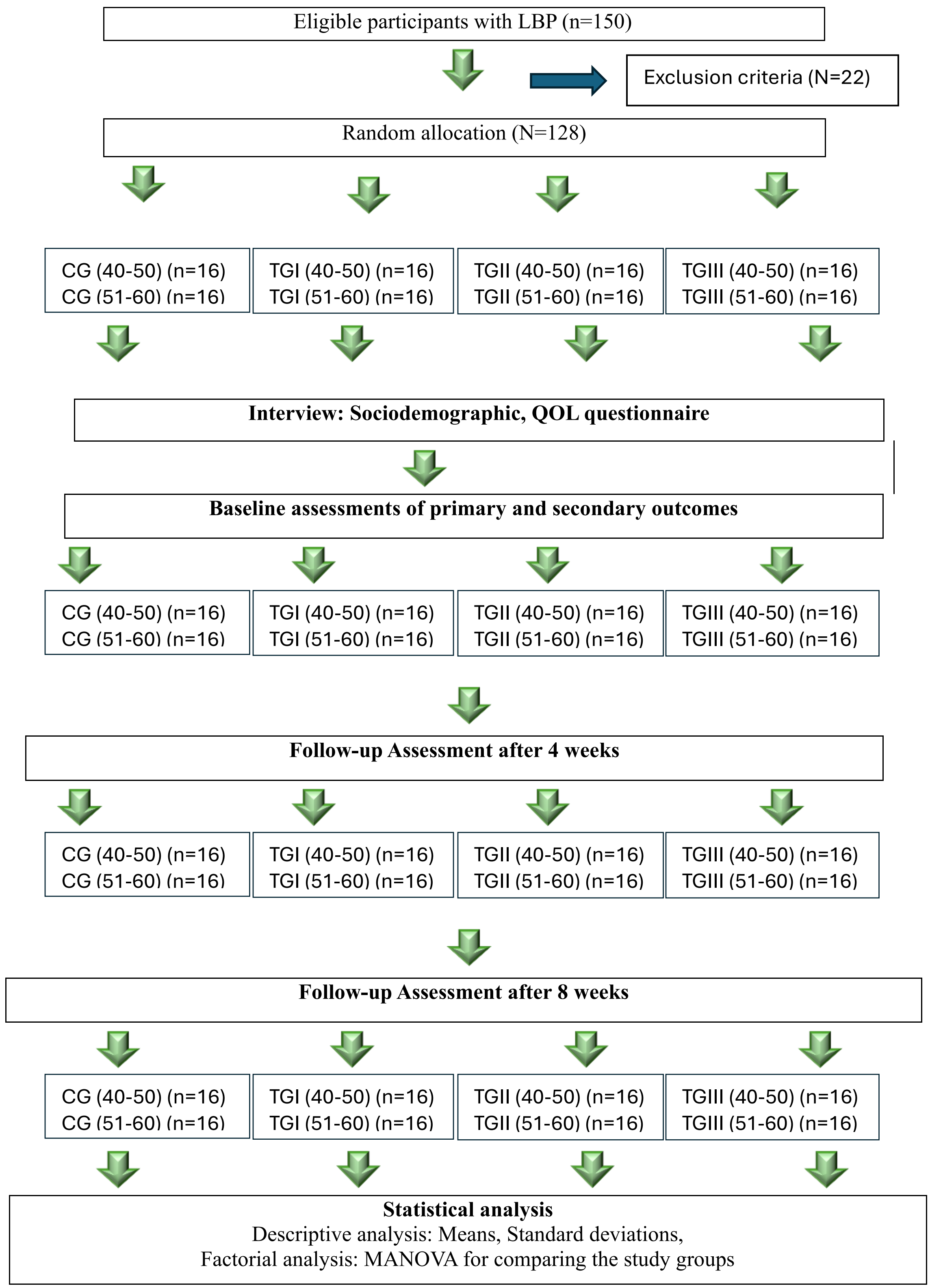


Figure 3.1 The flow of the study

3.7 Outcome Measures

3.7.1 Primary outcome:

i) Lumbar lordosis is measured by X-ray Cobb angle.

For the Lumbar lordotic measure, a standard 36-inch lateral radiograph will be taken from a distance of 6 feet in a standing position. The participant's arms will be positioned horizontally on a support bar to eliminate shadows that could obscure the measurement of the spine (Hammerberg and Wood, 2003).

