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The effect of adding uphill treadmill exercise to standard therapy on dynamic balance function in patients with knee osteoarthritis at RSUD Dr. Soetomo in Surabaya

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Abstract: Balance involves integrating sensory input and motor responses to maintain body position, while the "Timed Up and Go" test evaluates functional mobility quickly and effectively. The study aimed to determine the effect of adding uphill treadmill exercise to standard therapy on dynamic balance function in patients with knee osteoarthritis. The control group received standard therapy (TENS and Q-bench), while the treatment group also performed uphill treadmill exercise (8° incline, 1.1 m/s, 30 minutes, twice weekly for 5 weeks). Dynamic balance was assessed using the "Timed Up and Go" test. Measurements were taken three times: at the beginning of the study (1 day before exercise), at the end of the study (1 day after the last exercise), and 20 days after the last exercise. The treatment group demonstrated significant improvements in TUG scores compared to the control group at T1 ($p = 0.01$, Cohen's $D = 1.22$) and T2 ($p < 0.01$, Cohen's $D = 1.43$). Participants aged 55–59, predominantly female and with Grade II knee OA, showed significant improvements in Timed Up and Go scores, particularly in the treatment group receiving uphill treadmill exercise alongside TENS and quadriceps strengthening, highlighting the efficacy of this combined approach in enhancing functional balance and mobility by targeting muscle strength and reducing stiffness. There was a better improvement in "Timed Up and Go" values in measurements after exercise and follow-up in Grade II-III knee osteoarthritis patients who received additional uphill treadmill exercise compared to standard therapy.

Keywords: *Balance, Dynamic, Knee, Osteoarthritis, Treadmill.*

1. Introduction

Osteoarthritis (OA) of the knee is the most common chronic rheumatic disease and a leading cause of pain and disability worldwide. The prevalence of OA is more frequent in women than in men [1]. According to the Global Burden of Disease 2010 study, prevalence of OA peaks at the age of 50. In OA, there is an increase in articular tissue, and periarticular structures, including ligaments and muscles, become weakened. Furthermore, when examined histologically, the mechanosensory receptors (proprioceptors) around the knee, which are critical for preventing mobility injuries, are reduced. Information from these structures helps determine muscle coordination and control, including balance [2].

Balance is a crucial requirement for the successful performance of various ranges of human behaviour. The efficacy of balance is one form of self-confidence that individuals possess regarding their ability to maintain balance and prevent falls when engaging in activities such as standing on a chair to reach an object or walking on uneven ground. Maintaining balance depends on the integration of inputs

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from the somatosensory, visual, and vestibular systems [3]. Balance (both static and dynamic) is a complex function that requires the integration of sensory information about body position and the ability to make appropriate motor responses to assist body movement [4]. More specifically, it relies on sensory input from the somatosensory (proprioceptive), visual, and vestibular systems, as well as responses to the muscles. Static balance can be defined as the maintenance of balance while standing at a point, whereas dynamic balance, which includes movement, can also be defined as the maintenance of balance while the body is in motion [5].

There are several mechanoreceptors from proprioception located in the muscles and articular components. Sensory input reported from these receptors to the central nervous system is processed to provide appropriate responses to maintain balance [4]. Adequate balance helps maintain posture and efficiently respond to disturbances. Furthermore, it is intrinsically related to independence in daily living, and a reduction in balance can lead to an increased frequency of falls [6]. Balance disorders are the most common cause of falls. Numerous factors contribute to balance disorders, including cardiovascular diseases, metabolic diseases, musculoskeletal diseases, neurological disorders, visual and auditory impairments, as well as fear of falling, post-surgery, and specific treatments [7]. Among the mentioned disorders, changes in muscle strength and joint structure that occur in osteoarthritis disrupt proprioception, making individuals more prone to falls [8].

