Antigravity treadmill training after knee surgery: A scoping review

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Abstract

Antigravity treadmill training provides a viable option for physiotherapeutic care after knee surgery, especially for conditions that do not allow full weight bearing during the early phase post-intervention. This overview of the current state of knowledge identifies gaps and highlights areas where more research on antigravity treadmill training after knee surgery is needed. This review aimed to analyze and summarize the available evidence concerning the effects of antigravity treadmill training on patients after knee joint surgical procedures, including anterior cruciate ligament reconstruction (ACLR) and total (TKA) and unicompartmental knee arthroplasty (UKA). Several databases were searched for relevant material, including PubMed, Epistemonikos, the Cochrane Library, the Web of Science, and Google Scholar. Seven studies investigating antigravity treadmill training after various procedures were included, including ACLR and TKA. The studies were summarized, and the quality of evidence was evaluated using the appropriate tools. The evidence yielded by these studies suggests that antigravity treadmill training might be useful after knee surgery. However, the superiority over traditional physiotherapeutic measures has yet to be established. Therefore, future high-quality randomized controlled trials (RCTs) are needed to investigate the effect of antigravity treadmill training due to the low quality of available evidence. Also, a cost-effectiveness analysis is required to determine whether the investigated intervention fits the purpose.

Key words: knee arthroplasty, knee, total knee replacement, knee injuries, anterior cruciate ligament reconstruction

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Background

Rehabilitation interventions targeting the improvement in outcomes after surgical treatment on the knee primarily depend on the reason and type of procedure performed.[1–4] While early and intensive postoperative rehabilitation is allowed and even required for some conditions, weight-bearing restrictions are recommended for others.[5,6] However, partial weight-bearing primarily decreases muscular stimulation and, in the long run, a loss of muscle strength.[7]

It is commonly agreed upon that quadriceps and hamstring muscle strengthening should be a central target of therapy following knee surgery.[8,9] Mainly because of the restricted postoperative activity, the strength of the knee extensor muscles decreases significantly, impairing knee joint stability.[10–12] Also, knee flexor weakness is observed, which in anterior cruciate ligament reconstructed knees is linked to tendon harvesting for graft preparation purposes.[13–15] Subsequently, patients experience increased difficulty in performing daily activities, especially those requiring a more significant level of exertion with regard to the lower extremities.[16–18] This may result in a spiral where pain leads to inactivity, further exacerbating pain.[19] Moreover, a disturbed gait pattern has been shown to occur in patients undergoing knee surgery, such as total knee arthroplasty (TKA) and anterior cruciate ligament reconstruction (ACLR).[20,21]

Gait or run training using an antigravity treadmill is one method used during early rehabilitation following surgery. It aims to improve the functional outcome by early mobilization of patients despite weight-bearing restrictions. An antigravity treadmill, by either supporting the patient with ropes above a treadmill or using differential air pressures, enables patients to walk or run at a reduced body weight (BW) while maintaining a normal gait pattern.[22] Run training using an antigravity treadmill can also enhance sports performance.[23]

Antigravity treadmill training has been demonstrated to positively affect knee muscle strength in healthy individuals and those with different disorders.[23–25] In the field of orthopedics and sports medicine, antigravity treadmill training has been used in patients with hip replacements, ankle fractures, Achilles tendon rupture repairs, osteoarthritis, muscular dystrophy, and diabetic polyneuropathy.[26–33] However, there exists a need for evidence-based practices to consolidate, analyze and interpret the available literature and provide a foundation for future research and clinical decision-making in the context of antigravity treadmill training usage after knee surgery. The field of antigravity treadmill training after knee surgery is relatively new and rapidly evolving; therefore, a scoping review would be beneficial for providing an overview of the current state of knowledge, identifying gaps and highlighting areas where more research is needed.

Objectives

This systematic review aimed to analyze and summarize the available evidence concerning the usage of antigravity treadmill training in patients after knee joint surgical procedures, including ACLR and both TKA and unicompartmental knee arthroplasty (UKA). The evidence found was then ranked according to its power.

Materials and methods

Two reviewers independently searched multiple databases using the search strategy detailed in Table 1. The search was conducted using the Boolean operators of each column indexed with an "AND" in between. Between elements of the same column, an "OR" was introduced. The search strategy thus implicated the use of combinations of 1 search element per column with a search element for each of the other columns.

Table 1. The search strategy used for the present review purposes

Population	Intervention		Outcome
Knee* Ligament* TKR TKA ACL* LCL* MCL*	Anti*grav* Antigrav* Levitation* Zero-g Positive pressure Supported Suspended	Treadmill Running machine Walking machine	Pain Function Quality of life Adverse events Death Synovi* Cartilag* Osteo* *arthritis *nerv* Muscl* Blood Vascul* Imaging Radiography MRI CT Ultrasound

The asterisk (*) is used as a wildcard character in the search strategy. It represents any group of characters, allowing for the inclusion of all possible endings or variations of the term.

The searched databases included PubMed, Epistemonikos, the Cochrane Library, and the Web of Science. Additionally, Google Scholar was searched for relevant material. The search strategy included all articles published between 1980 and 2023 in English, German, Polish, French, and Arabic. The protocol for this review was not pre-registered, mainly because of its scoping character.

