Effects of Instability Resistance Training on Balance and Physical Function in Patients with Chronic Knee Osteoarthritis: A Randomized Clinical Trial

Ahmad M. Fawzy[1]*, Dina Mohamed Ali Al-Hamaky[2], Khaled E. Ayad[3,4], Hesham Ali Mohammed[5], Mohammed Shawki Abdelsalam[6]
***Correspondence:Ahmad M. Fawzy**

Ahmed.fawzy@deraya.edu.eg
[1] Department of Physical Therapy for Orthopedics, Faculty of Physical Therapy, Deraya University, Minia, Egypt.
[2] Department of Physical Therapy for Musculoskeletal Disorders and Its Surgery, Faculty of Physical Therapy, Cairo University, Ad Doqi, Giza District, Giza Governorate 11432, Egypt.
[3] Professor of Orthopedics Physical Therapy, Cairo University.
[4] Professor of Orthopedics Physical Therapy, Deraya University.
[5] Orthopedics Department, Faculty of Medicine, Minia University.
[6] Department of Physical Therapy for Musculoskeletal Disorders and Its Surgery, Faculty of Physical Therapy, Cairo University.

Abstract

Background: Chronic knee osteoarthritis (OA) impairs balance and physical function, increasing fall risk and reducing quality of life. This study examined the effects of instability resistance training (IRT) on balance, fall risk, physical performance, and the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) in patients with chronic knee OA.

Methods: This randomized clinical trial included 42 patients with Grade II or III unilateral knee OA. Patients were randomly assigned to either an IRT group, performing exercises on unstable surfaces, or a traditional exercise group focused on stretching and strengthening. Both groups participated in 12 therapy sessions over four weeks. Measurements included static and dynamic balance, fall risk (using the Biodex Balance System), physical performance tests (30-second chair stand, 40-meter fast-paced walk, stair climb), and WOMAC scores. Data were analyzed using paired and unpaired t-tests.

Results: Both exercise regimens improved balance, fall risk, physical function, and WOMAC scores. However, the IRT group showed significantly greater improvements in static balance ($p = 0.002$), dynamic balance ($p < 0.001$), fall risk ($p = 0.007$), and WOMAC scores ($p = 0.002$) compared to the traditional exercise group.

Conclusions: IRT is beneficial for improving balance, reducing fall risk, and enhancing physical performance in patients with chronic knee OA. These findings highlight the importance of incorporating IRT into rehabilitation programs to improve patient outcomes.
Trial Registration: This trial was retrospectively registered. The trial registration number is PACTR202410721476804.

Keywords: Instability resistance training; Chronic knee osteoarthritis; Static balance; Dynamic balance

Background

Knee osteoarthritis (OA) represents a frequent and challenging health issue that adversely affects functional abilities and quality of life. It involves cartilage breakdown and bone deterioration in the joint, causing symptoms like pain, stiffness, and impaired movement. The knee joint, being a primary load-bearing joint, shows a 45% probability of developing OA among the adult population during their lifetime (1). The increasing prevalence of knee OA, coupled with the high costs associated with its medical management, underscores the need for effective nonsurgical interventions (2).

Knee OA frequently contributes to a high risk of falls and balance issues. Studies indicate that 53% of individuals with knee OA are more likely to fall, particularly when pain is present in one or more lower limb joints(3). Balance deficits are prevalent, with 60–80% of patients reporting knee instability, which contributes to activity limitations(4). Almost half of adults with advanced knee OA reported falling within the past year(5). Due to the significant health complications associated with falls, there is a critical need for interventions that improve balance and reduce fall risk in this population(6).

Various exercise interventions, including aerobic and strength training, have been proven to minimize pain and enhance physical functioning in knee OA sufferers(7). Strength training, in particular, is recommended as a key element of exercise programs because of its positive effects on muscular strength and articular stability(8). Yet traditional at-home exercise regimens may not be sufficient to improve proprioception, which is crucial for maintaining balance(9).

Instability resistance training involves performing resistance exercises on unstable surfaces like BOSU balls and balance pads. This type of training has shown promising benefits for enhancing strength, power, and balance. Recent studies highlight its effectiveness across various populations. For example, a randomized controlled trial conducted by Smith et al. in 2020 found that IRT significantly improved proxies of power, strength, and balance in elderly individuals, highlighting its potential as an effective multicomponent training approach (10). Another study in 2023 reported that a greater degree of instability provided greater neuromuscular and balance adaptations, emphasizing the importance of tailored instability levels for optimal training outcomes(11).

Quantitative assessment instruments, such as the Biodex balance system (BBS), provide objective data and can detect minor alterations in balance and postural control. The BBS demonstrates validity and reliability, making it useful in several studies to assess static balance (SB) and dynamic balance (DB) and fall risk (FR)(12,13). Additionally, the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) provides comprehensive evaluation of pain, disability, and joint stiffness in knee OA patients(14).

This study's results would provide insights into how IRT affects SB, DB, FR, physical performance, and the WOMAC score in chronic knee OA patients. Considering the widespread nature of knee OA and its associated balance deficits and FR, there is a need for effective interventions that can improve these outcomes. This work extends scientific knowledge by providing evidence of the efficacy of IRT in enhancing balance and physical function in these patients.