The Timed Up and Go (TUG) test is a simple and quick assessment of functional mobility. Several studies have reported good reliability of the TUG, and it can be used as a highly specific test in elderly communities, individuals with Parkinson's disease, and those with unilateral lower limb amputations [9]. Some studies suggest that the TUG has a sufficiently high capacity to predict a patient's ability to leave the house independently and safely. Statistically, a significant positive correlation has been found between the TUG and the severity of knee OA as depicted in radiological images. A longer TUG duration indicates an increase in the severity of knee OA as shown in radiological findings. The results of the TUG are closely related to the Berg Balance Scale (BBS) scores and knee extension strength; these measurements represent various tasks and physical performance commonly encountered in daily life, such as maintaining balance, sitting and standing from a chair, picking up objects from above, and retrieving and returning items from the floor. The TUG can be demonstrated as a very useful measurement tool for predicting changes in functional balance. Higher BBS scores indicate shorter times to complete the TUG [10].

Transcutaneous Electrical Nerve Stimulation (TENS) is a clinical modality that is very useful and well-tolerated in clinical applications. The application of TENS to the skin over the gastrocnemius muscle can enhance balance ability in healthy adults. The use of TENS on the lower limbs in healthy adults can improve postural stability [3]. A meta-analysis indicates strong evidence that TENS can effectively manage pain in knee OA; however, there is still limited evidence to support the effectiveness of TENS in improving physical function [5]. In fact, pain is a major factor that limits physical function. Pain, weakness, and physical dysfunction create a vicious cycle as the disease progresses [11].

Patients with knee OA face several issues, such as difficulty walking, muscle atrophy, and knee instability. Balance training and strengthening exercises can be effectively provided to enhance knee stability [12]. Strengthening exercises for the quadriceps can be used as an adjunct therapy to TENS, which may represent a better rehabilitation strategy for reducing pain and improving function in patients with knee OA [11]. Stretching exercises can be beneficial for patients with knee OA, as demonstrated by walking on an uphill treadmill to reduce knee flexion contractures, subtalar joint pronation, tibial internal rotation, and femoral angle adjustments, as well as recovering the centre of pressure on the anterior knee joint and reducing patellofemoral joint stress [13]. Walking uphill at a slow pace is one of the moderate-intensity exercises that can reduce joint loading, enhance muscle activation, and positively affect joint range of motion (ROM), providing a situation that minimises the risk of further damage. Activation of the thigh, knee, and ankle extensors can increase during uphill walking [11, 14].

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To date, no studies have compared dynamic balance function assessed with the TUG test before and after the addition of uphill treadmill exercise. Therefore, this research was conducted to explore this potential effect. This investigation aims to determine whether incorporating uphill treadmill walking could improve dynamic balance function, as measured by TUG, providing valuable insights for clinical rehabilitation strategies, particularly for individuals with knee osteoarthritis.

2. Methods

This study employed a pretest and posttest randomized control group design to evaluate the impact of TENS, strengthening exercises, and uphill treadmill exercises on dynamic balance in patients with knee OA. Conducted from June to October 2023 at the Outpatient Rehabilitation Department of RSUD Dr. Soetomo, this research recruited patients diagnosed with knee OA, following American College of Rheumatology criteria, who met specific inclusion and exclusion criteria.

Participants aged 50-59, with Grade II or III knee OA as determined by X-ray (Kellgren-Lawrence scale), BMI below 30 kg/m^2, and ability to walk without assistance, were included. Exclusion criteria covered a history of knee injuries, recent injections, comorbidities affecting lower extremity function, and sensory disturbances. The study aimed to include 18 participants per group to accommodate potential dropouts, based on statistical calculations.

Two groups were formed: the control group (K1) received TENS and strengthening exercises, while the treatment group (K2) received TENS, strengthening exercises, and additional uphill treadmill exercises. Both interventions were administered twice weekly over five weeks, totaling ten sessions. Evaluations were conducted at three points: at 1 day before exercise (T0), at the end of the 5-week exercise period (T1), and during follow-up 20 days after the exercise ended (T2), using the TUG test to assess dynamic balance. This research has received ethical clearance from the Health Research Ethics Commission for basic/clinical research at Dr. Soetomo General Hospital, Surabaya, No. 0751/KEPK/VIII/2023. Informed consent was obtained from all participants and their legal guardians prior to inclusion in the study.

