EFFECTS OF EARLY REHABILITATION PROTOCOLS WITH LASER VISUAL FEEDBACK ON KNEE ANGLES AND FUNCTIONAL MOBILITY AFTER TOTAL KNEE ARTHROPLASTY: A RANDOMIZED CONTROLLED TRIAL

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ผลของโปรแกรมการฟื้นฟูสมรรถภาพในระยะแรกร่วมกับการให้ข้อมูลป้อนกลับด้วยแสงเลเซอร์ต่อมุมข้อเข่าและความสามารถในการเคลื่อนไหวหลังผ่าตัดเปลี่ยนข้อเข่า: การทดลองแบบสุ่มที่มีกลุ่มควบคุม

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SUMALAI KHLAYNEIAM

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Currently, the conventional treatment for total knee arthroplasty (TKA) rehabilitation employs exercises combined with verbal feedback, which may be a limitation for achieving ROM exercises and improving movement symmetry. Therefore, using exercises with visual feedback may be necessary for TKA patients to guide movement and increase motivation during early rehabilitation. The aim of this study was to investigate the effects of knee exercises and movement symmetry training with laser visual feedback on knee flexion and extension, and functional mobility in TKA patients. Thirty-two patients with TKA were randomized into the intervention group, received TKA rehabilitation protocol with laser visual feedback and the control group, received a TKA rehabilitation protocol alone within two weeks. The knee flexion and extension angles were analyzed by video camera and Kinovea program. The timed up and go test (TUG) were applied to assess functional mobility. Analysis of Covariance and repeated measure analysis of variance were used to analyze the data. The intervention group exhibited significantly more knee flexion and extension than the control group on postoperative day (POD) 7 and 14 ($p<0.001$). Additionally, TUG test in the intervention group required significantly less time than those in the control group on POD 14 ($p<0.001$). This study concluded that TKA rehabilitation protocol with laser visual feedback can improve knee flexion and extension angles, and functional performance after TKA.

Keyword : Laser visual feedback, TKA, knee exercises, movement symmetry, TUG

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CHAPTER 1
INTRODUCTION

Background and significance

Knee osteoarthritis (OA) is a degenerative joint disease of the knee. It is typically the result of wear and tear and gradual articular cartilage degradation. Common clinical symptoms are knee pain, joint stiffness (i.e., limited knee flexion and extension) .[(1)] Treatment for knee osteoarthritis begins with conservative methods or non-surgical treatments. The current non-surgical treatments for knee osteoarthritis include patient education, weight loss, exercise, physical activity, physical therapy intervention, and pharmacological.[(2-5)] Then, surgical options will be considered if conservative treatments are unsuccessful. Knee replacement is a useful treatment for end-stage osteoarthritis.[(5)]

Knee replacement, also called knee arthroplasty or total knee arthroplasty, is a surgical procedure to remove the damaged cartilage and bone, and then replaced with parts made of metal and plastic. Knee replacement aims to restore knee alignment, especially reduce pain, restore function, and improve quality of life.[(5)] In the United States, knee replacement is projected to grow 85%, or 1.26 million procedures, by 2030.[(6)] In Thailand, the number of TKA received by 9,559 in 2017, 10,434 TKA in 2018, 10,864 TKA in 2019, and the total average TKA received 9,735 TKA per year.[(7)]

Although knee replacement improves the patient's quality of life, it can also result in complications, persistent pain, and a decreased ability to perform daily activities, especially limited knee flexion and extension.[(8)] Knee range of motion (ROM) was essential for the activities of daily living.[(9-11)] The knee joint should bend at least 100 to 110 degrees for common daily activities (i.e. 60-75° of knee flexion for walking, 80-90° of knee flexion for ascending and descending stairs, 90-95°of knee flexion for standing up from a normal seat).[(9, 11, 12)] Some activities may require more knee flexion for maximum efficiency and comfort, 90-115° of knee flexion for standing up from a low chair, 110-165° of knee flexion for squatting, and 135° of knee flexion for sitting in the bathtub).[(12)] In contrast, limited knee extension resulted in asymmetrical weight bearing, decreased gait speed, decreased knee extension moment, and abnormal gait pattern especially stance phase.[13-16] Therefore, the improvement of knee ROM after TKA is clinically significant since it helps to achieve successful TKA.

For the American Physical Therapy Association (APTA) and American Academy of Orthopedic Surgeon (AAOS) standard treatment guideline for TKA rehabilitation included control of pain and swelling by cryotherapy, early ambulation, ROM exercise, strength exercise, motor function training.[17] The postoperative rehabilitation for day 1 included control of pain and swelling by cryotherapy, ankle pumping exercise, bed mobility training, and heel slide.[17-20] The postoperative rehabilitation for day 2 consisted of ankle pumping exercise, active ROM exercise, active-assisted ROM exercise, terminal knee extension, quadriceps sets, gluteal sets, heel slides, straight leg raises, supine hip abduction exercise, gait training with an assistive device, and functional transfer training.[17-20] From day 3 to day 5 or the discharge day, the postoperative rehabilitation program advanced range of motion, strengthening exercises according to the patient's tolerance, ambulation distance, and stair training.[18, 19]

The treatment guidelines for TKA rehabilitation strongly recommended knee ROM exercise and motor function training for TKA rehabilitation.[17] Although the TKA patients received the standard treatment for TKA rehabilitation, they were reported to still have limited knee range of motion (ROM), leading to poor functional mobility.[10] Motor function training resulted in increased functional mobility by improving weight bearing, improving balance, and increasing walking speed.[21-24]

The performance-based test to assess the functional mobility included 30 second chair stand test (30sCST), 4-meter walk test (4mWT), six-minute walk test (6MWT), and timed up and go test (TUG). TUG test was commonly used in acute phase of knee replacement to assess the function mobility during rehabilitation program.[25]

Currently, the standard treatment for TKA rehabilitation uses verbal feedback combined with exercises, which may be a limitation for achieving the ROM exercises and improving movement symmetry. Therefore, using visual feedback with exercises may be necessary for TKA patients to guide movement and increase motivation for movement.

Visual feedback, a form of augmented feedback, is defined as information provided from an external source. It can be categorized into knowledge of results (KR) and knowledge of performance (KP). KR refers to terminal feedback concerning the outcome of a movement relation to its intended goal, whereas. KP provides feedback on the movement patterns used to achieve that goal.(26)

Visual feedback has been recommended for early postoperative rehabilitation after knee replacement to effectively reduce pain, improve mobility, and improve gait symmetry.(27) It helps to promote confidence, increase motivation for movement, guide the motion, and increase compliance exercise.(27-29) Generally, visual feedback devices (e.g., mirrors,(30, 31) laser,(32) etc.) were often used in patients with neurological and musculoskeletal disorders to relearn the movements and correct walking pattern.(30-32)

Previous studies have combined visual feedback with standard rehabilitation after knee replacement.(24, 32, 33) Visual feedback was used in previous studies, such as robot-assisted gait retraining, the quadricep training machine and laser pointer. The robot-assisted gait retraining was applied with motor function training to promote weight-bearing symmetry.(24) Kondo et al., 2022(33) applied the quadricep training machine with quadricep exercise to increase quadricep muscle function, decrease pain and improve functional mobility by isometric quadricep exercise. These visual feedback devices were expensive, not portable and difficult to set up. The study of Lee et al., 2020(32) applied the laser pointer combined with dynamic balance exercise to improve physical function and balance ability in TKA patients.

Laser visual feedback, provided via a laser pointer, has been hypothesized to be an effective tool for enhancing short-term motor performance. The mechanism underlying these immediate performance improvements is believed to rely primarily on motivational factors.(26) Specifically, laser visual feedback may enhance intrinsic motivation by encouraging participants to exceed their maximal performance during knee exercises and movement symmetry training. Furthermore, laser visual feedback assists in guiding movements toward achieving specific exercise goals. However, there are no studies applying laser visual feedback combined with standard exercises for TKA rehabilitation (i.e., isometric quadricep exercise, straight leg raise exercise, terminal knee extension in supine lying, knee flexion and extension exercise in sitting position, and terminal knee extension exercise in standing position) to achieve the knee range of motion. In addition, there are no studies regarding laser visual feedback combined with movement symmetry training (i.e., mini-squat and sit to stand training) to promote functional mobility in TKA patients.

Therefore, this study aims to compare the knee range of motion and functional mobility between the standard post-operative TKA rehabilitation program and standard post-operative TKA rehabilitation program combined with laser visual feedback.

Objectives of this study

To determine the effect of knee exercises and movement symmetry training with laser visual feedback on knee motion and functional mobility in patients with post-operative TKA.

Hypothesis of this study

There are differences in knee range of motion and functional mobility between the standard post-operative TKA rehabilitation program (control group) and standard post-operative TKA rehabilitation program combined with laser visual feedback (intervention group).

Clinical implications

Laser visual feedback is a tool used in conjunction with a rehabilitation program to guide movement during knee ROM exercise and functional training in patients with TKA. This tool is an inexpensive and portable feedback. It can be applied in postoperative rehabilitation program for patients with TKA.

Keyword

Laser visual feedback, TKA, knee exercises, movement symmetry, TUG

Conceptual framework

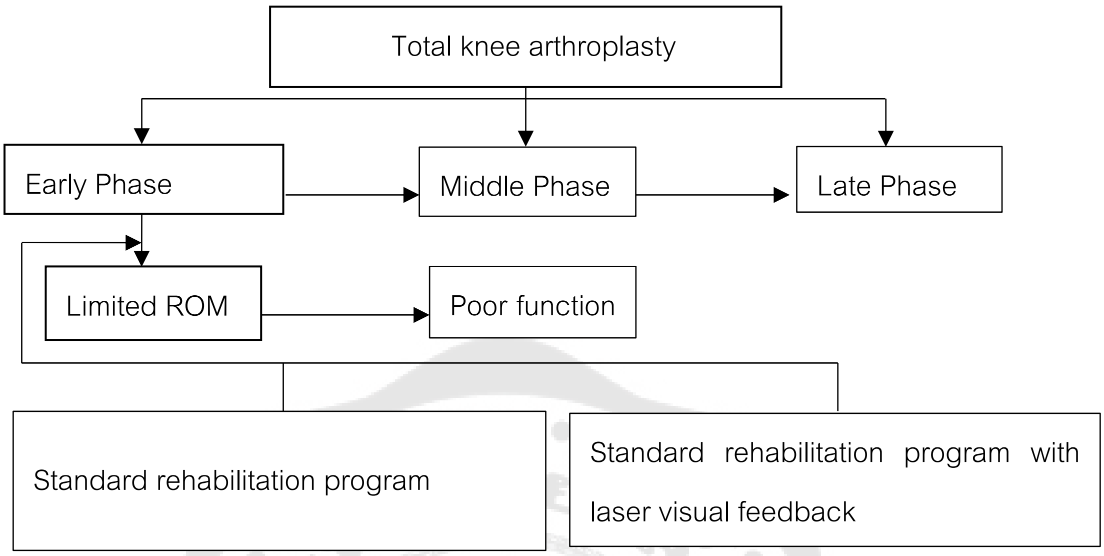


Figure 1 Conceptual framework

CHAPTER 2
THE LITERATURES REVIEW

Knee osteoarthritis

Prevalence of knee osteoarthritis

Knee osteoarthritis (OA) is a degenerative joint disease of the knee. It is typically the result of wear and tear and gradual articular cartilage degradation. Clinical symptoms are commonly knee pain, joint stiffness (i.e., limited knee flexion and extension, and joint instability.[1] OA causes functional limitations, poor quality of life, insomnia, depression, and loss of independence.[34] In the United States, there were more than 50 million people over 40 years with knee OA by 2020.[1] Age, obesity, and previous sports injuries are a risk for the progression of OA knee.[1] The cost of OA knee treatment was highly both direct and indirect expenses.[35] Currently, strategies, and management approaches for both the prevention, and treatment of osteoarthritis are emphasized.

Non-surgical management for knee OA is appraised as the initial course of treatment included patient education, weight loss, exercise, physical therapy intervention, physical activity, and pharmacological.[2-5] Patient education is an essential component of conservative treatment. The multidisciplinary team offered advice on knee OA disease education, possible consequences, adverse effects of medication, injury prevention, the importance of exercise and physical activity, and other treatment options.[3, 4] Education in knee OA patients led to patients awareness and effective self-management.[4] The best treatment for knee OA is weight loss. A 5%–10% weight loss resulted in a significant decrease in pain and disability and an increase in the quality of life.[36] Previous study discovered that the risk of osteoarthritis increased by 35 % when a body mass index (BMI) increased by 5 kg/m^2.[37] Weight loss and exercise can apply for knee osteoarthritis management. Exercise promoted physical activity in a moderately positive way.[4] As a result, individual with knee OA should perform strengthening exercises daily or at least twice a week by focusing on major muscle groups around the knee and hip joints, whereas aerobic exercise should focus on a low-impact program at least five days a week for half an hour.[4] Physical therapy intervention is a treatment that has been strongly recommended for knee OA including moist heat, diathermy, ultrasound therapy, radiofrequency therapy, on brace at knee joint.[3] For transcutaneous electrical nerve stimulation (TENS) treatment has been used for pain management. However, TENS has no effect on the function in patient with knee OA.[4] Massage therapy also has an effect on pain and only a small effect on function in patient with OA.[4] Using a cane is strongly recommended for a patient with knee OA to reduce pain and aid in ambulation.[3] For pharmacological therapy (i.e., paracetamol, topical non-steroidal anti-inflammatory drugs or NSAIDs, oral NSAIDs, and opioids)[2, 3], the goal of treatment is to relieve a symptom and improve mobility as much as possible. If conservative treatments are unsuccessful, then surgical options are considered.[5]

The surgical treatments for knee OA included arthroscopy, osteotomy, unicompartmental knee arthroplasty (UKA) and total knee arthroplasty (TKA). Arthroscopy was treated in mild to moderate knee OA and meniscus tears.[38, 39] Although arthroscopy provided a pain-relieving effect and increased the ability to move only for a short to moderate period, there was still the risk of loose joints, meniscal injuries, and abnormal alignment of the lower limbs in the younger patient.[39] However, a long-term of arthroscopy can increases the risk of TKA surgery.[38] Osteotomy is one method that reduces pain and improves mobility, like other types of surgery, which can slow down knee osteoarthritis.[40] One study on lifespan after osteotomy found that 93.1% had a lifespan of five years, and 74.1% had a lifespan of 10 years.[41] In addition, it reported that patients under 55 years old, female, and body mass index less than 25 kg/m^2 who underwent orthopedic surgery were more likely to live longer.[41] Orthopedic surgery can effectively treat knee OA, however there is ongoing concern about prosthetic durability in younger patients and the high risk of TKA.[40] The unicompartmental knee arthroplasty (UKA) has been replaced with only the medial or lateral prostheses, reducing pain, and improving mobility. The predicted implant survival for UKA was 93% at ten years and 89% at 15 years.[40] The previous studies have also reported that it is less durable and has a higher surgical revision rate in younger patients.[42, 43]

