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COMPARATIVE EFFECTIVENESS OF NINTENDO WII-BASED BALANCE TRAINING *VS.* CONVENTIONAL BALANCE TRAINING AFTER TOTAL KNEE ARTHROPLASTY: A PILOT RANDOMIZED CONTROLLED TRIAL

M. KAUR[1], M. MAKHIJA[1], B. NARIANI[2]

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[1]Department of Physiotherapy, Indian Spinal Injuries Centre – Institute of Rehabilitation Sciences, New Delhi, India
[2]Department of Orthopedics, Indian Spinal Injuries Centre, New Delhi, India

Corresponding Author
Manjyot Kaur, M.PT; e-mail: kaurmanjyot311@gmail.com

ABSTRACT – *Objective:* Balance and proprioceptive deficits persist after Total Knee Arthroplasty (TKA), resulting in disability in activities of daily living. Consequently, balance training has become an integral component of rehabilitation after TKA, with a recent shift to virtual reality-based exercises like Nintendo Wii Fit balance games, which enhance patient motivation and feedback. This study aimed at comparing the effectiveness of Nintendo Wii-based balance exercises with conventional balance exercises on static balance, dynamic balance, and disability after TKA.

Patients and Methods: In this two-arm parallel-group single-blinded pilot randomized clinical trial, 22 participants (2-6 months after TKA) were recruited, of which 10 participants completed the study. They were randomized to receive either Nintendo Wii Fit balance or conventional balance training, besides the same general rehabilitation exercises for both groups. Baseline (before) and post-intervention (after completing 6 sessions spread over 2 weeks) assessment for the primary outcomes – single limb stance time (SLST), timed up and go (TUG) test, stability and weight distribution indexes with tetrax posturography, and secondary outcomes – WOMAC score and 2-minute walk test, were performed.

Results: Per-protocol analysis revealed that the Nintendo Wii group showed better improvement in SLST than the conventional group [Right: mean between-group difference (MD) = 1.44 sec, 95% CI: -6.93, 9.81; Left: MD = 4.62 sec, 95% CI: -3.41, 12.65]. Improvements in TUG were similar in both groups (MD = -0.08 sec; 95% CI: -2.09, 1.93). Tetrax posturography indicated better scores with Nintendo Wii exercises for all positions other than eyes closed on an unstable surface.

Conclusions: This preliminary study favors using Nintendo Wii Fit balance gaming as an adjunct or alternative to conventional balance training after TKA, with greater effects on the static balance due to training specificity. Future studies with large sample sizes and follow-up are required.

KEYWORDS: Total knee arthroplasty, Balance training, Nintendo Wii Fit, Gaming rehabilitation, Virtual reality, Proprioception.

INTRODUCTION

Total knee arthroplasty (TKA) is a common treatment for patients with osteoarthritis suffering from unrelenting pain, symptoms, and deteriorating quality of life. In India, 97% of TKA surgeries were performed for osteoarthritis in 2013[1]. However, impairments in balance, muscle strength, proprioception, and postural control have often been observed even after TKA[2-7]. Despite significant improvements in proprioception and balance after TKA, these persisting deficits affect the patient's ability to undertake their tasks of daily living, such as walking, turning, climbing stairs, and gait stability[3,7]. Consequently, balance training has become an integral component of rehabilitation after TKA for improving physical function[8]. Over the years, virtual reality-based exercise regimens, which offer better feedback with enhanced patient interaction and motivation, are superseding conventional exercise interventions. In terms of game-based exercise training, Nintendo Wii has surpassed its contemporary game providers and is a widely used modality[9].

Nintendo Wii Fit gaming consists of the Wii Balance Board − a platform device that monitors alterations in the user's center of pressure by sensing the amount of body weight applied to it, and accompanying software that provides auditory and visual feedback on the users' movement on the balance board as they perform an exercise task[10]. Balance training using the Nintendo Wii gaming console has been used in patients with a variety of neurological disorders, as well as for rehabilitation in the elderly for fall prevention[10]. However, there is a dearth of evidence investigating its efficacy in musculoskeletal rehabilitation. A recent review[11] outlined the need for further research on Nintendo Wii Fit gaming, highlighting the lack of substantial evidence. Although a few studies[12,13] have employed virtual reality-based exercises after TKA, the exact effect of such training on static or dynamic balance is yet to be determined. Therefore, we conducted this study to evaluate the effectiveness of Nintendo Wii Fit balance games in postoperative rehabilitation for TKA patients. We compared the effects of Nintendo Wii-based balance exercises and conventional balance exercises on balance (static and dynamic) and disability after TKA.