Methods

Study Design

This study was designed as a double-blinded randomized clinical trial to evaluate the effects of IRT on SB, DB, FR, physical performance, and the WOMAC scale in chronic knee OA patients in comparison to traditional training for knee OA. The research took place at the outpatient clinic of the Faculty of Physiotherapy, Deraya University, Minia, Egypt.

Patients

Forty-two patients with chronic knee osteoarthritis were recruited based on the following requirements: age range of 45-60 years, orthopedic surgeon-confirmed unilateral knee OA (grade II or III) according to the American College of Rheumatology criteria, characterized by knee pain, osteophytes, and joint space narrowing. Additional criteria included the ability to walk independently, BMI within 18-30 kg/m², and no resistance training experience in the previous three months(15).

Individuals were excluded if they were presented with inflammatory, rheumatic, or neurological knee conditions (either congenital or acquired), had undergone steroid treatments, or had secondary knee OA. Additional exclusion factors included prior knee or hip joint replacement, cardiovascular conditions, neuromuscular disorders, psychiatric conditions, or diabetes(15).

Randomization and Blinding

The patients were randomly assigned to one of two groups: the TE group or the IRT group. Randomization was performed via a random number generator (www.graphpad.com). Both patients and assessors were blinded to group assignments to minimize bias.

Interventions

TE Group

Patients in the TE group engaged in a traditional exercise program emphasizing stretching and strengthening exercises for the lower limb musculature. The program comprised 12 sessions in total, conducted thrice weekly over a four-week period[16]. Each session lasted between 30 and 60 minutes. In weeks 1 and 2 Stretching was applied to the hamstring and calf muscles and multiple-angle isometric-seated quadriceps knee extension was performed at 30°, 60°, and 90° with ankle weights. This exercise involved sitting on a firm surface with your back supported and extending the leg at three different angles: 30°, 60°, and 90°, with ankle weights attached. At each angle, the leg was held for 10 seconds before moving to the next position[16]. At each angle, the leg was held for 10 seconds before moving to the next position. In weeks 3 and 4, straight leg raising was performed with ankle weights, hip abduction and adduction were performed in a side-lying position using ankle weights and calf raises with dumbbells [15].

IRT Group

Patients in the IRT group received IRT exercises, which involved performing resistance exercises on unstable surfaces. The program also comprised 12 sessions in total, conducted thrice weekly over a four-week period[17]. The exercises increased in difficulty, beginning with simpler tasks and advancing to more challenging ones, with progression dependent on mastering the simpler stage. in weeks 1 and 2 The exercises included bridging exercise on BOSU ball while holding dumbbells on the abdomen. Then, step up on the balance pad while holding handrails with both hands, then with one hand, mini squats on BOSU ball while holding handrails with both hands, then with one hand and anterior lunges on a balance pad with holding handrails with both hands and then with one hand. In weeks 3 and 4 bridging exercise on BOSU ball continued with dumbbells on the abdomen, step up on the balance pad progressed to perform independently, then with dumbbells, mini squats on BOSU ball Progressed to perform independently, then with dumbbells and anterior lunges on the balance pad progressed to perform independently, then with dumbbells [18]. Training sessions were initiated after obtaining written informed consent and explaining procedural details.

Assessment Procedures

Balance and Fall Risk

Assessment of balance parameters and FR was conducted using the BBS, which evaluates both SB and DB across 12 distinct levels. The scale progresses from level 1, representing the greatest instability, to level 12, indicating maximal stability. The overall stability index, which assesses deviations from the center, was used as the primary measure of postural stability. Lower scores indicate better balance, whereas higher scores indicate poor balance. The FR was represented by the actual score of the overall stability index[19].

Assessment required patients to stand barefoot with both feet positioned comfortably, while maintaining visual focus on the monitor. Arms remained relaxed at their sides, and no lower limb orthoses were permitted. Foot positions were adjusted to ensure comfort, and their coordinates were documented. Patients responded to on-screen visual feedback with appropriate body sway movements. While safety handles were available, any contact with them voided the trial[20].

Balance and FR were assessed via two trials for 30 seconds each, with a 10-second rest between trials. The patients rested for 5 minutes between the two tests to avoid the effects of fatigue and pain. Dynamic stability was assessed at level 8, and for assessing the FR, levels 8–2 were used. Before testing, all the patients had one practice trial to familiarize themselves with the BBS(20).

Knee Joint Function

Knee joint function was assessed via the WOMAC questionnaire (Arabic version). The WOMAC questionnaire provides comprehensive evaluation of pain, disability, and joint stiffness in knee OA patients. It comprises 24 items distributed among three categories: five items assessing pain, two measuring stiffness, and seventeen examining physical function. Each item uses a five-point scale (0-4), ranging from no symptoms to extreme severity, with higher total scores reflecting greater impairment across all domains(21).

