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Effect of additional uphill treadmill exercise combined with standard therapy on walking speed in patients with knee osteoarthritis

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ABSTRACT

Background: Knee osteoarthritis (OA) is a progressive musculoskeletal condition that limits mobility by reducing walking speed. Exercise therapy can improve walking speed in knee OA patients. This research aimed to demonstrate that the addition of uphill treadmill exercises to standard therapy protocols was more effective in enhancing walking speed in patients with grade II and III knee osteoarthritis compared to standard therapy alone.

Methods: This randomized controlled trial at Dr. Soetomo General Hospital included 36 patients with knee OA grade II-III (Kellgren-Lawrence scale), aged 50-60 years, BMI <30 kg/m^2, moderate pain (VAS 30-60mm), and independent walking ability. Exclusion criteria included recent knee injuries/surgeries, intra-articular injections, acute inflammation, inflammatory arthritis, significant deformities, uncontrolled cardiovascular/diabetes conditions, respiratory disorders, sensory disturbances, balance disorders, concurrent therapy, pacemaker contraindications, cognitive impairment, and substance abuse. Subjects were randomized into control (n=18) and treatment groups (n=18). Controls received standard therapy (Q-bench strengthening and TENS). The treatment group received identical standard therapy plus uphill treadmill exercise (8-degree inclination, 1.1 m/s, 30 minutes) twice weekly for 5 weeks. Walking speed was assessed using 10-Meter Walk Test at baseline, post-intervention, and 20-day follow-up.

Results: The treatment group demonstrated significantly superior walking speed improvements compared to controls. No baseline differences existed (*p*-value= 0.680; *Cohen's d*= 0.14), but significant improvements occurred at post-intervention (*p*-value= 0.030; *Cohen's d*= 0.79) and 20-day follow-up (*p*-value =0.02; *Cohen's d*= 0.83).

Conclusion: There was a significant improvement in walking speed in post-exercise measurements and follow-up measurements in grade II-III knee OA patients who received additional uphill treadmill training compared to standard exercises.

Keywords: hamstring tightness, knee osteoarthritis, knee osteoarthritis intervention, physical therapy, rehabilitation exercise, uphill treadmill exercise.

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INTRODUCTION

Knee osteoarthritis (OA) is the most common progressive musculoskeletal condition and a leading cause of rising social costs. It results in limited mobility by reducing walking speed and stride length. The prevalence of knee osteoarthritis among adults aged 50 to 60 and above is approximately 10% in men and 13% in women. The comparison based on symptomatic and radiographic evidence is 7% and 19%, respectively, making knee osteoarthritis one of the leading causes of disability in the elderly population.[1–3]

The Osteoarthritis Research Society International states that an improvement in walking speed can be observed following exercise, although initially, these exercises are aimed at pain relief and the enhancement of physical function. Several studies have indeed shown that exercise therapy can improve walking speed in individuals with knee osteoarthritis. However, current exercise interventions demonstrate significant limitations in both design and application. Most studies have focused on generalized exercise protocols without systematically comparing the efficacy of specific exercise modalities, particularly those that address the unique biomechanical challenges faced by knee OA patients during daily activities.[4]

Given these limitations in conventional exercise approaches, researchers have explored alternative training methods that can provide more targeted biomechanical benefits. Knee osteoarthritis patients exhibit impairments in walking ability, thus accurate measurement of gait parameters is necessary in clinical examination. Quantitative analysis of gait patterns using a treadmill can be performed at self-selected or predetermined speeds and inclines. Evaluating gait parameters using a treadmill at various speeds or inclines can reveal changes in normal gait patterns that may go undetected.[5]

Previous research indicates that uphill walking provides functional training that enhances muscle activation around affected joints, achieves appropriate joint range of motion, and offers a controlled environment that minimises the risk of further damage. An incline may reduce pronation and internal tibialis rotation, decrease external tibial rotation, and require eccentric control by the medial hamstrings during the propulsion phase of walking. Increased hip flexion and ankle dorsiflexion at heel strike during uphill walking can contribute to knee joint stabilization. Despite these theoretical advantages, critical gaps remain in the empirical evidence. Specifically, there is insufficient research quantifying the optimal incline angles, duration, and frequency of uphill treadmill training for knee OA patients. Furthermore, most existing studies have examined uphill walking in isolation without investigating its integration with established pain management techniques.[6]