The most common method of Cobbs angle calculation involves drawing a line through the first lumbar vertebra's superior endplate on a lateral lumbar radiograph, followed by a second line parallel to the fifth lumbar vertebra's inferior endplate. Perpendicular lines are then created, and the angle formed at their intersection is measured (Harrison et al., 2001; Russell et al., 2020). The method has an ICC of 0.99, with a 95% confidence interval (Harrison et al., 2001; Russell et al., 2020).

3.7.2 Secondary outcome:

i) LBP intensity is measured by the Numeric Pain Rating Scale.

The NPRS, a widely used 11-point scale in LBP research (Shafshak et al., 2021), will be used for this analysis. The participant will choose the score that best matches their perception of pain intensity, where 0 is no pain and 10 is maximum pain imaginable.

The NPRS is a highly reliable instrument with an ICC of 0.991 (Yao et al., 2020) and it is deemed to be a valid instrument used for measuring LBP severity. It has been proven to react adequately both in clinical as well as research settings (Von et al., 2000). The scale has good construct validity (Von et al., 2000), with good positive correlation with other measures of pain intensity, and is easy to administer and score (Ostelo et al., 2005).

ii) Quality of Life: Oswestry Disability Index (ODI)

The Arabic version of the ODI (Arabic-ODI) has been tailored for the Saudi population and will be used for functional disability measures because it has high metrological qualities. The self-completed ODI includes 10 items covering the topics of pain intensity, lifting, self-care, walking, sitting, sexual function, standing, social life, sleep quality and ability to travel. Patients are asked to choose the best phrase to describe their circumstances. Each item is scored on a 5-

point scale that ranges from 0 (no disability) to 5 (most severe disability). Subjects are free to skip the sexual-function question. The sum raw score from 0 to 50 is then transformed into percentile summary score as percentage (0% - 100%) (Cook et al., 2021).

It has been validated in the Kingdom of Saudi Arabia (KSA), demonstrating excellent intra-observer reliability (ICC: 0.99). Correlations of the index with the Visual Analog Scale (VAS) for pain (r = 0.708), the Roland–Morris Low Back Pain Disability Questionnaire (r = 0.656), and the Quebec Back Pain Disability Scale (r = 0.792) indicate strong construct validity (Algarni et al., 2014).

Among the tools specific to LBP, ODI is noted for its strong construct validity and reliability. The test-retest reliability values range from 0.94 to 0.99, with high inter-rater reliability at 0.94 and internal consistency values between 0.835 and 0.90 (Garg et al., 2020).

iii) Muscle strength using Hand-held dynamometer (HHD)

a) Lumbar muscle strength (Fakhro et al, 2022)

Lumbar extensor muscle strength will be assessed using a Hand-Held Dynamometer (HHD) (e.g., MicroFET or Lafayette Manual Muscle Tester). The testing of participants will be done while in a prone position on a treatment table with the arms placed alongside the body and the legs extended. A standardized warm-up consisting of light dynamic stretches will be provided prior to testing.

The examiner will position the HHD over the participant's thoracolumbar junction (T12-L1) while stabilizing the pelvis with a strap or manual fixation to prevent compensatory movements. Participants will be instructed to extend their trunk maximally against the resistance applied by the dynamometer, maintaining a steady effort for 3–5 seconds. Verbal encouragement will be given to help ensure maximum effort.

Each subject will perform three consecutive trials with a 30-second rest period between the repetitions, which will minimize fatigue. The maximum force in Newtons measured during the tests will be taken for analysis. High test-retest reliability has already been demonstrated for HHD in the measurement of trunk extensor strength, with an ICC above 0.90. All of the tests will be conducted by the same trained investigator, thus inter-rater variability is eliminated.

b) Postural control (Sarvestan et al, 2021)

Postural control will be assessed using the Y-Balance Test (YBT), a reliable and validated dynamic balance test that challenges single-leg stability in multiple directions. The test is based on the Star Excursion Balance Test (SEBT) and is widely used to assess neuromuscular control, dynamic balance, and risk of injury in clinical and athletic populations. Participants will perform the test barefoot to minimize shoe-related variability, unless footwear is standardized. The participant will be instructed to stand on the dominant limb at the center of a Y-shaped grid, with the other limb used to reach in three directions: Anterior (ANT), Posteromedial (PM), and Posterolateral (PL)