The obtained articles were then screened for eligibility. Articles eligible for inclusion included any original publication reporting clinically measured data. Title and abstract screening was performed independently by 2 researchers (H.T.H. and M.K.). Any conflicting views were resolved by a third party (R.P. and A.K.). Inclusion and exclusion criteria are detailed in Table 2. Additionally,

Table 2. Inclusion and exclusion criteria of the articles for the present scoping review purposes

Inclusion criteria	Exclusion criteria
• Original articles • Articles reporting findings of a clinical study, including: - Systematic reviews - Randomized controlled trials (RCTs) - Non-randomized controlled trials - Cross-sectional studies - Longitudinal studies - Cohort studies - Case-control studies - Case series - Case reports • Articles having a relevant PICO statement, including: - Population: Patients in the postoperative phase of any surgical procedures on the knee, including anterior cruciate ligament (ACL) repair, total knee arthroplasty, and unicompartmental knee arthroplasty - Intervention: Antigravity treadmill training in its various forms (rope suspension or positive pressure chambers) - Control: If present, any control, including conventional rehabilitative approaches or no treatment - Outcome: Any outcome, including patient-related outcome measures (PROMS), performance-based measures (PBMs), biomechanical or trigonometric as well as histopathologic or any other reported outcome.	• Non-original works: Studies reporting the work of a third research party. • Articles dealing with non-clinical data: - Expert and other types of opinions - Cost-effectiveness analyses - Literature reviews and any other type of reviews, excluding systematic reviews of randomized controlled trials - Editorials and any form of letters • Posters and conference papers, except for those reporting findings of clinical studies where no published article can be found • Any studies reporting data on non-human subjects, including animal and in vitro studies

the references of the included articles were screened for relevant material to ensure the comprehensiveness of the review. If the full text of the relevant article was not found, the authors attempted to contact the corresponding author to access it.

Relevant information extracted from the articles included the study design and level of evidence as well as the target population, the administered intervention, the comparators (control), the reported outcomes, the clinical and scientific recommendations, and the limitations of the study at hand. Full-text screening and subsequent data extraction were performed independently by 2 authors (H.T.H. and M.K.). Conflicts and discrepancies regarding the relevance of information were resolved by a third, more experienced party (R.P. and A.K.). Also, if necessary, additional notes were made during the data extraction. An appraisal using relevant Joanna Briggs Institute (JBI) instruments was conducted independently by the 2 previously mentioned reviewers. R.P. managed conflicts to assess the methodological quality of the studies.[34,35]

Results

The search yielded 8 articles that were deemed relevant to this review. However, the full text of one of them, a systematic review, was not found. Therefore, a request to provide the missing information was sent to the corresponding author indicated in the article. However, because no response was obtained, the systematic review was excluded from further analysis.

Finally, 7 articles were included in this scoping review: 1 randomized controlled trial (RCT),[36] 2 cohort studies,[37,38] 2 case series,[39,40] and 2 case reports.[41,42] A representation of the design and level of evidence of the included studies is presented in Table 3. Comparative analysis concerning the studied population, intervention and controls in the studies included in the present scoping review are shown in Table 4. Table 5 presents a comparative analysis of the main findings regarding the outcome, recommendations, limitations, and critical notes.

Table 3. A representation of the design and level of evidence of the included studies

Included study	Study design	Level of evidence
DeJong et al.[36]	randomized clinical trial	2
Bugbee et al.[37]*	cohort study	3
Sueyoshi and Emoto[38]	cohort study	3
Eastlack et al.[39]	case series	5
Huang et al.[40]	case series	5
Greig et al.[41]	case report	5
Hambly et al.[42]**	case report	5

*The study was a pilot and feasibility study; therefore, it was not assigned as a randomized clinical trial; **The report on the case was presented in 2 formats: a conference poster and a published article.

The results of the critical appraisal of the included studies using JBI critical appraisal checklists are presented in Fig. 1.

Discussion

Reviews are crucial in guiding and supporting the rationale for new clinical studies. They achieve this by identifying and addressing research gaps, thus minimizing the risk of redundant or wasteful research. The significance of different reviews in the context of improving evaluation standards for clinical studies in physiotherapy, orthopedics and sports medicine cannot be overstated.[43] This present review aims to analyze, summarize and critically appraise the available evidence on antigravity treadmill training in patients who have undergone knee surgery. The objective was achieved by searching multiple databases for