3. Results

Subjects were divided into two groups: the control group received standard therapy, including quadriceps strengthening exercises using a Q-bench and TENS twice weekly for five weeks, while the treatment group received the same standard therapy plus an uphill treadmill exercise with an 8-degree incline at 1.1 m/s for 30 minutes, twice a week for 10 sessions over five weeks. The primary outcome measured was dynamic balance function, assessed using the TUG test. Measurements were taken at three points: at 1 day before exercise (T0), at the end of the 5-week exercise period (T1), and during follow-up 20 days after the exercise ended (T2). A total of 36 subjects were recruited, with 18 in each group. One subject from each group dropped out, resulting in a final sample size of 17 in each group.

The demographic and baseline characteristics of the participants are presented in Table 1. Both groups were comparable in terms of age, gender distribution, OA severity, involved knee (unilateral or bilateral), weight, height, BMI, and initial TUG scores. The p-values indicated homogeneity across these baseline characteristics, confirming no significant differences between the groups.

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Table 1.
Characteristics of research participants

Characteristics	Control group (n=17)	Treatment group (n=17)	*p-value*
Age (years)	54.9 ± 2.98	55.76 ± 3.07	0.99
Gender (Male/Female)	17.6% / 82.4%	11.7% / 88.3%	-
OA Severity (Grade II/III)	76.5% / 23.5%	82.4% / 17.6%	-
Involved Knee (Unilateral/Bilateral)	52.9% / 47.1%	47.1% / 52.9%	-
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
Initial TUG (seconds)	10.21 ± 1.45	9.55 ± 1.23	0.88

Note: Values for age, weight, height, BMI, and initial TUG are presented as mean ± standard deviation, with a p-value threshold of <0.05 indicating significance.

Table 2 presents the TUG measurements for both the control and treatment groups. Measurements were conducted three times: T0, T1, and T2. The normality test, performed with the exact Monte Carlo method, showed that the data were normally distributed, allowing the use of a parametric paired t-test.

In the control group, paired t-test analysis revealed significant improvements in TUG from the initial measurement to the end of the study ($p<0.01$), from the end of the study to the follow-up ($p<0.01$), and from the initial measurement to the follow-up ($p<0.01$). Similarly, in the treatment group, significant improvements in TUG were observed from the start to the end of the study ($p<0.01$), from the end of the study to the follow-up ($p<0.01$), and from the initial measurement to the follow-up ($p<0.01$).

Table 2.
TUG assessment results.

Time point	Control group (Seconds)	Treatment group (Seconds)	*p-value* (Control)	*p-value* (Treatment)
Baseline (T0)	10.21 ± 1.45	9.55 ± 1.23	-	-
Post-intervention (T1)	7.92 ± 0.75	7.02 ± 0.73	<0.01	<0.01
20-day Follow-up (T2)	6.42 ± 0.56	5.74 ± 0.37	<0.01	<0.01

Note: Values for TUG are presented as mean ± standard deviation, with a p-value threshold of <0.05 indicating significance.

Between-group comparisons showed significant differences in TUG scores at T1 and T2, favoring the treatment group. Table 3 shows a comparison of the mean TUG values across measurements. The normality test using the exact Monte Carlo method indicated that the data followed a normal distribution. Consequently, a parametric independent t-test was applied to the TUG values to evaluate the effect of the treatment group on measurement outcomes. Statistical analysis revealed a significant effect of uphill treatment exercise on the treatment group compared to the control group at measurement T1 ($p=0.01$, Cohen's $D=1.22$) and T2 ($p<0.01$, Cohen's $D=1.43$). This finding suggests that the uphill treatment exercise notably improved TUG performance in the treatment group relative to the control group.

