EFFECTS OF OPEN AND CLOSED KINETICS CHAIN EXERCISE ON FUNCTIONAL OUTCOMES AND LOWER LIMB BIOMECHANICS IN MILD PRIMARY KNEE OSTEOARTHRITIS FEMALE PATIENTS

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by

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LIST OF ABBREVIATIONS

10 RM	10-Repetition Maximum
2D	2-Dimensional
3D	3-Dimensional
6MWT	6-Minute Walk Test
ASIS	Anterior Superior Iliac Spine
BMI	Body Mass Index
CC	Combined Chain
CKC	Closed Kinetic Chain
CoM	Centre of Mass
CONSORT	CONsolidated Standards of Reporting Trials
EDU	Education
FTSTS	Five Times Sit-To-Stand Test
HHD	Hand-Held Dynamometer
KAM	Knee Adduction Moment
KKP11	Klinik Kesihatan Putrajaya Presint 11
KKP14	Klinik Kesihatan Putrajaya Presint 14
KKP18	Klinik Kesihatan Putrajaya Presint 18
KKP9	Klinik Kesihatan Putrajaya Presint 9
KL	Kellgren–Lawrence
M- OAHKQOL	Malay Version Of Osteoarthritis Of The Knee And Hip Quality Of Life
MMT	Manual Muscle Testing
M-WOMAC	Malay version of Western Ontario and McMaster Universities Arthritis Index
NMRR	National Medical Research Register
OA	Osteoarthritis
OAHKQOL	Osteoarthritis Of The Knee And Hip Quality Of Life
OARSI	Osteoarthritis Research Society International
OKC	Open Kinetic Chain
PIA	Pain Interference Activities
PSIS	Posterior Superior Iliac Spine
QoL	Quality of Life
RCT	Randomised Clinical Trial

ROM	Range Of Motion
SLR	Straight Leg Raising
SPIRIT	Standard Protocol Items: Recommendations for Interventional Trials
SPSS	Statistical Package Social Sciences
SS	Study Supervisor
STS	Sit To Stand
TKR	Total Knee Replacement
TUG	Timed Up And Go Test
US	United States
VAS	Visual Analogue Scale
WOMAC	Western Ontario and McMaster Universities Arthritis Index

LIST OF APPENDICES

KESAN SENAMAN RANTAI KINETIK TERBUKA DAN TERTUTUP TERHADAP HASIL FUNGSI DAN BIOMEKANIK KAKI DALAM KALANGAN PESAKIT PEREMPUAN OSTEOARTRITIS LUTUT RINGAN PRIMER

ABSTRAK

Senaman merupakan intervensi bukan farmakologi utama yang disyorkan dalam pengurusan osteoartritis (OA) lutut. Antara kaedah senaman yang biasa digunakan ialah rantaian kinetik terbuka (OKC) dan rantaian kinetik tertutup (CKC), namun kesan perbandingan kedua-duanya terhadap hasil fungsi dan biomekanik anggota bawah masih belum jelas. Kajian ini bertujuan menilai kesan intervensi OKC dan CKC terhadap kesakitan, kualiti hidup (QoL), kekuatan otot, prestasi fungsi, dan biomekanik dalam kalangan individu yang mengalami OA primer lutut ringan. Seramai 66 peserta berusia ⩾50 tahun dengan OA simptomatik awal dan BMI antara 18.9 – 29.9 kg/m^2 di Putrajaya, Malaysia telah dibahagikan secara rawak kepada kumpulan OKC, CKC, atau kawalan. Semua peserta menjalani sesi fisioterapi permulaan dan diikuti program senaman di rumah selama lapan minggu. Kumpulan senaman menjalankan latihan tiga kali seminggu, manakala kumpulan kawalan menerima bahan pendidikan. Hasil utama termasuk skor kesakitan (VAS), ketidakupayaan (WOMAC), dan kualiti hidup (OAKHQOL); hasil sekunder menilai biomekanik semasa berjalan dan pergerakan duduk-ke-berdiri, serta kekuatan isometrik lutut. Analisis pasca intervensi menunjukkan kedua-dua jenis senaman memberi peningkatan yang ketara terhadap kesakitan, QoL, kekuatan otot, dan prestasi fungsi. CKC memberikan manfaat yang lebih dalam tugas dinamik, manakala OKC lebih sesuai bagi mereka yang mengalami sensitiviti kesakitan yang tinggi. Penemuan

ini menyokong penggunaan senaman OKC dan CKC yang disesuaikan dalam fisioterapi untuk meningkatkan mobiliti dan kualiti hidup pesakit OA lutut.

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ABSTRACT

Exercise is a key non-pharmacological intervention recommended for managing knee osteoarthritis (OA). Among the various modalities, open kinetic chain (OKC) and closed kinetic chain (CKC) exercises are commonly prescribed, yet their comparative effects on functional outcomes and lower limb biomechanics remain unclear. This study aimed to evaluate the impact of OKC and CKC interventions on pain, quality of life (QoL), muscle strength, functional performance, and biomechanics in individuals with primary mild knee OA. Sixty-six participants aged ⩾50 years with early symptomatic OA and BMI between 18.9 – 29.9 kg/m^2 in Putrajaya, Malaysia were randomly assigned to OKC, CKC, or control groups. All underwent an initial physiotherapy session, followed by an eight-week home-based program. The exercise groups trained thrice weekly, while the control group received educational materials. Primary outcomes included pain (VAS), disability (WOMAC), and QoL (OAKHQOL); secondary outcomes assessed gait, sit-to-stand biomechanics, and isometric knee strength. Post-intervention analyses showed that both OKC and CKC exercises significantly improved pain, QoL, muscle strength, and functional performance. CKC yielded greater benefits in dynamic tasks, whereas OKC was better tolerated by those with higher pain sensitivity. These findings support incorporating tailored OKC and CKC exercises into physiotherapy to enhance mobility and QoL in knee OA patients.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