Transcutaneous Electrical Nerve Stimulation (TENS) is widely used in managing knee osteoarthritis to alleviate pain and facilitate the performance of therapeutic activities to maintain or improve physical function. Systematic review guidelines for the management of knee osteoarthritis state that 8 out of 10 guidelines recommend the use of TENS. Based on the Gate Control Theory, the use of TENS inhibits pain perception as described by Melzack and Wall. This theory suggests that afferent stimuli, such as electrical stimuli, alongside painful stimuli at the spinal cord level, will diminish pain perception in the central nervous system. Other mechanisms include the stimulation of β-endorphin production. The use of TENS is recommended to improve clinical complaints of knee osteoarthritis, with fewer side effects compared to medical therapies. While TENS has demonstrated efficacy for pain reduction in knee OA patients, prior studies have primarily evaluated it as a standalone intervention or in combination with conventional exercise programs. The specific interaction between TENS and biomechanically optimized exercise protocols, such as uphill treadmill training, represents an unexplored therapeutic frontier with potential to enhance outcomes.[7]

The integration of TENS with exercise therapy presents a logical therapeutic approach, as pain reduction through TENS may enhance exercise tolerance and compliance. However, a significant research gap exists regarding the specific interaction between TENS and biomechanically optimized exercise protocols. While TENS has demonstrated efficacy for pain reduction in knee OA patients, prior studies have primarily evaluated it as a standalone intervention or in combination with conventional exercise programs. The specific synergistic effects of combining TENS with uphill treadmill training have not been systematically investigated, particularly regarding their combined impact on functional outcomes such as walking speed.[8]

The theoretical foundation for combining these interventions is further supported by the understanding that individuals with knee osteoarthritis have muscle weakness around the joint, which can lead to increased joint pressure. Weakness in the knee-supporting muscles, particularly the quadriceps femoris, is a primary factor in functional impairment. There is a proven correlation between quadricep femoris muscle weakness and knee pain and function. Exercise programmes primarily focus on strengthening muscles, especially the quadriceps, as a rehabilitation target for knee osteoarthritis patients. The combination of addressing pain through TENS and muscle weakness through targeted exercise may provide complementary benefits that could enhance overall outcomes for knee OA patients.[8]

The motivation for conducting this study stems from these identified research gaps and the clinical need for more effective rehabilitation interventions to improve mobility in knee osteoarthritis patients. Specifically, three critical areas require investigation: first, the establishment of evidence-based protocols for uphill treadmill training parameters in knee OA populations; second, the quantification of synergistic effects when combining TENS with biomechanically optimized exercise interventions; and third, the development of integrated treatment approaches that simultaneously address pain management and functional mobility enhancement. Previous research has highlighted the benefits of exercise and the efficacy of TENS individually, but no studies have systematically examined their combined application using uphill treadmill training with standardized parameters for walking speed improvement in knee OA patients.

Thus, the objective of this study was to demonstrate that the addition of uphill treadmill exercises to standard therapy protocols (TENS and conventional strengthening) was more effective in enhancing walking speed in patients with grade II and III knee osteoarthritis compared to standard therapy alone. This investigation addresses the identified research gaps by providing empirical evidence for an integrated treatment approach that combines established pain management techniques with biomechanically optimized exercise training.

METHODS

This study employed a randomised pre-test and post-test control group design to effectively evaluate the causal relationship between interventions and outcomes while controlling for potential confounding variables. Randomization was performed using a computer-generated sequence with sealed opaque envelopes prepared by an independent researcher not involved in patient recruitment or assessment, ensuring allocation concealment.

Patients were randomly assigned into two groups: a control group receiving Transcutaneous Electrical Nerve Stimulation (TENS) and strengthening exercises, specifically using a Q-bench, and a treatment group receiving this standard therapy plus additional uphill treadmill exercises. Walking speed measurements and evaluations were conducted at specific intervals: after 10 sessions for both groups, and after 20 days for more comprehensive assessments.

The research was conducted in the Medical Rehabilitation Polyclinic at Dr. Soetomo General Hospital, Surabaya, from June to October 2023. Subjects included patients referred to the rehabilitation clinic with a diagnosis of knee osteoarthritis, as per the American College of Rheumatology criteria during the study period. The sample size, determined using Lwanga and Lemeshow's formula, was set at 16 patients per group, with a 20% buffer added for possible dropouts, resulting in 18 patients per group. Simple random sampling ensured unbiased subject selection.

Inclusion criteria comprised patients with knee osteoarthritis grade II and III (Kellgren and Lawrence scale), aged between 50 and 60 years, with a BMI under 30 kg/m², and experiencing moderate pain (VAS between 30mm and 60mm). Participants needed to be capable of walking unaided and willing to sign informed consent. Exclusion criteria included a history of significant knee injuries or surgeries within 12 months, recent intra-articular injections within 3 months, acute inflammation, inflammatory arthritis, significant deformities exceeding 15 degrees, uncontrolled cardiovascular disease, uncontrolled diabetes (HbA1c greater than 9%), severe respiratory conditions, sensory disturbances affecting lower extremities, balance disorders, concurrent physical therapy participation, cardiac pacemaker contraindications for TENS, cognitive impairment, and substance abuse. Subjects were also at risk of dropout if they failed to complete assigned programmes or chose to withdraw voluntarily.

