EFFECT OF CLOSED KINETIC CHAIN AND WEIGHT SHIFTING EXERCISES ON POSTURAL STABILITY IN UNILATERAL POST MASTECTOMY LYMPHEDEMA

BY

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CHAPTER I
INTRODUCTION

Mastectomy often results in a decline in physical fitness, balance impairments, and upper limb lymphedema, all of which significantly impact stability in women post-surgery. This procedure can drastically affect body posture and overall physical performance. The adverse changes caused by breast removal frequently disrupt spinal and shoulder girdle alignment, shift the body's center of gravity, and impair stability **(Zabojszcz et al., 2022)**.

One of the most common complications following mastectomy is unilateral post-mastectomy lymphedema, a pathological condition characterized by chronic tissue swelling due to impaired lymphatic drainage. This condition commonly occurs because surgical procedures often involve lymph node removal in one or both upper extremities. The primary cause of lymphedema is the reduced ability to process lymph fluid in the axillary region of the affected side **(Ha et al., 2017)**. Post-mastectomy lymphedema significantly impacts the quality of life, as it involves the accumulation of protein-rich fluid due to lymphatic vessel damage or obstruction, typically caused by lymph node dissection or surgery **(Saafan et al., 2018)**. Breast cancer-related lymphedema (BCRL) results from the surgical disruption of lymphatic pathways. This condition can be further exacerbated by soft tissue fibrosis resulting from inflammation, infection, radiation, or chemotherapy, leading to additional damage to the lymphatic system. These impairments in upper body function can contribute to postural instability and balance challenges **(Crosbie et al., 2010)**. Maintaining balance, whether static or dynamic, is vital for performing daily and physical activities **(Elsayeh et al., 2018)**.

Postural stability, a critical component of balance, is the ability to control the body's center of gravity (COG). Postural sway, defined as any deviation of the COG on a supporting surface, is an indicator of stability and can be measured using a force platform. Various factors, including sensory-motor system impairments and weight asymmetry caused by conditions such as amputation or unilateral upper-body volume changes, can increase postural sway and compromise stability. Postural instability associated with unilateral post-mastectomy lymphedema has profound implications, including workplace challenges, difficulty in performing daily activities, and barriers to employment **(Saafan et al., 2018)**. Patients experiencing reduced balance or postural instability after injury may exhibit diminished proprioceptive and kinesthetic feedback and/or muscular weakness. These deficits hinder their ability to execute effective corrective responses when equilibrium is disrupted **(Prentice et al., 2024)**.

In addressing postural instability, closed kinetic chain (CKC) exercises are particularly effective. These exercises involve movements where the distal limb, such as the foot or hand, is fixed to a stationary object while the proximal segments move freely (DESAI et al., 2021). CKC exercises incorporate simultaneous isometric, concentric, and eccentric contractions across various muscle groups within the kinetic chain, promoting functional strength and stability **(Prentice et al., 2024)**.

Also, dynamic postural control often requires lateral weight-shifting ability, a crucial component of daily activities. Lateral weight shifting, commonly performed in standing tasks, can be encouraged by having individuals practice on an inclined surface. Research has shown that healthy individuals experience a leaning aftereffect when transitioning from standing on an inclined surface to a horizontal one, indicating adaptability in postural control mechanisms **(Inoue et al., 2021)**.

So, Integrating CKC exercises with weight-shifting activities can enhance balance and stability, offering a comprehensive approach to improving postural control in individuals affected by post-mastectomy lymphedema and related conditions.

Statement of the problem:

Are closed kinetic chain and weight shifting exercises effective on postural stability in unilateral post mastectomy lymphedema?

Purpose of the study:

The purpose of the study is to investigate the therapeutic effects of closed kinetic chain and weight shifting exercises on postural stability for unilateral post mastectomy lymphedema.

Significance of the study:

Post-mastectomy lymphedema is one of the most common chronic complications that significantly impacts patients' quality of life following breast cancer surgery. When untreated, it can lead to chronic inflammation, cellulitis, pain, stiffness, and a restricted range of motion due to swelling and structural changes in the affected limb. Additionally, biomechanical alterations in the thoracic and shoulder regions often exacerbate upper body impairments, resulting in postural instability and balance challenges **(Saafan et al., 2018)**.

Hence, postural stability is maintained through the intricate integration of muscular forces, sensory input from mechanoreceptors, and biomechanical feedback. This stability is essential for achieving balance and for acquiring or reacquiring complex motor skills critical for daily activities and functional movement **(Prentice et al., 2024)**.

Furthermore, closed kinetic chain (CKC) exercises play a crucial role in enhancing musculoskeletal stability by countering gravitational forces during both rest and movement. These exercises are particularly effective in promoting postural stability by facilitating coordinated muscle activation and joint stabilization **(Selvaraj et al., 2019)**.

In addition, weight shifting and balance are fundamental components of functional movement. Proprioceptive training, which focuses on improving body awareness and balance, is essential for developing trunk control. Activities performed on unstable surfaces have been shown to enhance proprioception and body position awareness, leading to improved stability and balance during dynamic activities **(Jung et al., 2014)**.

Therefore, integrating CKC exercises with weight-shifting and proprioceptive training offers a comprehensive approach to improving postural stability and functional outcomes in individuals with post-mastectomy lymphedema by addressing the interplay among these factors.