Total knee arthroplasty (TKA) has been used as a treatment for the end stage OA knee, which conservative treatments are unsuccessful.[5] TKA is a surgical procedure where the entire knee joint is changed using prostheses. It removed the damaged cartilage and replaced it with parts made of metal and plastic called tri-compartment. It aimed to correct knee joints with severely damaged articular cartilage pathology. Specifically, it can reduce pain, restore function, and improve quality of life.[5] In the 1970s, prostheses were designed by replacing condylar to resurface all three compartments.[5] The TKA procedure consists of four steps. The first step is to prepare the bone and remove the damaged cartilage surface at the end of the femur and the tibia. The patella must then be resurfaced, and the prosthesis must be aligned on the tibial and femoral surfaces. Finally, a plastic spacer must be inserted to assist the actors move more smoothly.[5]

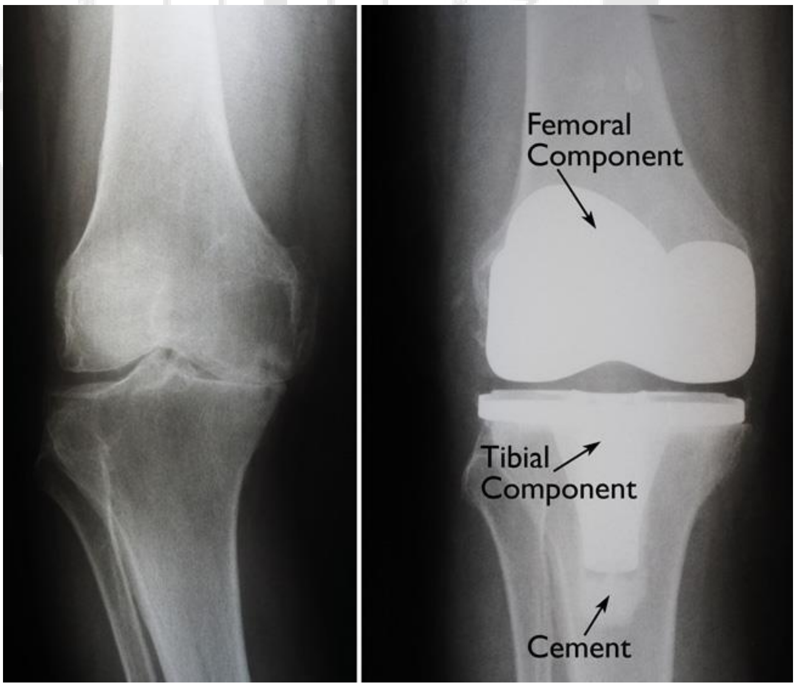


Figure 2 **(Left)** An x-ray of a severely knee osteoarthritis **(Right)**The x-ray appearance of a total knee arthroplasty.

Source : https://orthoinfo.aaos.org/en/treatment/total-knee-replacement/

Prevalence and burden of TKA

TKA is frequently referred to be the "gold standard" for treating severe end-stage symptomatic knee OA due to evidence that surgery can reduce pain, enhance function, and improve health-related quality of life.[5] Increased age, obesity, and previous knee ligament damage are risk factors for TKA, as are those for the development of knee osteoarthritis.[1] According to study that predicted an increase of 1,700 TKAs over a seven-year period, obese individuals with OA are more likely to need surgery. It revealed a substantial correlation between increased BMI and TKA.[44, 45]

Future demand for TKA surgery is expected to rise globally, as has been well-documented.[46] Analyzing future healthcare demands and optimizing resource allocation techniques can be aided by understanding expected patterns in TKA utilization.[47] In the United States, TKAs are conducted annually, and it is predicted that number would rise by 85%, or 1.26 million, by 2030.[6] In Australia, TKA expected to rise 276% by 2030.[48] In Thailand, the number of TKA received by 9,559 in 2017, 10,434 TKA in 2018, 10,864 TKA in 2019, and the total average TKA received 9,735 TKA per year.[7] The average hospital cost for these surgeries was $10,547, an increased cost compared to the previous year. In 2020–2021, more than $1.3 billion was spent on hospital costs (including physician costs and excluding rehabilitation) .[49] The anticipated exponential growth in the rate of TKA procedures is unlikely to keep up healthcare financing and resources. Therefore, both public and private health sectors should reduce the financial burden associated with TKA per-episode expenses by emphasis on modifiable expenses such as length of hospital stays, and rehabilitation options.[48, 50-52]

Post-surgical complications

Although TKA improves the patient's quality of life, it can cause complications including infection, deep vein thrombosis, especially limited knee flexion and extension problems[8] resulting in persistent pain and decreased ability to perform daily activities. Infection is a severe complication that occurs infrequently after knee replacement. It can occur during the first two months post-knee replacement. Infection symptoms included fever, chills, swelling, and sudden worsening of knee pain. Treatment for infection is to take antibiotics, fluid drainage, or the prosthesis must be removed and reinserted when there are no signs of infection.[53] According to the previous study the patients with obesity risk infection complications after TKA.[54]

Deep vein thrombosis (DVT) can occur after TKA. It is characterized by severe pain and swelling. Pulmonary embolism refers to the condition that a blood clot develops in the lungs. Many factors can increase your chances of developing deep vein thrombosis, such as recent surgery, a leg injury, or recent injuries or unable to move. The primary goal of deep vein thrombosis care is to stop the clot from growing and rupturing, which could lead to pulmonary embolism (PE). Treatment for deep vein thrombosis was similar to that for pulmonary embolism. Anticoagulant medication is used as treatment, in conjunction with regular walking encouragement.[55] In the previous study, it was found that patients had underlying diseases such as diabetes and obesity. There is a chance of deep vein thrombosis and pulmonary embolism after TKA.[56, 57]

Knee stiffness is a major complication that results in persistent pain, and decreased ability to perform daily activities, especially limited knee flexion and extension problems.[8] Knee range of motion (ROM) was essential to daily activities.[9-11] The knee joint should bend at least 100-110° of flexion for basic daily activities such as sitting, walking, and stair climbing. Some activities may require more knee flexion for maximum efficiency and comfort (i.e. walking requires 60-75° of flexion, ascending and descending stairs require 80-90° of flexion, standing up from a normal seat require 90-95°of flexion, standing up from a low chair require 90-115° of flexion, squatting require 110-165° of flexion, and sitting in the bathtub require 135° of flexion).[9, 11, 12] In contrast, limited knee extension (ROM) resulted in asymmetrical weight bearing, decreased gait speed, decreased knee extension moment, abnormal gait patterns, especially in stance phase of gait cycle.[13-16]

In the early stages of the postoperative period, the patient exhibited joint stiffness and poor functional mobility. Patients took post-TKA rehabilitation programs for a long time to achieve satisfactory results. If patients have severe knee flexion ($<70^{\circ}$ or 75°) and extension limitations ($>15^{\circ}$), they may undergo manipulation under anesthesia (MUA) to increase the range of motion in the knee joint.[58] In general, post-TKA patients who are in good health should bend their knees 90 degrees and extend them to their full range of motion at 2 weeks,[20] be able to walk with walking aids within 2-3 days,[59] reduce walking aids from walker to cane at 3 weeks, and be able to walk without assistive devices at 6 weeks after surgery.[20] In the first two weeks following surgery, recovery after knee replacement is crucial, especially for knee flexion and extension range of motion (ROM).[20] Early post-operation rehabilitation is the first step toward the next phase of mobility.[20] Therefore, restoration is essential to get the best outcomes following a knee replacement. Rehabilitation aims to enhance functional capacity while reducing side effects.

Factor affecting post TKA outcomes

Age

Younger age has improved outcomes more than old age. Patients younger age had lower levels of postoperative walking limitations. In the first postoperative year, patients with age more than 70 years had a higher chance of falling. At two years after surgery, older patients exhibited slower on gait speed.[17, 60-63]

Gender

In the first year following surgery, the female experienced a higher risk of falling.[17, 60, 62] In terms of the Oxford Knee Score, the female had lower scores than male. The male had worse terminal knee extension.[64]At postoperative after TKA, the female experienced more knee pain than the male.[65]

Comorbidity

Comorbidity such as diabetes mellitus, the higher comorbidity was factors related to worse patient-reported outcomes on WOMAC function.(17, 62, 64) Moreover, the higher comorbidity is related to a higher total complication rate following TKA.(66)

Quadricep muscle strength

Quadricep muscle strength was a preoperative factor. Quadricep muscle strength before surgery was correlated with performing functional mobility after knee replacement, such as walking speed and stair climbing.(17, 67-69) Preoperative muscle strength was associated with postoperative SF-36 physical function score.(70)

Body mass index (BMI)

High body mass index is a risk factor for worse functional mobility outcomes and risk post-complication after TKA, such as deep vein thrombosis, joint infection, unplanned readmissions, and wound complications.(17, 64, 71)

Depression

Depression is a risk factor for poor patient outcomes of TKA on the oxford knee score.(17, 72, 73)

Range of motion (ROM)

Preoperative ROM may be used to predict ROM following TKA. The average range of knee flexion and extension before surgery was 118° and 7°, respectively. At six months following surgery, the patient had a knee flexion contracture of more than 10° and a knee flexion range of less than 90°.(17, 62)

Physical function

A high level of preoperative function was associated with a high level of postoperative function. Patients had preoperative walking limitations, and at six months they were unable to walk for longer than 15 minutes(17, 62, 65, 74)

Enhanced recovery pathway (ERP) for improving recovery and early mobilization

The enhanced recovery pathway (ERP) referred to as "fast track" is an intraoperative treatment that combines many forms of treatment and is based on evidence.(75-77) The previous studies indicated that the enhanced recovery pathway

(ERP) improved patient safety and did not increase complications for patients after knee replacement.[75, 78] In addition, ERP reduced hospital stays, increased satisfaction, improved functional outcome,[75-78] and save costs after knee replacement.[78] This pathway was used in TKA treatment in Thailand and had an effective method to reduce the length of stay (LOS), opioid use, and pain score, and improving function without significant complications.[79] The ERP programs had the guidelines that are useful for implementation. It is divided into three phases: 1) preoperative, 2) intraoperative, and 3) postoperative.[76] The study have shown that the ERP program consisted of preoperative patient education, planning anesthetic drugs and optimal intraoperative fluid balance to reduce bleeding, using an opioid, and early movement after TKA. This study also found that ERP program was an effective program for TKA.[76] Although there is no specific evidence supporting the significance of physiotherapy in an ERP program, early mobilization is a standard ERP component that is frequently provided by the rehabilitation team.[76] Initial movement in the context of TKA is characterized by standing and/or walking within same-day surgery.[76, 77]

Protocol for total knee arthroplasty rehabilitation

The rehabilitation in acute and post-acute phases of patients post-TKA was widely accepted as a regarded. The guidelines and principles of TKA rehabilitation should be based on the stage of recovery, objectives, and targets in each movement. Immediate rehabilitation after TKA aims to ensure a safe acute discharge from the hospital. The goal of the musculoskeletal rehabilitation was to help the patients to move better and improve their quality of life which typically involved a rehabilitation team. After being discharged from the hospital, the patients should receive continuous rehabilitation. Although there were many rehabilitation programs available for patients after TKA, the conclusion for best rehabilitation program was unclear.[80]

The treatment approaches and modalities commonly used in post-TKA rehabilitation to restore ROM, strength, and mobility are known as a physiotherapy intervention.

In 2020, a guideline for total knee arthroplasty was developed from the American Physical Therapy Association (APTA) and the American Academy of Orthopedic Surgeons (AAOS) clinical practice guideline.(17) Postoperative rehabilitation guidelines included control of pain and swelling by cryotherapy, knee ROM exercise, early ambulation, resistive exercise, motor functional training, and electrical stimulation of the muscles and nerve (NMES). These modalities are essential for improving results after TKA.(17) Rehabilitation team should carefully monitor “based on patient tolerability criteria”, and has suggested that biofeedback was used in combination with movement guidance for optimal patient benefit.(17) Following TKA, exercise therapy serves as the foundation of physiotherapy. A Dutch guideline survey of physiotherapy providers reported prescribing 99% functional exercise, 96% strengthening exercise, 95% gait training, and 93% active ROM exercise, but either continuous passive movement or electrical muscle stimulation was not recommended.(81)

There is still lack of research on the most effective intensity, frequency, and duration of exercise for rehabilitation following TKA. However, exercise for TKA patients was recommended using the FITT principle (frequency, intensity, time, and type), which was also advised for patients with knee OA.(4) According to the American College of Sport Medicine (ACSM) guidelines have recommended for elderly adults with hip and knee osteoarthritis exercise for 30 minute, five days a week, at a moderate level for cardiovascular fitness. For functional and strength training, exercise should be done every day or at least twice a week and emphasize knee extensor, knee flexor, and hip abductor exercises.(4) For functional training should be focused the exercise in daily activities such as walking, climbing the stairs, getting up, and sitting on a chair.(4)

Range of motion (ROM) exercises

Knee range of motion (ROM) was an essential clinical outcome and the main goal following a knee replacement. Knee ROM achieving was necessary for the activities of daily living. It is related to the movement of different tasks, such as sitting, walking, climbing, and descending stairs. If the patients cannot achieve the goals in each stage, it becomes difficult to progress to the next recovery stage and leads to a long-term problem and negatively impact the quality of life (especially persistent pain, asymmetrical weight bearing, restriction during walking, decreased walking speed, difficulty turning, going up and down stairs, risk of falling, loss of balance and permanent loss of functional mobility.[9, 82, 83]

From the clinical practice guideline for physical therapy management of TKA strongly recommended knee ROM exercise. Nonetheless, there is insufficient study regarding ROM exercise.[17] The study of Iwakiri et al., 2020[84] showed that the patients who began ROM exercises post-TKA day 1 had significantly less postoperative pain than those who began post-TKA day 7. Kornuijt et al., 2018[85] showed that the correlation between recovery period of pre- and post TKA rehabilitation and knee ROM was not linear. Knee flexion increased the greatest ROM during the first week of post TKA which median of knee flexion was 80 degrees in first week of post TKA and 110 degrees at post TKA 1 month, whereas the knee extension improved the greatest ROM during the first 2 weeks of post TKA that the mean of knee extension had changed from -10.7 degrees to -3.2 degrees. However, patients with insufficient knee flexion (< 90 degree) at first week post TKA resulted in no improvement of knee flexion at week 7 to 8.[85] According to the study of Oka et al., 2020[10] the range of motion at 12 months was significantly correlated with ROM at day 5 and 1 month. Knee ROM at day 5 required 85 degrees and 105 degrees of knee flexion at 1 month. Therefore, the predict of knee ROM at 12 month can be acute phase post TKA.

Strengthening exercises

The quadriceps muscle is an important for supporting the knee and its function is knee extension.[86] If it is functioning properly, it can have a significant effect on the patient's ability to return to daily activities following TKA. The preoperative quadricep strength has an effect on the movement after knee replacement. Therefore, it is important to provide a preoperative quadricep muscle strengthening exercise program.[86] The maximal voluntary strength of the quadriceps was significantly reduced in the first three months following TKA,[87] which resulted in a decrease in knee extension strength.[86, 87] Quadriceps muscle weakness has a significant impact on gait after knee replacement.[88] It is necessary to consider a quadricep rehabilitation program in the acute post-TKA by focusing on the knee extensor muscle of the surgical side.[86-88] Capin et al., (2022)[89] suggested testing of the hamstring and quadriceps muscles both before and after surgery. As the assessment of quadriceps muscle strength and function after early TKA using isometric quadriceps contraction and straight leg raising, the patient's endurance criterion and wound healing period should be considered.[89] The resistance exercise was used to strengthen the quadriceps muscles in the acute postoperative phase to restore knee extension, mobility, and muscle strength of the knee.[90] Pozzi et al., 2020[90] reported that progressive resisted training of the lower limbs increased active knee extension, quadriceps strength, and stair climbing time (SCT) test to a level comparable to individuals who did not have knee pain (healthy group). A study by Bade et al., 2017[91] reported that high-intensity exercise (land exercise) was safe to exercise early after TKA. Both the high and low-intensity exercises promoted quadricep strength and functional mobility.