Interventions

Patients were randomly assigned into two groups. The control group received standard therapy consisting of Transcutaneous Electrical Nerve Stimulation and strengthening exercises using a Q-bench apparatus. The treatment group received identical standard therapy plus additional uphill treadmill exercises.

TENS treatment was rigorously standardized across all participants to ensure consistency and reproducibility. Conventional TENS was applied using a dual-channel portable TENS unit (TENStem eco basic, schwa-medico, Germany) with precisely defined parameters. The frequency was set at 100 Hz, pulse width at 200 microseconds, and intensity was individually adjusted to produce a strong but comfortable tingling sensation without inducing muscle contraction. This intensity level was maintained consistently throughout all treatment sessions for each participant. Four self-adhesive electrodes measuring 5×5 cm were positioned around the affected knee joint using a standardized placement protocol. Two electrodes were placed on the medial and lateral aspects of the knee joint line, while two additional electrodes were positioned on the anterior thigh approximately 10 cm above the superior pole of the patella. The TENS treatment was administered for exactly 30 minutes per session, with participants remaining in a comfortable seated position throughout the treatment.

The uphill treadmill exercises were conducted using a standardized protocol with an incline of 8 degrees and a speed of 1.1 meters per second. Each session lasted 30 minutes and was administered twice weekly for five consecutive weeks. The specific parameters were selected based on previous research indicating that this incline angle optimizes biomechanical benefits while remaining tolerable for patients with knee osteoarthritis.

Outcome Measures

The study employed walking speed as the primary outcome measure that was specifically selected to capture functional mobility in knee osteoarthritis patients.

Walking speed served as the primary functional outcome measure directly related to mobility in daily activities and overall quality of life. This parameter was assessed using the standardized 10-meter walk test, where participants walked at their comfortable self-selected pace over a 14-meter course. The first and last 2 meters were excluded from timing calculations to account for acceleration and deceleration phases, ensuring accurate measurement of steady-state walking speed. The time taken to complete the middle 10 meters was recorded using a digital stopwatch and subsequently converted to speed expressed in meters per second.

Walking speed was selected as the primary outcome based on established research demonstrating its significance as a reliable indicator of functional capacity in knee osteoarthritis patients. Research has shown that walking speed reflects the integrated function of multiple physiological systems including musculoskeletal strength, joint mobility, balance, and cardiovascular fitness. In knee osteoarthritis patients, reduced walking speed is commonly observed due to pain, joint stiffness, and compensatory movement patterns that develop to minimize discomfort during ambulation. The 10-meter walk test provides a standardized, reproducible method for assessing walking performance that correlates well with daily functional activities and quality of life measures in this population.

The selection of walking speed as the primary outcome provides direct information about functional capacity and mobility performance. Walking speed represents the integrated functional output of multiple physiological systems and serves as a practical measure of treatment effectiveness that translates directly to improvements in daily living activities. This approach allows for comprehensive assessment of overall functional improvement following the intervention.

Data Collection and Analysis

Walking speed was recorded at three critical time points to capture the progression and sustainability of treatment effects. Measurements were obtained at baseline (one day before the first treatment session), immediately post-intervention (one day after the final treatment session), and at a 20-day follow-up period after completion of the intervention to assess the durability of treatment effects.

Subjects underwent initial screening and provided written informed consent before baseline data collection commenced. Familiarization with the treadmill was established during the initial session to minimize learning effects and ensure participant comfort with the testing procedures. The control group received conventional treatment with TENS and Q-bench exercises, while the intervention group undertook identical standard therapy plus the specified uphill treadmill sessions. All treatment activities occurred twice weekly over five consecutive weeks, with systematic ongoing assessments conducted according to the predetermined schedule.

Data analysis was performed using SPSS software version 26.0. Normality of data distribution was assessed using the Shapiro-Wilk test given the sample size. Differences between pre-intervention and post-intervention measurements were evaluated using paired t-tests for normally distributed data or Wilcoxon signed-rank tests for non-parametric data. Between-group comparisons were conducted using independent t-tests or Mann-Whitney U tests as appropriate based on data distribution characteristics.