Table 3.
Comparison of TUG between groups.

Characteristic	Control group (Seconds)	Treatment group (Seconds)	p-value	Cohen's D characteristic
Initial TUG	10.21 ± 1.45	9.55 ± 1.23	0.16	0.49
Final TUG	7.92 ± 0.75	7.02 ± 0.73	0.01	1.22
Follow-up TUG	6.42 ± 0.56	5.74 ± 0.37	<0.01	1.43

Note: Values for TUG are presented as mean ± standard deviation, with a p-value threshold of <0.05 indicating significance.

Adverse events were monitored throughout the study, with one subject in the control group reporting back pain, which led to their withdrawal from the study. No adverse events were reported in the treatment group.

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This study demonstrates that the addition of uphill treadmill exercise to standard therapy (TENS and strengthening exercises) significantly improves dynamic balance in patients with knee OA, as evidenced by faster TUG scores. This finding suggests that uphill treadmill exercise could be a valuable component in the rehabilitation of knee OA to enhance mobility and reduce the risk of falls.

4. Discussion

The study subjects primarily fell within the age range of 55-59, a demographic where osteoarthritis (OA) of the knee is typically still in its early stages, allowing for optimal management through medical rehabilitation [15]. The prevalence of knee OA increases significantly in individuals aged 55 to 64 years, with older age being the most substantial risk factor for developing OA. Radiographic changes associated with OA, particularly osteophytes, are common in the elderly population; however, the presence of joint pain may not correlate with the severity of radiographic findings in many older adults. Age-related changes in the musculoskeletal system heighten the susceptibility to OA, but the affected joints and the severity of the disease are closely linked to other risk factors such as joint injuries, obesity, genetics, and anatomical factors that influence joint mechanics [16]. This aligns with the inclusion criteria of this study, which focused on subjects aged 50 to 59 years.

The study also revealed a predominance of female participants in both research groups. Female gender is a significant risk factor for knee OA, followed by obesity and aging. The previous study indicates that women tend to utilise healthcare services more frequently, experience greater pain perception, inflammation, reduced cartilage volume, and physical difficulties, and have smaller joints compared to men, leading to a higher prevalence of knee OA among women [17]. This finding is consistent with the current study, where the majority of subjects in both the control and treatment groups were female.

Regarding the severity of knee OA, most participants in both groups were classified with OA grade II, while the remainder had OA grade III. The previous research found a relationship between the effectiveness of physical therapy and exercise on the radiological grades of knee OA. Their study indicated that physical therapy and exercise are effective across all OA grades, with the best outcomes observed in grade I OA [15, 18]. This is in line with the inclusion criteria of the current study, where subjects presented with knee OA grades II-III, confirmed through X-ray imaging according to the Kallgren and Lawrence scale.

Both research groups exhibited homogeneous averages in terms of weight, height, and BMI. The weight range for both groups was between 20.57 and 29.64 kg/m², with grade 2 obesity as an exclusion criterion. Obesity is a primary risk factor for knee OA, alongside age and gender. It leads to excessive joint loading, altered biomechanical patterns, and hormonal and cytokine dysregulation. Obesity is associated with the incidence and progression of OA, responses to rehabilitation interventions, joint replacement rates, and surgical complications. Weight loss in knee OA patients can significantly improve pain and delay structural joint damage [19]. According to the WHO classification, a BMI of $\geq$ 30 kg/m² indicates obesity; thus, subjects in this study had a BMI of $<$ 30 kg/m².

Knee OA is a common musculoskeletal disorder that affects individuals' functional mobility. It is often characterised by knee pain, reduced functional mobility, stiffness, and decreased quadriceps muscle strength. The Osteoarthritis Research Society International (OARSI) recommends the use of the TUG test for patients with knee OA [7]. The previous study reported that the TUG test provides the best measurement evidence among sit-to-stand tests for hip/knee OA. The TUG measurement is reliable and sensitive for detecting small clinical changes and has high reliability [12]. The TUG test is recommended for individuals with knee OA of questionable to moderate severity and can be considered a predictive measure of physical function [20]. This aligns with the current study, which employed the TUG test as a measure of dynamic balance in patients with knee OA grades II-III, confirmed through X-ray imaging.