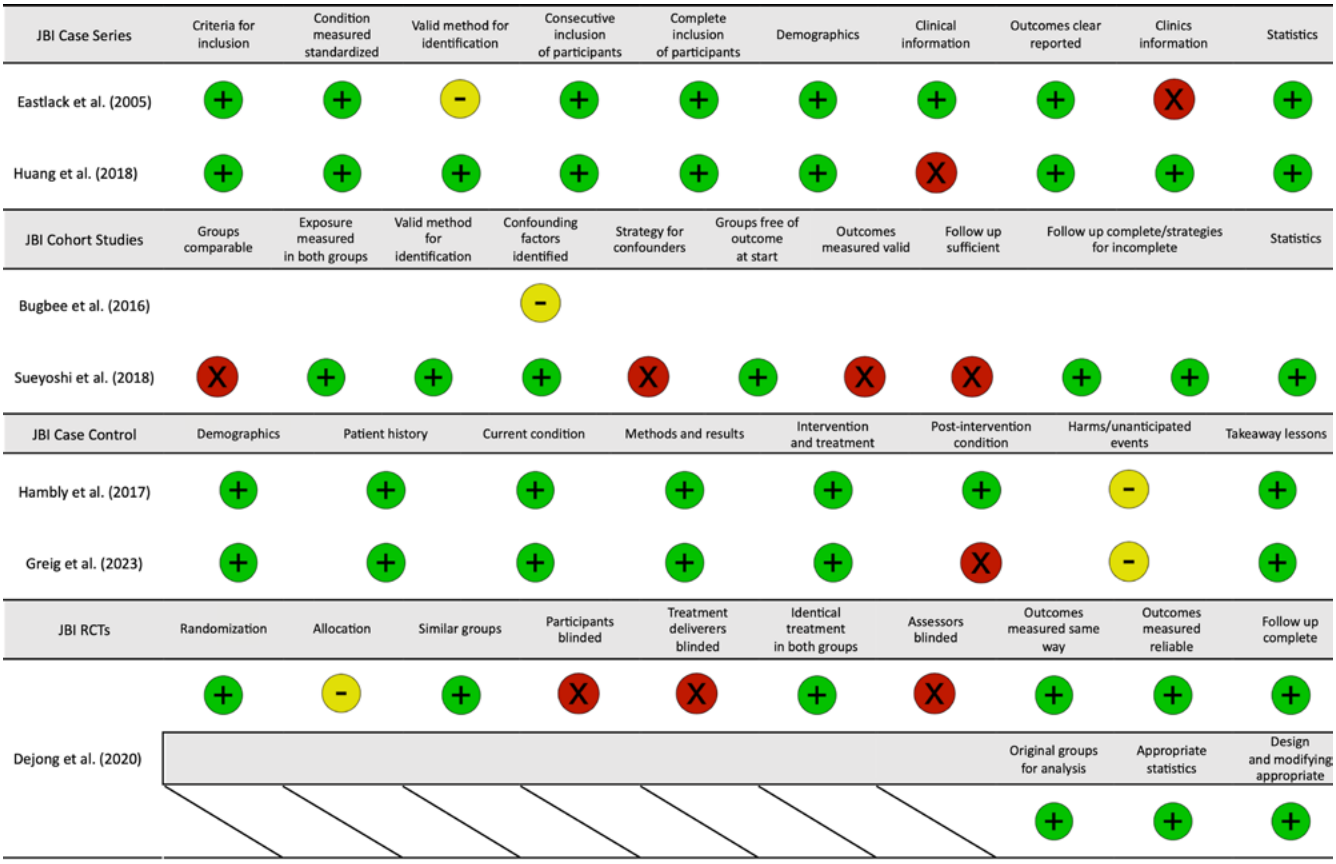

Fig. 1. The results of the critical appraisal of the included studies using the Joanna Briggs Institute (JBI) critical appraisal checklists

green – yes; yellow – unsure; red – no.

relevant materials. In short, the antigravity treadmill is a valuable device, and whether it is used in terms of gait or run training or for other purposes like balance exercises, it can improve outcomes of patients after knee surgery.[36–42] However, compared with procedures not involving an antigravity treadmill, its beneficial effects were not shown. The main findings of the particular analyzed studies will be discussed following the hierarchy of evidence.

The included RCT was deemed high-quality. However, no blinding was possible, and adverse events were not reported, even though they were a core outcome.[36] Although blinding decreases the risk of bias and improves a study's quality, it is rarely possible to blind patients to a physiotherapeutic intervention.[44–46] The main finding of the study of DeJong et al. was that no beneficial effects of using gait training with an antigravity treadmill were observed and that practitioners should, therefore, focus on the cost-effectiveness of the delivered interventions.[36,47,48]

Two cohort studies by Bugbee et al. and Sueyoshi et al. were included.[37,38] The Bugbee et al. study was analyzed as a cohort study, not as an RCT, because of its pilot and feasibility character, and it did not fulfill all the criteria of an RCT.[37] The study found no differences in the studied outcomes, including patient self-reported measures and mobility assessed using the Timed Up and Go test between the patients after TKA who received antigravity treadmill and land-based gait training.[37] Again, in light of cost-effectiveness, land-based gait training might be favored, although the pilot design of the study should be emphasized. In the other cohort study by Sueyoshi et al., patients after TKA, ACLR and other knee surgeries were divided into those performing balance exercises on an antigravity treadmill and those conducting the same balance exercises on the floor. In both studied groups, an improvement in timed single-leg stance was noted in the 2nd week postoperatively compared to the 1st week between the interventions carried out. However, a difference between the studied groups was not observed. It must be emphasized that the assignment to particular groups was based on patients' comfort level, precisely pain level, during the single leg stance on the floor using the involved limb. Patients who experienced a significant increase in pain during this test were assigned to balance exercises on an antigravity treadmill, while those who felt comfortable standing on the involved limb (no pain or a minimal increase in pain) were assigned to floor exercises.[38] Therefore, the study shows limited evidence due to the specific way assignments were issued for the studied interventions.