Ethical Considerations

The ethical feasibility of this research has been approved by the Health Research Ethics Committee of Dr. Soetomo General Academic Hospital with number 0751/KEPK/VIII/2023. Each subject was asked to sign a written informed consent form after receiving an explanation regarding the purpose, procedures, and potential risks that may occur during the study.

RESULTS

The total number of research subjects was 36 individuals, divided into two groups (intervention and control) with 18 subjects in each group. One participant from the intervention group met the drop-out criteria, and one participant from the control group withdrew from the study. At the conclusion of the research, data analysis was performed on 17 subjects from the intervention group and 17 from the control group. This study employed a per-protocol analysis approach, where only data from subjects who completed the entire intervention protocol were included in the final analysis. This analytical strategy was selected because the primary research question focused on the efficacy of the intervention among participants who received the complete treatment protocol as designed. No imputation methods were applied for the missing data from the two subjects who dropped out. This decision was justified by several factors: the dropout rate was minimal at 5.6% of the total sample, the dropouts were equally distributed between groups (one from each group), and the reasons for withdrawal were unrelated to the intervention itself, thereby minimizing the risk of systematic attrition bias that could compromise the validity of the findings. Prior to statistical analysis, an assessment of the general characteristics of the research subjects was conducted, as shown in Table 1.

Table 1 shows that the mean age of research subjects in the control group was 54.9 ± 2.98 years with an age range between 50-59 years. In the intervention group, the mean age was 55.35 ± 2.96 years with an age range between 50-59 years. Both research groups had homogeneous mean ages with *p*-value= 0.92.

Regarding gender distribution, the control group comprised 3 males (17.6%) and 14 females (82.4%). In the intervention group, there were 2 males (11.7%) and 15 females (88.3%). Concerning OA severity, 13 subjects in the control group had Grade II OA (76.5%) and 4 had Grade III OA (23.5%). In the intervention group, 14 subjects had Grade II OA (82.4%) and

Table 1. Characteristics of study subjects (n=17)

Characteristic	Control Group	Intervention Group	*P*-value
Age (years)	54.59 ± 2.98	55.35 ± 2.96	0.92
Gender			
Male	3 (17.6%)	2 (11.7%)	
Female	14 (82.4%)	15 (88.3%)	
Weight (kg)	66.82 ± 11.34	64.18 ± 9.41	0.30
Height (cm)	160.35 ± 9.17	156.94 ± 6.65	0.20
BMI (kg/m2)	25.87 ± 2.80	25.94 ± 2.47	0.40
Affected Knee			>0.05
Unilateral	9(52.9%)	8(47.1%)	
Bilateral	8(47.1%)	9(52.9%)	
Grade OA			>0.05
Grade 2	13(76.5%)	14(82.4%)	
Grade 3	4(23.5%)	3(17.6%)	
WS (P1) (m/s)	1.00 ± 0.19	0.98 ± 0.13	0,09

cm, centimeter; kg, kilograms; kg/m^2, kilograms per square meter; m/s, meters per second
Values for age, height, weight, BMI and WS = Walking Speed (P1 = Initial measurement before intervention) are presented as mean ± standard deviation; percentages for gender and OA severity; p-value represents homogeneity value, p is considered significant when p<0.05.

Table 2. Walking speed measurements in control and intervention groups

Group	P1	P2	P3	*P*-value P1-P2	*P*-value P2-P3	*P*-value P1-P3
Control (m/s)	1.00 ± 0.19	1.26 ± 0.15	1.35 ± 0.14	<0.01	0.03	<0.01
Intervention (m/s)	0.98 ± 0.13	1.40 ± 0.21	1.46 ± 0.12	<0.01	0.22	<0.01

Note: P1 = Initial measurement before intervention; P2 = Measurement after 5 weeks of intervention; P3 = Follow-up measurement 20 days after 5 weeks of intervention; values for WS = Walking Speed are presented as mean ± standard deviation; p-value is significant when p<0.05

Table 3. Comparison of walking speed between control and intervention groups (n=17)

Characteristic	Control Group	Intervention Group	*P*-value	*Cohen's d*
WS P1 (m/s)	1.00 ± 0.19	0.98 ± 0.13	0.68	0.14
WS P2 (m/s)	1.26 ± 0.15	1.40 ± 0.21	0.03	0.79
WS P3 (m/s)	1.35 ± 0.14	1.46 ± 0.12	0.02	0.83

Note: WS = Walking Speed; P1 = Initial measurement before intervention; P2 = Measurement after 5 weeks of intervention; P3 = Follow-up measurement 20 days after 5 weeks of intervention; *p*-value represents t-test result, *p*-value is considered significant when *p*-value< 0.05.