Motor function exercises

People who underwent knee replacement had asymmetrical loading compared to the non-TKA leg. Asymmetrical loading of the lower limbs was associated with poor physical mobility after knee replacement.[92] Asymmetrical load on the limb of the operative side during movement resulted in the compensation motions that were associated with a higher risk of osteoarthritis (OA) on the opposite side and led to TKA on the non-surgical side.[93] Asymmetrical loading was associated with quadriceps muscle weakness, a key muscle involved in the movement after knee replacement.[94] Therefore, the rehabilitation should focus on training leg limb symmetry to restore normal movement after knee replacement.[17]

For the clinical practice guideline also strongly recommended motor function training for TKA rehabilitation.[17] The study discovered that motor function exercises had the greatest effect on functional mobility such as improving weight bearing, improving balance, and increasing walking speed.[21-24] Recent studies have demonstrated that motor function exercise with visual feedback improved functional mobility following TKA.[24] However, there are no studies on movement symmetry using laser visual feedback for a functional mobility evaluation.

Electrophysical modalities

Currently, the rehabilitation team uses electrical stimulation for patients after TKA. There are both neuromuscular electrical stimulation (NMES) and transcutaneous electrical nerve stimulation (TENS). These treatments reduce pain and edema. At the same time, it stimulates the strength of quadricep muscles, gait speed, and functional mobility.[18, 95-97] These studies investigated the use of NMES during rehabilitation after acute postoperative knee arthroplasty. Results have shown that NMES used after surgery improved quadriceps muscle strength immediately and later, reduced discomfort and increased function in the middle period after knee replacement. However, these results were not found statistically significant difference, so there are necessary to do the further study to confirm these benefits.[98] Grade B evidence, one of eight RCTs from a systemic review, supported the use of NMES to help with quadriceps strength recovery after knee replacement, these parameters (a biphasic current, big electrodes, a duty cycle ratio of 1:2 to 1:3, a rate of 50 Hz, and 2- to 3-second ramp).[99] The study reported that nerve stimulation can be performed post-surgery within 2 week on both motor and sensory levels to increase quadricep muscle strength and function.[96, 100] However, the motor level of NMES will cause discomfort when applied to the skin.[96]

Rehabilitation phase in total knee arthroplasty

Acute phase

The primary goal of recovery immediately after TKA is to prepare the patient to leave the hospital safely as soon as possible. Stevens-Lapsley et al., (2012)[18] divided the standardized rehabilitation protocol into three phases for the inpatient (early phase), home health (middle phase; week 2 to 3), and outpatient (late phase; week 4 to 8). Inpatient or early phase rehabilitation started from day 1 until the discharge day. Regular exercise is the most recovery method during acute hospital stays. The goal of this stage, which began after surgery days 1-2 was to decrease pain and swelling, increase the knee joint's range of motion, and be capable of getting in and out of bed.[20]

The rehabilitation program for TKA patients included pumping exercises to prevent deep vein thrombosis and ROM exercise. If the patient still has a lot of pain, move by passive ROM or active assistance ROM or active ROM can move on their own. Exercise to increase muscle strength with quadricep isometric and straight leg raises. Patients started turning over, sitting up after laying down, standing up with aid, and getting out of bed (if the patient can do so).[18] Continuous passive joint movement (CPM) has been used in TKA studies. However, it hasn't been found to have any clinically important effects on knee mobility or work efficiency.[101, 102] The using CPM should only be used when there is a complication.[17] Cryotherapy is a widely used pain relief method in the acute phase after knee replacement.[103, 104] The goal of post-op day 3-5 or discharge day can be progression knee ROM, progression muscle strength, progression ambulate distance, and progression activities of daily living.[18]

There is little evidence for the recovery of motor functional exercise after early TKA.[17] Even though TKA patients receive rehabilitation, it is unclear the method and dose of TKA exercise, which is the best in acute phase of postoperative.[80] The results of this systematic review demonstrated that high-quality randomized clinical trials were urgently needed to assess the effects of early exercise after TKA surgery.[80]

Post-acute phase (discharge)

Post-acute recovery study was in the first two months after TKA.[18] It was advised to perform ROM exercises, activity training, walking training, balance training, and strengthening exercises.[81] Mid-term rehabilitation after TKA may take the form of home treatment in the second or third week.[18] After TKA surgery, there are several methods for rehabilitation TKA, such as individual or group treatment, or telerehabilitation.[105] The goal of postoperative 1-2 weeks was to improve pain control. At the end of the program, the second week, the patient was able to bend the knee 90 degrees, straighten the knee 0 degrees, and walk longer distances using assistive devices, emphasizing the program's active ROM in sitting, muscle strength exercise, exercise and up and down stairs.[20] The goal of postoperative 3-6 weeks was to reduce walking aid at 3 weeks, the patient was able to bend the knee 100-105 degrees, straighten the knee 0 degree, can bike and walk longer distances without assistive devices at 3-6 weeks.[20] The progressive muscle strengthening exercise program included exercises in the closed chain position and up and down stairs. The goal of postoperative 7-8 weeks was to walk independently, maximize functional mobility by emphasizing the progressive muscle strengthening exercise program and balance exercise.[20]

In a previous study, although there was insufficient evidence regarding the details of physiotherapy recovery in post-acute conditions, rehabilitation was a benefit to mobility following TKA.[106]

TKA Rehabilitation with visual feedback

Motor learning and Motor control

Motor learning and motor control play an integral role in both increasing the performance and rehabilitation of these skills in post-surgical rehabilitation.[107] Shumway-Cook has defined motor control as the ability to regulate mechanisms essential to movement. Motor control involves multiple body systems (input, output, and central processing) and multiple levels within the nervous system.[108] Motor learning is a complex process occurring in the brain in response to practice or experience of a skill resulting in changes in the central nervous system. It enables the development of new motor skills. It often involves improving the smoothness and accuracy of movements.[108]

Closed-loop processes of motor relearning theory

In a closed-loop process, sensory feedback is used for the ongoing production of skilled movement. The closed-loop theory of motor learning included two district types of memory that were important in this process. The first, called the memory trace, was used in the selection and initiation of the movement. The second, known as a perceptual trace, was then built up over a period of practice and became the internal reference of correctness (detect error). Performing the same movement repeatedly (block practice) to one accurate endpoint to increase practice and increase learning. Errors produced during learning contribute to the strength of incorrect perceptual traces.[108]

Stage of learning motor skill of Fitts and Posner three stage model

Fitts and Posner suggested that there are three main phases involved in skill learning. In the first stage, often known as cognitive stage, movements are slow, inconsistent, and inefficient. High levels of cognitive activity are necessary. In the second stage, also known as associative stage, movements are more fluid, reliable and efficient and less cognitive activity is required. The third stage, known as autonomous stage, is characterized by accurate, consistent, and effective movements, that require little to no cognitive effort.[108, 109]

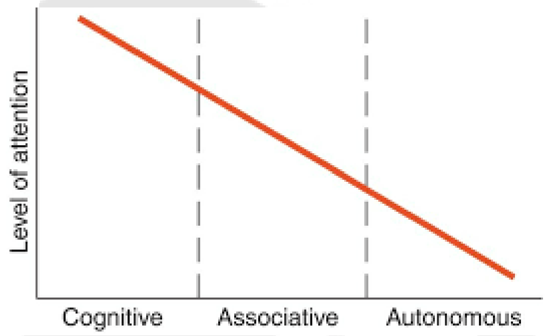


Figure 3 Stages of learning of Fitts and Posner three-stage model

Source: https://www.justineclarinet.com/blog/motor-learning-attention

Learning and memory

Short-term memory

Short-term memory (STM) is defined as the maintenance of information over a brief period which often occurs in seconds, which results from the conscious maintenance of sensory stimuli within this time frame. Short-term memory had increased neurotransmitter release but there was no alteration in the synaptic structure. It is also known as primary or working memory. It involves remembering and processing information at the same time. Only a limited amount of information is stored for a short period of time, typically 30 seconds. STM develops into long-term memory when information is consciously stored through a process known as consolidation. This process is enhanced through repetition, associating new information with previous knowledge and/or a topic of intense of interest and retrieval. The primary area of the brain involved for STM is the prefrontal cortex.[108, 110]

Long-term memory

Two main sub-categories of long-term memory were implicit memory and explicit memory (Figure 4) . They differed in terms of memory content, content retrieval mode, and the structure of the brain that is involved.[108, 111]

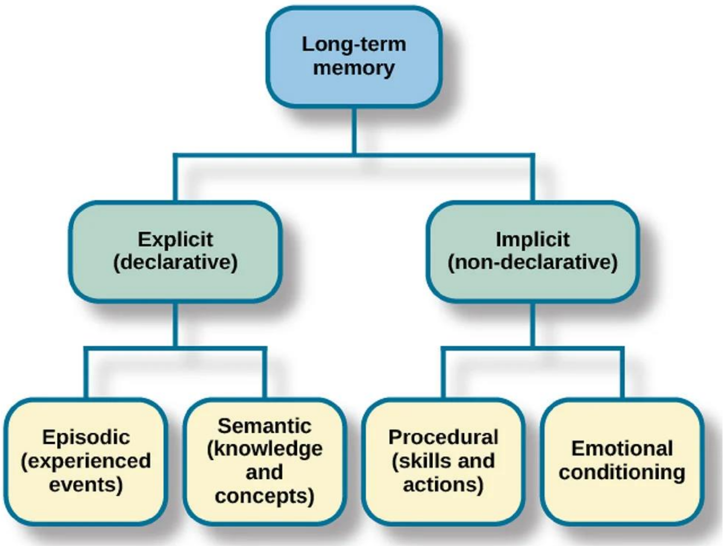


Figure 4 Long term memory

Source: https://simplypsychology.org/long-term-memory.html

Implicit memory, also known as non-declarative memory or procedural memory, is more reflexive, automatic, or habitual in character and requires frequent repetition for its formation. Implicit learning involves learning tasks that can be performed automatically without attention or conscious effort. It can affect thoughts and behaviors.[108] Procedural learning develops slowly through the repetition of an act over many trials, resulted in improved performance of the task that was practiced. During motor skill acquisition, repeating a movement continuously under various circumstances would typically lead to procedural learning, that is, automatically learning the movement itself. Implicit memory is related to the thalamus, striatum, cortical association area, motor cortex, and cerebellum.[108]

Explicit memory or declarative memory result in knowledge that can be consciously recalled and thus requires processes such as awareness, attention, and reflection.[108] It involves the ability to remember factual knowledge (often related to objects, places, or events). Explicit memory was used often when helping reacquired function skills, for instance, when patients first learn to stand, they may verbally describe the steps as they do them. However, constant repetition can transform the explicit into the implicit (that does not require conscious attention and monitoring). Explicit memory can be further divided into episodic memory (specific events) and semantic memory (knowledge about the world).[111] Explicit memory is related to the medial temporal lobe and the hippocampus.[108] Both implicit and explicit learning also involve four different types of processing, including encoding, consolidation, storage, and retrieval.

Application feedback for motor learning

Feedback is related to motor learning. Feedback is a well-established technique for physical rehabilitation. Participants use feedback during exercise to find error points and compare goal movement. Aim to give better treatment results, be able to do better next time, and be committed and interested. Feedback is usually further divided into two subclasses consisting of intrinsic feedback and extrinsic feedback. Intrinsic feedback (or inherent feedback) is the feedback that comes to the individual simply through the various sensory systems because of the normal production movement. Extrinsic feedback (or augment) is information that supplements intrinsic feedback. Extrinsic feedback can be given concurrently with the task and at the end of the task.[108, 112]

Knowledge of result (KR) and Knowledge of performance (KP)

Knowledge of result (KR) and knowledge of performance (KP) are two categories for extrinsic feedback. KR focuses on the end of the performance. KR is defined as terminal feedback about the outcome of the movement in terms of the movement's goal. KP is feedback relating to the movement patterns used to achieve the goal.(112) KP focuses on the information about how the action was performed.

Visual system

The visual pathway describes the anatomical pathway by which electrical signals generated by the retina are sent to the brain (Figure 5). The nerve fibers of the retina, representing the axons of the ganglion cells, collect together at the optic disk before passing out of the eye through the orbital bones and into the brain via the optic nerve (the second cranial nerve). The nerve fibers from different areas of the retina become more organized as they pass down the optic nerve. The optic nerves from each eye meet at the optic chiasm, a structure at the base of the brain. At this point, the nerve fibers, which are associated with the nasal half of the retina from each eye, cross over, so that on leaving the optic chiasm and passing into the optic tracts, the nerve fibers from the nasal retina of one eye travel down the optic tract with the nerve fibers originating in the temporal retina of the other eye. At the end of each optic tract, the retinal nerve fibers connect with other visual pathway nerves in a structure called the lateral geniculate nucleus (LGN), located in the midbrain. Some processing of the electrical signals occurs in the LGN before a series of radiating nerve fibers, the optic radiation, convey the information to the visual cortex in the posterior portion of the occipital lobe. The perception of sight ultimately derives from processing within this and adjacent areas of the brain. The visual cortex has six layers and is the very beginning of your brain's process of interpreting and recognizing what you see. Within these layers, depth perception is processed, and form, color, and motion are perceived.(108, 113)

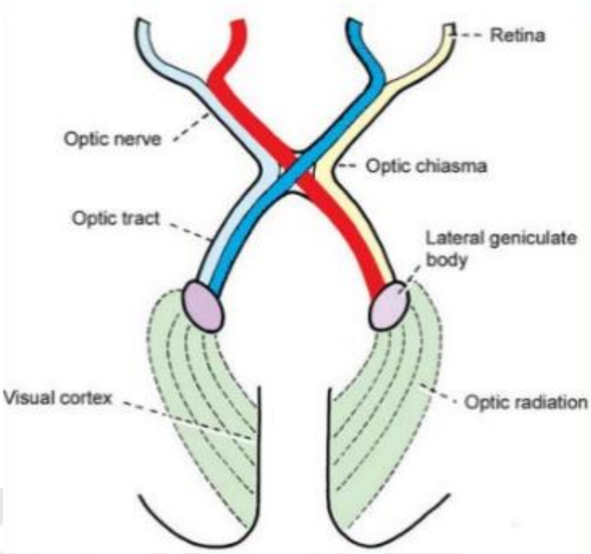


Figure 5 The optic pathway

Source: https://www.brainkart.com/article/The-Visual-Pathway-of-the-Brain_19029/

There are several modes of feedback, which are divided into verbal feedback, visual feedback, haptic feedback, auditory feedback, and multimode feedback.[114] It is often used in individuals with musculoskeletal and nervous system disorders. Feedback increases motor relearning engagement, and compliance with therapy and adjusts your walking pattern correctly to make joints and muscles work properly and reduce the chance of injury caused by incorrect movements.[115-117]

Visual feedback

Visual feedback promotes confidence, increases motivation to move, guides movement, and increases compliance with exercise.[27-29] Research suggests the use of visual feedback in the early rehabilitation of patients after TKA for about 15-45 minutes, 2-3 times/week.[27] The visual sensory system, which processes external sensation, will provide useful information. It is simple to memorize and put into practice. Visual feedback devices (i.e., mirrors,[30, 31] laser[32]) were used.