Participants will be allowed four practice trials in each direction, followed by three measured trials. The reach distance in each direction will be recorded to the nearest 0.5 cm using a standard YBT kit or a tape grid marked on the floor. Trials will be discarded and repeated if the participant: Fails to maintain single-leg stance, Touches down with the reaching foot, or cannot return to the starting position under control. The maximum reach distance in each direction will be normalized to leg length (measured from anterior superior iliac spine to the medial malleolus) and expressed as a percentage. A composite score will be calculated as:

$$\text{Composite Score} = \left(\frac{\text{ANT} + \text{PM} + \text{PL}}{3 \times \text{leg length}}\right) \times 100$$

This protocol provides a reliable measure of dynamic balance and postural control (ICC > 0.85), with demonstrated sensitivity to intervention effects and neuromuscular training.

c) Knee extensor strength

Hirano et al. (2020) demonstrated that measuring knee extensor isometric strength using the HHD is highly reliable with the subject in the sitting position. This method shows criterion-related validity when compared to an isokinetic dynamometer for males and exhibits acceptable reproducibility among different examiners. Specifically, the assessment of isometric knee strength using the HHD yielded high intra-rater and inter-rater intraclass correlation coefficients (ICCs), with values exceeding 0.950 and 0.927, respectively. Thus, using the HHD to measure knee extension strength seems to be a reliable way to measure strength objectively (Pinto-Ramos et al., 2022).

In the current research, we will utilize a valid and reliable handheld dynamometer, specifically the Lafayette Instrument brand (model number 01165, Lafayette, Sagamore, USA) as referenced by Nepomuceno et al. (2021). Assessment procedures will adhere to those outlined by Pinto-Ramos et al. (2022). Patients will be seated at the edge of the bed with their feet suspended, arms crossed over their chests, and examined knees flexed at 60 degrees. The observer will squat while supporting their back against the wall, extending both arms to stabilize the patient's leg. This positioning minimizes the influence of strength from either the patient or observer while maintaining the knee flexion angle at 60 degrees.

Each patient will have the HHD placed on their front leg, about five centimeters above the distal portion of the medial malleolus. Patients will exert and sustain their maximum knee extension strength for five seconds. To reduce the impact of fatigue, a rest period of one minute will be allowed between two measurements. An independent observer will register the results displayed on the HHD, ensuring that both the patients and observers using the HHD remain blinded to the readings. Strength measurements will be recorded in Newtons (N), and the higher of the two measurement values will be considered as the final result.

3.8 Rehabilitation protocol (8 weeks).

i. Knee extensor training.

1. Open kinetic chain exercise (Adegoke et al., 2019)

Quadriceps Setting

By bringing up their patella while maintaining an extended knee, participants will perform an isometric contraction of the quadriceps muscle while lying supine on a plinth. After holding the contraction for ten seconds, they will release it and perform the exercise in ten repetitions with a five-second rest between them. This task will be performed throughout the exercise intervention protocol.

Straight Leg Raising (SLR)

The participant will lift his lower extremity while isometrically contracting his quadriceps (quadriceps setting) in a supine position to attain about 45° of hip flexion while maintaining an extended knee. After ten seconds, they will lower the limb and repeat the exercise ten more times with a five-second rest in between. The contralateral hip and knee will be flexed to approximately 45° and 90°, respectively, to prevent excessive strain on the lower back. Participants will begin performing SLR with additional weight in the third week by fastening an ankle weight equal to their 10-repetition maximum (10RM) to their ankle.

Full-Arc Extension

While the participants are in a high sitting position, a weight equal to their 10RM will be attached to the lower limb, approximately above the ankle. The popliteal area will be covered by a towel roll for protection. The load will be gradually raised through a range of 90° knee flexion to 0° knee extension. They will hold the position for five seconds before decreasing it again. In each session, participants will complete three sets of ten repetitions of this exercise, taking a 10-second break between sets to rest their feet on a stool. This task will be performed from the fourth week to the eighth week.

2. **Closed kinetic chain exercise (Adegoke et al., 2019)**

Quadriceps Setting

While Participants are sitting in a chair with backs supported, their heels resting on the floor, knees outstretched, they will press their thighs against the chair's seat and their heels to the floor and hold for a count of 10. After ten counts, they will rest. This exercise will be performed throughout the study.