3 had Grade III OA (17.6%). Regarding affected knees, 9 subjects in the control group experienced unilateral OA (52.9%) and 8 experienced bilateral OA (47.1%). In the intervention group, 8 subjects experienced unilateral OA (47.1%) and 9 experienced bilateral OA (52.9%).

The mean weight in the control group was 66.82 ± 11.34 kg with a weight range between 52-89 kg. In the intervention group, it was 64.18 ± 9.41 kg with a weight range between 48-78 kg. Both research groups had homogeneous mean weights with p = 0.30. The mean height in the control group was 160.35 ± 9.17 cm with a height range between 145-177 cm, and in the intervention group, it was 156.94 ± 6.65 cm with a height range between 145-169 cm. Both research groups had homogeneous mean heights with *p-value*= 0.20.

The mean body mass index (BMI) in the control group was 25.87 ± 2.80 kg/m² with a BMI range between 20.57-29.64 kg/m², and in the intervention group, it was 25.94 ± 2.47 kg/m² with a BMI range between 21.23-29.55 kg/m². Both research groups had homogeneous mean BMI values with *p-value*= 0.40.

The mean initial walking speed (WS) value (P1) in the control group was 1.00 ± 0.19 m/s with a range between 0.71-1.45 m/s. In the intervention group, the mean initial WS value (P1) was 0.98 ± 0.13 m/s with a range between 0.75-1.25 m/s. Both research groups had homogeneous initial mean WS values with *p-value*= 0.09.

Table 2 shows the results of walking speed (WS) measurements in the control and intervention groups. Measurements were taken 3 times: at the beginning of the study (P1), at the end of the study after 5 weeks of training (P2), and at the follow-up 20 days after the training ended (P3). The 20-day follow-up period was selected based on prior research suggesting that initial adaptations in gait parameters typically begin to show patterns of retention or regression within this timeframe. While this duration provides valuable insights into the short-term sustainability of intervention effects, it should be acknowledged as a preliminary assessment rather than a comprehensive evaluation of long-term effects, which would require extended follow-up periods of 3-6 months.

Table 3 shows the comparison of mean walking speed values throughout the measurements. The normality test using the Shapiro-Wilk test showed that the data were normally distributed; therefore, the parametric independent t-test was used on the WS values to determine the effect of the intervention group on the measurement results.

Based on statistical analysis, there was an effect of uphill treatment exercise in the intervention group compared to the control group at measurements P1 (*p-value*= 0.68; *Cohen's d*= 0.14), P2 (*p-value*= 0.03; *Cohen's d*= 0.79), and P3 (*p-value*= 0.02; *Cohen's d*= 0.83). The persistence of significant differences at P3 suggests that the effects of the intervention were maintained during the short-term follow-up period, though longer follow-up would be necessary to determine if these benefits persist over extended periods.

In terms of adverse events during the study, there was 1 subject (5.8%) in the control group who complained of back pain, whilst no adverse events (0%) were reported in the intervention group. The subject with back pain reported this to the researcher after 7 training sessions and subsequently withdrew from the study. When reporting to the researcher, the subject had already sought treatment at the neurology clinic and received medication: Gabapentin, Sodium Diclofenac, and Diazepam. The subject also underwent a Lumbosacral X-Ray, with results available approximately 3 days after withdrawal, showing lumbar spondylosis. After follow-up for approximately one week (until the medication was finished), the researcher contacted the subject to inquire about changes after completing the medication and following the prescribed exercises. The subject reported improvement (reduced back pain, from an initial WBS of 6-7 to a WBS of 2-3). The researcher provided the subject with information, education, and communication regarding exercises for this complaint.

DISCUSSION

The age range of subjects in this study was similar to that of research conducted by Sedaghatnezhad on knee OA patients, which reported mean ages of 59.6 ± 7.43 years in the control group and 53.8 ± 7.43 years in the intervention group.[9] Both groups in our study were within the 55–59-year age range, where knee osteoarthritis (OA) damage is typically in its early stages and medical rehabilitation interventions remain optimally effective.[10] The prevalence of knee OA increases rapidly between ages 55-64 years. Radiographic changes, particularly osteophytes, are common in elderly populations. Age-related changes in the musculoskeletal system increase the predisposition to OA; however, the affected joints and disease severity are closely linked to other risk factors such as joint injury, obesity, genetics, and anatomical factors affecting joint mechanics.[11]

Gender distribution in our study resembled that reported by Sedaghatnezhad, with female subjects predominating in both groups. Female gender is the strongest risk factor for knee OA, followed by obesity and aging.[2] Research by Tschon indicates that women typically use more healthcare services, have different pain perception, inflammation responses, reduced cartilage volume, physical difficulties, and smaller joints compared to men, leading to increased prevalence of knee OA among females.[12]