The three studies have used visual feedback in combination with standard rehabilitation after knee replacement.[24, 32, 33] It also has been applied with motor function training or movement training to promote weight-bearing symmetry and improve balance for patients who have undergone TKA. [24, 32, 33]

Kondo et al., 2022[33] combined visual feedback with exercise training. Aim to increase quadriceps muscle function, decrease pain, and improve functional mobility. The patients were trained in isometric quadriceps exercises with the quadriceps training machine (QTM) equipment. This program started on postoperative day 2 to 14. The result shows reduced pain at week 1-3 and improved functional mobility in week 3. The quadricep strength improved, but not at all times.[33]

The dynamic balance of patients with TKA was assessed by Lee et al., (2020).[32] The intervention group underwent dynamic balance with visual feedback five times per week for four weeks. Dynamic balance, pain, and TUG were improved significantly at post training.[32]

In the previous study regarding robot-assisted gait retraining, visual feedback was used to improve weight bearing symmetry during gait, improve sitting-to-stand ability, and improve balance. The intervention group had better sagittal knee moment, balance, proprioception, and walking distance.[24]

From previous studies, there are a few studies regarding the use of visual feedback to promote movement symmetry in patients with knee replacement. However, there are no studies applying visual feedback to assist patients in achieving the range of motion for the involved knee following TKA. In previous studies, there have been different methods of using visual feedback and measuring outcomes. In this study, a laser pointer was selected as a small visual feedback device. They are easy to move around, serve as visual feedback during exercise, and are measured in ROM and functional mobility because early ROM training is the golden period that leads to good function.

Outcome measures of post TKA rehabilitation protocols

The basic goal of rehabilitation after TKA is the ability of the patient to resume normal activities. Therefore, the outcome measure following the TKA rehabilitation program should be evaluated as follows:

Pain

The numerical pain rating scale (NPRS) was used to record the patient's knee pain. Participants rated their level of pain (0: no pain, 10: severe pain, or the maximum amount of agony). NPRS effectively measured clinical pain levels. Excellent repeatability values (ICC=0.95), the standard error of the mean (SEM), and the minimal detectable change (MDC) were 0.48 and 1.33, respectively.(118)

Knee range of motion (ROM)

Knee range of motion was evaluated for recovery after knee replacement, which is an important factor to consider when evaluating functional mobility. If the range of motion after joint replacement is restricted, it may impede the ability to perform various activities. It is necessary to bend the knee at least 100-110° for basic daily activities such as sitting, walking, and stair climbing. Some activities may require more knee flexion for maximum efficiency and comfort.(12)

There are many methods to measure the range of knee joint motion. Radiographic measurement is the gold standard for calculating knee range of motion. A radiograph of the knee joint side was taken in this. The angle at the knee joint is measured to determine a range of motion (ROM) by drawing lines from the greater trochanteric of the femur and the distal of fibula. Although radiography is considered to be the most accurate and reliable measurement method (ICC=0.98-0.99) .(119) Other measurements may be more appropriate to avoid unnecessary radiation exposure.(120)

Other methods, including standard goniometers and visual estimation, are commonly used in ROM measurement.(120) A goniometer was used to measure the knee's range of motion. The lateral femoral condyle of the knee joint served as the goniometer's center when the subject was lying flat. The greater trochanter served as the near reference point and the lateral malleolus as the distant reference point. This is simple, time-saving, efficient, and has excellent reliability (ICC=0.98-0.99).[120] The main disadvantage of the goniometer is that measurements are taken with both hands while it is attached to the patient. The user must be in precise position. This method may increase the risk of measurement error.

Visual estimation of the knee joint ROM is the quickest form of ROM measurement and is more commonly used in clinical practice than in research. Visual estimation has been shown to be less accurate than standard goniometer measurements.[120]

Nowadays, technology for ROM measurements has advanced more than in the past. Two-dimensional (2D) motion analysis is commonly used in biomedical, clinical, and sports science applications because of its lower cost, the time- and cost-effective, portable, and simple-to-use tool.[121] Kinovea program is used to analyze movement, including calculating angles and distances. This program was reported that there was a excellent intra-reliability of ROM measurement. (ICC>0.971) the standard error of the mean (SEM) ranged from 0.52 to 0.85 and minimal detectable change (MDC_{95}) ranged from 1.43 to 2.35. Kinovea program has excellent inter-reliability (ICC ICC>0.987) the standard error of the mean (SEM) ranged from 0.54 to 0.58 and minimal detectable change (MDC_{95}) ranged from 1.51 to 1.62.[122] The current study will be used VDO camera with Kinovea program to measure ROM because it is a simple, repeatable, and non-invasive method.

Muscle strength

The isokinetic dynamometer and the hand-held dynamometer were the instruments used to measure the quadriceps muscle strength in the research laboratory. The Isokinetic dynamometer is considered the “gold standard” screening tool for the assessment of quadriceps strength.[123] However, its application is limited in clinical settings because of the high cost of devices, lack of portability, and time consumed to complete assessments.[124] The isokinetic strength test was reported that there was an excellent test-retest reliability with interclass correlation coefficients (ICC) ranged from 0.94 and 0.98.[125] Clinically, hand-held dynamometer is easy to use, low cost, a portable device and requires minimal training. There have been reports of significant positive correlations between the measurement of quadriceps and hamstrings muscle strength using a hand-held dynamometer and an isokinetic dynamometer (i.e., Pearson correlation coefficient range = 0.72-0.85).[126] Additionally, hand-held dynamometer demonstrated excellent intra-rater and inter-tester reliability of isometric muscle strength measurement. (ICC>0.950 and 0.927, respectively).[127]

Functional mobility test

The functional mobility test is commonly used to measure the quantity of functional activities. It is related to functional activities in daily. It should use to assess the movement both before and after treatment in patients with TKA. Moreover, it is an indicator for the achievement of rehabilitation after knee replacement. The functional mobility test consists of 30 second chair stand test (30sCST), 4-meter walk test (4mWT), six-minute walk tests (6MWT), timed up and go test (TUG)

Thirty second chair stand test (30sCST) is used to test leg strength and endurance. The instrumentation for 30sCST is a chair with a straight back without arm rest (seat 17" high) and stopwatch. The instructions for 30sCST, the participants sat in the middle of the chair, back straight, feet flat on the floor, arms cross and hold hands on the shoulder. After the command "GO", the participants stood up (body erect and straight) and then returned to the sitting position. They were encouraged to complete as many full stands as possible within 30 seconds. They were instructed to fully sit between each stand. During standing up, if they performed incorrectly or cannot hold their arm across and their hands moved from their shoulders, the assessor reminded them, and this stand was not counted. The assessor recorded the number of completed standing within 30 seconds.[128] The test-retest reliability of the 30s-CST was excellent (ICC= 0.974).[129]

Four-meter walk test (4mWT) is a simple method that is commonly used to assess walking speed in short distance. To perform the 4 MWT, the 8-meter path was marked with the first and last 2-meter spaces for acceleration and deceleration, respectively. These additional acceleration and deceleration spaces were not in the data collection.[130] The start and end points of the 4-m line were marked with colored non-elastic tape. Patients began walking and accelerated along the 8-meter path. When the patient's leg crossed the starting line, the stopwatch began. The stopwatch was stopped when the patient's leg passed over 4-m mark. Patients then slowed and came to a halt. The assessor gave the patients the same verbal instructions on how to perform the tests before each test trial. Patients were instructed to walk as quickly as possible. To ensure their safety, they were permitted to use assistive devices (walkers and crutches). During the tests, all patients used assistive devices.[130] This test demonstrated excellent test-retest reliability with interclass correlation coefficients ranged from 0.80 to 0.93. It also demonstrated small measurement error with a standard error of measurement (SEM) ranged from 0.15 to 0.35, showing high responsiveness sufficient for clinical outcomes in the immediate postoperative time periods.[131]

Six-minute walk tests (6MWT) is one of recommended set of performance-based test in patients with knee OA, recommended by the Osteoarthritis Research Society International (OARSI).[132] It is a test to assess submaximal aerobic capacity and ability to walk over long distances.[132] 6MWT may overburden for patients who use walking aids, have limited walking endurance, or have muscle weakness, which is common in TKA patients. 6MWT was measured on a 20-meter indoor loop with or without gait aid. Rests were permitted, but time did not stop.[133] Minimal clinically important difference (MCID) threshold of 74.36 m was identified, with sensitivity 0.60, specificity 0.67, and the area under curve (AUC) 0.65.[133] The intra-rater reliability of the 6-min walk test was high in patients with TKA (ICC = 0.97).[134]

The timed up and go test (TUG) is one test of recommended set of performance-based test in patients with knee OA.[132] It has also been used frequently in TKA patients to assess basic functional mobility and balance. TUG is an easy-to-use test that needs a little equipment and may be easily adopted as part of a routine examination.[89, 135] TUG has excellent repeatability. (ICC= 0.98) the standard error of the mean (SEM) and minimal detectable change (MDC_{95}) for TUG were 0.82 and 2.27, respectively.[135] There are six movement components for the TUG that are essential movements for activities of daily life (i.e., sit to stand, walking out, turning, walking in, turn around, and stand to sit).[136] The TUG testing was conducted using a chair with a backrest, height 43-50 centimeters (or adjust the chair height at the level where the patients sit with the back of the backrest and both feet flat on the floor), a cone placed in front of the chair approximately 3 meters or 10 feet, and stopwatch. The patients started from sitting position in a chair with backrest, After the assessor says “go”, the patients will stand up from a chair. They walked 3 meters to the cone, turn around the cone, and walk back to the chair and sit down. The timing of testing began at the instruction “go” and stop when the patients sit down with back at backrest.[137] The walking speed was a comfortable speed and safe pace. The patients can walk with walker. They walked barefoot.[138] On average, the duration of TUG in the elderly aged 60 to 90 years was 14 seconds.[139, 140] A shorter period indicates that is a better functional mobility. And if the patients perform TUG longer than 14 seconds, the patients will have a high risk of falling. The TUG test was first intended for those who were at risk for falling among elderly people who lived in their communities.[140] The TUG test was created more recently to assess the level of function in patients with diseases like multiple sclerosis,[141] chronic obstructive pulmonary disease,[142] total hip arthroplasty,[143] and stroke.[144] This showed that clinical examinations may be done with great simplicity and dependability.

CHAPTER 3
METHODOLOGY

Research design

This study is a single-assessor blinded, randomized controlled trial that will compare standard rehabilitation program (control group), and standard rehabilitation program with laser visual feedback (intervention group) to improve the range of motion of knee joint and functional mobility.

Setting

This study was taken at the physical therapy department, Krathumbaen hospital, Krathumbaen district, Samut Sakhon province.

Subject

Thirty-two patients awaiting total knee arthroplasty (TKA) for osteoarthritis (OA) were randomly assigned to either the control or intervention group. Sixteen patients in the control group received a standard rehabilitation program whereas sixteen patients in the intervention group received a standard rehabilitation program with laser visual feedback. Simple random sampling was used to allocate in each group by lottery method before surgery. Patients were allocated to their groups and remained unaware of their assigned treatments.

Inclusion criteria were: awaiting primary and unilateral TKA for knee OA, with the ability to understand, communicate, and follow instructions. Patients were excluded if they had postsurgical complications (e.g., thrombosis, infection), uncorrectable visual loss, significant neurological impairment (e.g., stroke), or severe cardiovascular conditions. Additionally, patients were excluded if they could not walk independently with a walking aid or if they could not understand the study's objectives due to cognitive impairment or mental illness.

For discontinuation criteria, patients were withdrawn from the rehabilitation program if they chose not to continue participate further or if they failed to perform the exercises for more than 3 consecutive days.

Ethical considerations

All patients were informed of the aims, protocols, risk, and benefits of this study before deciding to participate, and each provided written informed consent. This study was approved by the Ethics Committee of Krathumbaen Hospital in Samut Sakhon province. It has been registered in the Thai Clinical Trials Registry (TCTR20230706001).

Sample size calculation

The sample size was calculated by G*power 3.1.9.4 program, a statistical test for two independent means. The effect size for the timed up and go test (TUG), based on the study by Lee et al., 2020 [32] was 1.72, as shown in Figure 6. A two-tailed test was used with an alpha level of 0.05 and a power of 0.95. The total sample size calculation based on the TUG variable was 20 participants.

For knee range of motion (ROM), the effect size based on the study by Jin et al., 2020[145] was 1.27, as shown in figure 7. A two-tailed test was used with an alpha level of 0.05 and a power of 0.85. The total sample size calculation based on the ROM variable was 26 participants.

This study selected the ROM variable for sample size calculation. Allowing for a 20% dropout rate, 32 participants were recruited for this study, with 16 participants assigned to each group.