PATIENTS AND METHODS

This was a two-arm parallel-group single-blinded (participants were blinded to the group assignment) pilot randomized clinical trial conducted at the geriatric rehabilitation clinic of the Indian Spinal Injuries Centre Institute of Rehabilitation Sciences, associated with a tertiary-care hospital. Ethical clearance was obtained from the Institutional Ethical Committee (IEC No- ISIC/IIRS/RP/2015/091), and the study was conducted between December 2016 and April 2017. Retrospective hospital medical records were obtained; potential participants were invited by telephone, and flyers about the study were put up. Patients (aged 45-75 years) who had undergone primary TKA in the previous 2-6 months[14] (to allow pain and edema to subside after surgery, so they could tolerate balance exercises) and were able to comprehend written and verbal instructions, were included in the study. Those with any uncontrolled systemic disease (such as hypertension), musculoskeletal, cardiovascular, or neurological disorders that could affect balance, sensory deficit (uncorrected vision or vestibular), diagnosed with cognitive deficits, revision knee arthroplasty, and significant postoperative complications, were excluded[6,15]. All patients who agreed to participate were provided with a patient information sheet and written informed consent for participation was obtained.

Based on a significance level of 0.05 and 80% power to detect a difference of 1.34 seconds on TUG with an estimated standard deviation of 1.095 seconds and a 10% dropout rate, the sample size was calculated as 13 in each group[16]. The initial target sample size was 30 participants (15 in each group, as cleared by the IEC) who were randomized into two groups receiving either Nintendo Wii Fit balance exercises or conventional balance exercises, along with general rehabilitation after TKA. However, due to a low recruitment rate, the study was stopped at 22 participants in April 2017. Consequently, the number of participants allocated to each group was different, and the results for each group were computed using per-protocol analysis.

The included participants were then randomized using a computer-generated randomization list to receive either Nintendo Wii Fit balance exercises (experimental) or conventional balance exercises (control). Group assignment of the participants was performed by the second investigator keeping the patients blinded; the first investigator (physiotherapist) performed all interventions in individual sessions. Both groups received the same general rehabilitation exercises consisting of strengthening and flexibility exercises, and gait training carried out in a 40-45 minutes-long session (see **Appendix** for protocol). Additionally, each group received 15 minutes of balance exercises, according to their group assignment. These sessions were carried out thrice a week for 2 weeks.

The experimental group performed 15 minutes of Nintendo Wii Fit gaming. An adjustable walker was placed in front of the balance board which could be used for support, if required. The physiotherapist guided the participant during the session on how to perform the gaming task. Each participant started by playing the basic 'Deep Breathing' game and then continued to play all the games during all six sessions. The games used were the same as those used by Fung et al[17].

Lateral Weight Shifting

- Penguin slide: the participant plays as a penguin in the center of an iceberg; shifting weight to the right or left foot moves the penguin in the same direction on the iceberg.
- Ski slalom: the participant must lean right and left on the balance board to guide the movement of the character on the screen through a series of gates. On sharp turns, increased pressure is required to move the character to the desired side.
- Tightrope walk: the participant marches in place on the balance board, leaning to the right or left to move the screen character across a tightrope.

Multidirectional Balance

- Table tilt: this game requires the participant to shift weight in forward, backward, right, and left directions to tilt the table appearing on the screen and roll the marbles on the table into the holes.
- Hula hoop: like using a hula hoop, the participant rotates hips quickly in a circular motion so that the screen character spins a hula hoop around the waist.
- Balance bubble: the participant, appearing as standing within a bubble on the screen, leans forward, backward, right, or left to guide the bubble across the river.