Thus, the significance of the study lies in its investigation of the combined therapeutic effects of CKC and weight-shifting exercises as a potential strategy for enhancing postural stability and overall functional outcomes in patients with unilateral post-mastectomy lymphedema. By addressing the challenges of postural instability and balance deficits, this study aims to contribute to the development of more effective rehabilitation interventions, ultimately improving the quality of life for affected individuals.

Delimitations:

This study will be delimited in the following aspects:

1. Subjects:

Sixty female patients with unilateral post mastectomy lymphedema will be randomly divided into four equal groups in number, each one has 15 patients.

2. Equipment and tools:

2.1. Measurement equipment:

2.1.a. Kinesis Balance™ fall prevention app: smartphone-based machine learning algorithm for assessing standing balance (**Greene et al., 2021)**.

2.1.b. **Time up and go (TUG) test:** for assessing dynamic balance and gait efficiency **(Tomar et al., 2024)**.

2.1.c. **Functional reach test:** for assessing Functional reach and dynamic balance **(Alahmari et al., 2021)**.

2.2. Therapeutic equipment and tools:

2.2.a. Closed kinetic chain exercises.

2.2.b. Weight shifting exercises.

Hypothesis:

It will be hypothesized that:

Closed kinetic chain and Weight shifting exercises have no significant effect on postural stability in unilateral post mastectomy lymphedema.

Basic Assumptions:

It will be assumed that:

- All patients will continue in the study.
- All patients will follow the instructions during the treatment.
- All patients will be informed about and understood the details of the research procedure.
- All patients enrolled in the study will have their informed consent.
- The clinical methods of measurement will be reliable and valid.

Definitions of terms:

The following terms are defined for the clear understanding of the terminology that will be used in the present study:

1. **Closed kinetic chain exercises (CKC):**

Closed kinetic chain exercise is a movement where the distal part is fixed, as when the sole of the foot makes contact with the ground or the exercise equipment. With the distal part fixed, movement at any one joint in the kinetic chain requires motion as well at the other joints in the kinetic chain. Thus, both proximal and distal parts receive resistance training at the same time. In the case of the lower limb, CKC exercises are more functional, as weight bearing is, by definition, a closed kinetic chain activity of the lower limb. CKC exercise has been cited as producing superior eccentric contraction and co-contraction of muscles, as well as reducing shear forces while adding compressive forces to the joints, thereby enhancing joint stability (**Kwon et al., 2013)**.

2. **Lymphedema:**

It is the accumulation of protein rich fluid due to damage and obstruction in lymphatic vessels that can cause tightness, fullness, heaviness, paresthesia in the affected side and disturb the posture **(Babasaheb et al., 2021).**

3. **Mastectomy:**

Mastectomy is an operation to remove the breast tissue and related lymph node tissue invaded by cancer cells. It is an appropriate oncologic surgery for women with established breast cancers (**Ji et al., 2023).**

4. Postural stability:

Postural stability is a complex process that depends on both visual and proprioceptive input to maintain equilibrium (balance) and keeps the body upright. Accordingly, the terms balance and postural stability may be used interchangeably. Balance requires tension produced by muscle activity and involves the communication of automatic postural and voluntary motor commands of both the trunk and limbs **(Ryan et al., 2010)**.

5. Weight shifting exercises:

It is the ability to transfer body weight from one leg to the other, it is a basic aspect of human locomotion and everyday activities (**de Rond et al., 2023)**.

Weight-shifting constitutes an important component of dynamic postural control which refers to the ability to keep one's bodyweight within the base of support (**Tsaklis et al., 2012)**.

CHAPTER II
REVIEW OF RELATED LITERATURES

The review of the related studies and literatures of the main concept of this study will be presented under the following headings:

1. Mastectomy

1.1-Definition:

Mastectomy is a surgical removal of the breast glandular tissue (BGT) with the aim of removing all in-breast neoplasia and/or glandular tissue. Surgical resection plays a fundamental role in breast cancer treatment to remove the tumor with some axillary lymph nodes and prevent recurrence of the disease **(Surmeli and Cinar Ozdemir., 2022)**.

1.2-Types: (Kaidar-Person et al., 2021)

1.2.a- Simple (or total) mastectomy:

Consists of removal of all the breast tissue, the skin of the breast the nipple and the areola (the dark area around the nipple).

1.2.b- Modified radical mastectomy:

Includes complete removal of the breast, breast skin-envelop, and underlying fascia of the major pectoral muscle, along with the removal of the level I and II axillary lymph nodes.

1.2.c- radical mastectomy:

Removal of the breast tissue, the overlying skin, the pectoral muscles (major, minor and fascia), and regional lymphatics (axillary level I, II, and III nodes).

1.2.d- Nipple-sparing mastectomy:

All of the breast tissue is removed, but the nipple, areola, and the skin of the breast is left intact.

1.2.e- Prophylactic (risk-reducing) mastectomy:

Is done to reduce the risk of developing breast cancer in someone who is at high risk. A prophylactic mastectomy is usually done as a bilateral simple (or total) mastectomy, nipple-sparing mastectomy, or skin-sparing mastectomy. Most often, your lymph nodes will not be removed.