Mini Squats

While the participants are in a standing position, they will bend both knees to approximately 30-60 degrees while keeping their trunks upright. They will hold this position for 10 seconds. After that, they will relax and then repeat it for 10 repetitions. This exercise will be performed in the 2^{nd} week of the study, after which it will be stopped when participants begin doing weighted mini squats. Starting in the third week, participants will use a barbell with plastic weights, totaling 10RM, put across their shoulders for the mini squats with weight.

Step-Up and Step-Down

Participants will use a robust wooden box that is 5 cm high to do step-ups and step-downs in the following directions: forward, backward, and lateral. They should maintain an upright trunk, ensuring that their heels are the last to leave the floor and the last to return, which emphasizes the use of the quadriceps muscle. Each exercise will be repeated 10 times. This part of the program will be conducted only during the 4th week. From week 5 onward, ankle weights totaling 10RM will be strapped to participants' ankles for the weighted step-ups and step-downs. The knee extensor exercise program is illustrated in Table (3.1).

All participants will perform the exercises three times per week, on consecutive days, for both lower extremities, with a five-minute rest between each extremity. They will start with the dominant lower extremity, followed by the non-dominant one. The knee extensor exercise program is detailed in Table (3.1).

Table (3.1): knee extensor exercise program.

	OKC	**CKC**
W 1	• Quadriceps sets (10 rep.)	• Quadriceps sets (10 rep.)
W 2	• Quadriceps sets (10 rep.) • Straight leg raises (10 rep.)	• Quadriceps sets (10 rep.) • Mini squats (10 rep.)
W 3	• Quadriceps sets (10 rep.) • Straight leg raises with resistance (10 RM)	• Quadriceps sets (10 rep.) • Mini squats with resistance (10 RM)
W 4	• Quadriceps sets (10 rep.) • Straight leg raises with resistance (10 RM) • Full knee extension exercise (10 RM as resistance)	• Quadriceps sets (10 rep.) • Mini squats with resistance (10 RM) • Step up and step down
W 5-8	• Quadriceps sets (10 rep.) • Straight leg raises with resistance (10 RM) • Full knee extension exercise (10 RM as resistance)	• Quadriceps sets (10 rep.) • Wall slides with resistance (10 RM) • Step up and step down with resistance

ii. Lumbar Strengthening Exercise (Cai et al., 2017).

The goal of the 8-week progressive training program for the lumbar extensor exercises is to induce physiological changes in the muscles. A gradual approach will be used to protect the participants and reduce undue mental and physical stress from their exercise routine.

In the first week, participants will perform leg raises in a quadruped position while maintaining a neutral lumbar spine during both flexion and extension of the leg. In the 2nd week, participants will progress to raise one leg and the opposite arm. This structured progression will allow participants to do about 40% of their maximum voluntary isometric contraction (MVIC) at the start of the 2nd week, without raising the probability of injury to the muscles of the lower back. For all exercises, participants will complete three sets of 10 repetitions per session, which is recommended for improving muscle endurance and reducing fatigability.

At the end of each repetition, participants will include an isometric contraction which is essential for enhancing lumbar extensor fatigability. Before beginning the subsequent repetition, they will be asked to hold the end position for five seconds and take a two-second break. Additionally, a two-minute rest will be provided between sets.

To achieve the counseled intensity of about 60% of MVIC for lumbar extensors, participants will add 0.5 kg of ankle weights in the 3rd week and 0.5 Kg of wrist weights in the 4th week. Following this, an increment of 0.5 kg will be suggested every week for the ankle weights and every three weeks for the wrist weights. Starting in week 5, the prone back extension will replace the quadruped exercises, as this exercise produces a MVIC percentage above 65%. All participants will be advised that their back pain should not worsen while training. Instead, the body's response to exercise should be limited to feelings of "aching" or "soreness." If participants experience any increased discomfort, they should either reduce the exercise intensity or terminate the program.

