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RESEARCH ARTICLE

The Effect of Uphill Treadmill Exercise on VO_2 Max in Patients with Knee Osteoarthritis at RSUD Dr. Soetomo, Indonesia

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ABSTRACT

Knee osteoarthritis (OA) is a common chronic rheumatic disease that frequently causes pain and disability, particularly in women. Declines in cardiorespiratory function and muscle coordination due to OA can affect maximal oxygen capacity (VO_2 max). This study aims to evaluate how uphill treadmill exercise affects VO_2 max and 6-minute walking test (6 MWT) performance in patients with grade II–III knee OA. Subjects were separated into a control group (receiving standard therapy) and a treatment group (receiving standard therapy plus uphill treadmill exercise). Standard therapy included quadriceps-strengthening exercises using a Q-bench and TENS modalities (two sessions per week for five weeks). The treatment group received additional uphill treadmill exercise at an 8° incline for 30 minutes twice a week for five weeks. VO_2 max measurements were conducted one day before the intervention, one day after the intervention, and 20 days after the intervention. Data were analyzed using an independent t-test. The treatment group demonstrated much greater improvements in VO_2 max and 6 MWT performance than the control group ($p < 0.01$, Cohen's $D \geq 0.89$). These findings demonstrate that uphill treadmill exercise is an effective complementary therapy for improving functional capacity in patients with knee OA. This study demonstrates how uphill treadmill exercise can play a key role in knee OA rehabilitation. Further research is recommended to assess the optimal duration of training and its impact on long-term quality of life.

INTRODUCTION

Osteoarthritis (OA) is a degenerative joint disease characterized by damage to joint cartilage, the formation of osteophytes, subchondral sclerosis, morphological changes in the joint capsule and synovial membrane, as well as biochemical alterations due to an imbalance between the synthesis and degradation of subchondral bone and cartilage. OA tends to affect weight-bearing joints, including the ankles, hips, and knees. The main symptoms of OA include pain, joint stiffness, swelling, and significant physical disability (Salman et al., 2023; Sharma, 2021). Epidemiological data demonstrate that the prevalence of knee OA in Asia is 6.8% of the population and is expected to rise to 16.8% by 2040. Globally, knee OA cases are projected to increase by approximately 100,000 annually (Barbour et al., 2017).

VO_2 max is a physiological parameter that reflects the body's maximum ability to utilize oxygen during intense physical activity. VO_2 max levels are positively correlated with an individual's activity capacity. Higher VO_2 max levels are associated with reduced fatigue and optimal muscle performance during physical activity (Gannon, 2002). Biomechanical disturbances, such as muscle weakness and altered gait patterns, can affect oxygen consumption in patients with knee OA. Therefore, VO_2 max

measurement is crucial to assess patients' functional capacity and the effectiveness of therapeutic interventions (Fisher et al., 1997; Waheed et al., 2010).

Previous studies indicate that evaluating gait patterns on a treadmill, especially with varying inclinations, can reveal biomechanical changes that are not detected under normal conditions (Pacifico et al., 2020). Uphill walking exercises are known to enhance muscle activation around the affected joint, improve knee joint stabilization, and provide a controlled environment to prevent further damage (Lange et al., 1996; Jam et al., 2011). Meanwhile, the transcutaneous electrical nerve stimulation (TENS) modality has been widely used for pain management in knee OA. TENS operates via the gate control theory mechanism and β-endorphin stimulation to relieve pain and support therapeutic activities (Reichenbach et al., 2022; Al-Zaqeba et al., 2024).

This study aims to evaluate how adding uphill treadmill exercise to standard therapy involving TENS and strengthening exercises affects the VO_2 max of patients with knee OA. This research contributes to the field of medical rehabilitation, particularly strategies to improve the functional capacity of patients with knee OA. Additionally, this study is expected to form the basis for clinical recommendations for more effective and holistic knee OA management.

MATERIALS AND METHODS

Research Type and Design

This experimental study used a pre-test and post-test randomized control group design. Subjects were randomized to determine the control and treatment groups. The control group (K1) received interventions consisting of TENS and strengthening exercises, while the treatment group (K2) received TENS, strengthening exercises, and uphill treadmill exercises for 10 sessions.