The included studies for the present scoping review purposes consecutively involved case series by Eastlack et al. and Huang et al.[39,40]

Table 4. Details concerning the studied population, intervention and controls (if applicable) in the studies included in the present scoping review

Authors	Population	Intervention	Control
DeJong et al.[36]	Patients after unilateral primary TKA Assignment, n = 368 Group 1, n = 95; Group 2, n = 96; Group 3, n = 96; Group 4, n = 99 Data analysis, n = 363 Group 1, n = 92; Group 2, n = 91; Group 3, n = 90; Group 4, n = 90 Follow-up analysis, n = 298 Group 1, n = 74; Group 2, n = 76; Group 3, n = 78; Group 4, n = 70 Gender: female 53–58% Mean age: 62.7–64.9 years Mean BMI: 31.2–32.2 kg/m^2 Inclusion criteria: Patients after elective unilateral TKA who initiated their outpatient PT within 24 days post-TKA; 40 years or older; weight less than 300 pounds. Exclusion criteria: Patients after a lower extremity joint replacement procedure, including a revision, 2nd, or bilateral TKA or total hip arthroplasty less than 1 year prior to their current TKA; whose payer was workers' compensation; in litigation related to injury or disease associated with their current TKA; pregnant or may be pregnant; a medical history of neurologic disorders, rheumatoid arthritis, or gout (unless 6 months since last exacerbation or flare up and under control medically); under active cancer treatment with history of malignancy in either or both lower extremities, or with evidence of signs or symptoms of cancer, chemotherapy, or radiation less than 1 year prior to their current TKA; developed deep vein thrombosis post-TKA; unable to proceed or continue the planned outpatient program because of complications such as wound infection related to the TKA and severe orthostatic hypotension; who required manipulation under anesthesia post-TKA; received more than 2 weeks of other care in another post-acute setting prior to outpatient PT. Random assignment to the studied groups.	The study had a parallel design comparing 4 different interventions: Group 1, a usual-care group that used a stationary recumbent bike Group 2, a group that used a BW-adjustable treadmill for gait training Group 3, a group that combined using a stationary recumbent bike with patterned electrical neuromuscular stimulation (PENS) Group 4, a group that combined using a BW-adjustable treadmill for gait training with PENS. All patients received up to 12 weeks of outpatient PT. Each visit included an exercise, treatment, and finishing and prevention phases. The exercise phase when the studied intervention was applied, lasted for 15–20 min. Regarding the BW-adjustable treadmill, the physical therapists identified the speed and amount of BW needed to be unloaded to minimize pain and allow patients to properly ambulate. Over time, physical therapists decreased BW support and increased speed as tolerated by the patient while maintaining a proper gait pattern. Used device: AlterG® Anti-Gravity Treadmill™. The information and results of the other interventions will not be displayed as it is not in the context of the current investigation.	The study had a parallel design comparing four groups with different interventions, as described in the Intervention column.
Bugbee et al.[37]	Patients after TKA Data analysis, n = 29 AlterG group, n = 14; Control group, n = 15 Gender: female 50–60% Mean age: 66.5–69.9 years Mean BMI: 28.4–28.8 kg/m^2 Inclusion criteria: Patients after unilateral primary TKA; discharged from the hospital to home (not to a skilled nursing facility); had only 3–4 home PT sessions; agreed to further outpatient PT at a single site; agreed to complete patient questionnaires. Exclusion criteria: inability to meet inclusion criteria; gross musculoskeletal deformity; uncontrolled chronic or systemic disease; inability to follow instructions because of mental impairment, substance abuse, or addiction. Random assignment to the studied groups.	Patients attended outpatient PT two days per week for 4 weeks for a total of 8 sessions. Therapy sessions lasted 45–60 min and included manual therapy, gait training, therapeutic exercises/activities and treatment modalities. Depending on the studied group the gait training antigravity (AlterG group) or land-based (control group). Regarding antigravity gait training, on day 1, the antigravity treadmill pressure chamber was set to allow only 50% of the patient's BW to be transmitted to the treadmill floor, and speed was controlled by the patient according to his/her comfort level. The percentage of BW was adjusted to allow for a safe and normalized gait pattern with a pain level no greater than 5 (0–10 scale) throughout the PT session. For subsequent visits, the body-weight setting was started from the end point of the previous session. Used treadmill: AlterG® Anti-Gravity Treadmill™	In the control group, land-based gait training was performed with or without an appropriate assistive device (AD) and appropriate assistance, tactile cueing, and verbal cueing from a physical therapist. Duration [min] and gait-training progression were dependent on the participant's functional goals, pain level (assessed throughout treatment), and level of fatigue.

Eastlack et al. studied the usage of gait training under lower body positive pressure (LBPP) conditions in patients after a unilateral arthroscopic meniscectomy or ACLR. Various parameters were measured under LBPP conditions, including ground reaction forces, dynamic knee range of motion, and electromyographic activity of the vastus medialis obliquus and biceps femoris. Also, pain during the interventions was assessed. It must be highlighted that the study was not intended to evaluate the effectiveness of LBPP as a rehabilitation modality. It was established

Table 4. Details concerning the studied population, intervention and controls (if applicable) in the studies included in the present scoping review – cont.