1.3-Complications:

Postural changes are a major complication following unilateral mastectomy, leading to various physical, social, psychological, and functional issues such as shoulder pain, axillary web syndrome, muscle contracture, restricted range of motion, lymphedema, depression, anxiety, and a decreased quality of life. The extensive tissue damage in the thorax, particularly from large incisions involving the axilla and chest, creates significant scarring, which negatively impacts the mechanical properties of the skin. This can result in tissue shortening, loss of flexibility, and limited upper limb movement, all of which contribute to altered posture. Additionally, changes in the biomechanical properties of the scapula and related joints may lead to anterior tissue alterations, further affecting posture. The presence of lymphedema exacerbates these changes, as increased limb volume and weight add to the postural shifts. Furthermore, weight asymmetry in the upper trunk, resulting from mastectomy, radiation fibrosis, and muscle contraction in the cervical and scapular regions—often triggered by emotional stress, also plays a significant role in underlying posture disorders **(Surmeli and Cinar Ozdemir., 2022)**.

2. Lymphedema:

2.1-Definition:

Breast cancer related lymphedema (BCRL) results from disruption of the lymphatic system. This prevents adequate drainage that allows lymph fluid to accumulate in the interstitial space. BCRL has been defined as a 2- cm increase in

limb circumference, a 200- mm increase in limb volume, or a 5% to 10% change in limb volume as compared to the unaffected arm **(McEvoy et al., 2022)**.

Lymphedema arises from congenital malformations or damage of the lymphatic system. It is an indicator of damaged lymphatic transport that causes accumulation of tissue fluid in the interstitium, and results in an increase in the volume and the weight of the limb **(Surmeli and Cinar Ozdemir, 2022)**.

2.2-Classification:

It is classified in two main groups: primary and secondary lymphedema. However, secondary lymphedema is more common and is often related to trauma, infection, cancer, radiation, or surgical interventions regarding the lymphatic structure **(Surmeli and Cinar Ozdemir, 2022)**.

2.3- Stage and severity of lymphedema:

The four stages of lymphedema based on the International Society of Lymphology are described as follows: Stage 0 is subclinical with no visible changes. Stage 1 is mild and soft edema pits, has no dermal fibrosis, and subsides with limb elevation. Stage 2 is moderate with loss of elasticity and evolution of dermal fibrosis and no decrease in swelling with arm elevation. Stage 3 is chronic and irreversible **(McEvoy et al., 2022)**.

The severity of lymphedema is categorized as mild (<20% increase in extremity volume), moderate (20-40%), or severe (>40%). Limb volume measurements can be made using a tape measure, perometer, or by water displacement. **(Greene and Goss., 2018)**.

3.4. Symptoms of lymphedema

According to **(Rivere and Klimberg, 2018)**, symptoms of lymphedema include:

- Changes in skin texture or appearance, such as tightness, itching, rash, redness, or hardening.

- Tingling, discomfort, or increased warmth in the arm, hand, breast, chest, or underarm.
- Sensation of fullness or heaviness in the arm, hand, breast, chest, or underarm tightness.
- Decreased flexibility in nearby joints, such as the shoulder, hand, or wrist.
- Veins or tendons in the hand that are harder to see, knuckles that look less pronounced, or once-wrinkled skin that looks smoother.

2.5. Management of lymphedema:

The basic principles of lymphedema treatment are patient education, reduction or protection of lymphedema volume, and control of diseases that may increase lymphedema. In the current literature, complex decongestive therapy (CDT) is accepted as an international standard conservative treatment method for the treatment of lymphedema. CDT includes skin care, manual lymphatic drainage, compression bandages, compression garments and exercises **(Bilek et al., 2023)**.

3. Postural stability and Postural changes in unilateral post mastectomy lymphedema:

3.1-Definition of postural stability:

Postural stability, also referred to as balance, is the ability to control the center of mass (CoM) in relationship to the base of support. The nervous system generates forces to control the motion of the CoM. The center of pressure (CoP) is the center of distribution of the total force applied to the base of the support. Postural control involves controlling the body's position in space for the dual purposes of stability and vertical orientation of the posture, due to use of multiple sensory references – vestibular, somatosensory, and visual system **(Sipko et al., 2021)**.

Postural stability is one of the most important components for normal function, and it is necessary in daily activities such as walking or climbing stairs. The maintenance of postural stability reflects the contribution of many different joints and muscles manifests as postural sway. While lymphedema is a common health problem of women who suffer from breast cancer that affects their functional status negatively **(Angin et al., 2014)**.

3.2-Postural changes in unilateral post mastectomy lymphedema:

Surmeli and Cinar Ozdemir (2022) highlight the interconnected nature of the human skeleton, where abnormalities in one area led to compensatory adjustments in others to maintain body balance. These postural alterations primarily occur in the transverse, sagittal, and frontal planes. Common changes include shoulder protraction, upper back flexion, anterior translation of the head, and anterior trunk inclination, especially following mastectomy-related surgeries. These alterations result from an imbalance between muscle groups, leading to anterior trunk inclination and thoracic kyphosis.

On the spine, the spinous processes of vertebrae tend to shift in the vertical direction, with this change being more prominent in the T1-T6 vertebrae in younger individuals, and from the T7-T12 vertebrae in the elderly. Additionally, trunk rotation and shoulder protraction occur on the dominant side, particularly after mastectomy. This alteration leads to a greater trunk rotation angle, more noticeable changes in spinal alignment, increased scapula and shoulder asymmetry, and a larger pelvic tilt angle **(Liu et al., 2024)**. Unilateral lymphedema also causes greater asymmetry between the acromion and the major trochanter, contributing to further trunk rotation **(Bilek et al., 2023)**.