Location and Duration

The study was performed at the Outpatient Medical Rehabilitation Unit of Dr. Soetomo General Academic Hospital (RSUD Dr. Soetomo) from August to December 2023.

Study Subjects

The subjects were patients with knee OA according to the American College of Rheumatology (ACR) criteria who met the inclusion and exclusion criteria. The sample size was determined using Lwanga and Lemeshow's formula (1991), resulting in 16 subjects per group. To account for dropout, the sample size was increased by 20%, totaling 18 subjects per group. Samples were selected using simple random sampling.

Subject Criteria

Inclusion criteria: Patients with grade II and III knee OA according to the Kellgren and Lawrence scale, aged 50–59 years, with BMI < 30 kg/m^2, experiencing pain with VAS 30–60 mm in the past week, capable of walking independently without aids, and willing to participate with informed consent.

Exclusion criteria: Patients with a history of knee injury, knee injections in the past three months, heel pain, sensory disorders, acute inflammation, or severe comorbidities such as uncontrolled hypertension or heart failure.

Dropout criteria: Subjects who withdraw, do not adhere to the protocol, or experience complications such as chest pain or breathlessness during exercise.

Research Variables

Independent variables: TENS, strengthening exercises, and uphill treadmill exercise.

Dependent variable: Maximum oxygen capacity (VO_2 max), measured using the 6-minute walking test (6 MWT). Confounding variables: Sex, body weight, height, and excessive movement.

Operational Definitions

Grade II and III knee OA is defined by clinical, physical, and radiological examinations using the Kellgren-Lawrence scale. TENS is a modality designed to alleviate pain through electrical stimulation, utilizing gate control, descending pain control, and endogenous opiate mechanisms. Uphill treadmill exercise involves walking on an 8° inclined treadmill at 1.1 m/s for 30 minutes per session. Strengthening exercises include isotonic quadriceps muscle training following a specific protocol. VO_2 max is evaluated using the 6-minute walking test (6 MWT), which measures the distance covered in six minutes on a flat track. Demographic data includes age, sex, and BMI, measured according to standard procedures.

Instruments

The instruments used included a digital sphygmomanometer (ABN brand), a stethoscope (ABN brand), a pulse oximeter (Elitech® fox-2), a weighing scale (Onemed), a height measurement tape, a Q-bench, a stopwatch, a TENS unit, an uphill treadmill (8° incline), a measuring tape, informed consent forms, data collection sheets, stationery, and a medical emergency kit.

Procedure

The study began with patient screening in the Rehabilitation Unit according to the inclusion and exclusion criteria. Subjects received a pre-intervention briefing to ensure optimal readiness. The treatment group underwent familiarization with uphill treadmill exercises, while the intervention was conducted twice weekly for five weeks. Post-evaluation and follow-up (20 days later) utilized the 6 MWT, and results were recorded for analysis.

Data Analysis

SPSS software was employed for analysis. Normality was assessed using the Shapiro-Wilk test, with parametric tests employed for data that follow a normal distribution and non-parametric tests for data that did not follow a normal distribution. Paired t-tests were employed to compare pre-intervention and post-intervention conditions within groups, while independent t-tests or Wilcoxon-Mann Whitney tests were employed to compare inter-group differences. A p-value < 0.05 was considered statistically significant.

RESULTS

Characteristics of Research Subjects

This study was a true experimental research project using a pre-and post-test randomized control group design conducted at the Outpatient Medical Rehabilitation Unit of RSUD Dr. Soetomo from August to October 2023. This study obtained ethical clearance from the Ethics Committee of RSUD Dr. Soetomo, Surabaya (No. 0751/KEPK/VIII/2023).

The research subjects were separated into a control group, which received standard therapy consisting of quadriceps-strengthening exercises using a Q-bench and TENS modalities, and a treatment group, which received standard therapy supplemented with uphill treadmill exercise at an 8-degree incline and a speed of 1.1 m/s for 30 minutes, twice a week, for five weeks. Each group underwent a total of 10 therapy sessions, with 36 subjects participating (18 subjects in each group). However, during the study, one subject from each group met the dropout criteria, leaving 17 subjects in each group for the final analysis.