Authors	Population	Intervention	Control
Sueyoshi and Emoto[38]	Patients after TKA, ACLR and other knee surgery Data analysis, n = 49 AlterG group, n = 25 Control group, n = 24 AlterG group patients: n = 17 after TKA, n = 3 after TKA, n = 5 after other knee surgery Control group patients: n = 15 after TKA, n = 2 after TKA, n = 7 after other knee surgery Gender: not mentioned Mean age: 66.1–63.0 years Mean body mass: 56.6–58.6 kg Mean body height: 154.0–157.1 cm Inclusion criteria: not mentioned Exclusion criteria: not mentioned The assignment of patients to the studied groups depended on their performance in the initial balance test. Following the first assessment, individuals were allocated to either the AlterG group or the Control group based on their comfort levels. Patients who reported a "significant increase" in pain during the initial balance test were assigned to the AlterG group, while those who felt "comfortable" with no or minimal pain, or experienced no or minimal increase in pain, were assigned to the Control group.	Patients from the AlterG group performed balance exercise on antigravity treadmill. Performing antigravity or land-based balance exercise started at 1 week postoperatively and lasted 1 week. It was performed daily for at least 5 days a week. In each balance exercise session, patients were asked to stand on involved leg with their knee slightly bent targeting to stay on their foot for 30 s. This was repeated 3 times with 30 s rest in between trials. A balance exercise was made more challenging by having a participant stand on a form pad when appropriate. This decision was made by a licensed physical therapist. Regarding antigravity balance exercise the pressure on AlterG adjusted to a pain-free or minimal pain level at the beginning of each balance exercise session. Used device: AlterG® Anti-Gravity Treadmill™	Patients from the Control group performed described in the Intervention column balance exercise on a floor.
Eastlack et al.[39]	Patients after unilateral arthroscopic meniscectomy (n = 9) and ACLR with the use of autograft or allograft patellar tendon (n = 6); total number n = 15 Gender: female 33% Mean age: 41 years Mean body mass: 74.7 kg Mean body height: 175 cm Inclusion criteria: not mentioned Exclusion criteria: Pulmonary or cardiac disease; taking β-blocker medications; pregnancy; younger than 18 years.	Patients after meniscectomy exercised under lower body positive pressure conditions 1 week after surgery. Patients after ACLR exercised under lower body positive pressure conditions before surgery and once a week for 6 weeks postoperatively. Exercise under lower body positive pressure conditions was considered ambulation in the chamber in lower body positive pressure conditions (60% and 20% of BW). Each patient walked for 2 min at a comfortable walking speed of 0.67 m/s (1.5 mph) under 3 BW conditions (100%, 60% and 20% of BW). Used device: A developed device (Whalen and Hargens, US patent 5133339; Hargens waived rights to this patent to NASA) for unloading the lower extremities during walking or running. The device consist of a treadmill in a waist-high chamber that uses an airtight seal to create a pressure differential. By increasing pressure around the lower body in the chamber (called lower body positive pressure), the gravitational forces are counteracted.	None

to gain new knowledge about the effects of LBPP on gait after surgery. In patients after meniscectomies or ACLR, a significant decrease in ground reaction forces in both involved and uninvolved limbs was observed during gait training under LBPP conditions. The peak magnitude of electromyographic activity of the vastus medialis obliquus decreased as BW conditions were reduced, although the changes reached significance only at 20% of BW. Electromyographic activity of the biceps femoris trends towards decreased activity when exercising at 60% BW and 20% BW conditions, but the differences were not significant. Significant reductions in pain during LBPP training were observed in patients after ACLR. During the first 2 weeks after ACLR, no patient could ambulate on the involved limb under normal BW conditions. However, when ambulating under LBPP conditions, the same patients could participate in 2 min of exercise. All patients could tolerate ambulation at 100% BW by the 3rd postoperative week. One week after arthroscopic meniscectomy, patients could tolerate exercise at any BW condition with limited discomfort. Therefore, no significant differences in pain assessment were observed in this group of patients. Heart rate decreased along with a decreasing percentage of BW during training. No adverse events related to placement or exercise in the LBPP conditions chamber occurred.[39]

In the 2nd analyzed case series, the outcomes of patients after UKA significantly improved in terms of self-reported measures and gait parameters after 12 weeks of antigravity treadmill training in conjunction with a standard physical therapy program initiated within the 1st week following surgery.[40] It is crucial to highlight that the case series

Table 4. Details concerning the studied population, intervention and controls (if applicable) in the studies included in the present scoping review – cont.

Authors	Population	Intervention	Control
Huang et al.[40]	Patients after UKA n = 4 Gender: female 100% Mean age: 68.3 years Mean body mass: 68.5 kg Mean body height: 161.6 cm Inclusion criteria: Apart from information that there were included patients scheduled for UKA as a result of medial compartment osteoarthritis (OA) no specific criteria were mentioned. Exclusion criteria: Concomitant severe injury to contralateral knee; history of deep vein thrombosis or a disorder of the coagulative system; claustrophobia; general systemic disease affecting physical function; any other condition or treatment interfering with treadmill walking or rehabilitation.	Participants completed supervised antigravity treadmill training thrice weekly for 12 weeks in conjunction with their standard physical therapy program. Antigravity treadmill training and physical therapy were initiated the 1st week following surgery and progressed as follows: Weeks 1–2; weighting 50–55% of BW*; speed 1.0–1.4 mph; time 5–8 min; frequency 3 times per week; Weeks 3–4; weighting 55–60% of BW*; speed 1.4–2.0 mph; time 10 min; frequency 3 times per week; Weeks 5–8; weighting 60–75% of BW*; speed 2.0–2.5 mph; time 15 min; frequency 3 times per week; Weeks 9–10; weighting 75–85% of BW*; speed 2.5 mph; time 20 min; frequency 3 times per week; Weeks 11–12; weighting 85–90% of BW*; speed 2.5 mph; time 25–30 min; frequency 3 times per week. Physical therapy was performed 2 times a week and initially included icing, elevation and edema control. Treatment continued with passive and active range of motion exercise and progressed to strengthening. Soft tissue and joint mobilization techniques were added to improve joint range of motion. In addition, all patients could walk independently without an assistive device prior to initiating the treatment protocol described later. Used treadmill: AlterG® Anti-Gravity Treadmill™	None
Greig et al.[41]	One patient after ACLR with the use of autologous semitendinosus and gracilis tendons graft from the contralateral limb Gender: male Age: 26 years Body mass: not mentioned Body height: not mentioned Professional soccer player	At 4 weeks post-surgery, the patient completed 2-min running intervals at 10.2 km/h with linear progression from 70% to 95% of BW at 5% increments. Linear progression rather than a randomized allocation of speed was used to reflect the rehabilitation context of the player. This running speed was equivalent to 30% of the patient's maximum running speed determined from match-play and had been achieved during grass-based rehabilitation sessions in the preceding week. Before that, for the 4 weeks postoperatively, the patient was taking part in some kind of rehabilitation program; however, the details were not presented. Used treadmill: AlterG® Anti-Gravity Treadmill™	None