Regarding OA severity, both groups consisted primarily of grade II OA patients, with the remainder having grade III OA. Tuna, Çelik and Balci found a relationship between the effectiveness of physical therapy and exercise relative to the radiological grade of knee OA. Their research demonstrated that physical therapy and exercise are effective for all OA grades, though the best results were observed in grade I OA.[10]

Both research groups had homogeneous mean weight, height, and BMI. The BMI range across both groups was 20.57-29.64 kg/m², with grade 2 obesity as an exclusion criterion. Obesity is a major risk factor for knee OA alongside age and gender. Obesity causes excessive joint loading, biomechanical pattern changes, and hormone and cytokine dysregulation. Obesity was associated with OA incidence and progression, response to medical rehabilitation interventions, joint replacement rates, and surgical complications. Weight reduction can provide clinically significant improvements in pain and delay the progression of structural joint damage.[13] Recent studies indicate that obesity was associated with decreased walking speed in older adults, particularly among those at high risk of functional decline, such as knee OA patients.[14]

Both research groups had homogeneous initial walking speed values, similar to those reported in previous research by Sedaghatnezhad.[9] Both treatment groups exhibited lower walking speeds compared to healthy populations of similar age.[15] Knee osteoarthritis is a common musculoskeletal disorder affecting individuals' functional mobility, often characterized by knee pain, decreased mobility and physical function, stiffness, and reduced quadriceps muscle strength.[16] Walking speed is a useful clinical vital sign for health assessment that can be evaluated regularly. Slower walking speed is associated with increased mortality risk in adults with knee OA. Assessing the severity of walking difficulties is crucial for predicting health outcomes and can be objectively measured through walking speed examinations.[17]

Our findings demonstrate that standard therapy administered to the control group over 10 sessions within 5 weeks effectively improved walking speed. In the control group, walking speed increased from 1.00 ± 0.19 m/s at the beginning of the study to 1.26 ± 0.15 m/s at the end and further to 1.35 ± 0.14 m/s during the 20-day follow-up after the final training session. Statistical testing indicated that this improvement occurred in the post-test measurement and was maintained at follow-up.

These results align with Pietrosimone et al.'s research investigating the effect of adding TENS to physical therapy. Their study showed that standard physical therapy for 8 weeks could increase quadriceps muscle strength, voluntary quadriceps muscle activation, WOMAC scores, and physical function, including walking speed. That study also found that adding TENS to physical therapy did not provide significant improvements in walking speed.[18]

Knee osteoarthritis is associated with symptoms such as pain, instability, reduced range of motion, and consequently, decreased quality of life and function. Previous research has reported that patients with knee OA have lower quadriceps muscle strength compared to control groups. The quadriceps muscle acts as a pain buffer; weakness in this muscle reduces joint protection, resulting in stress and excessive loading on the knee, reduced physical performance during daily activities (e.g., walking speed, rising from sitting, climbing stairs), and increased patient-reported disability.[18,19]

The ability to generate muscle strength is partly regulated by voluntary muscle activation, which is determined by the capacity to maximize motor neuron recruitment and firing frequency. Knee effusion, common in knee OA patients, causes aberrant afferent activity from mechanoreceptors within the joint, resulting in inhibition of quadriceps muscle function by spinal reflexes and decreased voluntary activation of the quadriceps muscle.[20] Increasing voluntary quadriceps muscle activation is associated with improved muscle strength and physical function in those with knee OA.[18,21]

The improved walking speed observed in our study is likely due to the strengthening effect on the quadriceps muscle. Research by Imoto, Peccin, and Trevisani demonstrated improvements in walking speed among knee OA patients who received quadriceps strengthening exercises twice weekly for 2 weeks.[19] Bacon et al. also showed a relationship between quadriceps muscle strength and functional measurements such as walking speed in knee OA patients. Increased quadriceps muscle strength leads to improved physical function, including walking speed, in knee OA patients. In their study, physical function was assessed using the Five-Times Sit-to-Stand Test, 20-Meter Walk Test, and WOMAC Physical Function Score.[22]

Reduced pain perception in knee OA patients was also associated with improved walking speed. Shimoura's research showed that TENS was quite effective in alleviating pain and improving function and physical performance in those with knee OA.[23] TENS administration was also thought to inhibit spinal reflexes in the quadriceps muscle and increase quadriceps muscle activation, potentially enhancing physical exercise outcomes.[18,24]

In our study, walking speed in the intervention group receiving additional uphill treadmill training increased from 0.98 ± 0.13 m/s at the beginning of the study to 1.40 ± 0.21 m/s at the end and to 1.46 ± 0.12 m/s at the 20-day follow-up after the final training session. Statistical testing indicated that this improvement occurred at the post-test measurement and was maintained at follow-up.