The prevalence of knee osteoarthritis (OA) is estimated to affect 10-20% of Malaysia's adult population (Mohd Yusuf, Md-Yasin & Mohd Miswan, 2022). The prevalence of OA increased gradually in both low- and high-income countries and has affected over 303 million individuals worldwide (James et al., 2018). Specifically, the global prevalence rate of knee OA has reached 263 million people (James et al., 2018). According to the Global Burden of Disease Study, knee OA is expected to increase by 74.9% by 2050 globally (Steinmetz et al., 2023). According to the Malaysian Clinical Practice Guideline for Osteoarthritis management, “9.3% of adult Malaysians had knee pain, and more than half of those examined had clinical evidence of OA” (Ministry of Health, 2013). The prevalence of radiographic knee OA in Southeast Asia is about 35% and 31% in women and men, respectively (Fransen et al., 2011). The ageing population is expected to increase in both developed and developing countries from 1980 (e.g., 259 million people) to 2025 (e.g., 761 million people) (Tobi et al., 2017). Ageing is not only about the increased population of the elderly but also about their health, welfare, and quality of life (QoL) (Tobi et al., 2017). Knee OA commonly affects the elderly or even adults aged 40 years and above (Tobi et al., 2017). With an estimated 250% increase of the elderly aged 65 years and above in Malaysia, Singapore, India, Bangladesh, and the Philippines over the next three decades (Fransen et al., 2011), knee OA will significantly impact the healthcare system (Wilson & Abbott, 2019).

OA could affect any joint in the human body, but it commonly affects the knee, hands, hip, and spine (Kloppenburg & Berenbaum, 2020). The knee is the largest synovial joint and is most widely subjected to high stress as a weight-bearing joint (Mora et al., 2018). During walking, the knee endures forces three to six times the body weight due to biomechanical lever effects, and this amplified force significantly increases the risk of joint tissue damage (Berteau, 2021). Furthermore, aging, obesity, and trauma can lead to increased loading of the knee joint and biomechanical alterations (Martel-Pelletier et al., 2016). These factors can result in degeneration of the cartilage and subchondral bone, leading to frequent inflammation of the synovial tissue (Zeng et al., 2021). Hence, knee OA could result in significant mobility restrictions and a substantial financial burden. The typical clinical symptoms of knee OA include pain, stiffness, joint enlargement, crepitus, muscle weakness, deformity, impaired proprioception, reduced joint motion, and even affecting their normal daily activities and quality of life (Vos et al., 2012 & Steinmetz et al., 2023). Additionally, knee OA patients had a higher risk of falls compared to those without knee OA (Bozbas et al. 2017; Deng et al., 2021). Falls can severely impact elderly people which could cause disability or worse case death (Chen et al., 2019). Hence, prevention of OA development and progression is vital in reducing the risk of falls in elderly.

Early detection and intervention in knee OA could reduce further OA progression, such as the breakdown of the cartilage and bone (Brahim et al., 2019). Exercise treatment seems to be more effective in the early stage of knee OA before significant structural damage (Guermazi et al., 2012; Andriacchi & Favre, 2014; Bruyere et al., 2015; Prabhakar et al., 2020). Clinical guideline-recommended exercise as the crucial non-pharmacological management for knee OA (Nelson et al., 2014). In recent years, several studies found that exercises (e.g., land-based versus aquatic-based exercises, Taichi exercise which focuses on proprioception, weight-bearing and non-weight-bearing exercises) have positive effects on pain and functional movement improvement towards patients with OA (Juhl et al., 2014; Skou et al., 2018; Dong et al., 2018; Hu et al., 2020; Bennell et al., 2019; Williams & Pierre-Louis, 2023).

Exercise could improve muscle activity and strength, which helps support the movements during daily functional activities. The elderly with knee OA had higher risks of falls due to muscle weakness and reduced dynamic balance. This can seriously impact their physical activities, especially in squatting and stair climbing (Veerapen et al., 2007; Tobi et al., 2017). Hence, evaluating the effective treatment plan to improve their physical function and QoL is essential. However, the significant biomechanical effects of those exercises are still subtle, and further investigation towards biomechanical analysis is essential, particularly during gait and daily functional activity tasks (e.g., raising and sitting on a chair, stairs climbing, single leg stand).

The effectiveness of the open kinetic chain (OKC) and closed kinetic chain (CKC) exercises have been discussed in patients with knee OA. In the OKC exercise, the terminal segment of the body parts can move freely without being fixed on the ground. For example, the knee extension and straight leg raising. While in CKC exercise, the terminal segment of the body parts is fixed and stationary. Lower limbs CKC exercises include squats and leg presses. The effect of both exercises was comparable, and both were shown to improve pain scale, functional scores, and ROM (Adegoke et al., 2019). Twelve weeks of OKC, CKC, and combined kinetic chain exercises in 96 knee OA patients showed similar effects on the static and dynamic quadriceps strength and thigh muscle bulk (Olagbegi, Adegoke & Odole, 2017). However, no previous studies investigated the effects of OKC and CKC on biomechanical outcomes among mild knee OA patients. Therefore, this study aims to investigate the impact of OKC and CKC exercise on gait biomechanics and functional outcomes among mild knee OA patients.