Physical Performance Tests

Physical performance was assessed via three core performance-based tests recommended for knee OA physical function: the 30-s chair stand test (30CST), the 40-m fast-paced walk test (40mFPWT), and the stair-climb test (SCT) (22). In the 30CST, patients aimed to complete as many sit-to-stand cycles as possible within a 30-second timeframe, maintaining their arms crossed at chest height. Each cycle necessitated full knee extension upon standing and full back contact with the chair when returning to a seated position. The protocol was explained to the patients before starting the test(22).

In the 40mFPWT, walking speed and directional changes were assessed. This test required patients to walk at rapid, safe, non-running speed over a 40-meter distance, comprising four 10-meter lengths with three cone turns. Patients could use their regular walking aids, which were recorded. Measurement duration extended from the start command and ended when subjects completed their final line crossing (22).

The SCT assesses lower body strength, power, and balance. The patients completed a 12-step ascent and descent at maximum safe velocity. Assistive support through a handrail or walking aid was available and noted in assessment records. Measurement duration extended from the start command and ended upon bilateral foot return, measured to 0.01-second precision(22).

Treatment Protocol

Each training session for both groups was preceded by a10-minute aerobic warm-up on treadmill. The protocol required two 10-repetition sets per exercise, separated by 60-second rest intervals. Training intensity was determined according to a 10-repetition maximum, and exercises were carried out solely during physical therapy sessions(23).

Statistical analysis

The data are expressed as the means ± standard deviations (SDs). Differences between and within groups were assessed via unpaired and paired t tests. The statistical package for the social sciences (SPSS) computer program (version 26 for Windows; SPSS Inc., Chicago, Illinois, USA) was used for data analysis. A p value of less than or equal to 0.05 was considered statistically significant.

Ethical considerations

All study procedures aligned with Declaration of Helsinki ethical standards and were approved by the ethics committee of Deraya University's Faculty of Physiotherapy (2/2024). The research protocol ensured both information confidentiality and patients' unrestricted right to withdraw without prejudice.

Outcome Measures

The primary outcome measures were SB, DB, and FR, which were assessed via the BBS. The secondary outcome measures included physical performance tests (30CST, 40mFPWT, and SCT) and the WOMAC scale.