discussed did not include a control group, so care should be taken when attributing the improved outcomes solely to antigravity treadmill training. Also, it's crucial to note that the primary goal of the study of Eastlack et al. was not to assess the efficacy of LBPP as a rehabilitation method. Instead, the objective was to acquire new insights into the impact of LBPP on one's gait following surgery.[39]

The 2 case reports included in the present scoping review, representing the lowest level of evidence, were the studies by Greig et al. and Hambly et al.[41,42] Greig et al. assessed changes in parameters like uni-axial acceleration, vertical and mediolateral acceleration, and anteroposterior loading depending on the BW percentage during antigravity training in 1 patient after ACLR.[41] Hambly et al. assessed the effectiveness of a program comprised of 12 antigravity treadmill running sessions over an 8-week period in 1 patient after single-step arthroscopic osteochondral repair surgery comprised of microfracture and bone marrow aspirate concentrate (BMAC).[42] An improvement in the Self-Efficacy for Rehabilitation Outcomes and Knee Self-Efficacy scales and functional outcomes was noted in case report.[42]

Water-based rehabilitation is a popular treatment option that reduces BW due to buoyancy, so this alternative to antigravity treadmills might be considered. The advantage of antigravity treadmill training over water-based training is that the sterility of the wound is preserved, which makes antigravity treadmills an option that can

Table 4. Details concerning the studied population, intervention and controls (if applicable) in the studies included in the present scoping review – cont.

Authors	Population	Intervention	Control
Hambly et al.[42]	One patient after single step arthroscopic osteochondral repair surgery comprising microfracture and Bone Marrow Aspirate Concentrate (BMAC). Gender: female Age: 39 years Body mass: 60.3 kg Body height: 167 cm Endurance runner	The program comprised of 12 antigravity treadmill running sessions over an 8-week period taking the patient from 30% to 80% bodyweight as follows: Week 1; weighting 30% of BW; speed 6.7 km/h; time 5 min; RPE = 7 Week 2; weighting 30% of BW; speed 7.2 km/h; time 10 min; RPE = 7 Week 3 Session 1; weighting 40% of BW; speed 7.6 km/h; time 10 min; RPE = 8 Week 3 Session 2; weighting 40% of BW; speed 7.7 km/h; time 15 min; RPE = 9 Week 4 Session 1; weighting 50% of BW; speed 7.5 km/h; time 15 min; RPE = 9.5 Week 4 Session 2; weighting 50% of BW; speed 8.0 km/h; time 20 min; RPE = 11 Week 5 Session 1; weighting 60% of BW; speed 8.3 km/h; time 20 min; RPE = 11.5 Week 5 Session 2; weighting 60% of BW; speed 8.0 km/h; time 25 min; RPE = 11.5 Week 6 Session 1; weighting 70% of BW; speed 7.5 km/h; time 25 min; RPE = 11 Week 6 Session 2; weighting 70% of BW; speed 7.1 km/h; time 30 min; RPE = 11.5 Week 7; weighting 80% of BW; speed 8.0 km/h; time 30 min**; RPE = 11 Week 8; weighting 0% of BW; speed 7.5 km/h; time 30 min**; RPE = 10 The patient wore the Ossur Rebound® cartilage brace and the same running shoes during every session. The patient maintained their home exercises (including swimming, cycling and leg strengthening) as previously prescribed. Each treadmill session started with a 5 min. 100% BW self-paced walking warm up and ended with a 5 min 100% BW self-paced walking cool down. Used treadmill: AlterG® Anti-Gravity Treadmill™	None

*Progressed as tolerated; **Alternating 5 min running and 5 min walking; ACLR – anterior cruciate ligament reconstruction; BMI – body mass index; BW – body weight; n – number of participants; PT – physiotherapy; RPE – Rating of Perceived Exertion; TKA – total knee arthroplasty; UKA – unicompartmental knee arthroplasty.

be accessed earlier than water-based training regimens (wound infection and water-based therapy). One of the included cohort studies assessed the effectiveness of antigravity treadmills in reducing knee forces.[49] This study discussed that even though water provides buoyancy and thus reduces BW forces on the knee joint, the resistance due to hydrodynamic drag presents an anteroposterior component when walking in water. The 2nd advantage of LBPP is that it does not affect hydrodynamic or aerodynamic drags.