1.2 Theoretical framework

Knee OA is a progressive joint disorder characterised by articular cartilage degeneration, leading to pain, stiffness, and reduced functional ability (Kloppenburg & Berenbaum, 2020). Effective management of knee OA requires an understanding of the biomechanical and functional impacts of kinetic chain exercises, which can be categorised into OKC and CKC exercises (Nahayatbin et al., 2018; Olagbegi, Adegoke & Odole, 2016). The selection of these exercises must consider patient-specific factors, including the severity of OA, pain perception, functional ability, and rehabilitation goals, to ensure optimal outcomes. OKC exercises involve isolated activation of specific muscles, such as the quadriceps, with the distal limb moving freely without contact with a surface, making them effective in improving muscle strength and joint stability, particularly in early-stage OA (Alkhudhir et al., 2019; Nahayatbin et al., 2018). However, they generate higher shear forces within the knee joint and lack the multi-joint engagement required for functional daily activities. This can increase the risk of joint instability and cartilage damage in advanced OA stages (Alkhudhir et al., 2019). CKC exercises involve weight-bearing movements with the distal limb fixed on a stable surface, promoting multi-joint engagement and muscle co-contraction to improve joint stability, reduce shear forces, and enhance joint alignment (Boccia et al., 2019; Adegoke et al., 2019). These exercises are particularly beneficial in moderate to advanced OA stages as they simulate functional daily activities, improve proprioception, and reduce the risk of falls and injury by promoting safer movement patterns (Alkhudhir et al., 2019). The severity of OA plays a pivotal role in determining the appropriate exercise therapy. Both OKC and CKC exercises can be incorporated into rehabilitation programs for individuals with early-stage knee OA. However, the choice of exercise should consider the patient's pain intensity, functional mobility, rehabilitation goals, and available equipment to ensure the exercises are both effective and well-tolerated (Nahayatbin et al., 2018).

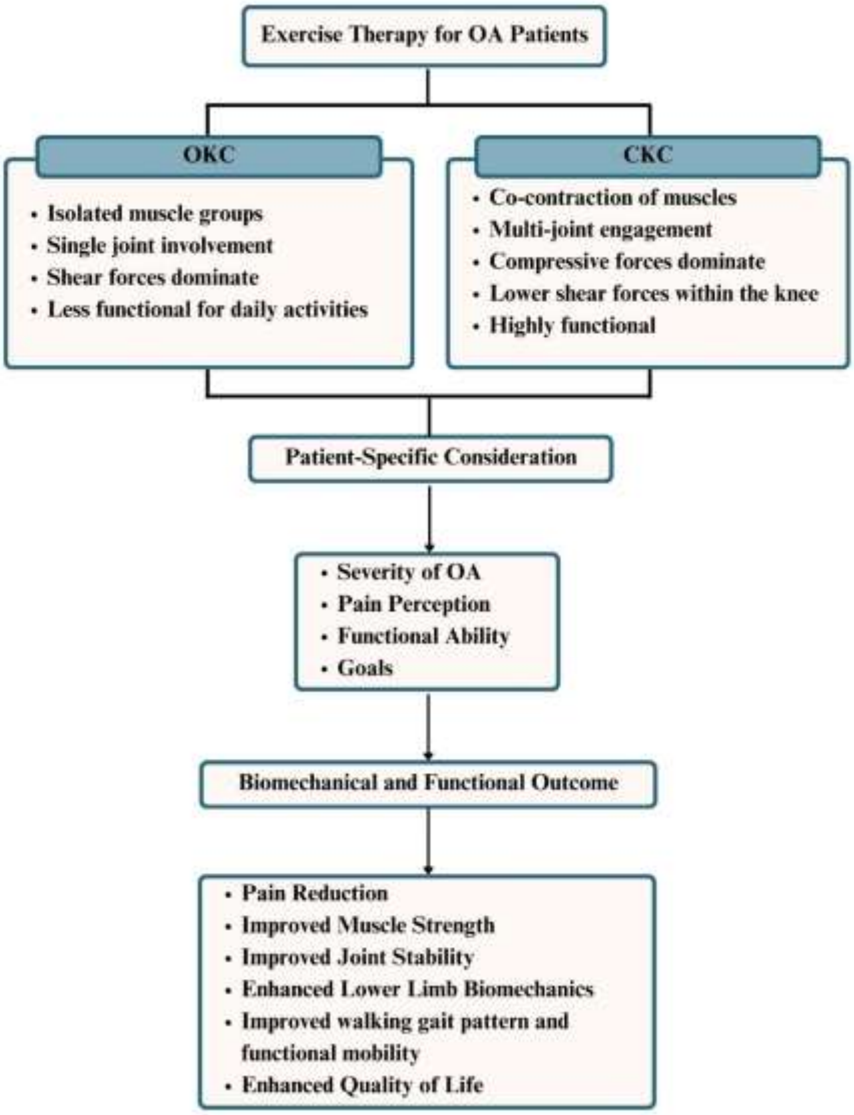


Figure 1.1 Theoretical Framework for Exercise Therapy in OA: Impact of OKC and CKC on Biomechanical and Functional Outcomes

As OA progresses to moderate and advanced stages, a shift toward CKC exercises is essential to reduce shear forces, improve joint stability, and enhance functional performance (Adegoke et al., 2019; Boccia et al., 2019). CKC exercises are particularly important for improving walking gait patterns, sit-to-stand transitions, and other functional movements that directly impact quality of life (Olagbegi, Adegoke & Odole, 2016). Ultimately, a well-structured exercise program tailored to each patient's pain perception, functional ability, and rehabilitation goals can lead to pain reduction, improved muscle strength, enhanced joint stability, and better lower limb biomechanics. By addressing the biomechanical demands of each OA stage through appropriate kinetic chain exercises, clinicians can not only reduce pain and functional limitations but also delay the progression of OA, improving QoL life for patients across the disease spectrum (Boccia et al., 2019; Nahayatbin et al., 2018).