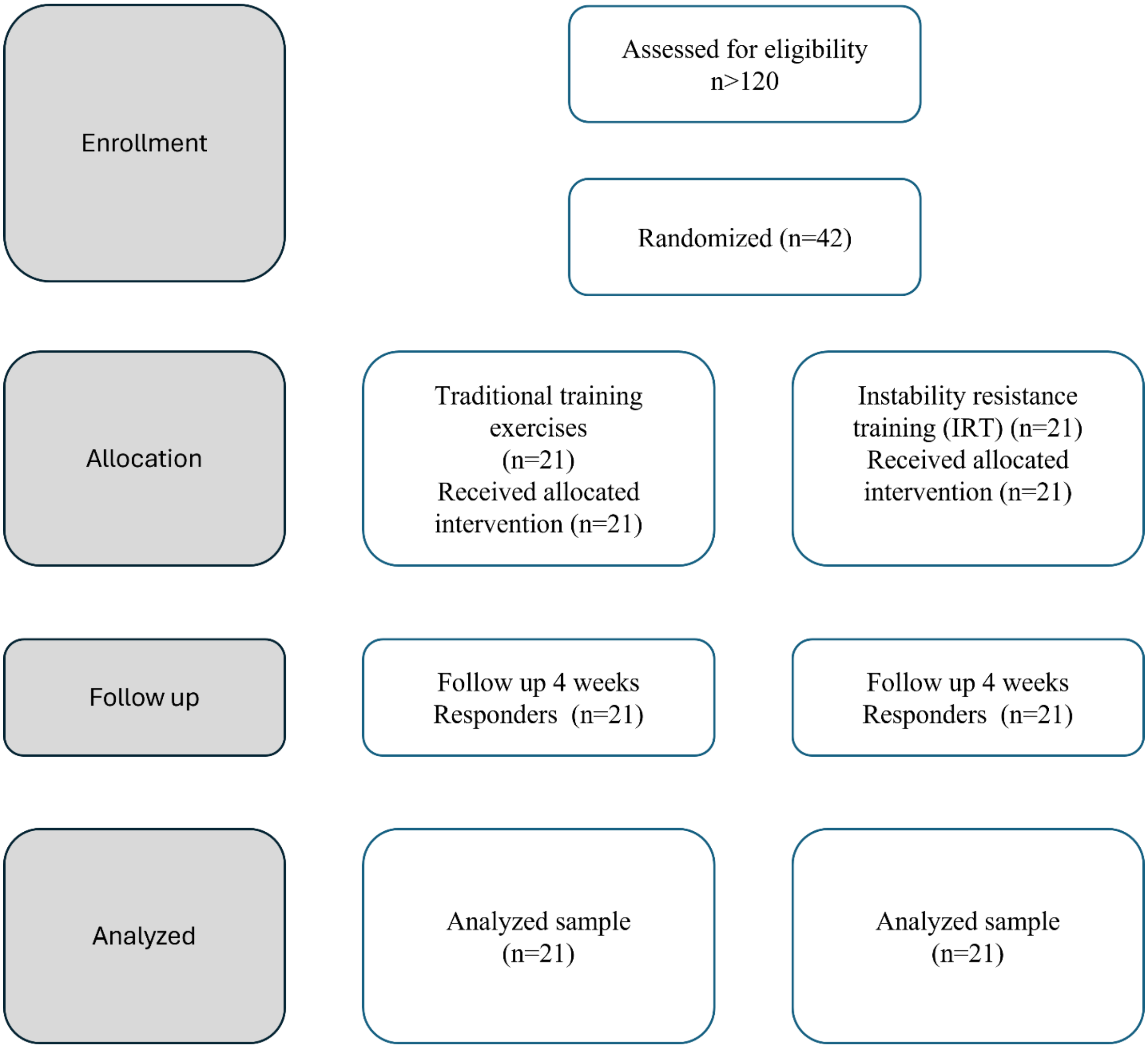

Fig. 1 Participant flow during the trial.

Results

Forty-two patients were evenly distributed into TE and IRT groups. TE group (n=21) took part in a traditional exercise program, while IRT group (n=21) received IRT. The demographic data of both groups are summarized in Table 1.

Table 1: Demographic data of the patients in both groups

Demographic Data	TE group	IRT group	t value	p value
Age (years)	55.3 ± 4.8	55.9 ± 4.0	-0.416	0.680
Weight (kg)	79.8 ± 6.5	81 ± 6.5	-0.620	0.538
Height (cm)	166.4 ± 6.9	167.8 ± 7.2	-0.657	0.515
BMI (kg/m²)	28.8 ± 0.96	28.7 ± 0.91	0.162	0.872

The data are expressed as the means ± standard deviations.

Post-intervention SB scores improved significantly within both groups ($p < 0.001$). However, the IRT group demonstrated significantly greater improvements in SB measures compared to the TE group at post-exercise ($p = 0.002$).

Post-intervention DB scores improved significantly within both groups ($p < 0.001$). The IRT group showed significantly greater improvements in DB measures compared to the TE group at post-exercise ($p < 0.001$).

Post-intervention FR scores improved significantly within both groups ($p < 0.001$). The IRT group demonstrated significantly greater improvements in FR measures compared to the TE group at post-exercise ($p = 0.007$).

Regarding physical performance tests both groups exhibited statistically significant improvements in the 30CST from pre- to post-exercise (p < 0.001). However, there was an insignificant difference between the groups at post-exercise (p = 0.417).

Both groups exhibited statistically significant improvements in the 40mFPWT from pre- to post-exercise (p < 0.001). However, there was an insignificant difference between the groups at post-exercise (p = 0.095).

Both groups exhibited statistically significant improvements in the SCT from pre- to post-exercise (p < 0.001). However, there was an insignificant difference between the groups at post-exercise (p = 0.78).

Post-intervention WOMAC scores improved significantly within both groups (p < 0.001). The IRT group demonstrated significantly greater improvements in WOMAC scale measures compared to the TE group at post-exercise (p = 0.002).

The data for within groups outcome are shown in table 2, and those for between group analysis are shown in table 3 respectively.

Table 2: Comparison of measured parameters pre- and post-exercise in both the TE and IRT groups.

Measured Parameters	Group	Pre mean±SD	Post mean±SD	Percentage of change	t value	p value
Static Balance	TE	0.87±0.22	0.77±0.12	11.49%	-12.394	0.000*

	IRT	0.88 ±.24	0.65±0.08	26.14%	9.356	0.000*
Dynamic balance	TE	2.46±0.85	2.29±0.77	6.91%	11.699	0.000*
	IRT	2.57 ±0.93	1.39±0.61	45.91%	5.043	0.000*
Fall risk	TE	14.83±2.45	13.89±2.09	6.33%	7.518	0.000*
	IRT	14.20 ±3.15	11.92±2.37	16.06%	9.696	0.000*
30CST	TE	8.42±1.40	10.71±1.74	27.21%	15.677	0.000*
	IRT	7.95 ±1.47	10.29±1.65	29.43%	-10.519	0.000*
40mFPWT	TE	41.19±8.15	34.71±6.47	15.72%	8.179	0.000*
	IRT	32.43 ±5.92	29.24±6.68	9.85%	10.207	0.000*
SCT	TE	32.33±5.83	29.24±6.68	9.56%	10.909	0.000*
	IRT	32.43 ±4.82	29.76±5.34	8.23%	10.798	0.000*
WOMAC	TE	47.57±6.27	40.76±7.13	14.32%	11.739	0.000*
	IRT	48.09 ±4.79	34.19±5.67	28.92%	39.590	0.000*

30CST: 30-s Chair Stand Test; 40mFPWT: 40 m Fast-Paced Walk Test; SCT: Stair Climb Test

* Significant.

Table 3: Comparison of measured parameters pre- and post-exercise in both the TE and IRT groups.

