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A comparison of Nordic walking and treadmill walking training outcomes after total knee arthroplasty in older women: a randomized controlled trial

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Abstract

Introduction. Evidence on gait training strategies for improving function in patients with knee arthritis after total knee arthroplasty (TKA) remains limited. This study aimed to determine whether Nordic walking training yields better outcomes than treadmill walking training in patients with knee arthritis after TKA.

Methods. This assessor-blinded trial included 38 female patients (mean age 68.7 ± 2.1 years) who had undergone TKA. Participants were randomly and equally assigned to an experimental (Nordic walking training) or a control (general treadmill walking training) group. Training consisted of 30-min sessions, five times weekly for 4 weeks. In addition, all participants received 60-min sessions of comprehensive physiotherapy five times weekly over the same 4-week period. Primary (stride length and stride, stance, and swing times) and secondary (knee flexion angle and pain score) outcomes were measured before and after the 4-week training period. The Shapiro–Wilk test was used to assess the normality of data distributions. Baseline comparability of the groups was assessed using the independent t-test (normally distributed continuous variables) and Fisher's exact test (categorical variables). Two-way repeated-measures analysis of variance (ANOVA) was used to examine group × time interactions, and eta-squared (η^2) values were calculated to quantify effect sizes.

Results. The experimental group achieved greater increases in stride length, walking velocity, and knee flexion angle than the control group (+4.5 *vs.* +1.7 cm, $p < 0.01$, $\eta^2 = 0.62$; +3.51 *vs.* +1.24 cm/s, $p < 0.01$, $\eta^2 = 0.88$; +30.7 *vs.* +20.7°, $p < 0.01$, $\eta^2 = 0.87$). Furthermore, the experimental group showed greater reductions in stride, stance, and swing times and in pain scores (–0.23 *vs.* –0.07 s, $p < 0.01$, $\eta^2 = 0.80$; –0.11 *vs.* –0.09 s, $p < 0.01$, $\eta^2 = 0.16$; –0.23 *vs.* –0.07 s, $p < 0.01$, $\eta^2 = 0.81$; –2.5 *vs.* –1.0 score, $p < 0.01$, $\eta^2 = 0.87$).

Conclusions. Nordic walking training may be more effective at increasing walking function and knee flexion angles and significantly more effective at reducing knee pain than treadmill training in knee arthritis patients after TKA.

Key words: aged, arthritis, exercise, gait, knee joint

Introduction

Knee osteoarthritis (KOA) is an age-related type of degenerative arthritis that is more prevalent in women [1]. The main symptom of KOA is pain, although joint crepitus, swelling, deformity, and increased muscle tone may also occur without constitutional symptoms [1–4]. This pain is aggravated when walking owing to increased load on the lower extremity joints and can restrict movement, leading to muscle atrophy, joint deformity, and increased risk of falls [2, 5].

Total knee arthroplasty (TKA) effectively reduces knee pain, corrects joint deformity, restores range of motion (ROM), and thus markedly improves quality of life (QoL) [5]. However, the procedure is associated with adverse effects, including surgical-site pain, pain-related lower extremity muscle weakness, and decreased proprioception, which impair balance and walking function [6–8]. Surgical-site pain is reported by 60% of patients after TKA, and 18% of these patients report moderate pain [9]. In addition, knee flexor and extensor strength decrease by 28–31% relative to preoperative values [10]. Consequently, pain management and strength and neuromuscular training constitute the main rehabilitation interventions [11, 12]. Gait training is also emphasised to minimise adverse effects and facilitate an early return to daily and social activities [13, 14].

Gait training methods include general treadmill walking training, partial weight-supported treadmill training, antigravity treadmill training, and overground walking training supervised by a therapist [15–17]. General treadmill training effectively increases leg strength, walking speed, and walking endurance, but it is monotonous, and the gait pattern differs somewhat from normal because the patient walks in a fixed location [18–20]. Partial weight-supported or antigravity treadmill training can be used as an alternative to general treadmill training in patients with KOA, but it requires expensive equipment and a longer set-up time [18, 21].