1.3 Problem statement

Knee OA is a prevalent degenerative joint condition that significantly impairs physical function and quality of life (Mohd Yusuf, Md-Yasin & Mohd Miswan, 2022). It is characterised by pain, joint stiffness, and muscle weakness, which limit the performance of daily functional activities such as walking, standing, and sitting (Tobi et al., 2017). Given the chronic nature of knee OA, exercise therapy is widely recommended as a non-pharmacological intervention for managing symptoms and preventing disease progression (Wellsandt & Golightly, 2018). Exercise therapy is cost-effective and promotes self-management, making it a preferred choice among individuals with knee OA (Wellsandt & Golightly, 2018). Numerous studies have demonstrated that exercise therapy reduces pain, improves muscle strength, and enhances physical function (Juhl et al., 2014; Olagbegi et al., 2016; Skou et al., 2018). However, there is limited evidence on the effects of exercise on biomechanical outcomes during functional activities, particularly gait and sit-to-stand movements.

The exercise interventions commonly prescribed in knee OA rehabilitation are OKC and CKC (Nahayatbin et al., 2018; Olagbegi, Adegoke & Odole, 2016). OKC exercises involve movements where the distal limb moves freely in space, such as leg extensions, targeting isolated muscle groups (Nahayatbin et al., 2018). In contrast, CKC exercises involve movements where the distal limb is fixed, such as squats, promoting co-contraction of multiple muscle groups and enhancing joint stability (Dincer et al., 2016). Both exercise types have shown benefits in reducing pain, improving muscle strength, and enhancing joint function (Brenneman & Maly, 2018; Davis et al., 2019; DeVita et al., 2018). Despite these known advantages, the impact of OKC and CKC exercises on lower limb biomechanics during real-world functional tasks such as walking and sit-to-stand remains underexplored. Understanding these biomechanical effects is essential for developing personalised exercise interventions that address specific impairments and prevent further joint degeneration.

In clinical practice, physiotherapists conduct subjective and objective assessments of knee OA patients before initiating treatment. Subjective assessments focus on pain levels, onset, and the history of knee symptoms, while objective assessments involve observing functional tasks such as walking and sit-to-stand movements. Common functional tests in clinical settings include the Timed Up and Go (TUG) test, the Six-Minute Walk Test (6MWT), and the Five Times Sit-to-Stand (FTSTS) test, which provide insights into mobility, endurance, and lower limb strength. However, these tests rely heavily on therapists' experience and visual observation for the quality of those movements, making them prone to inaccuracies and inconsistencies. They lack the precision to assess dynamic joint movements and biomechanics during real-world activities.

Accurate assessment of lower limb biomechanics is critical for optimising physiotherapy strategies in knee OA patients. Current clinical assessment tools are often limited in providing objective data on joint movements during dynamic tasks, which can hinder the development of personalised exercise programs. There is a growing need for advanced biomechanical measurement methods that can provide precise and detailed kinematic data to improve the accuracy and effectiveness of clinical assessments. Two-dimensional (2D) biomechanical analysis is one such method that offers a practical, efficient, and patient-friendly way to track joint movements during functional tasks, providing valuable insights into dynamic kinematics in real-world scenarios (Schurr et al., 2017).

By incorporating 2D biomechanical analysis into clinical assessments, clinicians can enhance their ability to develop tailored physiotherapy strategies that address specific biomechanical deficits in knee OA patients (Schurr et al., 2017). This approach would enable more personalised exercise prescriptions, improve functional outcomes, and reduce the progression of joint degeneration. Despite the growing recognition of exercise therapy as a cornerstone of knee OA management, research focusing on the biomechanical effects of OKC and CKC exercises during functional tasks is still limited. Addressing this gap could improve clinical practice and contribute to more effective, evidence-based interventions.

This study investigates the biomechanical effects of OKC and CKC exercises on lower limb movements during functional tasks such as walking and sit-to-stand in individuals with mild-grade knee OA. The study seeks to enhance the precision of clinical assessments and physiotherapy outcomes by providing detailed insights into how these exercises influence joint kinematics. Ultimately, this research could contribute to developing more personalised and effective exercise interventions that improve the quality of life for individuals with knee OA and prevent disability progression.

1.4 Research Questions

1) How do open kinetic chain OKC and closed kinetic chain CKC exercises improve pain and quality of life in people with mild-grade knee OA?

2) How do OKC and CKC exercises improve muscle strength in people with mild-grade knee OA?

3) How do OKC and CKC exercises improve lower limb biomechanics during walking in people with mild-grade knee OA?

4) How do OKC and CKC exercises improve lower limb biomechanics during sit-to-stand in people with mild-grade knee OA?

1.5 Research Objectives

General Objectives

To investigate the effects of open kinetic chain (OKC) and closed kinetic chain (CKC) exercises on pain, quality of life, functional outcomes, and lower limb biomechanics in mild-grade knee osteoarthritis (OA) patients

Specific Objectives

a. To compare the effects of OKC versus CKC exercises on pain and quality of life in people with mild-grade knee OA.

b. To compare the effects of OKC versus CKC exercises in muscle strength in people with mild-grade knee OA patients.

c. To compare the effects of OKC versus CKC exercises on lower limb biomechanics during walking at self-selected speed in mild-grade knee OA patients.

d. To compare the effects of OKC versus CKC exercises in lower limb biomechanics during sit-to-stand in people with mild grade knee OA.

1.6 Statistical hypothesis

Hypothesis I

Null Hypothesis (HO1): There is no significant effect of OKC and CKC exercises on pain and quality of life in people with mild-grade knee OA.

Alternative Hypothesis (HA1): There is a significant effect between OKC and CKC exercises on pain and quality of life in people with mild-grade knee OA.

Hypothesis II

Null Hypothesis (HO1): There is no significant effect of OKC and CKC exercises on muscle strength in people with mild-grade knee OA.

Alternative Hypothesis (HA1): There is a significant effect of OKC and CKC exercises on muscle strength in people with mild-grade knee OA.

Hypothesis III

Null Hypothesis (HO1): There is no significant effect between OKC and CKC exercises on lower limb biomechanics walking at self-selected speed in mild-grade knee OA patients.