Static and Dynamic Postural Control

- Deep breathing: the participant stands still on the balance board while taking slow deep breaths. A tracking dot on the screen depicts the participant's Centre of Gravity (COG) and weight distribution.
- Half moon: this requires maintaining the COG-tracking dot steady within the target circle while keeping arms elevated and fingers clasped.
- Torso twist: the participant abducts the arms to shoulder level, and then twists slowly by rotating the trunk from left to right to center and then back again while maintaining the COG-tracking dot steady within the target circle[17].

The control group participants performed the conventional balance exercises while standing. The exercises consisted of alternating hamstring curls, hip abduction, hip extension, lunges on a stool, and mini squats. They were allowed to hold onto a solid support (like a wall) if required while doing the exercises. All these exercises were performed for 3 sets of 10 repetitions each for either leg[17].

The study outcomes were assessed once before starting the intervention (baseline) and at the end of the six sessions. The primary outcomes evaluated were the single-limb stance time (SLST), timed up-and-go (TUG) test, and the WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index) score. The secondary outcomes were stability index and weight distribution index for eyes-open and eyes-closed positions on stable and unstable surfaces using Tetrax posturography and the two-minute walk test (2MWT). These were chosen to measure static, dynamic balance, and disability, and are the most frequently used outcome measures for balance in the TKA population[18,19].

- Single-limb stance time (SLST): it evaluates static balance by measuring the time (in seconds) for which the patient can stand on each leg. "For the test, the patients were asked to stand with arms by their side, bare feet and eyes open. The timing started when the subjects raised one foot off the ground. The test ended if the patients displaced the weight-bearing foot, touched the suspended foot to the ground, used the suspended limb to support the weight-bearing limb, or reached the maximum balance time of 30 seconds. A practice trial was given, followed by testing of two trials; the best trial time was recorded[20]".
- TUG test: this test assesses patients' dynamic balance; patients were timed as they rose from an armchair, walked 3 m, turned around, walked back to the chair, and sat back down (buttocks touching the chair)[21]. The patients' regular footwear and customary walking aids could be used. TUG shows an excellent test-retest reliability for TKA (ICC = 0.97)[22]. One practice trial was given to all patients, after which the time was noted during the next trial.

- Static posturography (Interactive Balance System - Tetrax): the patients were asked to stand barefoot on the force plates with arms freely hanging next to the body in a calm, distraction-free environment. Postural data were obtained from the attached computer installed with a dedicated software system. Four different positions were used for testing both stable surface – normal standing with eyes open and normal standing with eyes closed – and unstable surface (foam pillow) – standing with eyes open and standing with eyes closed. Each posture was maintained for 30 seconds[23] and the patient was not allowed to speak or move during the test. The stability and weight distribution indexes that indicated static balance for all four positions were obtained.
- WOMAC scale: this scale measured patient-reported disability. It consisted of three subscales: pain, stiffness, and physical function. Each response on the scale was recorded as a 5-point score. Higher scores indicated greater pain and stiffness, meaning greater functional difficulty. The scale was reported as reliable and valid for TKA patients[24].
- 2-minute walk test (2MWT): this test was used to evaluate functional mobility and dynamic balance as gait speed. The patients were instructed to walk for 2 minutes at a comfortable speed on a 30-m walkway in the corridor marked by two cones until they were asked to stop. The examiner walked behind the subjects, who could slow down or rest in between, if required, but should start walking as soon as they felt fine. The timer was stopped at 2 minutes and the distance covered was measured. Patients could use their regular assistive devices. The test-retest reliability of 2MWT for TKA was 0.97[22].

The primary investigator, who had provided all the interventions, also carried out the clinical assessments. Static posturography was performed as per the device manual, and the WOMAC scale was filled up by the participant, following which the score was calculated. No change in the interventions or outcome measures was done after starting the trial.

Statistical Analysis

Statistical analysis was performed using SPSS (version 20.0, IBM Corp. Armonk, NY, USA). The mean and standard deviation (SD) values for both groups for all outcome measures were calculated at baseline (week 0) and after the intervention (week 2). Next, the mean and SD values for the within-group differences (week 2-week 0) for both groups were calculated. Lastly, the two groups were compared by computing the mean between-group differences [experimental (week 2-week 0) – control (week 2-week 0)] for all outcome measures. The 95% confidence intervals (CI) for the mean between-group difference were calculated using an online calculator (available at: https://pedro.org.au/english/resources/confidence-interval-calculator/). Interpretation of clinical and statistical significance was done based on 95% CIs as described by Page P[25].