3.9 Description of variables.

3.9.1 The independent variables

The independent variable in this study is the knee extensor training program, which consists of two levels: OKC exercises and CKC exercises. The sample will be divided based on the independent variable into four groups: a control group (CG) that will not be exposed to the knee training program, a treatment group I (TGI) that will perform OKC exercises, treatment group II (TGII) that will engage in CKC exercises, and a treatment group III (TGIII) that will engage in OKC and CKC exercises. All groups will receive lumbar strengthening exercises.

3.9.2 The dependent variables:

3.5.1.1. Lumbar spine lordosis

3.5.1.2. Oswestry Disability Index

3.5.1.3. LBP intensity

3.5.1.4. Isometric strength of the knee extensor

3.5.1.5. Lumbar extensor muscle strength

3.5.1.6. Pelvic inclination

3.5.1.7. Postural control

3.10 Data Analysis Process

3.10.1 Exploratory data analysis

SPSS software (version 26) will be utilized to analyze the collected data. The Shapiro-Wilk test for normality, along with an inspection of histograms featuring normality curves, skewness, and kurtosis, will be employed to assess data normality.

3.10.2 Data analysis approach

Pre-tests and post-tests for each group will be analyzed using a mixed-design repeated-measures MANOVA to compare different study groups through the SPSS program. The syntax code will allow various pairwise comparisons using the Bonferroni test. The significance level will be determined at $p< 0.05$.

Covariate Adjustments: The study does not include covariates in the model, as participants have been stratified by age group before randomization, and any covariates controlled by the inclusion and exclusion criteria. This approach is expected to ensure baseline comparability across the six groups, rendering covariate adjustment unnecessary for our current design. Nonetheless, we will assess baseline characteristics to confirm group equivalence, and any significant imbalances identified will be documented and discussed.

Study Design Summary: The study comprises 128 participants assigned to eight groups based on a combination of two age strata and four treatment arms. This factorial design facilitates group comparisons utilizing MANOVA, which is appropriate given the multiple dependent variables involved.

Interaction Effects: While the primary objective is to evaluate the main effects of treatment within each age group, we may explore potential interactions between age group and treatment in secondary analyses, contingent upon data structure and sample size. Such interactions will be interpreted with caution, acknowledging power limitations.

Handling of Dropouts/Non-Adherence: As this is a controlled clinical trial, we anticipate possible challenges related to participant dropouts or non-adherence. To address these concerns, our primary analysis will adhere to the intention-to-treat (ITT) principle. In addition, per-protocol analyses will be conducted to further evaluate the data.

Missing data will be examined for patterns and handled using appropriate statistical methods such as multiple imputation or mixed-effects models, depending on the nature of the missingness.

3.11 Ethical considerations

Once the research plan is approved, the researcher will seek ethical approval from the Ethics Committee of the Ministry of Health in Taif. To confirm their agreement to engage in the study, all eligible participants will sign a written consent form in Arabic (see Appendix II).

3.12 Limitations of the study

This study aims to investigate the impact of knee extensor strengthening on lumbar spine posture, pain levels, and QOL in patients with NLBP. Considering the cultural and social context in Saudi Arabia (KSA), the study will involve only male participants. It will specifically recruit individuals diagnosed with NLBP, excluding those with other underlying causes of LBP.

3.13 Summary

This study, based on a randomized controlled trial, aims to explore the effects of strengthening the knee extensor muscles on the position of the lumbar vertebrae, the severity of pain, and the QOL in patients with LBP. The research plan reviewed recent literature addressing the relationship between the lower extremities and the spine, particularly the lumbar vertebrae. It also clarified the connection between knee extensor muscle weakness and low back pain, highlighting the bidirectional causal relationship involved.