The findings of this study underscore the effectiveness of standard therapy in improving functional mobility in patients with knee OA, as evidenced by the significant reduction in TUG scores in the

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control group. Over the course of five weeks, the control group demonstrated a decrease in TUG scores from 10.21 ± 1.45 seconds to 7.92 ± 0.75 seconds, with further improvement to 6.42 ± 0.56 seconds at the 20-day follow-up. This consistent improvement suggests that even standard therapeutic interventions can yield meaningful benefits in mobility for individuals with knee OA. These results align with previous research which highlighted the positive impact of standard therapy, including TENS and muscle strengthening exercises, on TUG scores, while also noting additional benefits from kinesiotaping [21].

The relationship between quadriceps strength and functional mobility is particularly noteworthy in this context. Previous studies have established that patients with knee OA often exhibit reduced quadriceps strength, which is critical for joint stability and pain modulation [20]. The current study's findings suggest that the improvements in TUG scores may be attributed to the strengthening effects on the quadriceps muscle, which plays a vital role in supporting knee function. This is in accordance with previous research which found a direct correlation between quadriceps strength and functional performance measures, including the TUG [22]. Strengthening exercises targeting the quadriceps not only enhance muscle strength but also contribute to improved balance and gait, further facilitating better mobility outcomes in patients with knee OA [22].

Moreover, the addition of uphill treadmill exercise in the treatment group resulted in even more pronounced improvements in TUG scores, decreasing from 9.55 ± 1.23 seconds to 7.02 ± 0.73 seconds, and further to 5.74 ± 0.37 seconds at follow-up. This finding is consistent with previous research which demonstrated that incline training can enhance gait performance and functional mobility [23]. The uphill treadmill exercise likely provides a unique stimulus that not only strengthens the lower extremity muscles but also improves cardiovascular fitness and overall functional capacity. The incline training may facilitate greater muscle activation in the quadriceps, hamstrings, and gastrocnemius, leading to enhanced performance in functional tests such as the TUG [13, 24, 25]. The study also highlights the importance of addressing pain perception in relation to functional outcomes. The control group, which received a combination of TENS and strengthening exercises, experienced a reduction in pain, which is known to correlate with improved mobility [14]. This underscores the multifaceted approach required in managing knee OA, where pain management, muscle strengthening, and functional training collectively contribute to better patient outcomes.

Unilateral knee osteoarthritis is common and can progress to bilateral OA over a 12-year period. The lower dynamic balance observed in both limbs of patients with unilateral knee OA is attributed to pain associated with knee extension strength and hip adduction [22]. Patients with unilateral knee OA exhibit lower hip strength, quadriceps strength, and dynamic balance compared to their asymptomatic counterparts. This indicates systematic differences in hip and quadriceps strength and dynamic balance between patients with unilateral and bilateral knee OA. Patients with unilateral knee OA may have poorer dynamic balance compared to those with bilateral OA, highlighting

This study has several limitations. Firstly, it did not assess muscle strength, muscle mass, or lifestyle factors prior to the intervention, which may influence the outcomes. Secondly, the intervention and follow-up periods were relatively short, making it difficult to examine the long-term effects of the exercise on dynamic balance evaluation. Future research should consider these factors to gain a more comprehensive understanding of the sustained impact of exercise on balance in knee osteoarthritis patients.

5. Conclusions

This study is that there is an improvement in TUG values that are better in measurements after exercise and follow-up in grade II-III knee OA patients who get additional uphill treadmill exercise compared to standard therapy.

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Transparency:
The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

Conflict of Interest:
The author stated there is no conflict of interest.

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Authors' Contributions
All authors contributed equally to the conception and design of the study. All authors have read and agreed to the published version of the manuscript.

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