RESULTS

The flow of study participants as per the CONSORT statement for randomized trials of nonpharmacologic treatments[26] is depicted in Figure 1. A total of 135 patients, who had undergone TKA at our hospital in the past 2-6 months (before December 2016), were approached; out of these, 22 eligible participants agreed to participate and were randomized into two groups. Since compliance with the study and participant recruitment was low, the trial was stopped at 22 participants. Furthermore, all 22 participants did not complete the intervention, and a few dropped out. A total of 10 (5 in each group) participants, who completed the intervention (all six sessions) and were available for post-intervention assessment, were included in the analysis. The baseline demographic details of these participants are represented in Table 1, and the results of the clinical outcomes measured before and after the intervention are presented in Table 2. No adverse events were reported during the intervention.

The mean SLST (primary outcome for static balance) for both legs increased after treatment in both groups. However, the increase was more pronounced in the experimental group, with a mean between-group difference (MD) of 1.44 sec (95% CI: -6.93, 9.81) for the right limb and 4.62 sec (95% CI: -3.41, 12.65) for the left. Therefore, the improvement in SLST for both limbs was greater with the Nintendo Wii Fit training as compared to the conventional balance training.

For each of the four positions in which posturographic measurements were performed, the stability index and weight distribution index so obtained were summed up to calculate the mean differences. All positions demonstrated improvement with the interventions, which was greater in the experimental group compared to the control group (Table 2), except for standing on an unstable surface (foam pillow) with eyes closed (MD: -6.63; 95% CI: -21.22, 7.96).