Nordic walking involves the use of poles similar to those used in cross-country skiing [22] and effectively reduces lower extremity joint loading, because the upper and lower extremities move simultaneously and part of the load is borne by the upper extremities [23]. Nordic walking training effectively increases lower extremity muscle strength and flexibility of the upper and lower extremities, as well as reduces pain in elderly patients with degenerative knee osteoarthritis [24, 25]. This type of training has been reported to be more effective at increasing functional performance, such as stair-climbing ability and walking endurance, in older patients with hip osteoarthritis than supervised strength training in a local fitness centre or unsupervised home-based exercise [26]. In addition, Nordic walking has been reported to be more effective than

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walking without poles at increasing pain tolerance in patients with chronic low back pain [27] and to be effective in reducing body mass index and increase muscular flexibility and maximal oxygen uptake in adults with obesity [28]. However, although it is a popular form of walking training, it has obvious limitations in patients with neurological disorders or cardiopulmonary disease [29, 30].

Most studies investigating the clinical effects of Nordic walking have involved patients with degenerative KOA [24], hip osteoarthritis [26], chronic low back pain [27], or diabetes with obesity [28]. However, to the best of our knowledge, no clinical trial has investigated the effects of Nordic walking on patients post-TKA, although knee osteoarthritis accounts for the largest proportion of degenerative osteoarthritis cases and TKA is the most frequently performed joint replacement procedure [31]. Therefore, this study investigated the clinical effects of Nordic walking training in older patients who had undergone TKA caused by osteoarthritis.

The study hypothesized that that Nordic walking training would improve physical function after TKA more effectively than general treadmill walking training.

Subjects and methods

The study followed the 2017 CONSORT extension for reporting non-pharmacological randomised controlled trials [32]. This single-centre, randomised, controlled intervention trial was conducted at the W Hospital (Daejeon City, Republic of Korea) from October 2024 to December 2024.

Participants

The participants were patients with KOA who had undergone TKA and were receiving inpatient treatment at the W Hospital in Daejeon City.

The inclusion criteria were as follows: age of ≥ 65 years, a diagnosis of degenerative arthritis of the knee joint, TKA surgery performed at least 2 weeks previously, and the ability to walk independently indoors without an assistive device for more than 30 min with up to 2 breaks of less than 2 min.

The exclusion criteria were as follows: paralysis due to damage to the central or peripheral nervous system, comorbidities other than OA of the knee joint, current pharmacotherapy, inability to communicate or complete the questionnaire, a history of lower extremity surgery other than knee surgery, and cardiopulmonary disease limiting aerobic exercise.

The withdrawal criteria were as follows: voluntary withdrawal, complications occurring during the intervention, and non-compliance with the study protocol.

Sample size

The required sample size was calculated for a two-way repeated-measures ANOVA using G*Power (version 3.1.9.7) [33] and an *a priori* power analysis, based on stride length data from a previous study [34].

In that study, the mean post-intervention stride lengths in the Nordic walking and control groups were 1.42 ± 0.10 m and 1.30 ± 0.15 m, respectively. The corresponding effect size (*f*) was 0.493; however, because that study had a small sample, a more conservative medium effect size (*f* = 0.25) was adopted. The following parameters were used: $\alpha = 0.05$, power $(1-\beta) = 0.80$, effect size (*f*) = 0.25, number of groups = 2, and number of measures = 2. Measurements were obtained before training and after the 4-week training period. The correlation for repeated measures was set at 0.5, and the non-sphericity correction was set at 1.0. *A priori* analysis indicated that 34 participants were required. Allowing for an anticipated dropout rate of 10%, 38 participants (19 *per* group) were recruited [35].

Randomisation and concealed allocation of participants

Simple randomisation was performed using a computer-generated randomisation table and an allocation ratio of 1:1. Sequentially numbered, opaque, sealed envelopes were used to conceal allocations. Each envelope contained either an 'X' or a 'Y', corresponding to allocation to the experimental or control group, respectively. The allocator and patients were blinded to allocations.