The primary parameter evaluated was maximal oxygen capacity (VO_2 max), measured through the 6-minute walking test (6MWT). Measurements were conducted in three stages: initial measurement (P0) conducted one day before the first treatment; final measurement (P1) conducted one day after the final treatment; and follow-up measurement (P2) conducted 20 days after the final treatment. Before statistical analysis, the subjects' general characteristics were evaluated and are presented in Table 1 to provide an overview of the demographic distribution and baseline conditions of the study participants. This study aims to compare the effectiveness of therapy between the two groups in improving VO_2 max.

Table 1. Characteristics of Research Participants

No.	Characteristic	Control Group (n = 17)	Treatment Group (n = 17)	p-value
1.	Age (years)	54.59 ± 2.98	55.35 ± 2.96	0.92
2	Sex Male Female	 3 (17.6%) 14 (82.4%)	 2 (11.7%) 15 (88.3%)	
3	OA Severity Grade II Grade III	 13 (76.5%) 4 (23.5%)	 14 (82.4%) 3 (17.6%)	
4.	Involved Knee Unilateral Bilateral	 9 (52.9%) 8 (47.1%)	 8 (47.1%) 9 (52.9%)	
5.	Weight (kg)	66.82 ± 11.34	64.18 ± 9.41	0.30
6.	Height (cm)	160.35 ± 9.17	156.94 ± 6.65	0.20
7.	BMI (kg/m2)	25.87 ± 2.80	25.94 ± 2.47	0.40
8.	VO_2 max (P0) (ml/kg/minute)	9.93 ± 3.58	9.39 ± 2.87	0.38

Note: The values for age, height, weight, BMI, and VO_2 max (P0) are presented as mean ± standard deviation, while the values for sex and OA severity are presented as percentages. The p-value represents homogeneity, with p considered significant if $p < 0.05$.

Table 1 reveals that the mean age of the research subjects in the control group was 54.9 ± 2.98 years (range: 50–59 years), while in the treatment group, it was 55.35 ± 2.96 years, with the same range. Both groups demonstrated age homogeneity (p = 0.92). In terms of sex distribution, the control group consisted of 3 males (17.6%) and 14 females (82.4%), while the treatment group consisted of 2 males (11.7%) and 15 females (88.3%). In terms of OA severity in the control group, 13 patients had grade II OA (76.5%), and 4 had grade III OA (23.5%). In the treatment group, there were 14 patients with grade II OA (82.4%) and 3 patients with grade III OA (17.6%). The distribution of unilateral and bilateral OA in the control group was 9 patients (52.9%) and 8 patients (47.1%), respectively, while in the treatment group, it was 8 patients (47.1%) and 9 patients (52.9%). The mean weight in the control group was 66.82 ± 11.34 kg (range: 52–89 kg), while in the treatment group, it was 64.18 ± 9.41 kg (range: 48–78 kg; p = 0.30). The mean height in the control group was 160.35 ± 9.17 cm (range: 145–177 cm), while in the treatment group, it was 156.94 ± 6.65 cm (range: 145–169 cm; p = 0.20). The mean BMI in the control group was 25.87 ± 2.80 kg/m^2 (range: 20.57–29.64 kg/m^2), while in the treatment group, it was 25.94 ± 2.47 kg/m^2 (range: 21.23–29.55 kg/m^2; p = 0.40). The mean initial VO_2 max (P0) in the control group was 9.93 ± 3.58 ml/kg/min (range: 6.20–14.23 ml/kg/min), while in the treatment group, it was 9.39 ± 2.87 ml/kg/min (range: 6.79–12.97 ml/kg/min). Both groups demonstrated initial VO_2 max homogeneity (p = 0.38).

Table 2. Normality of Variables

Control Group		Treatment Group	
Variable Name	**p-value**	**Variable Name**	**p-value**
Age	0.159	Age	0.258
Body Weight (BW)	0.525	Body Weight (BW)	0.327
Body Height (BH)	0.556	Body Height (BH)	0.231
BMI	0.074	BMI	0.059
Initial VO_2 Max (P0)	0.454	Initial VO_2 Max (P0)	0.204
Final VO_2 Max (P1)	0.076	Final VO_2 Max (P1)	0.074
Follow-up VO_2 Max(P2)	0.251	Follow-up VO_2 Max(P2)	0.064

Note: VO_2 max; The p-value represents the normality test, with p considered significant if $p < 0.05$.