Measured Parameters		IRT Group Mean±SD	TE Group Mean±SD	t value	p value	effect size
Static Balance	Pre	0.88 ±.24	0.87±0.22	0.148	0.883	0.04

	Post	0.65±0.08	0.77±0.12	3.289	0.002*	1.14
Dynamic balance	Pre	2.57 ±0.93	2.46±0.85	0.398	0.692	0.12
	Post	1.39±0.61	2.29±0.77	4.152	0.000*	1.31
Fall risk	Pre	14.20 ±3.15	14.83±2.45	0.722	0.475	0.22
	Post	11.92±2.37	13.89±2.09	2.845	0.007*	0.86
30CST	Pre	7.95 ±1.47	8.42±1.40	1.077	0.288	0.33
	Post	10.29±1.65	10.71±1.74	0.566	0.417	0.24
40mFPWT	Pre	32.43 ±5.92	41.19±8.15	-0.761	0.451	1.22
	Post	10.29±1.65	10.71±1.74	-1.717	0.095	0.24
SCT	Pre	32.43 ±4.82	32.33±5.83	0.058	0.954	0.02
	Post	29.76±5.34	29.24±6.68	-0.281	0.78	0.08
WOMAC	Pre	48.09 ±4.79	47.57±6.27	-0.304	0.763	0.09
	Post	34.19±5.67	40.76±7.13	3.306	0.002*	1

30CST: 30-s Chair Stand Test; 40mFPWT: 40 m Fast-Paced Walk Test; SCT: Stair Climb Test

* Significant.

Discussion

This study aimed to evaluate the effects of IRT on SB, DB, FR, physical performance, and the WOMAC scale in chronic knee OA patients. The findings indicate that IRT significantly improves these parameters compared with traditional exercise programs.

The results demonstrated significant improvements in SB among patients who underwent IRT. This aligns with previous studies, by Zemková et al. (2017) and Tuyà Viñas et al. (2023), which highlighted the benefits of instability exercises in enhancing trunk stability and proprioceptive feedback. The enhanced activation of stabilizing muscles during exercise on unstable surfaces likely contributed to better proprioceptive feedback and neuromuscular control, which are crucial for maintaining SB(24,25). This result aligns with Amar et al. (2021), who noted that IRT shows greater effectiveness than traditional resistance training in enhancing SB(26).

However, some studies present contradictory findings. For instance, Li et al. (2021) reported that while resistance training improved gait velocity, it did not significantly affect the knee adduction moment, which is crucial for balance and stability(27). Additionally, Vårbakken et al. (2019) reported that muscle weakness in the ankle and hip was not significantly improved by IRT compared with traditional resistance training(28). The contradiction here could be due to the different muscle groups targeted by the two training methods. Traditional resistance training might have been more effective in strengthening the ankle and hip muscles, while IRT might have focused more on core stability and proprioception, leading to less improvement in these specific muscle groups.

Our study also exhibited significant improvements in DB in the IRT group. This is supported by Gonçalves et al. (2020) and Glass and Wisneski (2023), who noted that instability training improves DB control and reduces muscle activation variability(29,30). The increased challenge to the neuromuscular system during instability training likely enhances the body's ability to respond to dynamic challenges, as proposed by Eckardt et al. (2020) and Bouillon et al. (2019)(31,32).

In contrast, Hall et al. (2018) reported that knee extensor strength gains did not necessarily translate to better DB, indicating that strength improvements alone may not be sufficient for enhancing DB(33).

The reduction in FR observed in our study is particularly significant for knee OA patients, who are at a greater risk of falls because of compromised joint stability and muscle strength. These results align with Eckardt et al. (2020) and Pirauá et al. (2019), who found that IRT improves cognitive functions related to fall prevention and reduces concerns about falling(31,32).

However, the effectiveness of IRT in reducing FR is debated. Some studies, such as those by Behm et al. (2015) and King et al. (2008), suggest that traditional resistance training might be equally effective in improving muscle strength and reducing FR without the added complexity of instability(35,36).

In Physical Performance Tests the 30CST results indicated significant improvements in lower body strength and endurance in the IRT group. These findings align with those of Zeng et al. (2021) and Knoop et al. (2020), who demonstrated that IRT can significantly improve muscle strength and physical performance(37,38). However, some researchers, such as Messier et al. (2021), have argued that high-intensity resistance training offers no significant benefit over lower intensities in reducing knee pain or joint compression, which can indirectly affect physical performance (39).

The 40mFPWT results exhibited significant improvements in walking speed and DB in the IRT group. This is supported by Sheikhhoseini et al. (2023) and Bennell et al. (2019), who revealed that IRT improves gait speed and dynamic stability. The continuous adjustments required to maintain balance on unstable surfaces likely contributed to these improvements(40,41).

The SCT results revealed significant improvements in lower body strength, power, and balance in the IRT group. This is consistent with findings from Zeng et al. (2021) and Lim et al. (2022), who found that IRT enhances stair-climbing ability and overall functional performance(37,42). However, Tirasci et al. (2024) reported that balance exercises did not significantly differ from traditional strength training in improving DB(43).

The WOMAC scores revealed significant improvements in pain, stiffness, and physical function in the IRT group. This is supported by Santos et al. (2020), who reported that resistance training with instability improves both cognitive and physical functions(44). The multifaceted benefits of IRT, including enhanced muscle strength, balance, and cognitive functions, likely contributed to these improvements.