Blinding

Participants and the physiotherapists delivering the interventions were aware of group allocation after assignment. Outcomes were assessed by two physiotherapists who were blinded to group allocation and to the content of the walking training programmes and were not otherwise involved in the study.

Intervention

All 38 participants received comprehensive physiotherapy consisting of physical agent modalities, range of motion exercise, muscle strengthening exercise, and functional training for 60 min *per* session, 5 times weekly for 4 weeks. Physical agent modalities involved thermal therapy and electrical therapy for 30 min over the same 4-week period to relieve pain at the surgical site [36, 37]. Range of motion exercise, muscle strengthening exercise, and functional training were performed for 30 min. Range of motion exercises were performed within the pain-free range in accordance with the degrees of freedom of the knee joint [38]. Muscle-strengthening exercises were also performed at a pain-free intensity, with isotonic muscle contraction induced in hip and ankle joint muscles, while isometric muscle contraction induced in knee joint muscles [39]. Functional training included standing up, maintaining a standing posture, and walking training [40]. Before all interventions, patients were educated about fall-inducing factors. They were also instructed to notify the physical therapist immediately if pain occurred during the intervention, in which case the intervention was stopped.

In addition, the experimental group performed Nordic walking training and the control group performed treadmill walking training, each for 30 min *per* session, 5 times weekly over the same 4 weeks, whereas the control group underwent treadmill walking training for 30 min *per* session, 5 times a week for four weeks. A physiotherapist with 5 years of clinical experience monitored participant adherence to the intervention protocol; there were no exclusions for non-compliance.

Nordic walking training

Patients were instructed to start by walking naturally, holding poles on either side. Pole lengths were set at 65% of participant's height [41]. Patients were asked to relax their shoulders and arms and swing their arms from their shoulders while maintaining a slightly forward-leaning upper body posture. The poles were used to push patients forward as much as possible, with the driving arm fully extended [42]. Participants



Figure 1. Nordic walking training (experimental group) in a patient who had undergone bilateral total knee arthroplasty: (A) view of the right lateral side, (B) frontal view, (C) rear view

walked on a 20 m track for 10 min and then rested comfortably for 5 min sitting on a chair with a backrest; this was defined as one set. Each training session consisted of three sets. All participants (n = 19) performed gait training at a rating of perceived exertion (RPE) of 9–11 (light intensity) (Figure 1) [42, 43]. If a patient complained of extreme fatigue or requested rest during training, training was immediately halted. After sufficient rest, training was resumed only once the patient had confirmed their willingness to continue.

Treadmill training

Participants assigned to the control group performed 30 min of walking training on a treadmill (AP2010-2S, Apsun Inc., Seoul, Korea). The gait training schedule was the same as that used for Nordic walking. Each patient was asked to look forward during gait training, and the treadmill speed was set at each patient's preferred, self-selected pace (RPE 9–11) [43]. A physiotherapist with more than 5 years of experience supervised the training to prevent accidents. Patients who felt unstable were allowed to walk while holding a handrail for less than 1 min. If a patient complained of fatigue, training was stopped immediately, and the patient was asked to step off the treadmill. Training was resumed after sufficient rest on a chair with a backrest.

Outcome measures

Primary and secondary outcome measurements were performed before (baseline) and after the 4-week training period.

Primary outcome measures

Kinesis Gait™ and QTUG™ sensors (Kinesis Health Technologies, Dublin, Ireland) were used to measure temporal and spatial values of gait. Gait metrics obtained with this system have shown high reliability (ICC > 0.90) [44]. To measure walking variables, participants walked without an assistive device along a 30 m-long walkway at a comfortable speed, with motion sensors attached to the upper two-thirds of the left and right tibiae. Sensors contained a triaxial accelerometer and a triaxial gyroscope and sampled at 102.4 Hz. The sensors also collected real-time data, which was sent to a handheld tablet *via* Bluetooth. Measurements were taken in triplicate and averaged. Stride lengths and stride, stance, and swing times of both legs were averaged.