The normality test results suggest that the baseline variables for both groups before and after the intervention followed a normal distribution. Therefore, homogeneity analysis for each variable was performed using parametric tests, including the independent sample t-test for interval and ratio scale data and the exact Monte Carlo test for other data.

Assessment of Maximum Oxygen Capacity (VO_2 max) in the Two Groups

VO_2 max measurements in the control and treatment groups were conducted three times: one day before the first treatment (P0), one day after the final treatment (P1), and 20 days after the final treatment (P2). The normality test using the Shapiro-Wilk test indicated that the data followed a normal distribution, allowing the use of the paired t-test for parametric analysis. However, data that were not normally distributed (paired with initial VO_2 max) were analyzed using the Wilcoxon Signed Rank Test. In the control group, the paired t-test results indicated that VO_2 max significantly increased from the initial to the final measurements ($p < 0.01$) and from the initial to the follow-up measurements ($p < 0.01$). However, no significant increase was found from the final to the follow-up measurements ($p = 0.59$). In the treatment group, VO_2 max increased significantly at all measurement points: from the initial to the final measurements ($p < 0.01$), from the initial to the follow-up measurements ($p < 0.01$), and from the final to the follow-up measurements ($p < 0.01$). The detailed results of the measurements are presented in Table 3.

Table 3. VO_2 max Measurements in the Two Groups

	Control Group	***p-value***	***Treatment Group***	***p-value***
P0 VO_2 Max (ml/kg/minute)	9.93 ± 3.58	Pair P0-1 <0.01*	9.39 ± 2.87	Pair P0-1 <0.01*
P1 VO_2 Max (ml/kg/minute)	13.33 ± 2.19	Pair P1-2 =0.59	15.10 ± 1.77	Pair P1-2 <0.01*
P2 VO_2 Max (ml/kg/minute)	13.22 ± 2.27	Pair P0-2 <0.01*	16.12 ± 1.85	Pair P0-2 <0.01*
P0 VO_2 Max (ml/kg/minute)	9.93 ± 3.58		9.39 ± 2.87	

Note: P0 = Initial measurement one day before the first treatment; P1 = Final measurement one day after the final treatment; P2 = Follow-up measurement 20 days after the final treatment. The values for VO_2 max are presented as mean ± SD; a p-value is considered significant if $p < 0.05$.

Comparison of VO_2 max Between the Groups

The analysis results (Table 4) present the mean VO_2 max values during the measurements, compared using various statistical methods. The Shapiro-Wilk normality test results indicated that the data followed a normal distribution, allowing the use of the independent t-test to evaluate the VO_2 max values. For data with non-normal distribution, the Wilcoxon-Mann Whitney test was applied.

At P0 ($p = 0.03$; Cohen's D = 0.79), statistical analysis revealed that the initial VO_2 max values of both groups were homogeneous (not significant) with $p = 0.38$ and Cohen's D = 0.25. However, the addition of uphill treadmill exercise to the treatment group revealed a significant effect compared to the control group at P1 ($p = 0.01$; Cohen's D = 0.89) and P2 ($p < 0.01$; Cohen's D = 1.39). Furthermore, statistical tests comparing the differences in VO_2 max values at each measurement endpoint revealed significant results at ΔP01 ($p < 0.01$; Cohen's D = 1.22), ΔP02 ($p < 0.01$; Cohen's D = 1.89), and ΔP12 ($p < 0.01$; Cohen's D = 1.36).

Table 4. Comparison of VO_2 Max and VO_2 Max Differences in the Control and Treatment Groups

Characteristic	***Control Group (n = 17)***	***Treatment Group (n = 17)***	***p-value***	**Cohen's D**
P0 VO_2 Max (ml/kg/minute)	9.93 ± 3.58	9.39 ± 2.87	0.38	0.25

P1 VO_2 Max (ml/kg/minute)	13.33 ± 2.19	15.10 ± 1.77	0.01*	0.89
P2 VO_2 Max (ml/kg/minute)	13.22 ± 2.27	16.12 ± 1.85	<0.01*	1.39
ΔP01 (ml/kg/minute)	3.41 ± 2.28	5.71 ± 2.28	<0.01*	1.22
ΔP02 (ml/kg/minute)	3.29 ± 1.49	6.72 ± 2.08	<0.01*	1.89
ΔP12 (ml/kg/minute)	-0.11 ± 0.83	1.01 ± 2.28	<0.01*	1.36

Note: P0 VO_2 Max = Initial measurement one day before the first treatment; P1 VO_2 Max = Final measurement one day after the final treatment; P2 VO_2 Max = Follow-up measurement 20 days after the final treatment. The p-value represents the result of the t-test, and a p-value of less than 0.05 is considered significant.