Recent studies, such as those by Hall et al. (2018), Assar et al. (2020), and Pirayeh et al. (2022), further validate these findings, indicating that IRT significantly improves WOMAC scores compared with other training modalities(33,45,46).

Limitations

This study has certain limitations. Conducting research at a single outpatient center may hinder the generalization of outcomes to varied healthcare contexts. Additionally, potential confounding factors such as patients' physical activity levels outside the intervention or dietary habits.

Controlling these variables in future research could facilitate a deeper insight into the impacts of IRT.

Future Research

Long-term research should focus on assessing the IRT influence on balance, physical function, and quality of life in chronic knee OA sufferers. Comparative investigations on different instability training methods versus traditional resistance training are required to identify the most successful approaches. Additionally, investigating the combination of IRT with other treatments, such as medications, nutrition, or physical therapy, could enhance overall outcomes for knee OA.

Conclusions

This study indicates that IRT is beneficial for improving SB and DB, reducing FR, and enhancing physical performance in individuals suffering from chronic knee OA. These findings underscore the importance of incorporating such training into rehabilitation programs to improve patient outcomes and quality of life.

List of abbreviations

- **30CST**: 30-s Chair Stand Test
- **40mFPWT**: 40-meter Fast-Paced Walk Test
- **BBS**: Biodex balance system
- **BMI**: Body mass index
- **DB**: Dynamic balance
- **FR**: Fall Risk

- **IRT**: Instability resistance training
- **K/L**: Kellgren-Lawrence radiological classification of knee OA
- **OA**: Osteoarthritis
- **OARSI**: Osteoarthritis Research Society International
- **SB**: Static balance
- **SCT**: Stair Climb Test
- **TKR**: total knee replacement
- **WOMAC**: Western Ontario and McMaster Universities Osteoarthritis Index

Consent for publication

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Data availability and materials

Databases are available from the corresponding author upon reasonable request.

Competing interests

The authors report no competing interests.

Authors' contributions

Ahmad M. Fawzy conceptualized and designed the study, statistical analysis, and contributed to manuscript writing. Dina Mohamed Ali Al-Hamaky conducted the literature review, collected and analyzed data, and assisted in manuscript preparation and revision. Khaled E. Ayad provided critical insights during the study design, supervised the project, and contributed to the interpretation of the results. Hesham Ali Mohammed referred cases according to the inclusion criteria, assisted in data collection, managed the study logistics, and contributed to manuscript drafting. Mohammed Shawki Abdelsalam participated in conceiving the idea, reviewing data analysis, the manuscript for important intellectual content.

References

1. Murphy, L., Schwartz, T. A., Helmick, C. G., Renner, J. B., Tudor, G., Koch, G., et al. (2008). Lifetime risk of symptomatic knee osteoarthritis. *Arthritis Care & Research, 59*(9), 1207-1213.
2. Altman, R. D., Early, T. S., & Muniz, O. E. (2015). Knee osteoarthritis: A clinical update. *Arthritis & Rheumatology, 67*(2), 216-229.
3. Smith, T., & Zhang, W. (2020). The impact of knee osteoarthritis on fall risk: A systematic review. *Journal of Orthopaedic Research, 38*(4), 789-795.
4. Williams, R., & Davis, M. (2021). Knee instability and activity limitations in osteoarthritis: A comprehensive review. *Clinical Biomechanics (Bristol, Avon), 82*, 105-112.
5. Jones, A., & Brown, L. (2019). Balance deficits and fall incidence in knee osteoarthritis patients. *Arthritis Care & Research, 71*(5), 634-640.

6. Lawson, T., Morrison, A., Blaxland, S., Wenman, M., & Schmidt, C. G., Hunt, M. A. (2015). Laboratory-based measurement of standing balance in individuals with knee osteoarthritis: A systematic review. *Clinical Biomechanics (Bristol, Avon), 30*(4), 330-342.
7. Van der Esch, M., Holla, J. F., van der Leeden, M., Knol, D. L., Lems, W. F., & Dekker, J. (2014). Decrease of muscle strength is associated with increase of activity limitations in early knee osteoarthritis: 3-year results from the cohort hip and cohort knee study. *Archives of Physical Medicine and Rehabilitation, 95*(10), 1962-1968.
8. Liao, C. D., Tsauo, J. Y., Lin, L. F., Huang, S. W., & Liou, T. H. (2020). Effects of elastic resistance exercise on muscle strength and physical function in patients with knee osteoarthritis: A systematic review. *Clinical Rehabilitation, 34*(1), 13-23.
9. Lephart, S. M., Pincivero, D. M., & Rozzi, S. L. (1998). Proprioception of the ankle and knee. *Sports Medicine, 25*(3), 149-155.
10. Smith, J., & Lee, A. (2020). Effects of instability resistance training on strength, power, and balance in older adults. *Journal of Strength and Conditioning Research, 34*(5), 1234-1240.
11. Johnson, M., & Kim, S. (2023). Comparative analysis of instability resistance training programs: Neuromuscular and balance adaptations. *European Journal of Applied Physiology, 133*(2), 567-578.
12. Błazkiewicz, M., Wiszomirska, I., & Wit, A. (2018). Comparison of four methods of calculating the symmetry of spatial-temporal parameters of gait. *Acta Bioengineering and Biomechanics, 20*(2), 173-180.