Secondary outcome measures

Knee flexion angle and pain level were measured at baseline and immediately after the 4-week intervention period.

A universal goniometer (Human Solution, NY, USA) was used to measure knee joint flexion angles (ICC of intra-rater reliability = 0.915; ICC of inter-rater reliability = 0.889) [45]. The reported minimal clinically important difference (MCID) for knee flexion in patients after TKA is 11.5° [46].

Participants were asked to lie prone with legs comfortably extended, and the universal goniometer was then positioned so that the goniometer axis rested over the lateral epicondyle. The stationary goniometer arm was aligned with the greater trochanter and parallel to the longitudinal axis of the femur, and the movable arm was aligned with the lateral malleolus and parallel to the longitudinal axis of the fibula. When the examiner was satisfied with a measurement, a recorder (an assistant) documented the angle to the nearest degree by reading the non-blinded side of the universal goniometer, ensuring that the universal goniometer arms did not move during recording [47]. Participants actively flexed the affected knee as far as possible within the pain-free range, and the examiner measured maximum flexion angles. Knee flexion angles were measured at surgical sites; average angles were calculated in bilateral cases. Measurements were performed three times and averaged.

A visual analogue scale (VAS) was used to measure knee joint pain intensity before and after intervention. The VAS scale was 10 cm long and marked at 1 cm intervals. Scores ranged from 0 to 10 points, with 0 representing no pain and 10 points the most severe pain imaginable. A score of ≤ 3.4 was considered to indicate mild pain, 3.5 to 7.4 to indicate moderate pain, and ≥ 7.5 to indicate severe pain [48, 49]. The reported MCID of the VAS for pain improvement after TKA is –2.3 points, and the scale shows excellent reliability (*ICC*s of 0.96 to 0.98) [48, 50]. Before each measurement, analgesic use during the intervention or before the assessment was checked, and measurements taken after analgesic use were excluded.

Data analysis

The Shapiro–Wilk test was used to assess the normality of data distributions, and Levene's test was used to assess the homogeneity of variances between the experimental and control groups. The independent t-test (continuous variables: age, height, and body mass) and Fisher's exact test (categorical variables: sex and surgical site) were used, as ap-

propriate, to compare baseline characteristics between the groups. The paired *t*-test was used to analyse intervention-associated improvements adjusted for baseline data. Minimal detectable changes (*MDC*s) with 95% confidence interval were determined using the formula: *MDC* = 1.96 * standard error of the measurement (*SEM*) * √2. *SEM*s were calculated using the following formula: *SEM* = standard deviation score/ √*ICC* [51]. Two-way repeated-measures analysis of variance (ANOVA) was conducted to compare group means as the first factor and time (pre-training *vs*. post-training) as the second factor. Multiple comparisons were corrected using the Benjamini-Hochberg false discovery rate (*FDR*) procedure at an *FDR* level of 0.05 [52]. *FDR*-adjusted *p*-values are reported. Eta-squared (η^2) values were calculated to determine the magnitudes of effect sizes, which were defined as small (0.02), medium (0.06), or large (0.14) [53].

Results

Fifty-three individuals were assessed for eligibility from October 2024 to December 2024. Of these, 39 met the eligibility criteria, but one declined to participate owing to depression. Thus, 38 participants were randomized, 19 to each of the study groups. No participant was excluded after randomisation, and all received the allocated intervention (Figure 2). No participant experienced any adverse effect; all participants completed the intervention. There were no dropouts; thus, per-protocol analysis was performed.

Baseline participant characteristics are provided in Table 1. All variables (age, height, body mass) used to compare general characteristics in the two groups were normally distributed ($p > 0.05$). No statistically significant differences were evident after comparing continuous (age, height, and body mass) and dichotomous variables (sex and surgical site) between the two groups, indicating that the groups were homogeneous ($p > 0.05$).

Table 2 summarises gait variables, knee flexion angles, and pain levels before and after training in the two groups.