Alternative Hypothesis (HA1): There is a significant effect between OKC and CKC exercises on lower limb biomechanics walking at self-selected speed in mild-grade knee OA patients.

Hypothesis IV

Null Hypothesis (HO1): There is no significant effect of OKC and CKC exercises in lower limb biomechanics during sit-to-stand in people with mild-grade knee OA.

Alternative Hypothesis (HA1): There is a significant effect of OKC and CKC exercises in lower limb biomechanics during sit-to-stand in people with mild-grade knee OA.

1.7 Significance of the study

The present study potentially contributes to the understanding and management of knee OA, a common and debilitating condition affecting millions worldwide. Understanding the effects of OKC and CKC exercise on functional outcomes and biomechanics is crucial for designing effective treatment strategies. Additionally, this study will further investigate the effects of CKC and OKC exercises on the gait and sit-to-stand (STS) kinematics among knee OA patients, which can help elucidate the underlying mechanisms of action and potential differences between OKC and CKC exercises. Overall, this study addresses a significant gap in the literature by investigating the effects of OKC and CKC exercises on functional outcomes and lower limb kinematics in mild knee osteoarthritis patients, thereby advancing our understanding of optimal exercise interventions for this population.

By using a 2D biomechanical analysis of the knee, clinicians can gain a more comprehensive understanding of the biomechanics involved in various activities such as walking, getting up and down from a chair, and stair climbing. This detailed insight allows for better identification of abnormal movement patterns and biomechanical deficiencies contributing to knee injuries or dysfunction. Whereas, 2D biomechanical analysis provides an objective assessment tool for evaluating knee function. Quantitative data on joint angles and velocities help clinicians assess the efficiency and effectiveness of movement patterns, aiding in the diagnosis and monitoring of musculoskeletal conditions and the effectiveness of physiotherapy interventions.

Moreover, by identifying aberrant movement patterns or biomechanical risk factors early on, 2D biomechanical analysis enables clinicians to implement preventive measures to reduce the risk of knee injuries and prevent knee osteoarthritis to moderate and severe stages. This approach can be beneficial for all individuals particularly for older adults before the knee structure damage and the symptom could affect their functional activities and quality of life.

1.8 Operational definition

Open kinetic chain exercise: In open kinetic chain exercises, the distal segment of the lower limb is free and not fixed to any object.

Closed kinetic chain exercise: In closed kinetic chain exercises, the distal segment of the lower limb is fixed or stationary.

Mild knee osteoarthritis: Mild knee osteoarthritis includes grades I and II of the Kellgren-Lawrence classification, demonstrating doubtful and possible narrowing of the joint space with probable and definite osteophyte formation.

Primary knee osteoarthritis (OA) is caused by degenerative changes in the articulation cartilage of the knee, which result in ageing and wear and tear but are not caused by trauma.

Biomechanics: In this study, we focused on the two-dimensional (2D) kinematics (kinematics is a branch of classical mechanics that deals with the study of motion, specifically focusing on the movement of objects without considering the forces that cause the motion) of the trunk, hip knee, and ankle joints during walking and getting up and down from the chair.

CHAPTER 2

LITERATURE REVIEW

2.1 Osteoarthritis

Musculoskeletal disease is defined as a disease that affects the muscles, bones, joints, tendons, and ligaments (Sebbag et al., 2019). Osteoarthritis (OA) is a slowly progressive chronic disorder caused by degenerative changes in the articular cartilage, bone, meniscus, and synovium (Driban et al., 2020; Liukkonen et al., 2017). It can happen to any joint in the human body, but the knee is the most commonly affected joint (Jerban et al., 2020; Kloppenburg & Berenbaum, 2020). OA and lower back pain are the most known musculoskeletal diseases (Sebbag et al., 2019). Due to the low death rate and irreversibility of musculoskeletal disease, fewer people are taking it as an essential issue. Still, it tremendously impacts the patient's quality of life (QoL). OA has been discussed as a Serious Disease in the White Paper of the Osteoarthritis Research Society International (OARSI) as it significantly impacts the disease's economic burden to the patients and society (Kloppenburg & Berenbaum, 2020). Annual healthcare costs are approximately 1568 dollars for adults with OA and approximately 167 dollars for those without OA in the United States (US) (Zhao et al., 2019). Additional national total healthcare costs of around 23.3 billion dollars were needed for OA adults with no/mild pain interference activities (PIA) in the US, such as hospitalization, emergency visits, specialist clinic visits, and opioid use (Zhao et al., 2019). Also, the wage loss was about 1.3 billion dollars in OA adults with no/mild PIA, and higher in OA adults with moderate/severe PIA (2.2 million dollars) (Zhao et al., 2019). While in New Zealand, health care cost of OA was estimated to raise from NZ$199 million (2013) to NZ$370 million (2038), as annual total knee replacement (TKR) (Zhao et al., 2019).

The prevalence of knee OA globally has reached 263 million people (James et al., 2018), while in the Asian population, the prevalence of knee OA ranges from 13.1% to 71.1% (Zamri et al., 2019). The prevalence of OA is 10 % to 20 % of the elderly population in Malaysia (MOH, 2013). With the increase of both obesity rate and the elderly in Malaysia, the population possibly having knee OA condition will be increasing as well (Wilson & Abbott, 2019; Afolabi et al., 2019; Kamarudin et al., 2020). A survey done by Mat et al. (2019) in Malaysia found that the ethnic Malays (44.6%) had the highest prevalence of knee pain compared to Chinese (23.5%) and Indians (31.9%). Moreover, most previous studies in the Asian population stated that knee OA is commonly found in adults aged the 50s and older (Pal et al., 2016; Lee et al., 2015; Lee & Kim, 2017). The prevalence of knee OA in Asian countries is increasing annually, probably due to the rise of the ageing population and obesity (Zamri et al., 2019). In the US, approximately $108 billion in wages was lost, and almost $80 billion was spent on medical costs yearly due to knee OA (Lespasio et al., 2017). Knee OA contributes a significant burden to the economy and healthcare system.