Patients with lymphedema exhibit increased postural sway, indicating poor postural stability. Notably, there is a significant increase in the range of postural sway during unilateral stance with eyes closed on the contralateral side, compared to the

ipsilateral side. This is due to the increased volume and weight of the affected upper extremity, leading to a significant displacement of the center of gravity (CoG) towards the ipsilateral side during bilateral stance tests **(Angin et al., 2014)**.

4.Closed kinetic chain exercises (CKC):

4.1-Definetion:

The term "kinetic chain" is used to describe how the body moves, with the limbs functioning either in an open kinetic chain (OKC) or a closed kinetic chain (CKC) condition. The difference between these two conditions is determined by whether the terminal ending of the limb is free or fixed **(Kim et al., 2017)**. CKC exercises are those exercises that emphasize a weight-bearing component to the movement. Closed chain exercises allow the distal segment of the extremity to be fixed. Motion results from movement of the proximal segment over the fixed distal segment **(Nadeem et al., 2022).**

4.2- Kinetic Chain Concept:

The human body is a multisegmented system consisting of many skeletal levers that are linked together by a series of joints, interactive through muscle action, and coordinated through central nervous system (CNS) mechanisms. Together these systems make up the human kinetic chain. The CNS has the ability to control all active, skilled, purposeful movement patterns. Thus, the CNS is considered the first link in the kinetic chain **(Nadeem et al., 2022)**.

4.3- Principles of CKC exercises:

Closed-chain exercises involve movements where the body moves on a distal segment that is fixed or stabilized on a support surface. Movement at one joint leads to simultaneous motion at both distal and proximal joints in a predictable manner.

These exercises stimulate joint and muscle mechanoreceptors, facilitate co-activation of agonist and antagonist muscles (co-contraction), and ultimately enhance dynamic stability. Additionally, closed-chain exercises provide greater proprioceptive and kinesthetic feedback since multiple muscle groups crossing various joints are activated. This activation generates more stress on bones, which promotes osteogenesis, and stimulates more sensory receptors in muscles and both intra-articular and extra-articular structures, thereby improving balance and postural control **(Thabet et al., 2017)**.

CKC exercises lead to muscular co-contraction, resulting in improved stability. They require coordination and co-contraction of anti-gravity muscles, which enhances muscle power, particularly in the lower extremities **(Suryawanshi et al., 2022)**.

However, CKC exercises activate antagonistic muscle groups across multiple joints, which means they cannot be used to isolate or target a single muscle group (Kim et al., 2017). These exercises are designed to replicate the forces and motions involved in walking, running, stair climbing, and other activities of daily living. A common example is the squat, where an individual simultaneously flexes the hips and knees while standing to lower their body weight over their feet. This movement mimics the actions of sitting down and rising from a chair. During this exercise, co-contraction of muscles such as the quadriceps, gastroc-soleus, and gluteals helps coordinate movement across multiple joints, including the ankle and knee joints **(Nadeem et al., 2022)**.

4.4-Types of CKC exercises:

Closed kinetic chain exercises included leg press in horizontal position, bicycling, Stairmaster climbing, Wall sits exercise, Squatting lunges exercise. Examples of CKC exercises include push-ups, pullups, squats, and lungs. All types of CKC exercises can be performed with or without weights. **(Thabet et al., 2017)**.

5. Weight shifting exercises:

5.1- Definition:

Weight-shifting is a critical element of dynamic postural control, which involves maintaining one's body weight within the base of support. As individuals age, their ability to perform weight-shifting becomes slower and less accurate **(de Rond et al., 2023)**.

Maintaining posture under dynamic conditions requires the capacity for lateral weight-shifting, which is frequently involved in many activities of daily living. One technique to encourage weight shifting in a specific direction is by having an individual stand on an inclined surface. Research shows that healthy individuals exhibit a leaning aftereffect when transitioning from an inclined surface to a horizontal one **(Inoue et al., 2021)**.

5.2- Weight-shifting concept:

Weight-shifting training-induced neural activation changes would be apparent mostly in the hemodynamics of the frontal and motor areas of the brain, in line with previous studies. Brain activation pattern during a mediolateral weight-shifting task in older and young adults, showing increased brain activity with age, particularly in the prefrontal cortex (PFC), supplementary motor area (SMA) and somatosensory cortex (SSC). More specifically, as we previously found the PFC to be highly involved in weight-shifting task, we expected a rise in cortical HbO2 levels directly after training and a lowering at retention indicating an increase of neural efficiency **(de Rond et al., 2023)**.

CHAPTER III

SUBJECTS, MATERIALS AND METHODS

In this part of the study, the materials and methods will be presented under the following headings: subjects, equipment, procedures of the study and statistical procedures.

1- Subjects:

Sample size calculation

Sample size calculation was done using Anteroposterior stability index, as reported in (Elsayeh et al, 2018), with 95% power at α = 0.05 level, number of measurements 2, for 4 groups and effect size = 0.6 using F-test MANOVA repeated measures within and between interaction. The minimum proper sample size is 52 subjects, adding 8 subjects (15%) as drop out, so total sample size is 60 subjects, 15 subjects in each group. The sample size was calculated using G*Power software (version 3.0.10) (figure 1).