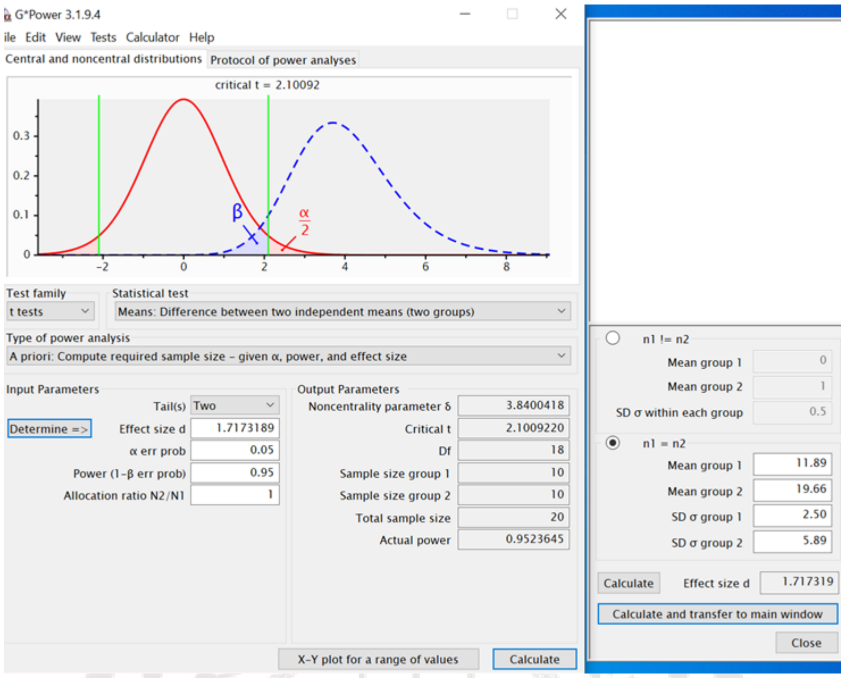


Figure 6 The sample size calculation from TUG variable by using two independent means in G*power 3.1.9.4

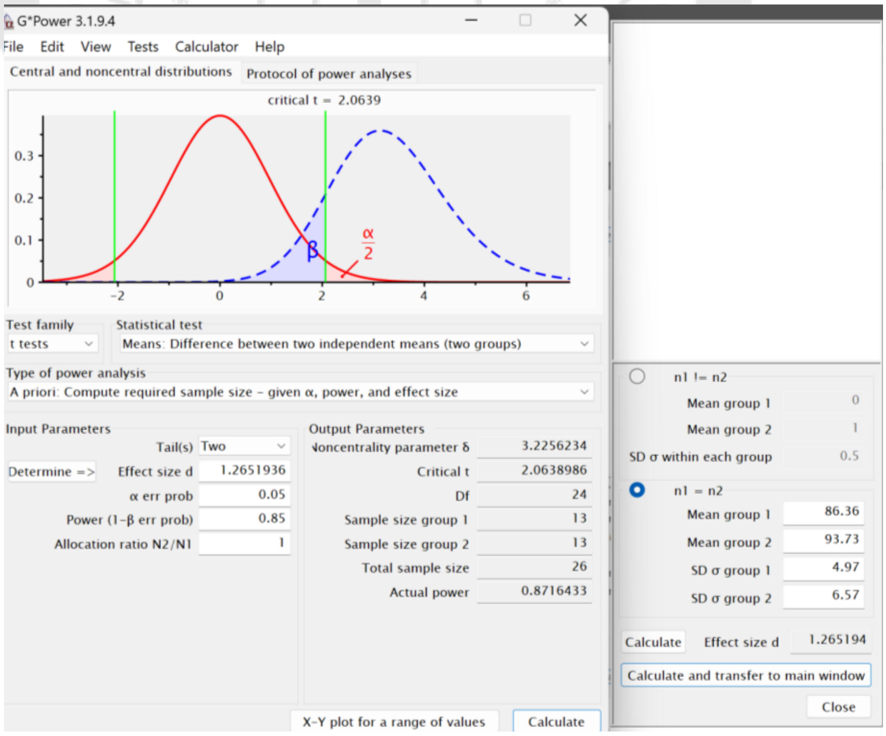


Figure 7 The sample size calculation from ROM variable by using two independent means in G*power 3.1.9.4

Outcome measures, instrumentation, and follow-up

Pain intensity

Pain at rest and pain during movement were measured using Numeric Pain Rating Scale. Pain at rest and pain during movement measurements were taken at three-time points; postoperative day 0, postoperative day 7, and postoperative day 14.

Range of Motion (ROM)

Active ROM of knee flexion and extension were measured using Kinovea program version 0.9.5. Video recording was used while patients bent and straightened their knees. The video camera was placed parallel to the ground on the side of the affected leg (the TKA leg). Patients were in a supine lying position and were instructed to bend or extend their knee until they felt stiffness. Knee ROM measurements were taken at four-time points; pre-operative day, postoperative day 0, postoperative day 7, and postoperative day 14.

Total durations in Timed-up and Go test (TUG)

The timed up and go test was used to assess the functional mobility of patients. The TUG testing was conducted using a chair with a backrest (43-50 cm in height or adjusted so that patients could sit with their back against the backrest and both feet flat on the floor), a cone placed approximately 3 meters or 10 feet in front of the chair, and a stopwatch. The timer started with the instruction “go” and stopped when the participant was seated again.[137]

On average, the TUG duration for elderly individuals aged 60 to 90 years is 14 seconds.[139, 140] A shorter time indicates better functional mobility, whereas times exceeding 14 seconds indicates a high risk of falling. The TUG test was measured at three-time points: on the pre-operative day, postoperative day 7, and postoperative day 14, as shown in Figure 8.

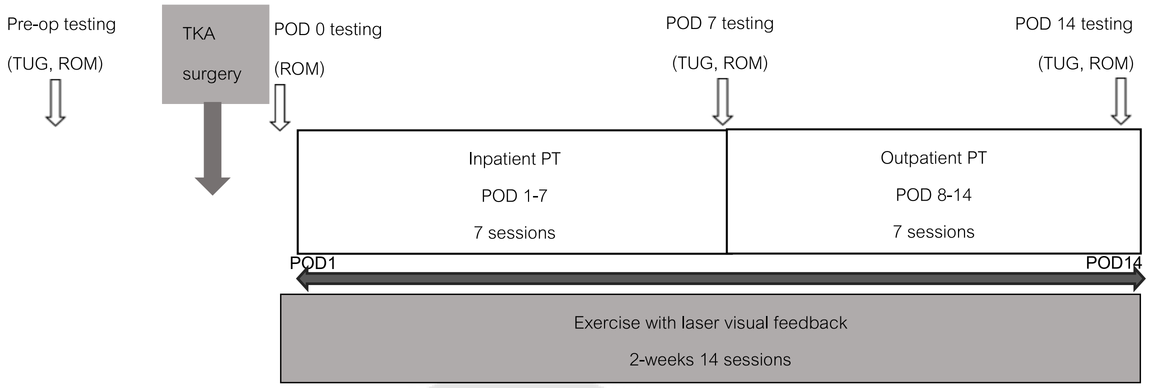


Figure 8 Timelines for the testing session and rehabilitation program.

Procedures

All patients were informed about general information such as gender, age, weight, height, body mass index (BMI) and medical history (Appendix A). The KOOS questionnaire (quality of life subscale)[146] (Appendix B) and a depression assessment (Appendix C) were also recorded.

Prior to testing, two experienced physical therapists assessed the intra-rater reliability (ICC 3,1) of using the Kinovea program to measure knee range of motion and the TUG test to assess functional mobility in healthy participants. The intra-rater reliability testing was examined under the same conditions at two different time intervals. The assessor marked bony prominences (greater trochanteric, lateral condyle of femur, and lateral malleolus) with stickers to represent the knee joint angle. Patients were positioned on a bed 80 cm above the floor, with their lower limbs placed parallel to the edge of the bed. A video camera mounted on a tripod at 125 cm above the floor was positioned 120 cm from the patient's limb. The video camera and tripod and maintained were set at a 90-degrees angle to the long axis of the bed,[147] as shown in Figure 9.

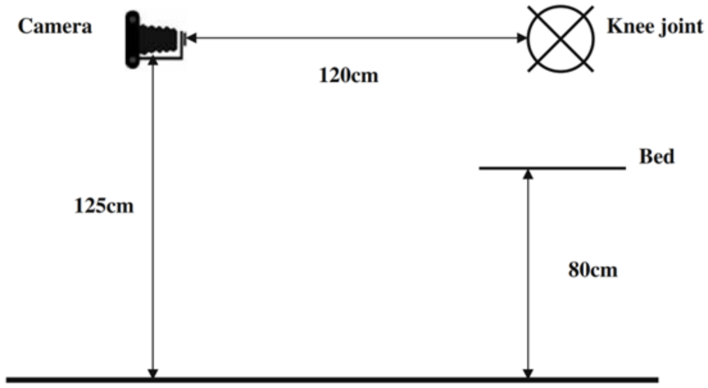


Figure 9 Schematic of video camera and patient positioning

The patients bent and straightened their knees in a supine lying until they felt stiff. The video camera was placed parallel to the ground to record the knee motion. The Kinovea program was then used to analyze the angle of knee flexion and extension from the video recording. After 5 days, the same assessor measured the knee ROM again using the Kinovea program. Following the ROM measurement, the patients rested for 10 minutes. Then, the same patients performed the TUG testing in one session. A video was recorded during the TUG test, and the assessor recorded the time in seconds when the patient completed the test. After 5 days, the same assessor recorded the TUG test time in seconds again using the previous video recording.

Before each testing, the patients were given the opportunity to practice until they could perform the tests correctly. Video recording was used to observe knee motion and verify the timing of the TUG test in case of any data misinterpretation. The video was recorded from a side view of the patients for both the knee ROM measurement and the TUG test.

The procedure for measuring knee ROM was described by Lenssen et al., 2007.[148] The starting position for the patients was supine, and they were instructed to slide their heel while bending and straightening their knee until they felt stiffness in the joint. The assessor stood at the end of the bed and instructed the patients to control their knee flexion and extension in the sagittal plane before recording the video. The testing procedure is shown in Figure 10.

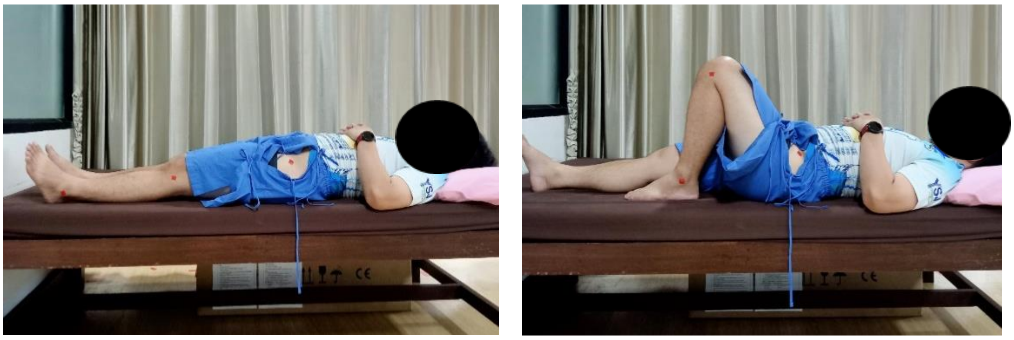


Figure 10 Knee flexion and extension

The instructions for the TUG test were described by Barry et al., 2014.[140] The patients start from a sitting position in a chair with a backrest, After the assessor says “go”, the patients stand up from a chair, walk 3 meters to a cone, turn around the cone, and walk back to the chair and sit down. The timing of testing begins when the assessor says “go” and stops when the patient sits back down. The patients are instructed to walk at comfortable speed and safe pace. They are allowed to use a walker if needed and walk barefoot. The testing procedures is shown in Figure 11.

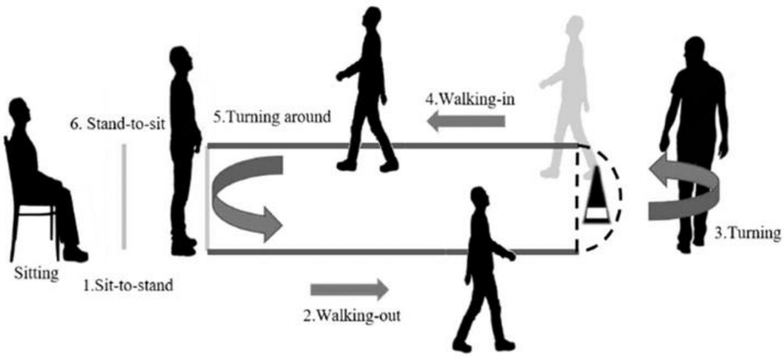


Figure 11 The Timed up and go test

Source: Hsieh CY, Huang HY, Liu KC, Chen KH, Hsu SJ, Chan CT. Subtask segmentation of timed up and go test for mobility assessment of perioperative total knee arthroplasty. Sensors (Basel). 2020;20(21)

Standard rehabilitation program (P1)

All patients began the standard rehabilitation program for TKA following the guidelines of Krathumbaen Hospital, based on Stevens-Lapsley et al., 2012.[18] The program started on postoperative day 1 through day 7. This rehabilitation protocol has been implemented at Krathumbaen Hospital since 2012. After discharge, all participants received an additional seven outpatient treatment sessions from postoperative day 8 through day 14, as illustrated in Figure 8. If patients were discharged before day 7, they continued with the outpatient rehabilitation protocol.

On postoperative day 1, the program included pain and swelling management with cryotherapy, bedside exercises (ankle pumping, passive knee ROM flexion/extension, heel slide, isometric quadricep exercise, gluteal sets), bed mobility training, and assistance with sitting and standing (if possible). Day 2 added active-assisted knee ROM, straight leg raises (SLR), hip abduction, terminal knee extension exercise in supine, and function mobility training (sit-to-stand and short-distance gait training with aid, if possible). On day 3, patients performed active knee ROM in a seated position and terminal knee extension during standing. Days 4 to 7 introduced mini squat, marching with aid, and step-ups, while days 8 to 14 involved longer-distance gait training with aid.

All exercises began with 1 set of 10 repetitions on days 1-2, progressed to 2 sets by day 5, and to 3 sets by day 7. Gait training intensity was increased by gradually extending the walking distance based on each patient's tolerance. The detailed standard rehabilitation program is shown in Table 1.

Standard rehabilitation program with laser visual feedback (P2)

Laser visual feedback which is a type of visual feedback consists of a laser pointer, a base for attaching the laser pointer, and an adjustable strap. This device emits a red laser beam with a wavelength of 650 nm, an output power of 0.4-1.0 mW, and a size of 5.4×1.6 cm. The laser pointer is mounted on the base with an adjustable angle. Previous research has shown that combining a laser pointer with the dynamic balance exercises can effectively improve physical function and balance in patients following total knee replacement.[32]

Before beginning the rehabilitation program, the laser visual feedback was placed above the superior border of the patella with an adjustable strap. Patients were instructed to perform each exercise so that the laser beam aligned with the second toe, setting a target for each movement. The laser visual feedback was used to guide and maintain proper movement during standard rehabilitation exercises, including isometric quadriceps exercise, SLR exercise, terminal knee extensions (supine and standing), active knee extensions (sitting), sit-to-stand training, and mini squats), as outlined in Table 1.

For non-weight bearing exercises, the first exercise, an isometric quadriceps exercise with laser visual feedback, was performed with the patient a semi-Fowler's position (head and trunk elevated approximately 45 degrees) and the knee slightly flexed at 10 degrees. Patients contracted the quadriceps while controlling the laser beam aligned with the second toe, holding the position for 10 seconds, then resting for 10 seconds, repeating 10 times per set.[149] In the second exercise, SLR exercises with laser visual feedback, patients lied in a supine position, raising the leg without hip rotation, with a straight knees and ankle dorsiflexion, while controlling the laser beam in line with the second toe. For the third exercise, terminal knee extension exercise in a supine position, the knee was set at 30 degree of knee flexion, and the patients straightened the knee with ankle dorsiflexion, aligning the laser beam with the second toe. In the fourth exercise, active knee extension in a seated position, patients straightened the knee and dorsiflexed the ankle as much as possible, controlling the laser beam aligned with the second toe.

For weight bearing exercises, the terminal knee extension exercise in a standing position with laser visual feedback involved the patient standing in a staggered stance using a walker, with the surgical leg slightly flexed in front. The patients straightened the surgical knee as much as possible, aligning the laser beam with the second toe, and then shifted weight from the non-surgical leg to the surgical leg.

In movement symmetry training, the first functional movement is a mini squat with laser visual feedback. The patients were instructed to stand upright, distributed weight evenly on both legs, and place their hands on their waist (or use a walker for stability if needed), bending their knees as tolerated. The researcher marked the laser position as patients squat as low as possible. For the second functional movement, the sit-to-stand exercise, the laser visual feedback was placed on the trunk with an adjustable strap. Patients sat, leaned forward, shifted weight to both legs, and stood, aiming to control the trunk's laser to align with a red line on the wall (a walker may be used for support).