These results are consistent with previous research by Sedaghatnezhad et al., who found a group-by-time effect on walking speed in knee OA patients receiving a combination of standard therapy and uphill treadmill exercise for 2 weeks.[2] Uphill walking is a functional stretching method for posterior knee joint muscles that corrects short flexors and restores the centre of knee joint pressure anteriorly. It also reduces quadriceps muscle activity and compression forces on the patellofemoral joint, thereby reducing knee pain. Another advantage of uphill walking is increased ankle plantar flexion, reduced subtalar joint pronation, reduced internal rotation of the tibial and femoral bones, and ultimately reduced knee joint degeneration. According to Lange et al., treadmill inclinations greater than 12% (7 degrees) might be beneficial for knee rehabilitation.[6,9]

Uphill treadmill exercise can also improve balance function, as demonstrated in Samaei et al.'s research. This improvement was attributed to the strengthening effect on lower extremity muscles obtained after undergoing uphill treadmill exercise. The scales used in this study were the Modified Fatigue Impact Scale, mobility by Modified Rivermead Mobility Index, disability by Guy's Neurological Disability Scale, functional activities with 2-Minute Walk Test, timed 25-Foot Walk test, Timed Up and Go test, and Biodex Balance System.[25]

Walking speed is an important dimension of gait function known to decline with age. Gait function is a process of dynamic balance and motor control that depends on various sensory inputs (e.g., visual, proprioceptive, and vestibular) and motor outputs. These sensory and motor physiological systems also play a role in static postural control, which has been shown to decline with age.[26] The improvement in balance function caused by uphill treadmill training also positively influences walking speed improvement in knee OA patients.[2]

The superior outcomes observed in our intervention group can be explicitly linked to specific biomechanical adaptations that occur during uphill treadmill walking. Biomechanical studies have demonstrated that uphill walking significantly alters muscle activation patterns in ways that are particularly beneficial for knee OA patients. Franz and Kram reported an 83% increase in gluteus maximus activation and a 66% increase in vastus medialis oblique activation during walking at 9° incline compared to level walking.[27] This specific activation pattern directly benefits our knee OA patients by improving quadriceps-hamstring co-activation ratios, which are typically impaired in this population. Enhanced vastus medialis oblique activation is especially important for patellofemoral joint stabilization and improved tracking, directly addressing one of the common pain mechanisms in knee OA.

Additionally, uphill walking creates a significant biomechanical advantage by reducing patellofemoral joint reaction forces while simultaneously increasing muscle strength. This apparent paradox occurs because the inclined position shifts the center of pressure more anteriorly, reducing the knee extension moment arm and subsequently decreasing compressive forces on the patellofemoral joint by approximately 12-15% compared to level walking, as reported by Haggerty et al.[28] This reduction in joint loading during active exercise provides our patients with a mechanism to strengthen the supporting musculature without exacerbating pain, explaining the absence of adverse events in our intervention group.

Furthermore, electromyographic studies by Lay et al. have demonstrated that uphill walking increases hamstring-to-quadriceps co-contraction ratios, which enhances dynamic knee joint stability.[29] This improved neuromuscular control directly translates to the increased walking speeds observed in our intervention group by allowing patients to step with greater confidence and reduced pain apprehension. The specific grade used in our protocol (approximately 7°) was selected based on research showing this was the optimal angle to maximize these biomechanical benefits while remaining tolerable for patients with knee OA.

These biomechanical advantages – increased gluteal and vastus medialis activation, reduced patellofemoral joint loading, improved quadriceps-hamstring co-activation, and enhanced dynamic stability – directly explain the improved walking speed outcomes observed in our patient population. The continuation of these benefits during the follow-up period suggests that these adaptations were not merely temporary accommodations but represented meaningful neuromuscular learning that persisted beyond the intervention period.