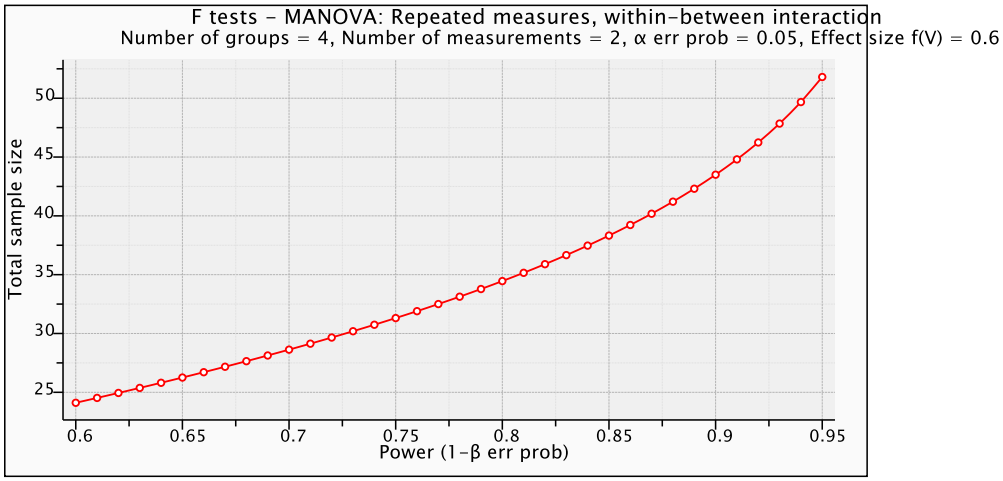


Figure (1): sample size calculation

Sixty patients who have unilateral post mastectomy lymphedema will participate in this study. Their ages will range from 40 to 60 years. The patients will be subdivided randomly into four equal groups by using simple randomization technique 1:1 ratio to four equal groups according to sample size calculation (15 patients for each group). The allocation will be performed with a blinded investigator using sealed opaque envelopes including a code for each group to avoid allocation bias. They will be selected from the Outpatient Clinic of Faculty of Physical Therapy, Cairo University and Alexandria oncology center.

All participants were informed about nature and the effect of measurement and treatment methods and have signed the informed consent which includes their agreement to participate in the study **(Appendix I)**. They were instructed to report any side effects during management.

1.1- Design of the study:

The study will be four-armed, single-blind (assessor), parallel-group, randomized control trial.

1.1.a- Group A (n= 15) (CKC group):

This group will include 15 patients who will receive closed kinetic chain exercises, in addition to complex decongestive therapy (CDT) for the treatment of lymphedema. CDT includes (skin care, manual lymphatic drainage, compression bandages, compression garments and exercises). The total exercise time will be 30 minutes, three times per week for eight weeks.

1.1.b- Group B (n= 15) (WS group):

This group will include 15 patients who will receive weight shifting exercises, in addition to complex decongestive therapy (CDT) for the treatment of lymphedema. The total exercise time will be 30 minutes, three times per week for eight weeks.

1.1.c- Group C (n= 15) (Combined group):

This group will include 15 patients who will receive closed kinetic chain and Weight shifting exercises, in addition to complex decongestive therapy (CDT) for the treatment of lymphedema. The total exercise time will be 60 minutes; 30 minutes of

CKC and 30 minutes of WS exercise three times per week for eight weeks.

1.1.d- Group D (n= 15) (control group):

This group will include 15 patients who will receive complex decongestive therapy (CDT) for the treatment of lymphedema. CDT includes (skin care, manual lymphatic drainage, compression bandages, compression garments and exercises).

1.2 Criteria for the patient selection:

1.2. a. Inclusion Criteria:

- Women who had a history of BCRS with upper limb lymphedema.
- Age range of 40-60 years.
- The body mass index (BMI) is less than 30 Kg/m^2.
- Consciousness and ability to communicate orally or in writing.
- Treatment by unilateral mastectomy with lymph node dissection.
- No obvious abnormal spine morphology or postural abnormalities visible to the naked eye.
- All participants had moderate lymphedema according to the lymphedema severity assessment.

1.2.b. Exclusion Criteria:

The potential patients will be excluded if they meet one of the following criteria:

- Patients with metastases.
- Differences between lower limb length.
- Having acute or chronic vestibular, neurological, and orthopedic diseases.
- Surgery related to spine causing limitation of motion.
- Women with psychiatric disorders, reconstructive surgery.
- Bilateral mastectomy.

- Diagnosis with a neurological, skeletal, or rheumatic disorder or other disease that seriously affects body posture.
- History of bodily injury such as a spinal, shoulder, or neck injury, resulting in permanent alteration of the normal body posture prior to the unilateral mastectomy.
- Failure to complete follow-up for any reason over the course of the study.
- Peripheral polyneuropathy, cognitive dysfunction.
- Patients taking medication that affects body balance.
- Severe arthritis or orthopedic conditions in their lower extremity
- Poor conditioning, acute pain in any reason,
- Neurological disorders including visual problems.

2-Equipment:

2.1- Measurement equipment:

2.1.a. Kinesis Balance™ fall prevention app:

Smartphone-based machine learning algorithms for assessing standing balance. The app uses a questionnaire on clinical falls risk factors, combined with a standing balance test and machine learning algorithms to assess balance and fall risk. A reference data set is embedded within the app and was used to compare against the smartphone inertial sensor data. The algorithm includes data quality checks to ensure tests are performed correctly including checking phone is oriented correctly during the test, removing signal artefact resulting from movements due to changes in initial positioning of the phone as well as detection and removal of unusual behavior or phone movement during the test (**Greene et al., 2021)**.