All exercises started with 1 set of 10 repetitions at days 1-2, progressing to 2 sets by day 5 and to 3 sets by day 7. Laser visual feedback was used throughout to guide and control the movement, as shown in Figure 11. If patients report severe pain (numeric rating scale > 7) during an exercise session, the rehabilitation program will be continued on the following day.

Table 1 Standard rehabilitation program and standard rehabilitation program with laser visual feedback

Standard rehabilitation program (P1)	Standard rehabilitation program with laser visual feedback (P2)
Postoperative day1 - Bedside exercise: ankle pumping, passive ROM knee flexion/extension, heel slides, isometric quadriceps exercise, and gluteal sets - Bed mobility training - Supine to sitting and standing with assistance (If possible) - Control pain and swelling with cryotherapy	Postoperative day1 - Bedside exercise: ankle pumping, passive ROM knee flexion/extension, heel slides, **isometric quadriceps exercise with laser visual feedback**, and gluteal sets - Bed mobility training - Supine to sitting and standing with assistance (If possible) - Control pain and swelling with cryotherapy
Postoperative day 2 - Ankle pumping - Knee ROM: active-assisted ROM knee flexion/extension and heel slides - Strengthening exercise: isometric quadriceps, assisted SLR (assisted) , terminal knee extension in supine, and assisted hip abduction - Function mobility training: sit-to-stand, and gait training with aid at short distance (If possible) - Control pain and swelling with cryotherapy	Postoperative day 2 - Ankle pumping - Knee ROM: active-assisted ROM knee flexion/extension and heel slides - Strengthening exercise: **isometric quadricep with laser visual feedback, assisted SLR with laser visual feedback, terminal knee extension in supine with laser visual feedback,** and assisted hip abduction - Function mobility training: **sit-to-stand with laser visual feedback**, and gait training with aid at short distances (If possible) - Control pain and swelling with cryotherapy
Postoperative day 3 Knee ROM: sitting with active knee flexion and extension - Strengthening exercise: terminal knee extension exercise in supine, active SLR, terminal knee extension in standing, and active hip abduction	Postoperative day 3 - Knee ROM: **sitting with active knee flexion and extension using laser visual feedback** - Strengthening exercise: **terminal knee extension exercise in supine with laser visual feedback, active SLR with laser visual feedback, terminal knee extension in standing with laser visual feedback**, and active hip

- Function mobility training: sit-to-stand, sitting, and gait training with aid at short distances - Control pain and swelling with cryotherapy (if symptoms persist)	abduction - Function mobility training: **sit-to-stand with laser visual feedback**, sitting, and gait training with aid at short distances - Control pain and swelling with cryotherapy (if symptoms persist)
Postoperative day 4-7 - Knee ROM: sitting with knee flexion and extension - Strengthening exercise: active SLR, terminal knee extension in standing, and active hip abduction - Function mobility training: marching with aid, step-ups, gait training, mini squats and sit-to-stand	Postoperative day 4-7 - Knee ROM: **sitting with knee flexion and extension with laser visual feedback** - Strengthening exercise: **active SLR with laser visual feedback, terminal knee extension in standing with laser visual feedback,** and active hip abduction - Function mobility training: marching with aid, step-ups, gait training, **mini squats with laser visual feedback and sit-to-stand with laser visual feedback**
Postoperative day 8-14 - Sitting with knee flexion and extension, SLR exercise, terminal knee extension in standing, sit-to-stand, mini squats, marching with aid, step-ups, and gait training with aid at long distance	Postoperative day 8-14 **- Sitting with knee flexion and extension with laser visual feedback, SLR exercise with laser visual feedback, terminal knee extension in standing with laser visual feedback, sit-to-stand with laser visual feedback, mini squats with laser visual feedback**, marching with aid, step-ups, and gait training with aid at long distance

Isometric quadriceps exercise
with laser visual feedback

Terminal knee extension in supine lying
with laser visual feedback

SLR exercise with laser visual feedback

Knee flexion and extension
with laser visual feedback

Terminal knee extension in standing with laser visual feedback

Mini-squat exercise with laser visual feedback

Sit to stand exercise with laser visual feedback

Figure 12 Standard rehabilitation program with laser visual feedback

Statistical analysis

Demographic characteristics of participants were presented as descriptive statistics. The Shapiro-Wilk test was conducted to assess the normality of all variables. Analysis of covariance (ANCOVA) was employed to compare knee angles, the durations of TUG, and pain intensity between the control and intervention groups at each measurement time. Repeated measures analysis of variance (RM-ANOVA) was performed to evaluate within-group differences across the four ROM measurement times (pre-operative day, postoperative day 0, postoperative day 7, and postoperative day 14), the three TUG measurement times (pre-operative day, postoperative day 7, and postoperative day 14), and the three pain intensity measurement times (postoperative day 0, postoperative day 7, and postoperative day 14). Missing data were imputed using the last-observation-carried-forward (LOCF) method for the intention-to-treat analysis. A significant level was set at a p-value of less than 0.05.

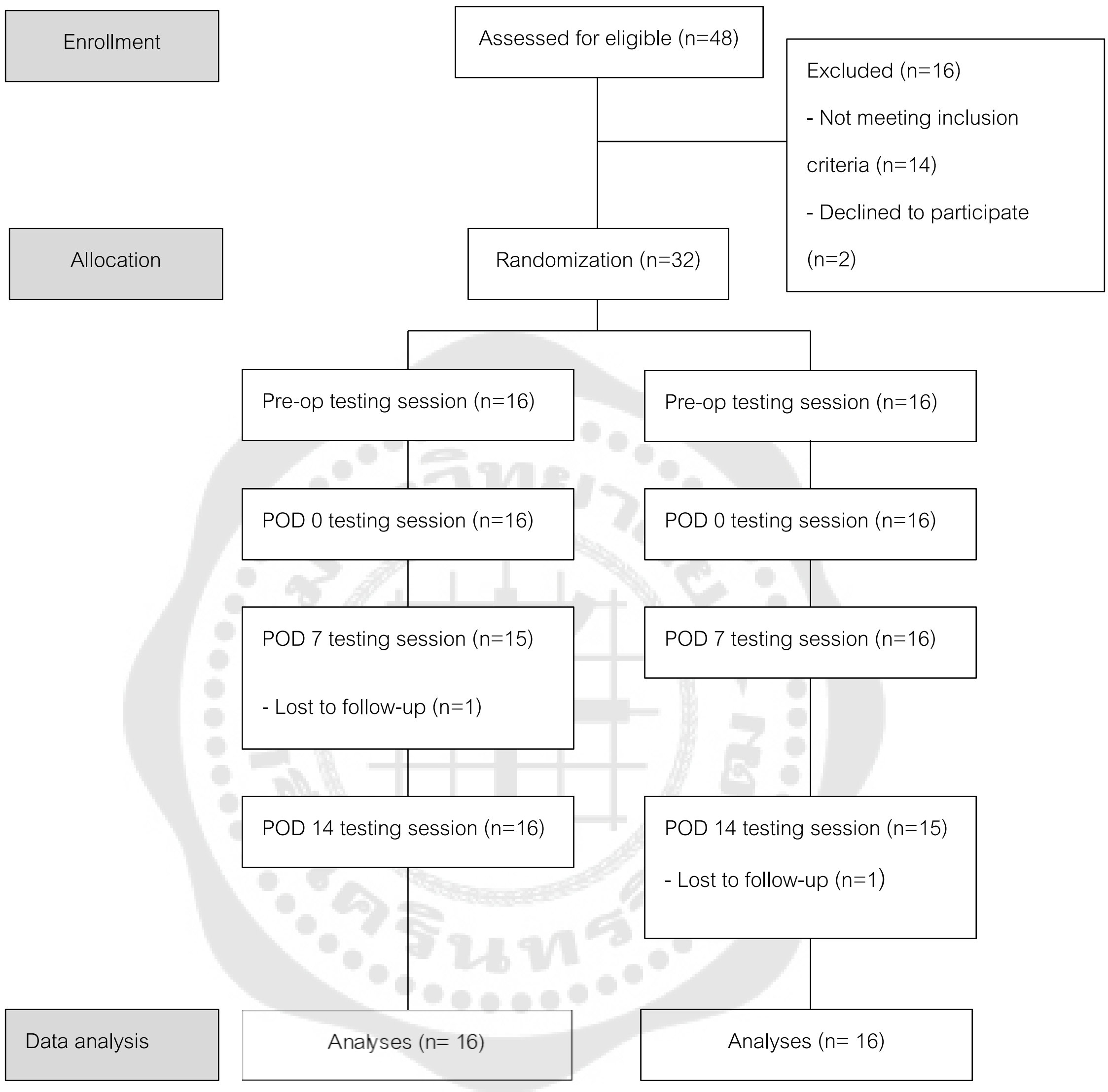


Figure 13 Consolidate standards of reporting trial (CON-SORT) flow chart diagram for summarizing process of this study

CHAPTER 4

RESULTS

This study investigated the effects of rehabilitation protocols, including knee exercises and movement symmetry training, combined with laser visual feedback on knee motion and functional mobility in patients with total knee arthroplasty (TKA). The primary outcomes measured were knee flexion and extension angles, as well as performance in the Timed Up and Go (TUG) test. This study aimed to compare knee flexion and extension angles between the intervention and control groups, as well as within each group at different time points (preoperative; pre-op, postoperative day; POD 0, 7, and 14). In addition, this study aimed to compare TUG times between the intervention and control groups, and within each group at pre-op, POD 7, and 14.

Demographic characteristics

The demographic characteristics of all patients were presented in table 2. There were no significant differences between the intervention and control groups in terms of baseline characteristics, including age, gender, weight, body mass index (BMI), co-morbidity, quality of life prior to TKA, and depression prior to TKA. This ensured that the groups were comparable before the intervention began.

Table 2 Baseline demographic and clinical characteristics of total knee arthroplasty patients in the control and intervention groups

Characteristics	Control group (n=16)	Intervention group (n=16)	p value
Age (years)			
mean±SD	69±6.78	67.94±6.69	0.659[a]
range	(60-84)	(60-79)	
Gender (n, %)			
Male	2(12.5%)	1(6.25%)	0.544[b]
Female	14(87.5%)	15(93.75%)	
Weight (kg)			
mean±SD	60.69±6.62	60.66±7.78	0.988[a]
range	(50-78)	(48-73)	
Body mass index (kg/m^2)			
mean±SD	25.41±1.93	24.99±2.27	0.575[a]
range	(22.22-28.88)	(20.73-28.11)	
Co-morbidity (n, %) yes	(13, 81.25%)	(15, 93.75%)	0.285[b]
- Diabetes Mellitus	5	7	
- Hypertension	12	12	
- Dyslipidemia	7	8	
- Other (CA, thyroid)	0	2	
Quality of life prior to TKA (n, %)	(15, 93.75%)	(15, 93.75%)	0.096[b]
Mild symptom	2	7	
Moderate symptom	7	7	
Severe symptom	6	1	
Most severe symptom	0	0	
Depression prior to TKA (n, %)			0.544[b]
No	(14, 87.5%)	(15, 93.75%)	
Yes	(2, 12.5%)	(1, 6.25%)	

Note: [a] p value of the comparison between intervention and control group by independent t-test

[b] p value of the comparison between intervention and control group by chi-square test

Knee flexion angles

On POD 7 and 14, there was a significant mean difference in knee flexion angles between the intervention and control groups (p<0.001). The intervention group exhibited significantly higher knee flexion angles than the control group on both POD 7 and POD14, with mean differences of 13.05° and 11.80°, respectively (p<0.001) as shown in Table 3. In the within-group comparison, there was a significant difference in knee flexion angles among the pre-op, POD 0, POD 7 and POD 14 assessments in both groups (p<0.001).

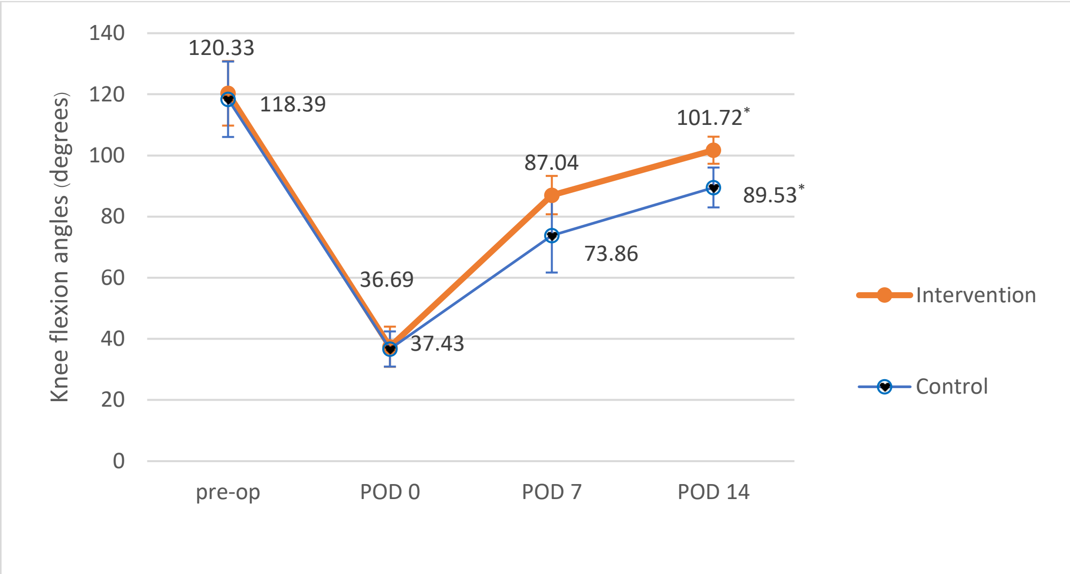
Following surgery, all patients in both groups demonstrated significantly increased knee flexion angles on POD 7 compared to POD 0. Specifically, the intervention group had a mean knee flexion angle 87.04° on POD 7 and 37.43° on POD 0, while the control group showed mean angles of 73.86° on POD 7 and 36.69° on POD 0 (p<0.001 for both groups). Additionally, both groups showed significant increases in knee flexion angles on POD 14 compared to POD 0. The intervention group's mean angles of 101.72° on POD 14 and 37.43° on POD 0 (p<0.001), whereas the control group's mean angles of 89.53° on POD 14 and 36.69° on POD 0 (p<0.001). On POD 14, both the intervention and control groups showed significantly increased knee flexion angles compared to POD 7 (p < 0.001). These results are illustrated in Figure 14.