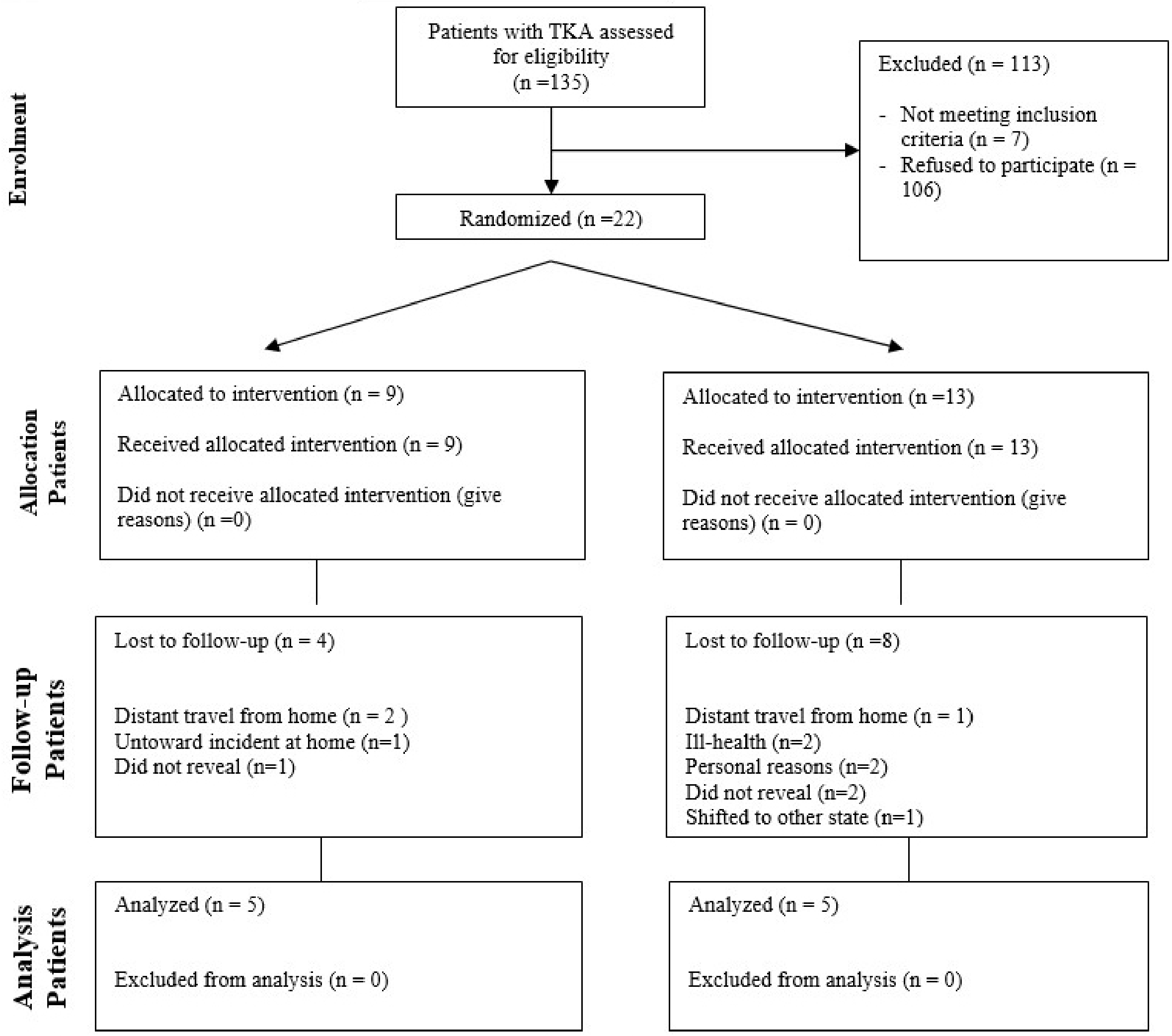

Figure 1. Modified CONSORT flow diagram for participant flow during the study.

The TUG test (primary outcome for dynamic balance) showed similar improvements in both groups (MD -0.08 sec; 95% CI: -2.09, 1.93), indicating that the effect of balance training on dynamic balance was similar with both interventions after 2 weeks. However, the mean within-group difference obtained with both interventions was lower than the minimal clinically important difference (MCID) for TUG, which is 3.4 seconds. The 2MWT demonstrated a mean difference of -1.52 m (95% CI: -7.46, 4.42).

Lastly, the mean difference in WOMAC score was 0.2 (95% CI: -8.91, 9.31), meaning that both interventions led to similar improvements in disability (reduction in the WOMAC score). Notably, both groups had an approximately 9-point improvement in the WOMAC score, which is close to the MCID = 10 for WOMAC in patients undergoing TKA.

None of the outcomes attained statistical significance as all CIs contained '0' values[25].

Table 1. Demographic characteristics of participants.

Characteristic	Experimental group (n=9)	Control group (n=13)
Age (yrs), median (IQR)	61 (17)	65 (16)
Gender, n (%) female	5 (55.6)	8 (61.5)
Body Mass Index (kg/m^2), median (IQR)	27.2 (2.1)	27.9 (2.6)

Table 2. Mean (SD) of groups and mean (95%CI) within and between-group differences.

	Groups				Differences within groups		Differences between groups	
Outcome	**Exp (n=5)**		**Con (n=5)**		**Week 2 minus Week 0**		**Week 2 minus Week 0 Exp minus Con**	
	Week 0	**Week 2**	**Week 0**	**Week 2**	**Exp**	**Con**		
SLSRT	13.1 (11.3)	16.56 (12.8)	7.88 (5.2)	9.9 (8.8)	3.46 (6.22)	2.02 (5.21)	1.44	(- 6.93, 9.81)
SLSLT	13.42 (11.1)	19.62 (12.7)	9.54 (6.3)	11.12 (5.6)	6.2 (7.33)	1.58 (2.62)	4.62	(-3.41, 12.65)
TUG	9.82 (2.9)	8.4 (1.9)	10.66 (1.7)	9.32 (1.4)	-1.42 (1.36)	-1.34 (1.39)	-0.08	(-2.09, 1.93)
NO	24.7 (5.1)	26.9 (7.3)	24.89 (8.5)	26.6 (7.6)	2.26 (6.71)	1.38 (2.98)	0.88	(-6.69, 8.45)
NC	27.16 (3.1)	29.3 (5.5)	27.89 (8.1)	28.28 (8.9)	2.19 (2.4)	0.39 (2.35)	1.8	(-1.66, 5.26)
PO	28 (5.1)	29.6 (4.9)	27.22 (7.9)	26.34 (8.5)	1.64 (1.15)	-0.88 (3.69)	2.52	(-1.47, 6.51)
PC	44.27 (17.1)	38.1 (11.6)	35.71 (9.7)	36.15 (11.2)	-6.19 (13.47)	0.44 (4.31)	-6.63	(-21.22, 7.96)
WOMAC	29.0 (11.1)	19.8 (8.4)	34.0 (14.5)	24.6 (8.9)	-9.2 (4.44)	-9.4 (7.64)	0.2	(-8.91, 9.31)
2MWT	129.4 (24.9)	135.64 (24.2)	107.2 (16.31)	114.96 (13.9)	6.24 (3.51)	7.76 (4.57)	-1.52	(-7.46, 4.42)