Smartphone data were sampled at the maximum rate allowed by the operating system. To ensure data were sampled evenly, data were interpolated to a 100 Hz

sampling rate using linear interpolation. Accelerometer and gyroscope data from the inertial sensor were band-pass filtered between 0.1–5 Hz and calibrated to produce acceleration and angular velocity vectors (**Cerca., 2018**).

Built-in sensors in every smartphone, including accelerometers and gyroscopes, are key to making smartphones capable of detecting balance. Therefore, by combining mobility and built-in IMUs, smartphones offer the potential to provide an objective and convenient balance assessment method. Furthermore, smartphones have been applied to individuals who have experienced stroke and have been proven feasible in assessing balance (**Hou et al., 2019)**.

Test-retest reliability and effect sizes for stability measures obtained with a force plate and smartphone as well as correlations between force plate and smartphone measures based on a large sample of older adults. The test-retest reliability of the smartphone outcome parameters was moderate (0.5− 0.75) to good (0.75− 0.9). smartphone application is a valid and reliable way to measure balance **(De Groote et al., 2021)**.

The results of this study show some of the highest correlation between a mobile device application and that of the results measured from long-accepted force plate. A similar study had a correlation of 0.63 with regards to positional sway. Therefore, the approach to the smartphone application presented here allows for an accurate way to capture the positional balance and sway without need of the stationary force plate **(Cimera and Voloshin., 2021)**.

2.1.b. Time up and go test (TUG):

The Timed Up and Go (TUG) test is a simple and efficient functional mobility assessment that measures the time taken for a subject to rise from a chair with armrests, walk three meters, turn, walk back, and sit down. The time to complete the task is recorded in seconds using a stopwatch **(Tomar et al., 2024)**.

This test evaluates gait, functional fitness, agility, and balance. It involves a series of functional tasks: transitioning from a sitting to a standing position, walking 3 meters, performing a 180° turn, and returning to a seated position. The TUG test provides valuable insights into an individual's mobility and balance performance **(Zabojszcz et al., 2022)**.

2.1.c. Functional reach test (FRT):

The Functional Reach Test (FRT) is a simple and cost-effective clinical tool used to assess dynamic balance ability **(Alahmari et al., 2021)**. It measures the maximum distance a person can reach forward beyond the length of one arm while maintaining a fixed base of support in a standing position. This test is particularly useful in institutionalized settings, as it is well established that balance is crucial for reducing the risk of falls and enhancing the performance of activities of daily living (ADLs) in older adults **(Ferreira et al., 2021)**.

2.2. Therapeutic equipment and tools:

2.2.a- Closed kinetic chain exercises (CKC):

Closed kinetic chain (CKC) exercises emphasize weight-bearing movements where the distal segment of the extremity is fixed, and motion occurs as the proximal segment moves over the stabilized distal segment **(Nadeem et al., 2022)**. These

exercises stimulate joint and muscle mechanoreceptors, promoting co-activation of agonist and antagonist muscles (co-contraction), which enhances dynamic stability (**Thabet et al., 2017).** CKC exercises are particularly effective in generating muscular co-contraction, leading to improved stability and coordination. They also engage anti-gravity muscles, boosting muscle power in the lower extremities **(Suryawanshi et al., 2022)**.

2.2.b- Weight-shifting exercises:

Weight-shifting is a crucial aspect of dynamic postural control, which refers to the ability to maintain one's bodyweight within the base of support. As individuals age, the ability to perform weight-shifting becomes slower and less accurate **(de Rond et al., 2023)**.

Lateral weight-shifting, in particular, is essential for maintaining posture under dynamic conditions and is commonly performed in various activities of daily living **(Inoue et al., 2021)**.

3-Procedures of the study:

3.1-Measurement procedures:

All patients will be evaluated before and after eight weeks of using closed kinetic chain and weight shifting exercises.

3.1.a. Kinesis Balance™ fall prevention app:

Patients will be instructed to hold the phone firmly against their sternum and stand with their eyes open, in a semi-tandem stance, for 30 s. The app contains audio and visual instructions on how to prepare for and complete the test as well as an audio cue to indicate test start and stop.

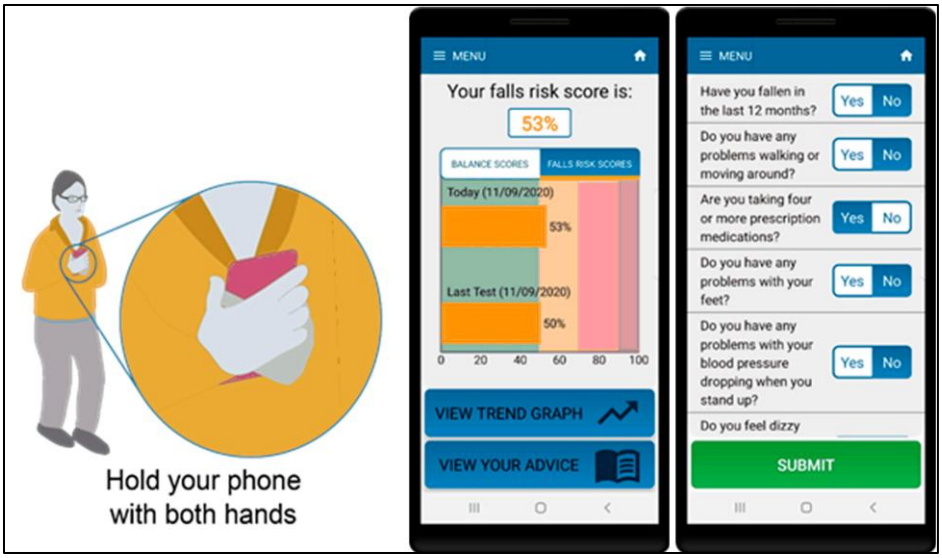


Figure (2): Shows Smartphone app for assessment of balance and falls risk using questionnaire and standing balance test (in semi-tandem stance **adapted** from **(Greene et al., 2021).**