Stride time, stance time, and swing time decreased, whereas walking velocity increased after training in both groups. In the experimental group, stride length, stride time, stance time, swing time, and pre-to-post intervention walking velocity differences exceeded the *MDC* ($p < 0.01$), and in the control group, stride time, stance time, swing time, and pre-to-post walking velocity difference exceeded the *MDC* ($p < 0.01$). Significant time × group interaction effects were observed for all gait variables. The experimental group showed greater reductions in stride time, stance time, and swing time after the intervention than the control group [stride time, $F(1, 36) = 143.887$, $p < 0.035$, $\eta^2 = 0.800$; stance time, $F(1, 36) = 6.590$, $p < 0.050$, $\eta^2 = 0.155$; swing time, $F(1, 36) = 152.084$, $p < 0.028$, $\eta^2 = 0.809$, respectively]. In addition, the experimental group exhibited a greater mean increase in stride length and walking velocity than the control group [stride length, $F(1, 36) = 58.147$, $p < 0.042$, $\eta^2 = 0.618$; walking velocity, $F(1, 36) = 267.734$, $p < 0.007$, $\eta^2 = 0.881$, respectively].

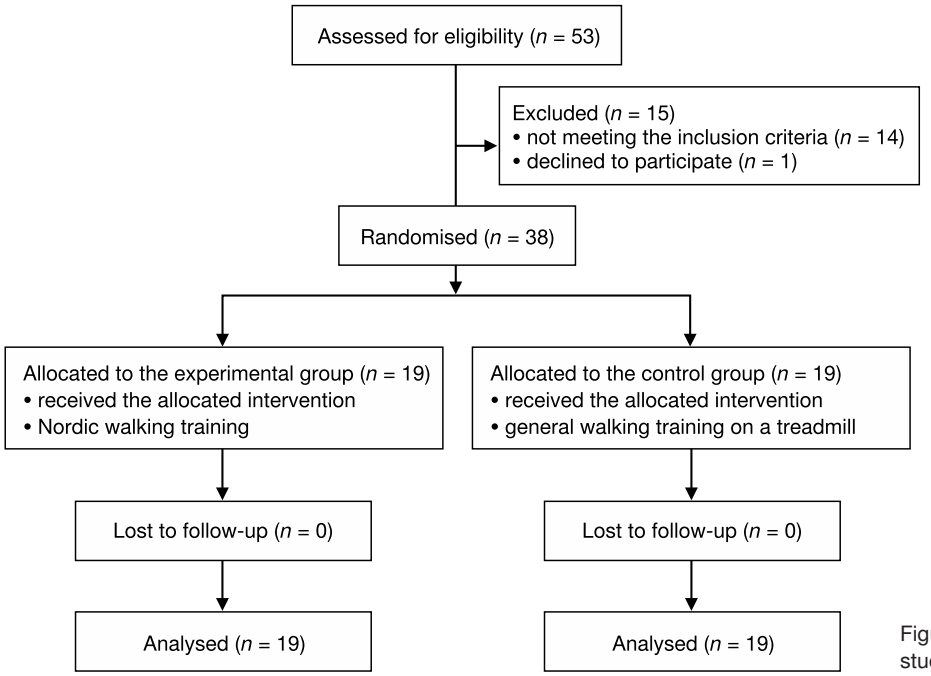


Figure 2. CONSORT diagram showing the study flow

Table 1. General characteristics of the participants

Variable	EG (*n* = 19)	CG (*n* = 19)	*t*/χ^2	*p*
Age (years, mean ± *SD*)[a]	68.4 ± 2.1	69.1 ± 2.1	–1.083	0.286
Sex (male/female, *n*/%)	0/19 (0/100)	0/19 (0/100)	N/A	N/A
Height (cm, mean ± *SD*)[a]	158.7 ± 3.8	158.9 ± 3.4	–0.180	0.858
Body mass (kg, mean ± *SD*)[a]	65.7 ± 4.8	64.4 ± 4.3	0.891	0.379
Surgical site (*n*, Lt/Rt/both)[b]	6/10/3	5/10/4	0.234	1.000

EG – experimental group, CG – control group, Lt – left, Rt – right, N/A – not applicable
[a] The independent *t*-test was used to analyse continuous variables.
[b] Fisher's exact test was used to analyse dichotomous variables.