Exp= Experimental group, Con= Control group, SLSRT= Single Limb Stance time on Right Leg, SLSLT= Single Limb Stance Time on Left Leg, TUG= Timed Up and Go test, WOMAC= Western Ontario and McMaster Universities Osteoarthritis Index, 2MWT= Two-Minute Walk test, NO=Eyes Open Stability and Weight Distribution, NC= Eyes Closed Stability and Weight Distribution, PO= Eyes Open, on Pillow Stability and Weight Distribution, PC= Eyes Closed, on Pillow Stability and Weight Distribution.

DISCUSSION

The substantial results with virtual reality-based rehabilitation as seen in our study can be attributed to the continuous visual and auditory feedback provided throughout the session in the form of 'knowledge of performance' and 'knowledge of result'. This form of feedback complements the motor learning that occurs during the exercise session; this effect has been acknowledged in the existing reviews on the use of virtual reality training in patients with multiple sclerosis and stroke[27,28].

Our results revealed comparable improvements in the outcome measures for both groups; however, the effect on static balance was more evident in the experimental group than in the control group. While the results were not statistically significant, the participants who received the Nintendo Wii balance exercises showed increased SLST, along with notable improvements in static posturography. It is important to note that the experimental group performed all balance exercises while standing on the Nintendo balance board; this may have led to 'specificity in training' regarding the posture assumed during the balance exercises. In comparison, the control group intervention had no such consistency in the base of support used; some tasks in the control group balance exercises required widening the base of support.

The secondary outcome for measuring static balance control – the stability and weight distribution indices – revealed higher values after the intervention in the experimental group for the stable surface (both eyes open and eyes closed), and with eyes open on an unstable platform. Closing the eyes obscures the visual input necessary for balance control, while standing on a foam pillow challenges the somatosensory system for balance control, and a combination of both considerably enhances task complexity. Nintendo Wii balance exercises were successful in facilitating balance control during tasks that challenged the proprioceptive input; however, complex tasks, such as standing on an unstable surface with eyes closed, require more specific training, and since our exercises required the participant to focus on the visual stimulus from games, this training was not specific for balance control with eyes closed.

Nevertheless, our results concur with the findings of a recent systematic review of virtual reality interventions which reported changes in the static CoP (Centre of Pressure) following balance gaming exercises in musculoskeletal conditions[11]. Likewise, a study using Nintendo Wii gaming exercises in cerebral palsy patients also demonstrated improved static balance on static posturography in the eyes open position and not with eyes closed. This further corroborates our findings that while stimulating the proprioceptive mechanism, virtual reality game-based training greatly relies on visual input[29]. Additionally, Bragonzoni et al[30] in their review pointed out that statistically significant balance changes may not be evident within one year after TKA; this explains the lack of statistical significance in our results for static balance. A recent experimental study reported comparable changes in the static balance in TKA patients receiving conventional training or virtual reality gaming exercises; it is noteworthy that this intervention was conducted in the immediate postoperative period[13].

Our results are consistent with most of the findings in another study[31] where TKA patients were given balance training using a dynamometric platform. They also obtained improvement in the eyes-open position and not in the eyes-closed position on the Romberg test; the scores on the Berg balance and functional reach tests also improved, but TUG scores were similar for both groups. Notably, they had initiated balance exercises in the early phase of rehabilitation, and the control group did not receive any balance training besides the general exercises. Gauchard et al[32] delineated the mechanisms for balance control in the first few weeks after TKA; while the dynamic balance improved earlier than the static balance in their study, the mode of balance treatment used for the intervention was not detailed. Elucidating these mechanisms before and after a focused balance or virtual reality-based balance intervention will be worthwhile in understanding the effect of the phase of postoperative rehabilitation on the static and dynamic balance after TKA. A similar recommendation was made in a review[11] of virtual reality interventions about the effect of the timing of intervention in musculoskeletal rehabilitation.