Adverse Event

One subject from the control group reported experiencing back pain after completing seven exercise sessions and chose to withdraw from the study. Prior to reporting the issue to the researchers, the subject consulted with a neurologist and received treatment, including Gabapentin, Sodium Diclofenac, and Diazepam. The subject also underwent a lumbosacral X-ray, with the results received approximately three days after withdrawal, revealing a diagnosis of lumbar spondylosis. The researchers ensured the subject received proper exercise guidance to alleviate the discomfort. More details about the adverse events can be found in the Appendix.

Table 5. Adverse Event in the Study Subjects

	Control (n = 17)	Treatment (n = 17)
Back pain	1 (5.8%)	0 (0%)

DISCUSSION

Characteristics of the Study Subjects

The subjects' age distribution in this research was comparable to that reported by Sedaghatnezhad et al. (2019b) in patients with knee OA, with a mean age of 59.6 ± 7.43 years in the control group and 53.8 ± 7.43 years in the treatment group (Sedaghatnezhad et al., 2019). Most subjects were in the 55–59 age range, where knee OA damage is typically still in the early stages, and medical rehabilitation is more effective (Tuna et al., 2022). Knee OA demonstrates a rapidly increasing prevalence in the 55–64 age range, with radiographic changes such as osteophytes commonly occurring (Shane Anderson and Loeser, 2010). Age-related VO_2 max decline is also a major concern, with an annual decline ranging from 0.35 to 0.62 ml/kg/min in females, depending on physical activity levels (Brown et al., 2000; Fitzgerald & Oatis, 2004; Wilson & Tanaka, 2000). Contributing factors include a decline in maximum heart rate, blood volume, peripheral oxygen extraction, and sarcopenia, which becomes significant after age 50 (Kim et al., 2018). This study also found a predominance of female subjects, consistent with previous research identifying the female sex, obesity, and age as major risk factors for knee OA (Sedaghatnezhad et al., 2019; Tschon et al., 2021). Obesity increases the risk of OA through excessive joint loading, biomechanical changes, and hormonal dysregulation; therefore, weight loss can significantly improve clinical symptoms (King et al., 2013; Oyeyemi & Bakare, 2013). In this study, both groups had similar mean weight, height, and BMI, with the exclusion of grade 2 obesity (BMI ≥ 30 kg/m^2). The initial VO_2 max values in both groups were also similar and lower than those of healthy populations, as seen in previous studies (Hasan & Pane, 2022). The decline in VO_2 max in knee OA is linked to decreased mobility, pain, joint stiffness, and weakened quadriceps strength (Zeng et al., 2021). Light-intensity aerobic exercise, whether treadmill-based or multicomponent, is recommended for pre-seniors to improve fitness and quality of life (Neumann et al., 2018). This research highlighted that VO_2 max capacity is a vital health indicator that can predict mortality risk in patients with knee OA and monitor walking difficulties (Master et al., 2020; Peel et al., 2013).

Discussion of the Treatment Effect on VO_2 max Values in the Control and Treatment Groups

This study indicated that the administration of standard therapy for 10 sessions over five weeks in the control group resulted in a VO_2 max improvement from 9.93 ± 3.58 ml/kg/min to 13.33 ± 2.19