2.2 Knee osteoarthritis

The knee joint bears most of the body weight daily during mechanical loading (Jerban et al., 2020). Older adults, active athletes with a meniscus injury, people with excessive body mass index (BMI), alteration in knee alignment, and history of knee trauma or injury could have higher risk factors of knee OA (Jerban et al., 2020). OA is commonly diagnosed by clinical presentation, physical examination, and radiographic imaging in most clinics and hospitals in Malaysia (Azmillah et al., 2013). However, early knee OA is not detected through radiographic images (Liukkonen et al., 2017), thus early-stage knee OA is diagnosed based on the signs and symptoms (Azmillah et al., 2013). The common signs and symptoms of knee OA are pain, morning stiffness, swelling, joint deformity, limited knee range of motion (ROM), muscle atrophy, crepitus of the knee joints, slow gait, and pain at the knee while climbing up or down the stairs (Azmillah et al., 2013).

Development and progression of knee OA often relate to ageing, knee trauma, obesity, and gender (Duffell et al., 2017). Patients with knee OA commonly suffer from pain and muscle weakness of the knee flexors and extensors (Culvenor et al., 2017). The decrease in muscle strength may then affect their gait biomechanics. For instance, older OA patients walked noticeably at a slower gait speed and reduced cadence relative to similar-age healthy adults (Duffell et al., 2017). In the frontal plane of gait, the biomechanical analysis found a reduction of hip ROM and higher knee adduction moment (KAM) in patients with OA (Duffell et al., 2017). This is an adaptation strategy to avoid the painful knee from weight-bearing, whereby knee OA patients tend to lean laterally towards the ipsilateral leg during gait to decrease the external hip adduction moment (Iijima et al., 2019). This proximal adaptation might cause weakness in hip abductors and lower back pain (Iijima et al., 2019). Higher KAM in knee OA patients may also increase the risk of OA progression and uneven load distribution within the knee joint (Foroughi et al., 2011; Hunt et al., 2020).

According to Lu et al. (2019), females had more morphological changes compared to males. As age increases, the femur and tibial axis in females are found to be more varus, and it causes the collapse of the medial tibial plateau (Lu et al., 2019). Hence, significant changes in the articular cartilage degenerate in females than in males (Lu et al., 2019). Generally, females have a higher prevalence than males in knee OA in an Asian country (Pal, et al., 2016). Mat et al. (2019) & Sasaki et al. (2020) found that OA symptomatic were correlated with the female gender. Specifically, in India and

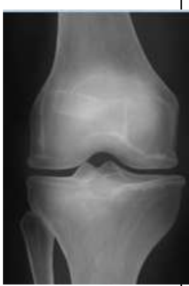
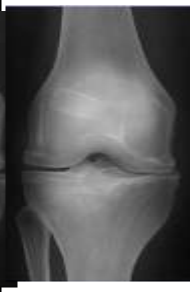
Korea, Venkatachalam et al. (2018) and Yoo et al. (2018) found that being female is strongly associated with OA and is a risk factor for knee OA. Similarly, in Malaysia, a few OA studies that run in Malaysia, all the demographic data are shown to have a higher number of female participants (83%, 66%) than male (17%, 34%) (Shafii et al., 2018; Foo et al., 2017). Knee OA was also highly correlated with being female and obese (Mat et al., 2019). Moreover, Yoo et al. (2018) stated that radiographic knee OA progresses faster in females (22.09%) than in males (3.33%). A study showed that females with knee OA have higher knee abduction and hip adduction than males with OA (Phinyomark et al., 2016). However, there is no difference between age-matched subjects with and without knee OA (Phinyomark et al., 2016). Therefore, this study will focus on analysing the effect of eight weeks of exercise intervention on the biomechanics of gait and functional tasks among female knee OA patients.

Vitaloni et al. (2019) concluded that knee OA had seriously impacted the individual's QoL, while females with knee OA had worse QoL than males. As knee OA progresses, patients complain that they suffer more episodes of pain and swelling, limited knee ROM, and muscle weakness (Lespasio et al., 2017). These symptoms could cause significant difficulties in daily function, such as prolonged standing or walking, climbing stairs and squatting or kneeling, feeling their knees giving way or less balance while standing on uneven surfaces (Vitaloni et al., 2019). These difficulties further limit the patients' social activities, which affects their mental health (i.e., stress, depression, isolation and loneliness). OA is the primary cause of locomotion impairment, especially in the elderly (18% in females, 9.6% in males) (Verlaan et al., 2018).

The clinical practice guideline of OA management in Malaysia suggests that knee OA can be clinically diagnosed according to the Classification of Idiopathic OA of the Knee Based on the American College of Rheumatology 1986 Criteria (Altman et al., 2013). According to the diagnostic criteria, a patient with knee pain, age more than 50, having joint stiffness of less than 30 minutes, having crepitus at knee joint movement, bony tenderness, and enlargement and palpable warmth can be diagnosed as having at least a mild knee OA (Altman et al., 2013).

The severity of knee OA can be detected by the anterior-posterior and lateral views of the radiographic images using the Kellgren–Lawrence (KL) grading (Kellgren & Lawrence, 1957). KL grading focuses on reducing joint space and osteophytes' formation around the knee joint's articulation cartilage (Kellgren & Lawrence, 1957; Liukkonen et al., 2017). Based on KL grading, OA is classified as grade I (doubtful), grade II (mild), grade III (moderate), and grade IV (severe) (Kellgren & Lawrence, 1957). KL grading is also commonly used by orthopaedic surgeons regarding the severity of the knee OA and before planning on any surgical intervention towards the patients (Abdelaziz et al., 2019). A detailed description with examples of the radiographic images is shown in Table 2.1.