When conducting a study with comparators or control arms, the intervention and the control groups should be comparable.[50] It is safe to say that patients with different conditions cannot be taken into the same group as weight-bearing capabilities greatly affect the capacity of patients to exercise (weight-bearing and exercise). This is obvious considering the study that analyzed meniscectomy and ACLR patients.[39] While meniscectomy patients can ambulate with little to no pain at any percentage of their BW,[51] ACLR patients could not ambulate at all BWs.[52] Also, demographic variations such as age, gender and BW should be considered, as these are predictive factors for outcomes after knee surgery.[53–55]

Concerning outcome measurements, recommendations for future studies include the adherence to reporting core outcome measures. These outcomes include pain, function, quality of life and adverse events, and should be added to the measurements of the research agenda.[56,57] Surprisingly, most analyzed studies in the present scoping review did not include adverse events, although the importance of this measurement has long been established.[58,59] Only 2 studies assessed pain intensity, and interestingly, it was only assessed during the intervention, so no effectiveness of antigravity treadmill training on everyday pain intensity levels was evaluated.[37,39] Other recommendations would be to remember published details on the frequency of the intervention, the walking speed, the inclination, the duration of the intervention, and the percentage of BW applied.

Table 5. Details concerning the main findings concerning the outcome, recommendations, limitations, and critical notes of the studies included in the present scoping review

Authors	Outcome	Recommendations	Limitations	Notes
DeJong et al.[36]	Assessment at discharge from outpatient therapy: 1) Patient self-reported measure KOOS: Improvement when compared to baseline; no between-group differences both at the subscale level and for the combined KOOS 2) Patient performance-based measure Walking speed over 10-m curse: Improvement when compared to baseline; no between-group differences	Clinical practice: Neither BW-adjustable treadmill nor in combination with PENS provide benefits to TKA patients when compared to usual care. The choice of intervention defaults to the issue of costs. Research: Cost-effectiveness or a cost-savings analysis should be made to help providers make informed choices about which of the 4 equally effective interventions they should select for their patients. If the study is replicated, it is recommended to reduce the post-TKA enrollment window to a week or less. This is because the benefits of newer interventions may be more apparent in the early stages of post-TKA rehabilitation.	The main limitation is that it was confined to a single regional health system, albeit across 15 geographically dispersed outpatient centers. This should be seen in the light of variations in standard PT regimens nationwide.	None
Bugbee et al.[37]	Assessment at final therapy session: 1) Patient self-reported measure KOOS: Improvement when compared to baseline; no between-group differences 2) Mobility TUG: Improvement when compared to baseline; no between-group differences Assessment throughout intervention: 1) Pain NRS: Improvement when compared to baseline; no between-group differences Assessment at 3 months postoperatively: 1) Patient self-reported measure KOOS: Improvement when compared to baseline; no between-group differences. 2) Mobility TUG: Improvement when compared to baseline; no between-group differences.	None given	None given	The study was a pilot and feasibility study. It showed that use of the antigravity treadmill was safe and feasible during postoperative TKA rehabilitation. It was well tolerated by patients and rated highly satisfactory by physical therapists. Further studies are needed to determine the efficacy of antigravity compared to traditional land-based gait training.
Sueyoshi and Emoto[38]	Assessment at the end of protocol (2 weeks postoperatively): Timed single leg stance on a floor, improvement when compared to baseline; no between-group differences.	None given	The use of oral pain medication given by a surgeon was not controlled. No assessment of pain perception was taken. There was no group of patients with an increased pain level during the baseline balance test due to a safety concern.	The assignment to particular groups was based on patients' comfort level, precisely pain level during the single leg stance on the involved limb on a floor. Further investigation is required to examine the effects of using an antigravity treadmill during the acute recovery phase following knee surgery.

Adherence to the Template for Intervention Description and Replication (TIDieR) checklist is recommended when administering an intervention and its subsequent description in a publication.[60] Additionally, we advocate for participation in future high-quality RCTs to address existing gaps in knowledge and clarify the role of antigravity treadmill training in optimizing patient outcomes post-knee surgery.

Table 5. Details concerning the main findings concerning the outcome, recommendations, limitations, and critical notes of the studies included in the present scoping review – cont.