Table 3 Knee flexion angles for control and intervention groups at each measurement time (n=32)

Variables	Control group (n=16)		Intervention group (n=16)		Mean Differences Between the groups$^{\#}$ (95%CI)	P value
	Mean±SD (95%CI)	Mean Change Scores$^{\$}$ (95%CI)	Mean±SD (95%CI)	Mean Change Scores$^{\$}$ (95%CI)		
Knee flexion angle (degrees)						
pre-op	118.39±12.34 (111.82,124.97)		120.33±10.56 (114.70,125.95)			
Post-op day 0	36.69±5.75 (33.63,39.75)		37.43±6.58 (33.92,40.93)			
Post-op day 7	73.86±12.16 (67.38, 80.34)	37.18* (28.28,46.07)	87.04±6.27 (83.70, 90.38)	49.61* (42.84,56.39)	13.05 (5.93,20.17)	P<0.001
Post-op day 14	89.53±6.52 (86.05,93.00)	52.84^{*,c} (47.41,58.27)	101.72±4.43 (99.36,104.08)	64.29^{*,c} (57.43,71.16)	11.80 (8.06,15.55)	P<0.001

Abbreviation: 95%CI, 95% confidence interval

Note. The data are presented using mean ± standard deviation (95%CIs).$^{\$}$The mean change from pretest data and analyzed using the repeated measure analysis of variance and post hoc (Bonferroni) test. $^{\#}$Mean Differences Between the groups at each reassessment period with adjusted for baseline data and analyzed using the analysis of covariance, *Significance difference from POD 0 at p<0.001, ^{c}Significance difference from POD 7 at p<0.001



Note *significantly increased knee flexion angles compared to POD 7at p<0.001

Figure 14 Knee flexion angles between the control and intervention group on pre-op, POD 0, POD 7 and POD 14

Knee extension angles

On POD 7 and 14, there was a significant mean difference in knee extension angles between the intervention and control groups ($p<0.001$). The intervention group exhibited significantly lower knee extension angles than the control group, with mean differences of -5.17° on POD 7 and -5.02° on POD 14 ($p<0.001$ for both time points), as shown in Table 4. These results indicate that patients in the intervention group were able to achieve greater knee extension compared to those in the control group on POD 7 and 14.

Within-group repeated measures analysis revealed a significant difference in knee extension angles among the pre-op, POD 0, POD7 and POD14 assessments for both groups ($p<0.001$). Following surgery, all patients in both groups demonstrated significantly decreased knee extension angles (indicating improved ability to extend the knee) on POD 7 and POD 14 compared to POD 0. In the intervention group, the mean knee extension angles on POD 0, POD 7, and POD 14 were 17.29°, 8.28°, and 5.27°, respectively, whereas in the control group they were 16.68°, 12.74°, and 9.98°, respectively.

On POD 14, the intervention group exhibited significantly decreased knee extension angles compared to pre-op (5.27° vs. 9.01°, $p < 0.001$), indicating improved knee extension ability. In contrast, the control group showed a slight but significant increase in knee extension angles when compared to pre-op (9.98° vs. 8.01°, $p < 0.05$). Additionally, on POD 14, both groups showed significantly decreased knee extension angles compared to POD 7 ($p < 0.001$ and $p < 0.05$, respectively). These findings are illustrated in Figure 15.

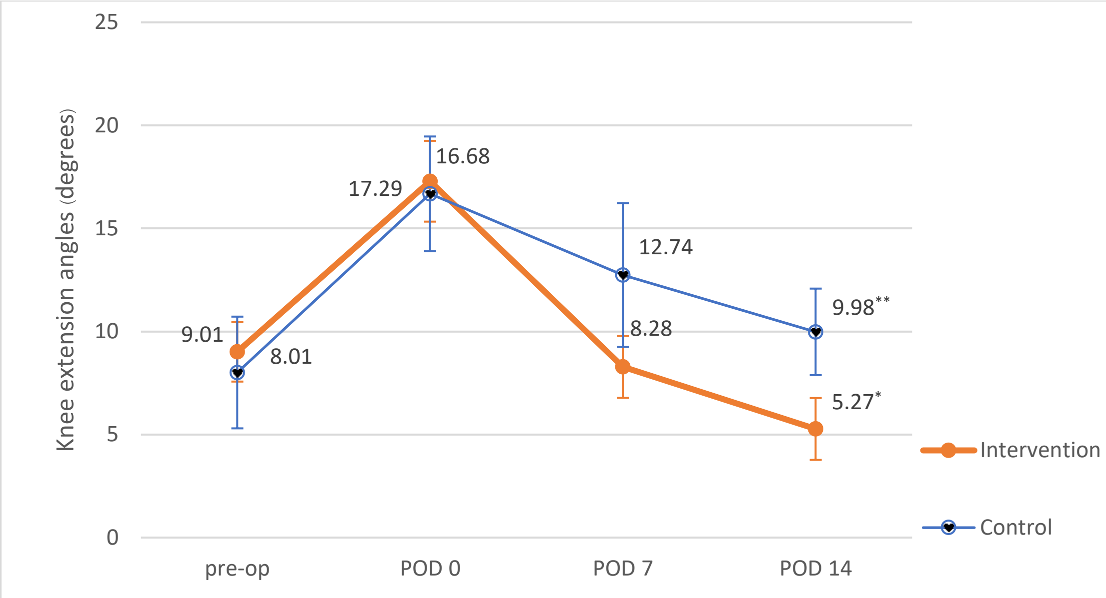
Table 4 Knee extension angles for control and intervention groups at each measurement time (n=32)

Variables	Control group (n=16)		Intervention group (n=16)		Mean Differences Between the groups[#] (95%CI)	P value
	Mean±SD (95%CI)	Mean Change Scores[$] (95%CI)	Mean±SD (95%CI)	Mean Change Scores[$] (95%CI)		
Knee extension angle (degrees)						
pre-op	8.01±2.71 (6.56,9.45)		9.01±1.44 (8.25,9.78)			
Post-op day 0	16.68±2.78 (15.19,18.16)		17.29±1.96 (16.24,18.33)			
Post-op day 7	12.74±3.49 (10.88,14.60)	-3.93[*] (-5.45,-2.42)	8.28±1.50 (7.48,9.07)	-9.01[*] (-10.62,-7.39)	-5.17 (-6.84,-3.50)	P<0.001
Post-op day 14	9.98±2.10 (8.86,11.10)	-6.70[*,b,d] (-8.38,-5.02)	5.27±1.50 (4.47,6.07)	-12.02[*,a,c] (-14.21,-9.82)	-5.02 (-6.30,-3.74)	P<0.001

Abbreviation: 95%CI, 95% confidence interval

Note. The data are presented using mean ± standard deviation (95%CIs).

[$] The mean change from pretest data and analyzed using the repeated measure analysis of variance and post hoc (Bonferroni) test, [#]Mean Differences Between the groups at each reassessment period with adjusted for baseline data and analyzed using the analysis of covariance, [*]Significance difference from POD 0 at p<0.001, [a] Significance difference from pre-op at p<0.001, [b] Significance difference from pre-op at p<0.05, [c]Significance difference from POD 7 at p<0.001, [d]Significance difference from POD 7 at p<0.05



Note: * significantly decreased knee extension angles compared to POD 7 at p<0.001

** significantly decreased knee extension angles compared to POD 7 at p<0.05

Figure 15 Knee extension angles between the control and intervention group on pre-op, POD 0, POD 7 and POD 14

Timed up and go test (TUG)

On POD 14, the mean differences of TUG times in the intervention group were significantly lower than those in the control group ($p<0.001$), while no significant difference was found between groups on POD 7. Within-group comparisons showed that the TUG times on POD 7 and POD 14 took significantly longer than pre-op in both the intervention group ($p<0.001$ and $p<0.05$, respectively) and control group ($p<0.001$), as shown in Table 5.

However, on POD 14, the TUG time in the intervention group was nearly the same as the pre-op time (28.91 vs 23.94 sec, $p<0.05$), whereas the control group still showed a significantly longer TUG time (36.55 vs 23.18 sec, $p<0.001$). Additionally, on POD 14, TUG times in both the intervention and control groups were significantly shorter than on POD 7 ($p < 0.001$), as shown in Figure 16.

Table 5 Duration of the timed up and go test for control and intervention groups at each measurement time (n=32)

Variables	Control group (n=16)		Intervention group (n=16)		Mean Differences Between the groups[#] (95%CI)	P value
	Mean±SD (95%CI)	Mean Change Scores[$] (95%CI)	Mean±SD (95%CI)	Mean Change Scores[$] (95%CI)		
TUG (seconds)						
pre-op	23.18±4.13 (20.98,25.38)		23.94±5.83 (20.84,27.05)			
Post-op day 7	46.97±6.79 (43.35,50.58)	23.79[a] (18.08,29.49)	44.09±6.88 (40.42,47.76)	20.14[a] (14.39,25.90)	-2.88 (-7.92,2.17)	P=0.25
Post-op day 14	36.55±2.32 (35.31,37.79)	13.37[a,c] (10.20,16.54)	28.91±3.96 (26.80,31.03)	4.97[b,c] (0.22,9.72)	-7.64 (-10.04, -5.24)	P<0.001

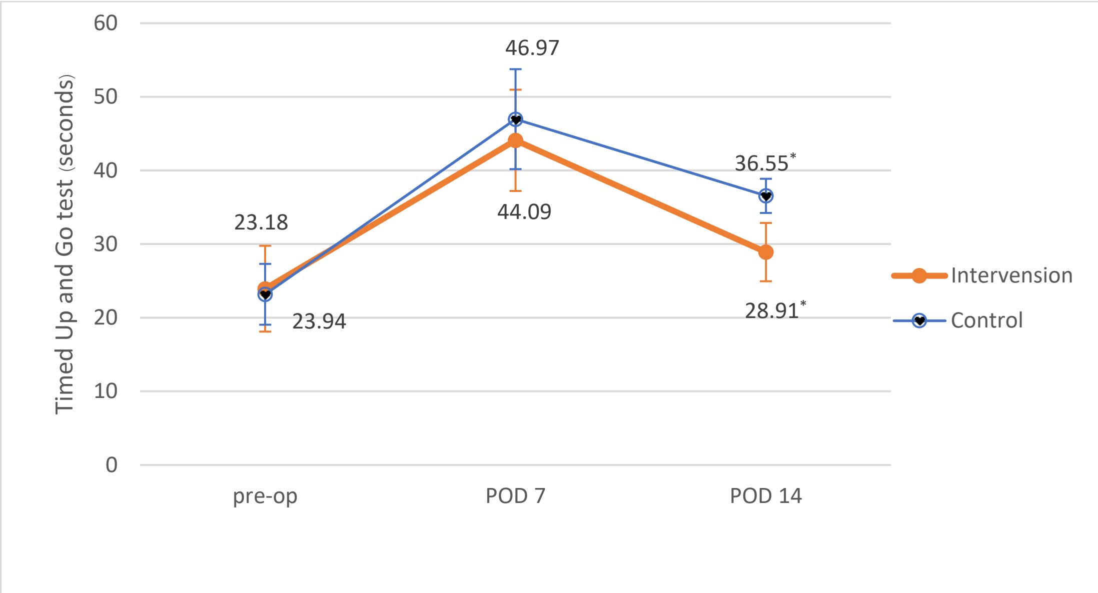
Abbreviation: 95%CI, 95% confidence interval

Note. The data are presented using mean ± standard deviation (95%CIs).

[$] The mean change from pretest data and analyzed using the repeated measure analysis of variance and post hoc (Bonferroni) test.

[#]Mean Differences Between the groups at each reassessment period with adjusted for baseline data and analyzed using the analysis of covariance.

[a]Significance difference from pre-op at p<0.001, [b]Significance difference from pre-op at p<0.05, [c]Significance difference from POD 7 at p<0.001



Note: *significantly longer TUG times compared to POD 7at p<0.001

Figure 16 The timed up and go test between the control and intervention group on pre-op, POD 7 and POD 14

Pain intensity

On POD 14, the mean levels of pain at rest and during movement in the intervention group were significantly less than those in the control group (p<0.001), whereas no significant difference was observed between groups on POD 7. Within-group comparisons revealed that the pain at rest and during movement on POD 7 and POD 14 significantly decreased compared to POD 0 in both intervention and control group (p<0.001), as shown in Table 6

Table 6 Pain at rest and during movement in control and intervention groups at each measurement time (n=32)

Variables	Control group (n=16)		Intervention group (n=16)		Mean Differences Between the groups# (95%CI)	P value
	Mean±SD (95%CI)	Mean Change Scores$ (95%CI)	Mean±SD (95%CI)	Mean Change Scores$ (95%CI)		
Pain at rest (score)						
Post-op day 0	6.31±1.01 (5.77,6.85)		6.38±0.96 (5.87,6.89)		0.06 (-0.65,0.78)	
Post-op day 7	2.38± 0.62 (2.05,2.71)	3.94* (3.27,4.61)	2.13±0.5 (1.86,2.39)	4.25* (3.53,4.97)	-0.25 (-0.66,0.16)	P=0.22
Post-op day 14	2.31±0.48 (2.06,2.57)	4.00* (3.35,4.65)	0.13±0.34 (-0.06,0.31)	6.25* (5.62,6.88)	-2.19 (-2.49,-1.89)	P<0.001
Pain during movement (score)						
Post-op day 0	6.38±0.96 (5.87,6.89)		6.38±1.15 (5.76,6.99)		0 (-0.76,0.76)	
Post-op day 7	2.81±0.40 (2.60,3.03)	3.56* (2.91,4.21)	2.56±0.51 (2.29,2.84)	3.81* (2.95,4.67)	-0.25 (-0.58,0.08)	P=0.14
Post-op day 14	2.50±0.52 (2.23,2.78)	3.875* (3.23,4.52)	0.56±0.51 (0.29,0.84)	5.81* (4.99,6.64)	-1.94 (-2.31,-1.57)	P<0.001

Abbreviation: 95%CI, 95% confidence interval Note. The data are presented using mean ± standard deviation (95%CIs).$ The mean change from pretest data and analyzed using the repeated measure analysis of variance and post hoc (Bonferroni) test.#Mean Differences Between the groups at each reassessment period with adjusted for baseline data and analyzed using the analysis of covariance,*Significance difference from POD 0 at p<0.001

CHAPTER 5
DISCUSSION AND CONCLUSION

This study aimed to investigate the effect of knee motion and functional mobility by using laser visual feedback combined with knee exercises and movement symmetry training in patients with TKA. The hypothesis of this study was that knee range of motion and functional mobility in the intervention group would increase when compared to those in the control group.

In terms of baseline demographic and clinical characteristics such as age, gender, weight, body mass index, co-morbidities, patients' quality of life, and depression prior to TKA, there were no significant differences between the intervention and control groups ($p>0.05$). The current study defined the knee flexion and extension angles by measuring the end range of motion during knee bending and knee straightening. According to the results, the knee flexion angles in the intervention group were significantly higher than those in the control group on POD 7 and 14 ($p<0.001$). This finding is consistent with the results reported in other studies.[145, 150]

Jin et al., 2018 [145] evaluated the effects of virtual reality (VR) intervention on postoperative rehabilitation in osteoarthritis (OA) patients undergoing TKA, reporting higher knee flexion angles in the intervention group (79.64° on POD 7 and 93.73° on POD 14) compared to the control group (71.76° and 86.36°, respectively). Similarly, Hardt et al., 2018 [150] investigated an app-based, feedback-controlled active muscle training program, finding knee flexion angles of 78° and 67° in the intervention and control groups, respectively, on POD 14.

In the current study, knee flexion angles in the intervention group on POD 7 and POD 14 were 87.04° and 101.72°, respectively, compared to 73.86° and 89.53° in the control group. However, the findings of the current study contrast with previous studies in which knee flexion angles in the intervention group showed no significant difference compared to the control group.[33, 151]

For example, Kondo et al., 2022 [33] assessed a rehabilitation program involving isometric quadriceps exercise with auditory and visual feedback after TKA. They reported no difference in passive knee flexion angles between or within groups at pre-op, and at 2- and 3-weeks post-surgery (p>0.05). Knee flexion angles in the intervention group at 3 weeks post-surgery were nearly equal to those at pre-op.[33] In contrast, the current study measured active knee flexion angles only at weeks 1 (POD 7) and 2 (POD 14), whereas Kondo et al., 2022 [33] measured passive knee flexion angles. Unlike passive range of motion ROM, which depends primarily on soft tissue management and surgical technique, active ROM relies on muscle function and strength and is affected by pain.