Table 2.1 Kellgren Lawrence Grading for knee osteoarthritis (Kellgren & Lawrence, 1957)

Imaging					
Radiographic Grade	0	I	II	III	IV
Classification	Normal	Doubtful	Mild	Moderate	Severe
Description	No features of osteoarthritis	Minute osteophyte; doubtful significance	Definite osteophyte; normal joint space	Moderate joint space reduction	Joint space greatly reduced; subchondral sclerosis

Knee OA could progress within one year if no active intervention has been done (Driban et al., 2020). Driban et al. (2020) concluded that at least one in seven symptomatic OA knee OA Grade I patients may accelerate to knee OA Grade III or IV within 12 months. Exercise intervention was also found to be more effective in the early stage of knee OA than in a later stage when significant structural damage had happened (Guermazi et al., 2012; Bruyere et al., 2015). Thus, it is imperative to diagnose knee OA early and manage it in the early stage to delay the progression of knee OA. Furthermore, muscle weakness in the lower limbs could contribute to OA knee progression as the knee joint's stability is reduced (Shorter et al., 2019). Ageing is closely related to skeletal muscle mass reduction (i.e., sarcopenia), whereby the skeletal muscle mass could reduce by approximately one per cent yearly from the 50s (Wilkinson et al., 2018). Therefore, a decrease in muscle strength could cause instability and uneven load distribution in the knee joint during daily activities, and degenerative of the articular cartilage could progress even faster (Lu et al., 2019; Shorter et al., 2019).

As knee OA progresses until the end stage, patients will need invasive surgery to replace the articular cartilage's severe damage, called total knee replacement (TKR) surgery (Tiulpin et al., 2019). The surgery is very costly, and its effectiveness is not guaranteed in terms of physical function and QoL (Tiulpin et al., 2019). Management of OA could be a significant economic and healthcare burden globally (Kloppenburg & Berenbaum, 2020). Hence, it is imperative to slow down the progression of knee OA from the early stage before cartilage damage.

Moreover, patients with knee OA are also found to have an increased risk of falls, and it could cause a fracture, brain injury, functional limitation, fear of falls, a rise in medical cost, and even death (van Schoor et al., 2020). Hence, it is essential to have a treatment plan to prevent those disabilities in the elderly population globally. As the prevalence of knee OA rises gradually every year, primary care prevention plays a vital role in knee OA awareness, lifestyle modification, weight reduction, increased strengthening activities, and physical activities (Zamri et al., 2019). Exercise should be prescribed in the early stage of knee OA to delay the OA progression before articular cartilage starts to damage (Roos & Arden, 2016).

2.3 Exercise intervention in knee osteoarthritis

Exercise intervention is usually conducted in the hospital or physiotherapy clinic with supervision by the physiotherapists. However, some patients might face logistics and time constraints in attending the exercise sessions (McKnight et al., 2010). Moreover, long-term hospital care will increase the burden of medical resources (Bennell & Hinman, 2011). Hence, physiotherapy exercise sessions could move from the hospital to other settings, such as at home and in community settings (Chen et al., 2019). Previous studies showed that self-management home-based exercise and supervised exercise successfully reduced pain scores and improved physical function in patients with knee OA (Çolak et al., 2017; Safari et al., 2020). Patient education was also crucial to ensure exercise compliance and long-term self-management at home (Skou et al., 2018).

Home-based exercises are fundamental to maintaining long-term outcomes and promoting self-management toward the condition (Anwer, Alghadir & Brismée, 2016; Page et al., 2011). From Malaysian OA patients' perspective, home exercises that were taught during the physiotherapy session were essential (Ahmad et al., 2018). They believe that home exercise could delay the worsening of their condition, and improve their pain and daily functional activities level (Ahmad et al., 2018). 83% of the OA adults are compliant with the home exercises because they feel better about the exercises (Ahmad et al., 2018). However, the significant challenges faced by physiotherapists and OA adults are the continuity of the home-based exercises beyond the supervision period and adherence to the home-based exercise. Hence, this study investigates the eight weeks of OKC and CKC home-based exercises among female patients with mild knee OA.

2.4 Open and closed kinetic chain exercise

Exercise improved pain and function in knee OA adults compared to none or minimal treatment (Verhagen et al., 2019). However, the type of exercise most suitable or effective for improving pain, strength, and function and preventing knee OA progression is still questionable. Simple home-based exercise is vital for maintaining compliance and ensuring the long-term effectiveness of home-based strengthening exercises in elderly individuals with knee osteoarthritis (Jansons et al., 2018). The elderly at home might find difficulty in those exercises that need a pool, weight cuffs, dumbbells, and other special techniques. Furthermore, both OKC and CKC strengthening exercises with simple objects at home could be easy and practical for them to practice at home. A survey by D'Gasper et al. (2018) showed that most of the elderly aged 50 to 80 with knee OA in Malaysia could continue the exercise at home if exercise is taught by verbal instruction, demonstration, and pamphlets with diagrams. Hence, CKC and OKC exercises can be practical strengthening interventions for knee OA patients in Malaysia. Patient education regarding the awareness and importance of strengthening exercise is also crucial in improving pain, function, and self-management in elderly knee OA patients (Gay et al., 2016).

Both OKC and CKC exercises are commonly prescribed in the strengthening exercise regime for knee OA adults (Nahayatbin et al., 2018; Olagbegi, Adegoke & Odole, 2016). OKC exercise (Figure 2.1), such as knee extension in sitting, and straight leg raising in lying position, is an exercise in the distal end that is freely moving, non-weight bearing, and involves only a single joint (Figure 2.2) (Boccia et al., 2019). Whereas, CKC exercise (Figure 2.3), such as squatting, step-up and step-down exercises, is the exercise that the distal end is fixed, frequently related to weight-bearing and involved with multiple joints (Figure 2.4) (Boccia et al., 2019).