In our study, dynamic balance, as measured using the TUG test, showed no differences between the control and experimental group. This is possibly due to the specificity of Nintendo Wii balance games for training on a stable balance board. A review of studies[33] that used Nintendo Wii games in the elderly reported that improvement in the TUG test was obtained with more exercise sessions. This indicates that we could have achieved improvements in dynamic balance as well, had we extended the number of sessions. In a systematic review[34] regarding the use of virtual reality for older adults, it was discussed that virtual reality-based balance training offers a static mode of exercising rather than the dynamic mode offered in conventional balance training regimes; authors also concluded that virtual reality-based balance training allowed better improvement in static balance than that in dynamic balance and gait speed in the elderly.

Lastly, the WOMAC score improved equally in both groups, indicating the equivalence of both modes of balance training to reduce disability in patients undergoing TKA. The gait speed in the 2-MWT was slightly better in the experimental group than in the control group. The gaming tasks involved multiple joint movements and weight shifting in various directions, which influence postural balance and gait speed by acting on the proprioceptors[30]. However, proprioception was not checked directly in our study which could validate this mechanism.

Limitations

The study had several limitations. The small sample size and the absence of follow-up due to time and logistic constraints limit the power of our results. Also, there was a lack of assessor blinding, i.e., the same physiotherapists performed the interventions as well as outcome measurement. Most patients had PCL-stabilized prosthetic designs, and only a few had PCL-retaining. However, this difference was unlikely to affect the interventions or outcomes since recent evidence[35] has suggested that the prosthetic design does not influence proprioception after TKA. As compared to the control group, all participants in the experimental group did not have bilateral TKA (few had unilateral surgery). We could not desist from this, since only a limited number of subjects agreed to participate in the study. Also, there is evidence[36] that the prosthetic and contralateral sides demonstrate comparable performances on SLST. Another study[37] described that weight transfer to each leg during a sit-to-stand task was symmetrical in patients with unilateral TKA, while asymmetry between the dominant and non-dominant legs might persist even after bilateral TKA.

We acknowledge that, while our protocol resulted in significant gains in static balance and gait speed, there is no consensus on the treatment parameters and best timing for balance and gait rehabilitation[34,38,39]. Our results provide preliminary evidence of the benefits of virtual reality-based intervention in improving balance after TKA, which were largely comparable to conventional training. A recent systematic review[40] pointed out that while virtual reality-based rehabilitation was comparable to conventional training, it may be more cost-effective to improve patient adherence and accessibility to postoperative rehabilitation. Therefore, we recommend further research with larger samples, greater duration of balance training, and follow-up to standardize the protocols for such treatment modalities and to achieve the desired effects on both static and dynamic balance.

CONCLUSIONS

Nintendo Wii balance exercises can be used as an adjunct or alternative to conventional balance exercises after TKA to improve static balance, especially with eyes opened owing to the specificity of training. However, changes in the dynamic balance and function may be substantiated by using a greater number of sessions or increased duration of Nintendo Wii training. There is a need to study the influence of knee proprioception and the timing of such interventions for recovery of both static and dynamic balance after TKA.

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Authors' Contributions:

M.K. and M.M. conceptualized the study design and methodology. M.K. performed data collection; B.N. provided clinical support and resources. M.K. and M.M. analyzed and interpreted the result. The initial draft of the manuscript was prepared by M.K.; all authors then reviewed and finalized the manuscript.

ORCID ID:

Manjyot Kaur: 0000-0001-6936-2825
Meena Makhija: 0000-0002-3395-2214

Conflict of Interest:

The authors declare that they have no conflicting interests to disclose.

Ethics Approval:

The study protocol was approved by the Institutional Ethics Committee, Indian Spinal Injuries Centre, New Delhi (ISIC/IIRS/RP/2015/091).

Informed Consent:

A written informed consent was obtained from all the participants before inclusion in the study.

Availability of Data and Materials:

The datasets related to the study can be obtained from the corresponding author upon reasonable request.

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