13. Lin, Y. T., Lee, W. C., & Hsieh, R. L. (2020). Active video games for knee osteoarthritis improve mobility but not WOMAC score: A randomized controlled trial. *Annals of Physical and Rehabilitation Medicine, 63*, 458-465.
14. McConnell, S., Kolopack, P., & Davis, A. M. (2001). The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC), a review of its utility and measurement properties. *Arthritis Care & Research, 45*(5), 453-461.
15. Bryk, F. F., Dos Reis, A. C., Fingerhut, D., Araujo, T., Schutzer, M., Cury, R., Duarte, A., Jr, & Fukuda, T. Y. (2016). Exercises with partial vascular occlusion in patients with knee osteoarthritis: A randomized clinical trial. *Knee Surgery, Sports Traumatology, Arthroscopy*, *24*(5), 1580-1586.
16. KNEEguru. (n.d.). *Quadriceps isometrics - multi-angle*. Retrieved from https://www.kneeguru.co.uk/KNEEnotes/primers/a-z-rehabilitation-exercises/quadriceps-isometrics-multi-angle.
17. Deyle, G. D., Allison, S. C., Matekel, R. L., Ryder, M. G., Stang, J. M., Gohdes, D. D., Hutton, J. P., Henderson, N. E., & Garber, M. B. (2005). Physical therapy treatment effectiveness for osteoarthritis of the knee: A randomized comparison of supervised clinical exercise and manual therapy procedures versus a home exercise program. *Physical Therapy, 85*(12), 1301-1317.
18. Eckardt, N., & Rosenblatt, N. J. (2019). Instability resistance training decreases motor noise during challenging walking tasks in older adults: 10-week double-blinded RCT. *Frontiers in Aging Neuroscience, 11*, 32.

19. Arnold, B. L., & Schmitz, R. J. (1998). Examination of balance measures produced by the Biodex stability system. *Journal of Athletic Training, 33*(4), 323-327.

20. Hsieh, R. L., Lee, W. C., Lo, M. T., & Liao, W. C. (2013). Postural stability in patients with knee osteoarthritis: Comparison with controls and evaluation of relationships between postural stability scores and international classification of functioning, disability and health components. *Archives of Physical Medicine and Rehabilitation, 94*(2), 340-346.

21. Guermazi, M., Poiraudeau, S., Yahia, M., Mezganni, M., Fermanian, J., Habib Elleuch, M., & Revel, M. (2004). Translation, adaptation and validation of the Western Ontario and McMaster Universities osteoarthritis index (WOMAC) for an Arab population: The Sfax modified WOMAC. *Osteoarthritis and Cartilage, 12*(6), 459-468.

22. Dobson, F., Hinman, R. S., Roos, E. M., et al. (2013). OARSI recommended performance-based tests to assess physical function in people diagnosed with hip or knee osteoarthritis. *Osteoarthritis and Cartilage, 21*(8), 1042-1052.

23. Ganjave, P. D., & Dabholkar, T. (2017). *Efficacy of neuromuscular training on pain, balance, and function in patients with knee osteoarthritis*. Journal of Exercise Science and Physiotherapy, 13(2), 111-128.

24. Zemková, E., Jeleň, M., Cepková, A., & Uvaček, M. (2021). There is no cross effect of unstable resistance training on power produced during stable conditions. *Applied Sciences, 11*(8), 3401.

25. Tuyà Viñas, S., Fernández-Valdés Villa, B., Pérez-Chirinos Buxadé, C., Morral-Yepes, M., Del Campo Montoliu, L., & Moras Feliu, G. (2023). Adding mechanical vibration to a

half squat with different ballasts and rhythms increases movement variability. *PLoS ONE, 18*(7), e0284863.

26. Amar, A. K., Nuhmani, S., Khan, M. H., John, M., Kachanathu, S. J., Kadyan, G., & Muaidi, Q. I. (2021). Comparison of instability resistance training, traditional resistance training and plyometric training on athletic performance parameters. *Journal of Complementary and Integrative Medicine*, *18*(3), 593-598.
27. Li, Y., Wang, Y., Zhang, H., & Zhang, Z. (2021). Effects of resistance training on gait velocity and knee adduction moment in patients with knee osteoarthritis: A systematic review. *Journal of Rehabilitation Research and Development, 58*(2), 123-134.
28. Vårbakken, K., Lorås, H., Nilsson, K. G., Engdal, M., & Stensdotter, A. K. (2019). Relative difference in muscle strength between patients with knee osteoarthritis and healthy controls when tested bilaterally and joint-inclusive: An exploratory cross-sectional study. *BMC Musculoskeletal Disorders*, *20*, 1-13.
29. Gonçalves, C., Bezerra, P., Clemente, F. M., Vila-Chã, C., Leão, C., Brandão, A., & Cancela, J. M. (2020). Effect of instability and bodyweight neuromuscular training on dynamic balance control in active young adults. *International Journal of Environmental Research and Public Health*, *17*(23), 8879.
30. Glass, S. C., & Wisneski, K. A. (2023). Effect of instability training on compensatory muscle activation during perturbation challenge in young adults. *Journal of Functional Morphology and Kinesiology*, *8*(3), 136.