Table 2. Gait variables, knee flexion angles, and pain scores before and after training within and between the two groups

Variable	Experimental group (n = 19)				Control group (n = 19)				Mean differences between groups (95% *CI*)	p (time × group)	η^2
	pre (means ± *SD*)	post (means ± *SD*)	mean differences within group (95% *CI*)	minimal detectable changes	pre (means ± *SD*)	post (means ± *SD*)	mean differences within group (95% *CI*)	minimal detectable changes			
SRL†,‡ (cm)	57.5 ± 3.6	62.0 ± 4.4*	3.9 to 5.2	3.8	57.4 ± 3.3	59.1 ± 3.7	1.3 to 2.1	2.4	2.1 to 3.5	< 0.042	0.618
SRT†,‡ (s)	1.54 ± 0.07	1.27 ± 0.36*	–0.29 to –0.25	0.16	1.51 ± 0.07	1.40 ± 0.06*	–0.13 to –0.09	0.09	–0.19 to –0.14	< 0.035	0.800
STT†,‡ (s)	0.94 ± 0.04	0.83 ± 0.04*	–0.12 to –0.10	0.04	0.95 ± 0.05	0.86 ± 0.04*	–1.1 to –0.08	0.08	–0.03 to –0.00	< 0.050	0.155
SWT†,‡ (s)	0.76 ± 0.08	0.52 ± 0.03*	–0.26 to –0.21	0.17	0.72 ± 0.07	0.65 ± 0.07*	–0.08 to –0.06	0.01	–0.19 to –0.14	< 0.028	0.809
WV†,‡ (cm/s)	45.08 ± 4.98	48.58 ± 4.95*	3.27 to 3.74	1.34	44.03 ± 4.15	45.27 ± 4.10*	1.07 to 1.42	1.00	–0.19 to –0.14	< 0.007	0.881
KF†,‡ (°)	91.4 ± 3.5	122.1 ± 3.5*	30.1 to 31.4	3.8	93.1 ± 2.4	113.8 ± 2.0*	19.5 to 21.9	9.0	8.8 to 11.4	< 0.014	0.874
VAS†,‡ (score)	3.9 ± 0.6	1.4 ± 0.3*	–2.6 to –2.3	1.1	3.4 ± 0.4	2.4 ± 0.3*	–1.1 to –0.9	0.7	–1.7 to –1.3	< 0.021	0.868

SRL – stride length, SRT – stride time, STT – stance time, SWT – swing time, WV – walking velocity, KF – knee flexion angle, VAS – visual analogue scale
Mean intra-group differences (95% *CI*), mean differences with 95% confidence intervals for intra-group pre-to-post changes
Mean inter-group differences (95% *CI*), mean differences with 95% confidence intervals for inter-group differences post-intervention
* significantly different *vs.* baseline (exceeded the *MDC*).
† significant group × time interaction after the Benjamini-Hochberg correction for multiple comparisons. The *p*-values presented in the table reflect significance thresholds adjusted for multiple comparisons using the Benjamini–Hochberg false discovery rate (*FDR*) procedure.
‡ effect size (η^2) > 0.13

Knee flexion angle increased after training in both groups, with pre-to-post changes exceeding the *MDC* ($p < 0.01$). A significant time × group interaction was found for this variable. The experimental group showed a greater mean increase in knee flexion angle than the control group [$F(1, 36) = 250.824$, $p < 0.014$, $\eta^2 = 0.874$].

In both groups, pain decreased after training, and pre-to-post intervention pain score differences exceeded the *MDC* ($p < 0.01$). A significant interaction effect between time and group was also identified for this variable. The experimental group showed a greater reduction in pain scores after intervention than the control group ($F(1, 36) = 236.232$, $p < 0.021$, $\eta^2 = 0.868$).