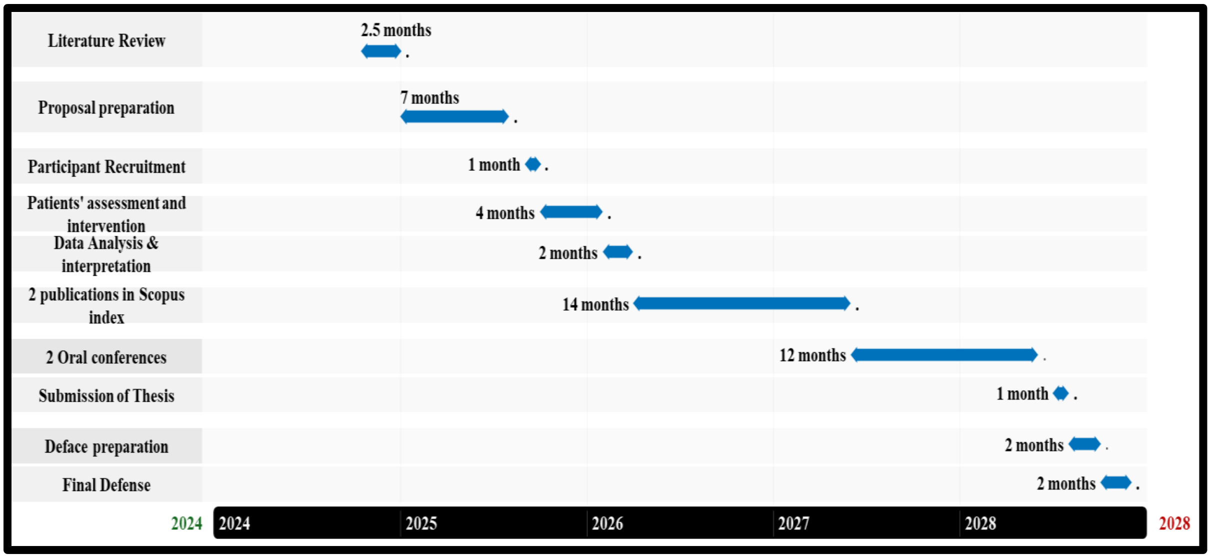
After reviewing previous research, the study aims to investigate the effects of two different patterns of knee extensor muscle strengthening on patients with LBP. The findings are intended to inform the development of rehabilitation programs for these patients. Additionally, the study may contribute to knowledge in this area and generate research hypotheses for future investigations.

Reliable and accurate measurement methods will be used to assess participants before and after the therapeutic intervention. The study also will clarify methods for collecting and analyzing data, ensuring that the final results can be interpreted and applied in practical contexts.

3.14 Research Gantt Chart

Table (3.2): Timeline of the PhD milestones

Task	Start date	End date
Literature Review	10/15/2024	06/26/2025
Proposal preparation	01/01/2025	07/31/2025
Ethic approval	08/1/2025	08/30/2025
Data collection	09/01/2025	09/30/2025
Folow up	10/01/2025	01/31/2026
Data Analysis & Interpretation	02/01/2026	03/31/2026
2 publications in Scopus index	04/01/2026	05/31/2027
2 Oral presentation conferences	06/01/2027	06/01/2028
Submission of Thesis	07/01/2028	08/01/2028
Deface preparation	08/01/2028	10/01/2028
Final Defense	10/02/2028	11/30/2028


Literature Review
Proposal preparation
Participant Recruitment
Patients' assessment and intervention
Data Analysis & interpretation
2 publications in Scopus index
2 Oral conferences
Submission of Thesis
Deface preparation
Final Defense
2.5 months
7 months
1 month
4 months
2 months
14 months
12 months
1 month
2 months
2 months
2024
2024
2025
2026
2027
2028
2028

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Appendix I

Oswestry Disability Index

Oswestry Low Back Pain Disability Questionnaire

Instructions

This questionnaire has been designed to give us information as to how your back or leg pain is affecting your ability to manage in everyday life. Please answer by checking ONE box in each section for the statement which best applies to you. We realise you may consider that two or more statements in any one section apply but please just shade out the spot that indicates the statement which most clearly describes your problem.

Section 1 – Pain intensity

- ☐ I have no pain at the moment
- ☐ The pain is very mild at the moment
- ☐ The pain is moderate at the moment
- ☐ The pain is fairly severe at the moment
- ☐ The pain is very severe at the moment
- ☐ The pain is the worst imaginable at the moment

Section 2 – Personal care (washing, dressing etc)

- ☐ I can look after myself normally without causing extra pain
- ☐ I can look after myself normally but it causes extra pain
- ☐ It is painful to look after myself and I am slow and careful
- ☐ I need some help but manage most of my personal care
- ☐ I need help every day in most aspects of self-care
- ☐ I do not get dressed, I wash with difficulty and stay in bed

Section 3 – Lifting

- ☐ I can lift heavy weights without extra pain
- ☐ I can lift heavy weights but it gives extra pain
- ☐ Pain prevents me from lifting heavy weights off the floor, but I can manage if they are conveniently placed eg. on a table
- ☐ Pain prevents me from lifting heavy weights, but I can manage light to medium weights if they are conveniently positioned
- ☐ I can lift very light weights
- ☐ I cannot lift or carry anything at all