3.1.b. Time Up and Go Test (TUG):

Patients will be asked to stand up from a chair with armrests, walk three meters, turn, walk back, and sit down, figure (3). The time taken to complete this task will be measured in seconds using a stopwatch **(Tomar et al., 2024)**.

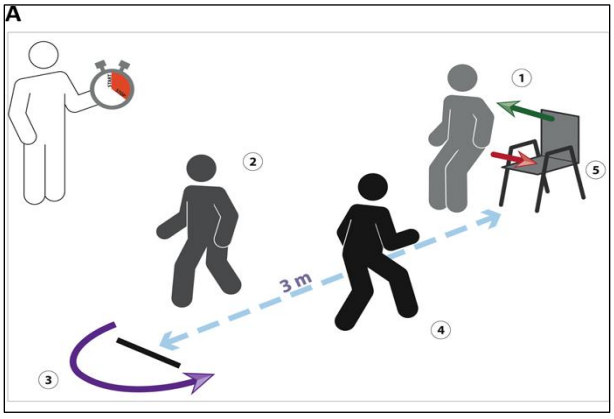


Figure (3): Shows Principle of the timed-up-and-go (TUG) test **adapted** from **(Nierat et al., 2016).**

3.1.c- Functional Reach Test (FRT):

The patient will enter a standing position on a line marked on the floor. An inch tape will be attached to a wall at approximately shoulder height of the subject. The therapist will stand 5–10 feet away from the patient and instruct them to stand close to the wall without touching it, while facing the inch tape, with the shoulder flexed at 90° and the hand in a fist, figure (4). The therapist will record the starting position at the knuckle of the third metacarpal head on the ruler. The patient will then be instructed to reach as far forward as possible along the length of the tape without moving their feet. The therapist will once again record the location of the knuckle of the third metacarpal. Patients will be required not to lean against the wall during the test. If they lose balance, the therapist will stop the test. The scores will be determined by assessing the difference between the starting and ending positions. Three trials will be conducted with one minute of rest between each trial, and the average distance will be recorded in centimeters **(Alahmari et al., 2021**).

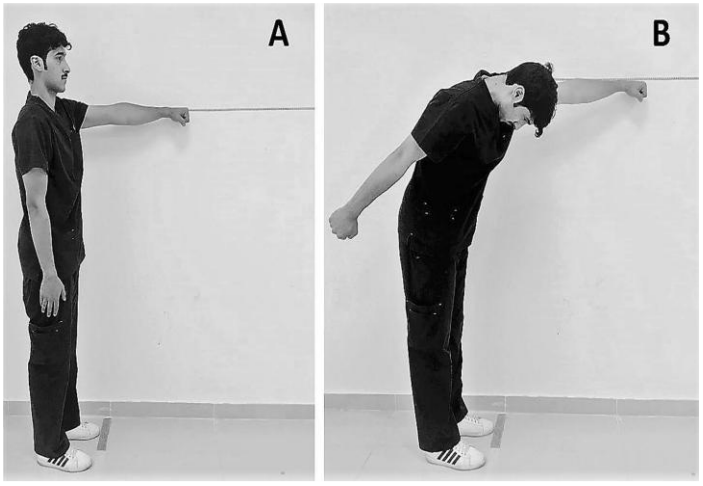


Figure (4): Shows Measurement of dynamic balance by functional reach test. **a** Starting position. **b** Final position adapted from (**Alahmari et al., 2021**)

3.2-Therapeutic procedures:

3.2.a- Closed kinetic chain exercises (CKC):

Three sets of ten repetitions will be performed in each exercise session and a duration of 30 minutes will be conducted three times a week for eight weeks. There will be two-minute breaks between sets to avoid fatigue **(Sajjad et al., 2024).**

All types of CKC exercises can be performed with or without weights. **(Thabet et al., 2017).**

The following closed kinetic chain exercises will be carried out by the patients in the treatment group figure (5) (**Gbiri et al., 2013; Adegoke et al., 2019)**:

- **Quadriceps Setting Exercise**

  Patients will sit on a chair with their back supported, knee extended and heel on the floor. They pressed their heels against the floor and thighs against the seat of the chair. The position was held for a count of 10 after which the participant relaxed.

- **Toe Raises**

  Patients will be standing with feet approximately shoulder width apart and extend arms out slightly forward and lower than the shoulder. Lift both heels of the floor and try to hold the position for 10 seconds.

- **Standing with feet side by side**, hold arms in the same position as described in the previous exercise. Place one foot on the inside of the opposing ankle and try to hold the position for 10 seconds.