Discussion

The goal of rehabilitation after TKA is to enable patients to recover physical function and return to normal activities of daily living. This study compared Nordic and treadmill walking training to determine which method provides more effective gait training after TKA. The study results shows that Nordic walking training produced significantly greater improvements in walking function, knee flexion angle, and pain than treadmill training. Thus, these findings support the hypothesis that Nordic training is more effective at improving physical function than treadmill training.

Both training methods significantly improved gait parameters (the primary outcome variables). Stride length increased in both groups, but significantly more after Nordic walking training, which suggests that Nordic walking training is more effective than treadmill training for improving the spatial variables of gait function after TKA. Nordic walking involves the use of two poles on both sides, which provides additional body support, facilitate lower limb joint movement, erector spinae activation, maintenance of a standing posture, and correct trunk alignment [23]. Park *et al.* [34] compared intervention stride lengths after Nordic walking and standard walking training in men in their 20s, and found that Nordic walking significantly increased stride length by 12 cm more than standard walking training [34], which is consistent with the present findings. Hansen *et al.* [54] compared stride lengths after walking training with and without poles in middle-aged women and reported a 6 cm greater stride length increase for Nordic walking than walking without poles [54], which also aligns with our study results. Tanpure *et al.* [55] reported that TKA increased mean stride length from 78 cm preoperatively to 93 cm in older patients, and Fukui *et al*. [56] reported a 9.2 cm increase in mean step length after TKA. These findings suggest that Nordic walking may enhance the beneficial effects of TKA on gait. In addition, surgical-site pain and reduced knee ROM, the typical adverse effects of TKA, are the major causes of reduced stride length [57]. Therefore, the increase in stride length after the intervention implies that Nordic walking can ameliorate the adverse effects of TKA. Redfern *et al.* [58] reported that the average MCID for stride length in TKA patients was 4 cm. In the present study, Nordic walking training increased stride length by 3.9 to 5.2 cm, whereas treadmill training increased it by 1.3 to 2.1 cm. As only the change achieved with Nordic walking exceeded the MCID, the Nordic walking training appears to be more effective than treadmill training for improving the spatial variables of gait function in TKA patients.

Similarly, changes in stride time, stance time, swing time, and walking velocity showed that Nordic walking training improved these temporal variables significantly more than treadmill walking training. These effects are believed to be due to the ground reaction force in the forward-diagonal direction generated by the poles during Nordic walking. This force provides a mechanical advantage that assists forward displacement of the centre of gravity, which may have contributed to the shorter step and swing times [34]. Kim and Yang [59] investigated the effects of Nordic walking training in older individuals with KOA and reported reductions in the average stance time on the dominant side by 0.01 s and in the average swing time by 0.02 s *vs*. pre-intervention. These study results are consistent with our findings and demonstrate that Nordic walking effectively improves swing and step times in KOA patients, irrespective of whether they have undergone TKA.

Maniwa *et al.* [60] analysed the training effects of Nordic walking in elderly female patients with moderate-to-severe

hip OA. After 3 months of training, the 10-m walk test time decreased by 1.0 s compared to baseline, and after 6 months, the reduction reached 1.5 s. These authors concluded that Nordic walking training effectively increased walking speed [60]. These results also support the finding from the present study that walking speed increased after Nordic walking. In addition, another study that compared stride times after Nordic walking and regular walking in men in their 20s found that Nordic walking significantly shortened stride time by 0.15 s compared to regular walking [34], which is in line with the reduction in stride time observed after Nordic walking training in the present study. A previous study reported that the average MCID for walking velocity in TKA patients was 1.7 cm/s [58]. In the present study changes in walking velocity after Nordic walking and treadmill training were 3.5 and 1.2 cm/s, respectively. As only Nordic walking training exceeded the MCID, it appeared to be the more effective intervention for improving temporal variables of gait function in patients after TKA.