A.

B.

Figure 2.1 Examples of open kinetic chain exercises A. knee extension exercise in sitting and B. straight leg raising exercise in lying position

Figure 2.2 Open kinetic chain

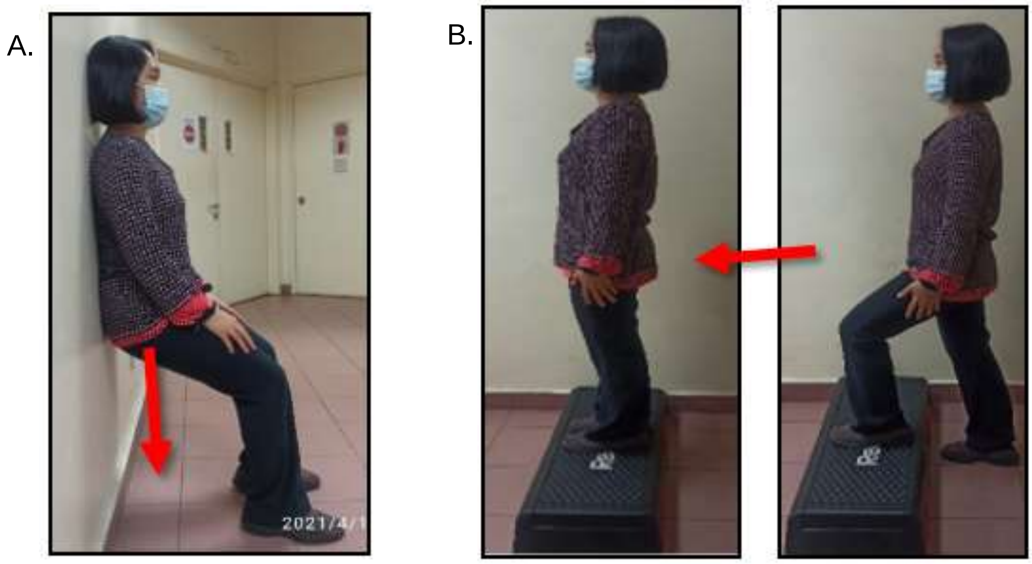


Figure 2.3 Examples of closed kinetic chain exercises A. Wall slide and B. Step-up and step-down exercise

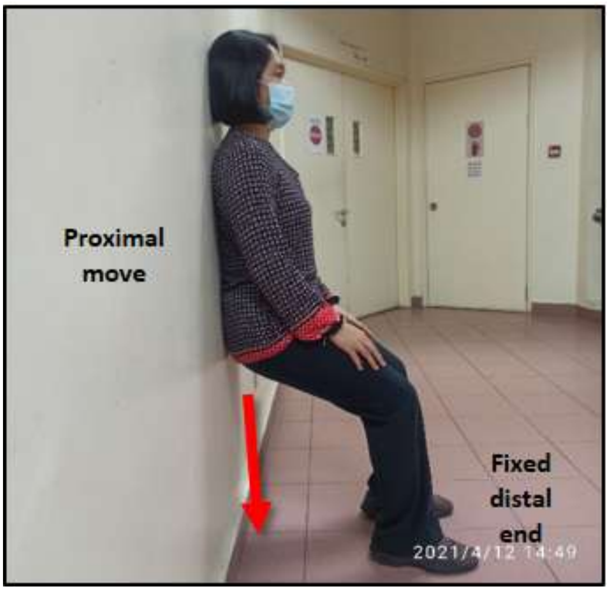


Figure 2.4 Closed kinetic chain

Previous studies on knee OA often discuss the effects of OKC and CKC exercises on pain, range of motion (ROM), muscle strength, muscle bulk, and functional scores (Adegoke et al., 2019; Alkhudhir et al., 2019; Nahayatbin et al., 2018; Olagbegi, Adegoke & Odole, 2016). In particular, studies by Dincer et al. (2016), Olagbegi et al. (2016), and Özüdoğru and Gelecek (2023) have demonstrated the effectiveness of OKC and CKC exercises in improving pain relief, functional mobility, and muscle power in knee OA patients. These findings show that both exercise modalities can enhance lower limb function and alleviate symptoms associated with knee OA. However, studies assessing the impact of these exercises on lower limb biomechanics are relatively limited. Most biomechanical analyses have focused on general progressive strengthening exercises rather than specifically evaluating OKC and CKC interventions (Brenneman & Maly, 2018; Davis et al., 2019; DeVita et al., 2018; Olagbegi, Adegoke & Odole, 2017).

The majority of previous biomechanical studies have concentrated on gait analysis, leaving a gap in understanding how OKC and CKC exercise impact biomechanics during essential daily functional tasks, such as sit-to-stand, stair climbing, and single-leg stance (Brenneman & Maly, 2018; Davis et al., 2019; DeVita et al., 2018). According to research by Nahayatbin et al. (2018) and Olagbegi, Adegoke, and Odole (2017), CKC exercises improve pain and functional performance in dynamic movement tasks. Similarly, Dincer et al. (2016) observed that CKC exercises and physiotherapy modalities positively influence pain and physical function, even though no significant change was noted in cartilage volume. Despite these findings, the biomechanical aspects of these exercises during transitional movements, such as sit-to-stand, remain underexplored. Furthermore, the study by Özüdoğru and Gelecek (2023) highlights that CKC exercises are safer and more beneficial for low-grade knee OA patients, especially for improving muscle strength and reducing stiffness during functional tasks. The limited attention to biomechanical analysis during daily functional activities presents a significant research gap. While the studies by Adegoke et al. (2019) and Olagbegi, Adegoke, and Odole (2016) provide evidence that OKC and CKC exercises offer comparable benefits in pain reduction and ROM improvement, there is