Backer et al., 2021[151] studied app-based rehabilitation and found no significant difference in active and passive knee flexion angles between groups (p>0.05), which may be attributed to their intervention providing visual feedback only for isometric quadricep exercises in an open kinetic chain.[151] In contrast, the current study used visual feedback for quadricep exercises in both open and closed kinetic chain. Backer et al., 2021[151] began ROM exercises in week 3, which may delay knee ROM improvement. Additionally, they focused on continuous passive motion of less than 90 degrees in the early phase.[151] However, previous studies strongly recommended ROM exercises in the early phase of rehabilitation to enhance knee ROM.[17, 89, 152]

Within group comparison showed a significant difference in knee flexion angles among pre-op, POD 0, POD 7 and POD 14 measurements in both groups (p<0.001). The improvement in knee flexion angles TKA patients was not linear but showed notable increases on days 7 and POD 14. This finding was consistent with the results of other studies.[85, 153] After surgery, all patients experienced reduced knee flexion angles on POD 0, with the intervention group averaging 120.33° and 37.43°, and the control group averaging 118.39° and 36.69°, likely due to pain, swelling, and anxiety on the day of surgery, which may result from high levels of C-reactive protein and increased local temperature.[154, 155]

Both groups showed significantly increased knee flexion angles at POD 7 and 14 compared to POD 0. These findings are consistent with the study by Kornuijt et al.,[85] which reported an average weekly increase of 19.6° in knee flexion among TKA patients, with mean angles of 80° in week 1 and 90° in week 2, followed by a gradual increase of approximately 1.4° per week during weeks 7 and 8.[85] Similarly, Mutsuzaki et al., 2017[153] observed that average knee flexion angles were 78.2° and 90.6° in weeks 1 and 2, respectively.

In the current study, knee flexion angles in the intervention group were 87.04° on POD 7 and 101.72° on POD 14, exceeding the averages reported in previous studies.[85, 153] The intervention group improved knee flexion angles more than control group. In both groups, change in knee flexion angles from POD 0 to POD 14 exceeds the minimal clinically important difference (MCID) or minimal clinically important change (MCIC) of 12.8° for knee flexion in knee OA patients following non-surgical interventions.[156]

However, knee flexion angles on POD 14 remained lower than pre-op levels in both groups, as full recovery of knee flexion angles may take up to three months after knee arthroplasty.[153] Additionally, knee flexion angles after surgery have been found to correlate with knee flexion angles before surgery and acute knee ROM may predict long-term knee ROM.[157, 158] This suggests that limited preoperative knee flexion angles may result in similarly limited angles post-surgery, which is why some studies establish target range of knee flexion after TKA rehabilitation based on preoperative knee flexion angles.[153]

Regarding knee extension angles, a significant difference was observed between the intervention and control groups on POD 7 and POD 14 ($p<0.001$), with the intervention group demonstrating better extension. This outcome is consistent with previous research.[159] Maeda et al., 2024[159] discovered that the intervention group showed greater knee extension angles than the control group from days 1 to 3 ($p<0.05$), with improvements continuing through day 5.

In the current study, repeated-measure analysis within group found a significant difference in knee extension angles among pre-op, POD 0, POD 7 and POD 14 ($p<0.001$) in both groups. At POD 0, all TKA patients experienced reduced knee extension, likely due to pain, swelling, and anxiety associated with elevated C-reactive protein levels and tissue temperature.[154, 155] Both groups showed significantly improved knee extension on POD 7 and 14, with the intervention group achieving 8.28° and 5.27° on days 7 and 14, respectively, a more substantial improvement in knee extension than previous reports.[85, 153] By POD 14, patients in the intervention group exhibited better extension than pre-op ($p<0.001$).

Quadriceps strength, which often declines significantly in the early postoperative days,[87, 160] plays a role in knee ROM recovery. To address this, laser visual feedback was employed to guide patients in achieving exercise goals, such as isometric quadriceps exercises, straight leg raises (SLR), terminal knee extensions in both supine and standing positions, and seated knee extension exercises. This approach also encouraged active knee extension exercises, thereby facilitating quadriceps contraction.

In the intervention group, laser visual feedback not only helped patients achieve exercise goals but also improved movement quality through verbal feedback. According to motor relearning theory, repeating the same movement to a precise endpoint enhances practice, promotes learning, and facilitates the development of new motor skills. This process often focuses on improving the smoothness and accuracy of movements.[108] Consequently, repeated knee extension exercises combined with laser visual feedback resulted in significant improvements in knee extension angles. Furthermore, laser visual feedback was associated with improved quadriceps strength, which correlated with enhanced knee extension ROM. This improvement is critical for the stance phase during walking and overall gait.[90, 161, 162] Therefore, it is important to focus on the rehabilitation of knee extensor muscles from the early stages.[153, 163]

A systematic review and meta-analysis by Tippo et al., (2019)[164] defined postoperative acquired idiopathic stiffness as a flexion contracture of >5°. The intervention group exhibited an average loss of knee extension of approximately 5°, compared to 9.98° in the control group. Thus, patients in the control group experienced greater stiffness than those in the intervention group. This confirms that the effectiveness of the laser visual feedback protocol combined with movement symmetry training in enhancing knee extension angles after TKA. The nonlinear improvement of knee extension angles observed aligns with previous findings.[85, 153] Kornuijt et al., 2019[85] reported that knee extension angles initially increased on POD 1, then decreased by an average of 2.3° per week, with a slight decline of 0.2° during weeks 7-8. Their study reported average knee extension angles of 8.5° and 6.4° in weeks 1 and 2, respectively.[85] Mutsuzaki et al., 2017[153] reported similar angles of 8.3° and 5.8°, while Yoshioka et al., 2021[165] found extension angles of 6.3° and 5.2° on days 10 and 15 in patients using a robotic suit post-TKA.

In the current study, the mean differences in TUG test times on POD 7 showed no significant differences between the intervention and control groups ($p=0.25$), likely due to similar pain levels at rest and during movement ($p=0.22$ and $p=0.14$, respectively). Both groups also exhibited limited knee flexion and extension angles, resulting in asymmetrical weight bearing during sit-to-stand activities and shorter step lengths in walking, which led to longer TUG times. However, on POD 14, the TUG time in the intervention group was significantly less than that in the control group ($p<0.001$). This was likely due to a significant decrease in pain levels at rest and during movement ($p < 0.001$), as well as the dramatic improvement in knee flexion and extension angles 101.72°, 5.27°, respectively).

Additionally, the intervention group received functional activity training, including mini-squats and sit-to-stand exercises combined with laser visual feedback. which may have promoted more symmetrical and effective movement compared to the control group. These findings align with previous studies. Kondo et al., 2022[33] reported that exercises with visual feedback reduced pain by 1.28 cm on POD 14, resulting in an improved gait pattern by reducing mechanical stress on the knee joint during walking.[166] Several studies incorporating visual feedback with a standard program have demonstrated greater improvements in functional mobility compared to programs without visual feedback.[24, 32, 151, 167] For example, Lee et al., 2020[32] reported that the intervention group, which received dynamic balance training with visual feedback, showed greater improvement in the TUG test times.[32, 167] Further studies on related functional activities, such as the sit-to-stand test, 10-meter walk test, and 6-minute walk test, also support these findings.[24, 151] Abujaber et al., 2017[168] reported that weight distribution training with visual feedback during sit-to-stand exercises had an immediate positive effect on movement symmetry, increased vertical ground reaction force (VGRF) symmetry, and improved knee and hip extension moments in patients undergoing total hip arthroplasty (THA).

Within-group comparisons showed that TUG times on POD 7 and POD 14 were significantly longer than pre-op times in both the intervention ($p < 0.001$ and $p < 0.05$, respectively) and control groups ($p < 0.001$). TUG times after TKA are typically longer than pre-op times.[169-171] Additionally, TUG times on POD 7 were longer than those on POD 14 in both groups, as pain and swelling persisted. However, on POD 14, the TUG time in the intervention group was closer to the pre-op time compared to the control group (intervention: 28.91 and 23.94 seconds, $p < 0.05$; control: 36.55 and 23.18 seconds, $p < 0.001$). The changes in TUG times from POD 0 to POD 14 in both groups exceeded the minimal detectable change (MDC) of 3.04 seconds for TKA patients.[172] These changes confirm that patients in the intervention group showed greater improvements in functional mobility compared to the control group.

Iwata et al., 2023[171] reported that gait speed at two weeks post-TKA (1.01 ± 0.28 m/s, $p < 0.01$) was faster than at one week (0.85 ± 0.27 m/s, $p < 0.01$). They concluded that functional mobility did not return to the preoperative levels even two weeks after surgery,[171] with full recovery potentially taking up to three months.[169] Achieving adequate knee ROM is essential for activities of daily living,[173] as it supports movements involved in tasks such as sitting, standing, squatting, stair climbing, and walking,[9-11] all of which require good knee ROM and symmetrical movement between both limbs. Therefore, early rehabilitation to restore knee ROM to target levels after surgery will help expedite recovery of functional activities.

In the current study, the intervention group demonstrated greater improvements in all outcomes compared to the control group. This was attributed to the intervention group receiving training with laser visual feedback during knee flexion and extension exercises, including movement symmetry training. The laser visual feedback guided the movements of patients during exercises, helping them achieve exercise goals. Consequently, the correct and continuous repetition of these exercises led to increased movement efficiency

A limitation of the current study is that it focused only on the early phase within the first 2 weeks. Further research should include the late phase with long-term follow-up at 1 and 3 months. This TKA training program incorporated a small, portable laser visual feedback device, which is convenient for use in the ward and can also be applied to other conditions, such as ACL injuries and total hip arthroplasty.

Conclusion

The TKA rehabilitation protocol, which includes knee exercises and movement symmetry training with laser visual feedback, can improve knee flexion and extension angles, as well as functional performance after TKA compared to a standard rehabilitation program. These findings suggest that laser visual feedback can be effectively incorporated into the TKA rehabilitation protocol to guide movement and motivate patients during knee exercises and functional training in the early stages of rehabilitation.

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APPENDIX

Appendix A General information

ชื่อ______________________________สกุล____________________________อายุ_______ปี

เพศ ☐ Male ☐ Female น้ำหนัก____kg ส่วนสูง____cm BMI___kg/m^2

History of medical condition ☐ DM ☐ HT ☐ Stroke ☐ Heart disease

☐ Cognitive impairment ☐ RA or Inflammatory arthritis

☐ Visual loss ☐ Other _______________

Appendix B Thai version of KOOS

คุณภาพชีวิต

Q1 ท่านรู้สึกว่าเข่าของท่านมีปัญหาบ่อยเพียงใด

ไม่มีปัญหาเลย	ทุกเดือน	ทุกสัปดาห์	ทุกวัน	ตลอดเวลา
☐	☐	☐	☐	☐

Q2 ท่านได้ปรับเปลี่ยนวิถีชีวิตหรือกิจวัตรประจำวันเพื่อหลีกเลี่ยงไม่ให้เกิดการบาดเจ็บของข้อเข่ามากขึ้นหรือไม่

ไม่เลย	เล็กน้อย	ปานกลาง	มาก	มากที่สุด
☐	☐	☐	☐	☐

Q3 ท่านรู้สึกไม่มั่นใจต่อสภาพของข้อเข่ามากน้อยเพียงใด

ไม่รู้สึกเลย	ไม่มั่นใจเล็กน้อย	ไม่มั่นใจปานกลาง	ไม่มั่นใจมาก	ไม่มั่นใจมากที่สุด
☐	☐	☐	☐	☐

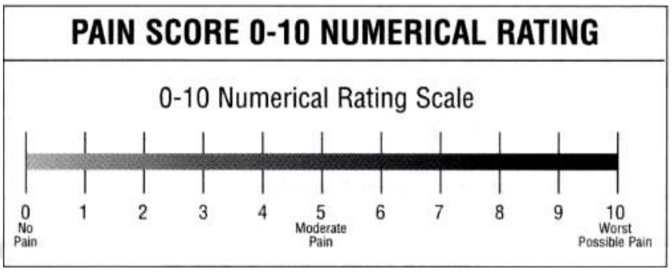
Q4 โดยทั่วไปแล้ว ท่านคิดว่าข้อเข่าของท่านทำให้เกิดความยากลำบากต่อท่านมากน้อยเพียงใด

ไม่ลำบากเลย	ลำบากเล็กน้อย	ลำบากปานกลาง	ลำบากมาก	ลำบากมากที่สุด
☐	☐	☐	☐	☐

Appendix C Depression assessment (2Q)

คำถาม	มี	ไม่มี
1. ใน 2 สัปดาห์ที่ผ่านมา รวมวันนี้ ท่านรู้สึกหดหู่ เศร้า หรือท้อแท้สิ้นหวัง หรือไม่		
2. ใน 2 สัปดาห์ที่ผ่านมา รวมวันนี้ ท่านรู้สึกเบื่อ ทำอะไรก็ไม่เพลิดเพลินหรือไม่		

Appendix D Numerical Rating Scale (NRS)



Source:https://www.physiotherapy-treatment.com/pain-rating-scale.html

Appendix E NRS recording form

Time point	Date	Pain at rest	Pain while moving
Post-operation day 0			
Post-operation day 1			
Post-operation day 2			
Post-operation day 3			
Post-operation day 4			
Post-operation day 5			
Post-operation day 6			
Post-operation day 7			
Post-operation day 8			
Post-operation day 9			
Post-operation day 10			
Post-operation day 11			
Post-operation day 12			
Post-operation day 13			
Post-operation day 14			

Appendix F TUG recording form

Time point	Date	Time (Seconds: 00:00)	Adaptations	Assistive walking aid
Pre-op			☐ Uses walking aid ☐ Not tested, unable ☐ Not tested, refused	
POD 7			☐ Uses walking aid ☐ Not tested, unable ☐ Not tested, refused	
POD 14			☐ Uses walking aid ☐ Not tested, unable ☐ Not tested, refused	

Appendix G ROM recording form

Time point	Date	Knee flexion	Knee extension
Pre-op			
POD 0			
POD 7			
POD 14			

Appendix H Intra-rater reliability and SEM

The Kinovea program was used to measure knee flexion and extension angles at the end of movement in 10 healthy participants at 5-days intervals. The intra-rater reliability of these measurements was assessed by using the intraclass correlation coefficient model 3, 1 ($ICC_{3,1}$). The Kinovea program demonstrated excellent intra-reliability, with ICC values ranging from 0.99 to 0.997. The standard error of measurement (SEM) for knee flexion and extension angles ranged from 0.51 to 0.52 degrees. The intra-rater reliability of the timed up and go (TUG) test was calculated using the intraclass correlation coefficient model 3, 1 ($ICC_{3,1}$). The TUG test demonstrated excellent intra-reliability, with an ICC of 0.998, and the SEM was 0.50 second.

VITA