ml/kg/min by the end of the study, and it remained stable at 13.22 ± 2.27 ml/kg/min after a 20-day follow-up. Pietrosimone et al. (2020) reported similar results, where standard physical therapy for eight weeks improved quadriceps strength, voluntary activation, physical function, and VO_2 max, although additional TENS did not lead to significant improvements. The reduction of pain and strengthening of the quadriceps, which act as pain modulators and joint protectors, were important factors in improving VO_2 max (Bokaeian et al., 2018; Imoto et al., 2012). Knee effusion in OA can lead to spinal reflex inhibition and reduced voluntary activation of the quadriceps, but increasing this activation is directly related to improved physical function and VO_2 max (Mizner et al., 2005; Palmieri-Smith et al., 2013). In the treatment group, the addition of uphill treadmill exercise increased VO_2 max from 9.39 ± 2.87 ml/kg/min to 15.10 ± 1.77 ml/kg/min by the end of the study and 16.12 ± 1.85 ml/kg/min at follow-up, indicating significant improvement compared to the control group. This exercise improved shortened knee flexors, reduced pain, and enhanced balance and flexibility in the lower extremity muscles (Samaei et al., 2017; Sedaghatnezhad et al., 2019). The biomechanical advantages of uphill treadmill walking, including the reduction of patellofemoral joint compression forces and knee degeneration, support knee OA rehabilitation, with the best results at inclines greater than 12% (Lange et al., 1996). Additionally, improved balance and dynamic postural control gained from uphill treadmill walking contributed to VO_2 max and endurance enhancement. The combination of muscle strengthening, pain reduction, and biomechanical improvements makes this method effective for managing knee OA.

Comparison of VO_2 Max Values Between the Groups

The results of this study revealed that the VO_2 max values of the treatment group at the end of the study and after the 20-day follow-up improved greater than those of the control group. Sedaghatnezhad et al. (2019a, 2019b) found similar results, which indicated that the combination of standard therapy and uphill treadmill exercise improved quality of life, joint range of motion, stride length, VO_2 max, and pain perception in patients with knee OA. This research differs from previous studies in the intensity and duration of standard therapy. Earlier studies used higher intensity but shorter durations, such as 10 sessions over two weeks, which were insufficient to improve all study parameters (Sedaghatnezhad et al., 2019). In contrast, the 10 sessions over five weeks in this study were more effective, indicating that more than four weeks are needed for optimal physical therapy benefits in knee OA (Fitzgerald & Oatis, 2004). The addition of uphill treadmill exercise also provided additional benefits, such as decreased gastrocnemius and soleus stiffness, improved flexibility, and strengthened lower extremity muscles, especially the quadriceps, which significantly improved VO_2 max (Franz & Kram, 2013; Jeon & Hwang, 2018; Whitehead et al., 2007). Additionally, the results indicated that patients with unilateral OA tend to experience biomechanical knee asymmetry, whereas bilateral OA tends to be more symmetrical, although the mean walking speed was similar in both groups (Creaby et al., 2012; Messier et al., 2021). This suggests that more focused biomechanical management could enhance the effectiveness of physical therapy interventions for knee OA.

Study Findings: Implications and Recommendations

This is the first study at RSUD Dr. Soetomo, Surabaya, that compares standard therapy with added uphill treadmill exercise over five weeks to improve VO_2 max in patients with knee OA. These findings indicated that both therapies improved VO_2 max, which was maintained up to 20 days after training, with the group receiving the added uphill treadmill exercise demonstrating more significant improvements in knee OA patients with grade II–III OA. Additionally, during the training period, only one case of mild adverse event, specifically lower back pain, was reported in the control group, while the treatment group did not experience side effects, suggesting that both therapies could be recommended for similar populations. However, this study had several limitations, such as the lack of pre-intervention muscle strength and mass measurements and the brief duration of training and follow-up, meaning the long-term effects of this training on VO_2 max could not be assessed. Future studies are recommended to include muscle strength and mass measurements and extend the duration of both intervention and follow-up periods to explore the long-term benefits of exercise on VO_2 max values in knee osteoarthritis patients.

CONCLUSION

The administration of TENS and quadriceps-strengthening exercises for five weeks successfully increased VO_2 max in patients with grade II–III knee osteoarthritis, with results maintained for 20 days after the last training session. The combination of TENS, quadriceps-strengthening exercises, and uphill treadmill exercise provided additional benefits, resulting in more significant improvements in VO_2 max based on post-training and follow-up measurements. Overall, exercise with added uphill treadmill walking yielded better results in improving VO_2 max compared to standard therapy alone.

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DISCLOSURE

The authors have declared that they have no conflicts of interest regarding this study.

AUTHOR'S CONTRIBUTION

A.K.: Study design, data collection, statistical analysis, manuscript preparation; A.: Study design, statistical analysis, manuscript preparation; A.K.N.: Study design, statistical analysis, manuscript preparation.

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