- **Standing on one extremity** for 30 seconds (repeated in both extremities), leaning forward, backward, and to the sides on one extremity (eyes open), leaning forward, backward, and to the sides on one extremity (eyes closed), and sitting down and standing up from a highchair slowly.

- **Wall Squat**

With feet shoulder-width apart, knees aligned over ankles and back to wall, tighten buttocks and quads, attempting to tighten VMO first, then slide down wall until knees are bent, Hold.

- **Double Leg Squat**

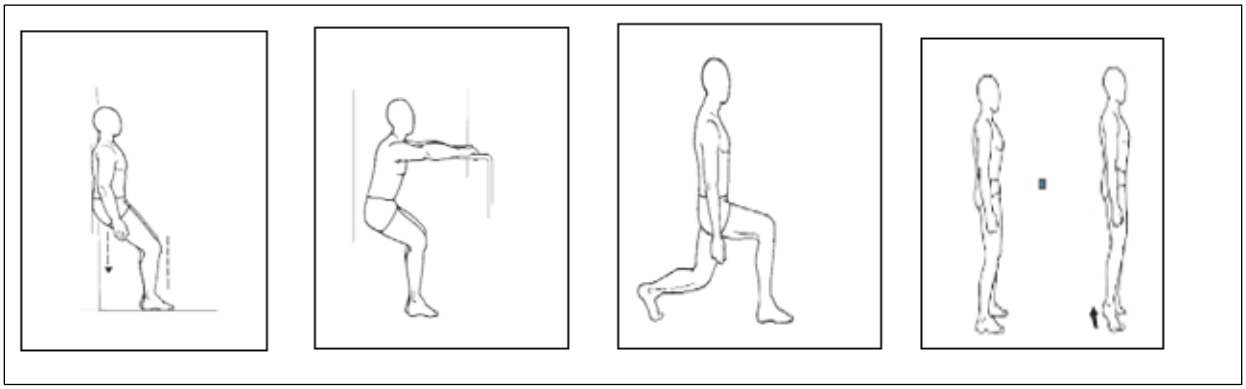
Stand with feet shoulder-width apart, using hand support as necessary. Align knees over ankles, tighten buttocks, tighten quads, attempting to tighten VMO first. Bend knees. Do not allow knees to go forward past toes. Keep your back straight, bending forward at the hips. Hold for 5 to 10 seconds. Return to standing.

- **Lunge**

From standing position (hand support as needed), keep the forward knee over the ankle while allowing the "back" knee to bend, lunge forward. Return. Alternate legs.

- **Step-up and step-down**

Patients will perform forward, backward and lateral step-ups and step-downs using a 5cm – high sturdy wooden box. They will be instructed to keep their trunk upright. Patients will perform 10 repetitions of each component of the exercise.



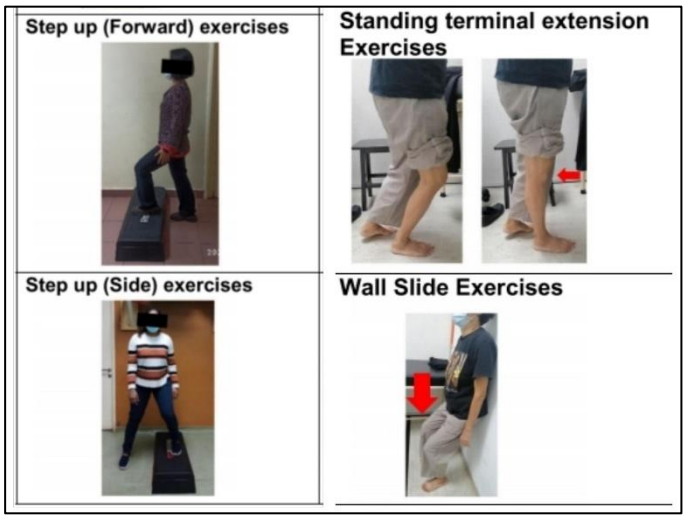


Figure (5): Shows closed kinetic exercises adapted from **(Ng et al., 2022).**

3.2.b- Weight shifting exercises (WS):

The training will be conducted on both a stable surface and an unstable surface (balance board) and will consist of the following five tasks, figure (6):

1. In a standing position, shift the weight left and right maximally.
2. In a standing position, shift the weight forward and backward maximally.
3. In a standing position, perform bending and stretching of both knees.
4. In a standing position, raise and lower both feet's heels.
5. While sitting on a chair, perform sit-to-stand exercises on the balance board.

Each session will last for 30 minutes, occurring three days a week for a duration of 8 weeks **(Lee et al., 2015).**

Figure (6): Shows Weight Shifting adapted from (**Diebal et al., 2011**)

3.3. Complex decongestive therapy:

Complex decongestive therapy (CDT) for the treatment of lymphedema for both groups. CDT includes (skin care, manual lymphatic drainage, compression bandage and exercises).

4-Statistical procedures:

The collected data will be statistically analyzed using:

- Descriptive statistics (mean and standard deviations).
- Inferential statistics; ANOVA will be used to compare between subjects characteristics of the three groups.
- Shapiro-Wilk test will be used for testing normality of data distribution.
- Mixed MANOVA will be used to compare parametric measured variables between and within groups.
- Statistical analysis will be conducted using SPSS for Windows, version 20 (SPSS, Inc., Chicago, IL). Statistical significance will be set at the ($p< 0.05$).

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