Knee joint flexion angles (the secondary outcome variable) increased more after Nordic walking training than after treadmill training. This may be because the wider based of support provided by the poles increases lower extremity stability during the stance phase, and thus, facilitates knee flexion during the pre-swing and initial swing phase [24], which supports the finding that the peak knee flexion angle in the stance phase was 4.6° greater during Nordic walking than walking without poles [54]. Nordic walking has also been reported to increase chair sit-and-reach test results by 91% in older women (mean age 73.2 ± 2.3 years) with degenerative knee arthritis [24]. These findings indicate that Nordic walking training has a positive effect on changes in knee joint range of motion, which is one of the main goals of TKA for knee arthritis [31, 61]. Solomito *et al.* [46] reported the mean MCID for patients who underwent TKA was 11.5° [46]. In the present study, average changes in knee flexion angle for Nordic walking and treadmill training were 30.7° and 20.7°, respectively. Both training methods met the MCID, but Nordic walking training was more effective than treadmill training in increasing the knee flexion angle of TKA patients. Regarding the other secondary outcome, knee pain decreased significantly more after Nordic walking training than after treadmill training. Weight bearing is the primary cause of pain in patients with knee OA [62]. Therefore, the results of this study may be explained by body mass reductions, as Nordic walking training distributes body weight load on lower extremities to poles during the stance phase [23]. Nordic walking has been reported to reduce knee pain in older women with osteoarthritis by 35% [24], which supports the finding of the present study. In contrast, a study in patients with mild to moderate low back pain found no difference in pain between walking with and without poles [27]. This discrepancy is probably due to their use in patients with low back pain and the assessment of pain in the lumbar region. This result suggests Nordic walking is more effective at reducing pain in the lower extremities. Approximately 30% of older patients who undergo TKA experience reduced independence in daily life and a decrease in the QoL due to pain at the surgical site [6]. Therefore, the analysis reported here suggests that Nordic walking might improve the independence and QoL of elderly patients who undergo TKA. Danoff *et al.* [50] reported a mean MCID of VAS pain improvement of –2.3 points. In the present study, average changes in pain scores before and after Nordic walking and treadmill training were –2.5 and –1.0 points, respectively. Furthermore, Nordic walking training met the MCID criteria, indicating it was a more effective than treadmill training for reducing knee pain in TKA patients.

Limitations

This study has several limitations. First, the rehabilitation hospital where this study was conducted specialises in older women who have undergone TKA, and therefore, the findings of this study cannot be generalised to older male patients or patients with more complex comorbidities. Second, the participants underwent TKA on the right, left, or both knee joints. Because gait variables were averaged for each individual, the relationship between gait outcomes and the side of surgery could not be investigated. Third, knee flexion angles were measured in the prone position to minimise leg muscle fatigue; therefore, the possibility that limited rectus femoris extensibility influenced the measured knee flexion angles cannot be ruled out. Fourth, quality of life outcomes were not assessed, and therefore, it was not possible to determine whether psychological patient satisfaction was based on intervention results. Lastly, a lack of follow-up data precluded assessment of the long-term effects of Nordic walking. Therefore, future studies that allow longitudinal follow-up are needed. Despite these limitations, this study has considerable merit because, to the best of our knowledge, it is the first to investigate the clinical effects of Nordic walking training in patients after TKA.

Conclusions

Nordic walking training produced significant improvements in stride length; walking velocity; stride, stance, swing times; knee flexion angle; and pain, and these improvements were significantly greater than those achieved after treadmill training. In addition, all of these variables had a larger effect size, with the largest observed for walking velocity. Therefore, Nordic walking training may be recommended in preference to treadmill training to improve walking function, increase knee flexion angle, and reduce pain in older women after TKA. Future studies should include older men and examine the effects of different TKA surgical sites on functional recoveries, and the long-term sustainability of the intervention effects.

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Ethical approval

The research related to human use complied with all the relevant national regulations and institutional policies, followed the tenets of the Declaration of Helsinki, and was approved by the author's institutional review board (Daejeon University, approved No. 1040647-202406-HR-022-03), and registered in the national trial registry on September 9, 2024 (KCT0009772).

Informed consent

Informed consent was obtained from all individuals included in this study.

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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