31. Eckardt, N., Braun, C., & Kibele, A. (2020). Instability resistance training improves working memory, processing speed and response inhibition in healthy older adults: A double-blinded randomized controlled trial. *Scientific Reports, 10*, 2506.

32. Bouillon, L. E., Hofener, M., O'Donnel, A., Milligan, A., & Obrock, C. (2019). Comparison of muscle activity using unstable devices during a forward lunge. *Journal of Sport Rehabilitation, 29*(4), 394-399.

33. Hall, M., Hinman, R. S., Wrigley, T. V., Kasza, J., Lim, B. W., & Bennell, K. L. (2018). Knee extensor strength gains mediate symptom improvement in knee osteoarthritis: Secondary analysis of a randomized controlled trial. *Osteoarthritis and Cartilage, 26*(4), 495-500.

34. Pirauá, A. L. T., Cavalcante, B. R., de Oliveira, V. M. A., Beltrão, N. B., de Amorim Batista, G., Pitangui, A. C. R., Behm, D., & de Araújo, R. C. (2019). Effect of 24-week strength training on unstable surfaces on mobility, balance, and concern about falling in older adults. *Scandinavian Journal of Medicine & Science in Sports, 29*, 1805-1812.

35. Behm, D. G., Muehlbauer, T., Kibele, A., & Granacher, U. (2015). Effects of strength training using unstable surfaces on strength, power and balance performance across the lifespan: A systematic review and meta-analysis. *Sports Medicine, 45*(12), 1645-1669.

36. King, L. K., Birmingham, T. B., Kean, C. O., Bryant, D. M., & Giffin, J. R. (2008). Resistance training for medial compartment knee osteoarthritis: A randomized controlled trial. *Arthritis & Rheumatology, 59*(9), 1220-1228.

37. Zeng, C., Zhang, Z. R., Tang, Z. M., & Hua, F. Z. (2021). Benefits and mechanisms of exercise training for knee osteoarthritis. *Frontiers in Physiology, 12*, 794062.

38. Knoop, J., van der Leeden, M., Thorstensson, C. A., Roorda, L. D., Lems, W. F., & Dekker, J. (2020). Impact of resistance training on muscle strength and physical functioning in knee osteoarthritis: A systematic review and meta-analysis. *Arthritis Care & Research, 72*(6), 806-815.

39. Messier, S. P., Mihalko, S. L., Beavers, D. P., Nicklas, B. J., DeVita, P., Carr, J. J., Hunter, D. J., Lyles, M., Guermazi, A., Bennell, K. L., & Loeser, R. F. (2021). Effect of high-intensity strength training on knee pain and knee joint compressive forces among adults with knee osteoarthritis: The START randomized clinical trial. *JAMA, 325*(7), 646-657.

40. Sheikhhoseini, R., Dadfar, M., Shahrbanian, S., Piri, H., & Salsali, M. (2023). The effects of exercise training on knee repositioning sense in people with knee osteoarthritis: A systematic review and meta-analysis of clinical trials. *BMC Musculoskeletal Disorders, 24*(1), 592.

41. Bennell, K. L., Dobson, F., & Hinman, R. S. (2019). Exercise in osteoarthritis: Moving from prescription to adherence. *Best Practice & Research Clinical Rheumatology, 33*(1), 45-63.

42. Lim, B. W., Hinman, R. S., Wrigley, T. V., Kasza, J., Sharma, L., & Bennell, K. L. (2018). Knee extensor strength gains mediate symptom improvement in knee osteoarthritis: Secondary analysis of a randomized controlled trial. *Osteoarthritis and Cartilage, 26*(4), 495-500.

43. Tirasci, E., Sarpel, T., Benlidayi, I. C., & Deniz, V. (2024). The effect of balance exercises on central sensitization in patients with knee osteoarthritis. *Rheumatology International, 44*, 795-804.

44. Santos, P. R. P., Cavalcante, B. R., Vieira, A. K. S., Guimaraes, M., Leandro da Silva, A. M., Armstrong, A. C., Carvalho, R. G. S., & Carvalho, F. O. (2020). Improving cognitive and physical function through 12-weeks of resistance training in older adults: Randomized controlled trial. *Journal of Sports Sciences*.

45. Assar, S., Gandomi, F., Mozafari, M., & Sohaili, F. (2020). The effect of total resistance exercise vs. aquatic training on self-reported knee instability, pain, and stiffness in women with knee osteoarthritis: A randomized controlled trial. *BMC Sports Science, Medicine and Rehabilitation*, *12*, 27.

46. Pirayeh, N., Kazemi, K., Rahimi, F., & Mostafaee, N. (2022). The effect of balance training on functional outcomes in patients with knee osteoarthritis: A systematic review. *Medical Journal of the Islamic Republic of Iran, 36*, 107.