Our findings indicate greater improvement in walking speed measurements in the intervention group at both the end-of-study measurement and the 20-day follow-up measurement. These results align with previous research by Sedaghatnezhad et al., who found a treatment group effect over time on pain perception, range of motion, step length, walking speed, and quality in knee OA patients receiving a combination of standard therapy and uphill treadmill exercise.[2,9]

There are several differences between our study and previous research, including differences in the intensity and duration of standard therapy provided. In previous studies, standard exercises were provided at higher intensity but with shorter training duration. In previous research, 10 sessions of standard therapy provided over 2 weeks were unable to improve all research parameters.[2,9]

Our study shows improved walking speed with 10 sessions of standard therapy over 5 weeks. Research by Fitzgerald and Oatis indicates that responsiveness to physical therapy and exercise was related to the duration of intervention, requiring more than 4 weeks to obtain benefits from physical therapy and exercise in knee OA patients.[30]

High-intensity exercise can be defined as increasing the amount of time (duration or frequency) or resistance (strength or effort) required in an exercise programme. Knee osteoarthritis patients performing high-intensity resistance exercises may experience slight improvements in knee pain and function at the end of the exercise programme (8 to 24 weeks) compared to low-intensity exercise programmes.[31]

The superior results in the group with additional uphill treadmill training may be attributed to reduced gastrocnemius and soleus stiffness resulting from inclined walking exercises. Research indicates a relationship between knee and ankle ROM and walking speed. Reduced flexibility and ROM of knee and calf muscles decrease walking speed, while increased flexibility of gastrocnemius and hamstring muscles increases walking speed.[2,32,33]

Additionally, this improvement may result from strengthening lower extremity muscles, particularly the quadriceps, through uphill treadmill exercise. Compared to walking on flat surfaces, uphill treadmill exercise produces increased hip, quadriceps, hamstring, and triceps surae muscle activity. Enhanced muscle activation can benefit lower limb muscle strengthening and improve functional tests, including walking speed.[34–36]

In our study, 9 subjects in the control group had unilateral OA (52.9%) and 8 had bilateral OA (47.1%). In the intervention group, 8 subjects had unilateral OA (47.1%) and 9 had bilateral OA (52.9%). In unilateral OA, the contralateral limb may receive higher overloading due to compensation during gait, potentially contributing to accelerated onset of bilateral OA. Fernandes' research also showed that elderly individuals with unilateral knee pain experience increased plantar pressure and Ground Reaction Forces not only in the OA-affected foot but also in the healthy foot.[37] Pain on one side of the knee appears to be associated with asymmetry in knee biomechanics, while bilateral pain is associated with symmetrical knee biomechanics. This is demonstrated through greater varus angles and lower external flexion moments in those with unilateral knee pain. Research by Creaby found that patients with radiological unilateral knee OA had lower mean walking speeds compared to subjects with radiological bilateral knee

OA.[38] Messier's research showed different results, with subjects with unilateral and bilateral OA having almost identical mean walking speeds.[39]

This was the first study at Dr. Soetomo General Hospital Surabaya comparing standard therapy with additional uphill treadmill exercise over 5 weeks to improve walking speed in knee osteoarthritis patients. Our research demonstrates that both standard therapy and standard therapy with additional uphill treadmill exercise over 5 weeks can positively affect walking speed improvement in knee osteoarthritis patients, sustained up to 20 days follow-up. We found better walking speed improvement in post-exercise and follow-up measurements in grade II-III knee OA patients receiving additional uphill treadmill training compared to standard exercise. During the 5-week training period, mild adverse events such as lower back pain were found in the control group, while no adverse events were observed in the intervention group, suggesting that both types of exercise can be recommended for this population. The results of this research can serve as a reference for future studies.

Several limitations should be noted in our study design and implementation. First, this study did not assess muscle strength and mass before the research began, which could have provided additional insights into the mechanisms behind walking speed improvements. Second, interventions were conducted with relatively short training durations and follow-up periods, making it impossible to examine the long-term effects of exercise on walking speed assessment.

CONCLUSION

This study demonstrated that grade II-III knee OA patients who received additional uphill treadmill training experienced significantly greater improvements in walking speed compared to those receiving standard therapy alone. The intervention group showed a substantial increase in walking speed from baseline to post-intervention, while the control group exhibited a more modest improvement. These enhancements were observed in both limbs and were maintained during the follow-up period, with the intervention group sustaining a significantly higher walking speed than the control group at the 20-day follow-up assessment. These findings suggest that adding uphill treadmill training to standard therapy protocols provides superior and sustainable benefits for functional mobility in knee OA patients.

ETHICAL CONSIDERATION

The ethical feasibility of this research has been approved by the Health Research Ethics Committee of Dr. Soetomo General Academic Hospital with number 0751/KEPK/VIII/2023. Each subject was asked to sign a written informed consent form after receiving an explanation regarding the purpose, procedures, and potential risks that may occur during the study.

CONFLICT OF INTEREST

This study has no conflicts of interest.

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AUTHOR CONTRIBUTIONS

TK prepares study designs, collects data, processes data, and writes manuscripts. DT, DI, and S direct data collection and revise the manuscript.

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