Section 4 – Walking*

- ☐ Pain does not prevent me walking any distance
- ☐ Pain prevents me from walking more than 2 kilometres
- ☐ Pain prevents me from walking more than 1 kilometre
- ☐ Pain prevents me from walking more than 500 metres
- ☐ I can only walk using a stick or crutches
- ☐ I am in bed most of the time

Section 5 – Sitting

☐ I can sit in any chair as long as I like

☐ I can only sit in my favourite chair as long as I like

☐ Pain prevents me sitting more than one hour

☐ Pain prevents me from sitting more than 30 minutes

☐ Pain prevents me from sitting more than 10 minutes

☐ Pain prevents me from sitting at all

Section 6 – Standing

☐ I can stand as long as I want without extra pain

☐ I can stand as long as I want but it gives me extra pain

☐ Pain prevents me from standing for more than 1 hour

☐ Pain prevents me from standing for more than 3 minutes

☐ Pain prevents me from standing for more than 10 minutes

☐ Pain prevents me from standing at all

Section 7 – Sleeping

☐ My sleep is never disturbed by pain

☐ My sleep is occasionally disturbed by pain

☐ Because of pain I have less than 6 hours sleep

☐ Because of pain I have less than 4 hours sleep

☐ Because of pain I have less than 2 hours sleep

☐ Pain prevents me from sleeping at all

Section 8 – Sex life (if applicable)

☐ My sex life is normal and causes no extra pain

☐ My sex life is normal but causes some extra pain

☐ My sex life is nearly normal but is very painful

☐ My sex life is severely restricted by pain

☐ My sex life is nearly absent because of pain

☐ Pain prevents any sex life at all

Section 9 – Social life

☐ My social life is normal and gives me no extra pain

☐ My social life is normal but increases the degree of pain

☐ Pain has no significant effect on my social life apart from limiting my more energetic interests eg, sport

☐ Pain has restricted my social life and I do not go out as often

☐ Pain has restricted my social life to my home

☐ I have no social life because of pain

Section 10 – Travelling

☐ I can travel anywhere without pain

☐ I can travel anywhere but it gives me extra pain

☐ Pain is bad but I manage journeys over two hours

☐ Pain restricts me to journeys of less than one hour

☐ Pain restricts me to short necessary journeys under 30 minutes

☐ Pain prevents me from travelling except to receive treatment

Appendix II

Informed Consent to Participate in a Research Study

You are being asked to participate in a research study. Researchers conduct studies in order to answer important questions that may help change or improve the way we perform medical procedures in the future.

You may choose not to participate in this study, and you may also withdraw from the study at any time. Your decision not to participate, or to withdraw later, will not result in any penalty or loss of benefits to which you are entitled, and it will not affect your relationship with the researchers or their institution.

Before you agree to participate, the researcher will summarize the important information that will allow you to decide whether or not to take part. After that, the researchers will provide you with details of the study, including:

- Why the researchers are conducting the study.

- The number of people participating in the study.

- What will happen during the study, including how long your participation will last and whether the study involves any experimental procedures.

- Any potential risks or benefits.

- Whether there are alternative treatment options besides participating in the study.

- The procedures that will be taken to protect your personal information and how it may be used in the future.

- How you will be informed of new findings that may affect you personally or your participation.

- Who will cover the costs of treatment if you are injured during your participation in the study.

- Whether there are any costs to you, and whether you will be paid for participating in the study.

- What happens if you decide to stop participating, or the reasons the researchers may terminate your participation.

If you have any questions about the study or about a study-related injury, please contact:

Name: ____

Telephone Number: _______________________________

Participant Consent

The research study has been explained to me verbally, including the information listed above, and I agree to participate in this research study. I will receive a signed copy of this form and an English version of the informed consent statement to keep for my records. I agree to participate in this study.

Participant's Name (printed clearly and in capital letters):

____

Participant's Signature: ________________________ Date: __________

Parent/Guardian/Legally Authorized Representative (if applicable):

____

Date: _________________

Appendix III

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week**

   ☐ No moderate physical activities → ***Skip to question 5***

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.