Authors	Outcome	Recommendations	Limitations	Notes
Eastlack et al.[39]	Outcomes measured under LBPP conditions: Peak Ground Reaction Force: Significant decrease in both involved and uninvolved limbs; values obtained in patients after ACLR showed similar reductions when compared with patients after meniscectomies Dynamic knee ROM: no significant reduction at 1 week postoperatively at 60% of BW but significant decrease at 20% of BW. In patients after ACLR the knees had a greater decrease in dynamic ROM than after meniscectomy. Longitudinal knee ROM gradually increased during the 6 weeks. Electromyographic activity of the vastus medialis obliques: decrease in peak magnitude as BW conditions were reduced, although the change reached significance only at 20% BW. Electromyographic activity of the biceps femoris: Trends toward decreased activity when exercising at 60% of BW and 20% of BW conditions, but the differences were not significant. Pain: Reduction as much as 80% in patients after ACLR. During the first 2 weeks after ACLR, no patient could ambulate on the involved limb under normal BW conditions. However, when ambulating under LBPP conditions, all of the same patients could participate in 2 min of exercise. All patients could tolerate ambulation at 100% of BW by the 3rd postoperative week. One week after arthroscopic meniscectomy, patients could tolerate exercise at any body weight condition with limited discomfort, therefore, no significant differences in pain assessment were observed. Heart rate: A significant decrease at 60% and 20% of BW, when compared with exercise at 100% of BW. No adverse events related to placement or exercise in the LBPP conditions chamber occurred.	Research: It is important to conduct further evaluation on patients who have undergone significant injuries or surgeries. In the future, studies should investigate how effective LBPP is as a rehabilitation measure following severe injuries and orthopedic surgeries that involve limiting lower-extremity loads.	None given	It is important to mention that the study was not intended to evaluate the effectiveness of LBPP as a rehabilitation modality. It was established to gain new knowledge about the effects of LBPP on gait after surgery. The authors mention a total of 15 patients (9 after meniscectomy and 6 ACLR), but they report 5 women and 9 men. The patient's pain was primarily reported based on their ability to ambulate. Although the study mentions the use of the VAS and an 80% decrease in pain in ACLR patients, it is not clear when the pain was measured (during rest, ambulation, under which BW, point in time before or after surgery). No data on VAS results were reported in the results. No reports on function or quality of life were assessed for in this study.
Huang et al.[40]	Assessment at post-intervention (12 weeks of intervention): 1) Patient self-reported measures KOOS: Improvement for each subscale when compared to baseline 2) Gait parameters Gait speed: Improvement when compared to baseline. Peak sagittal plane knee flexion angle and peak sagittal plane knee extensor moment during the weight acceptance phase of gait (0–15% of the gait cycle): improvement when compared to baseline, the average peak knee flexion angle and knee extensor moment reached respectively 99.3% and 90.2% of normal values	Research: Comparative studies are needed to establish the effectiveness of antigravity treadmill training usage in restoring joint function in UKA patients.	Care should be taken when attributing the improved knee kinematics and kinetics solely to antigravity treadmill training since this case series did not include a control group. Also, the presurgical gait status was not assessed.	None

Table 5. Details concerning the main findings concerning the outcome, recommendations, limitations, and critical notes of the studies included in the present scoping review – cont.

Authors	Outcome	Recommendations	Limitations	Notes
Greig et al.[41]	Outcomes measured under LBPP conditions: Uni-axial acceleration: No linear increase with step progression in % of BW. Vertical and mediolateral acceleration: Infliction point at 85% of BW. Antero-posterior loading: Infliction point at 80% of BW.	Clinical: Weighting amounting 70% of BW and 85% of BW represent discrete rehabilitative progressions. Being able to run at 85% of BW on antigravity treadmill could be considered sufficient to safely recommend land-based running with full bodyweight. Research: Possible future research could investigate changes in loading strategy during the rehabilitation process, compare running on grass with a speed-matched control group, and establish criteria for returning to training and playing. Additionally, statistical parametric mapping techniques could be used to examine temporal variations in loading during the stance phase.	None given	Eight months after ACLR the patient reported pain in the medial aspect of the involved knee and underwent a medial meniscectomy.
Hambly et al.[42]	Self-efficacy for rehabilitation outcomes scale and Knee Self-Efficacy Scale: The present and future self-efficacy scores showed an improvement from baseline to 8 week of the program. KOOS and IKDC: Improvement from baseline to 8 week of the program.	Research: Future studies should evaluate the role of antigravity treadmill intervention, supervised rehabilitation sessions, and/or the addition of a further 2 months of time post-surgery by comparing standard care with standard care plus an antigravity treadmill program in patients with knee cartilage lesions. Additionally, the psychometric properties of the Self-Efficacy for Rehabilitation Outcomes and Knee Self-Efficacy scales have not been evaluated for a knee osteochondral surgery population, and this also provides an opportunity for further studies.	Design of the study (case report).	A VAS pain score was collected before, during and after every session. No pain was reported throughout the program.

BW – body weight; IKDC – 2000 IKDC Subjective Knee Evaluation Form; KOOS – Knee injury and Osteoarthritis Outcome Score; LBPP – lower body positive pressure; NRS – Numerical Rating Scale; PENS – patterned electrical neuromuscular stimulation; ROM – range of motion; TKA – total knee arthroplasty; TUG – Timed Up and Go test; UKA – unicompartmental knee arthroplasty; VAS – visual analogue scale.

For control groups, future studies to determine the effectiveness of using antigravity treadmills should include appropriate comparators. The only difference between groups should be the intervention being investigated.[61] Both groups should also be comparable at baseline. It has already been mentioned that in one of the analyzed studies for the present scoping review, patients were assigned to studied groups based on their so-called comfort level during single leg stance on the floor using the involved limb, which, of course, may, in some way, undermine the evidence regarding the effectiveness of the tested methods.[38]

Potential practical implications of the scoping review may include rehabilitation protocol development and optimizing treatment strategies. Incorporating antigravity treadmill training into post-knee surgery rehabilitation protocols could offer valuable benefits, particularly for patients unable to bear full weight during the early recovery phase. Our scoping review highlights the potential utility of this intervention, especially in cases such as ACLR, TKA and UKA, where traditional physiotherapeutic measures may be insufficient. However, it is crucial to acknowledge the limitations of the current evidence, as our review underscores the need for further research to establish its superiority over conventional approaches.

As clinicians, it is essential to carefully consider patient selection criteria when contemplating the integration of antigravity treadmill training into rehabilitation plans. Engaging patients in shared decision-making processes, informed by discussions of the available evidence and potential benefits, can empower them to actively participate in their recovery journey. Moreover, while antigravity treadmill training shows promise, it should complement rather than replace traditional physiotherapy methods, emphasizing a comprehensive and multidisciplinary approach to postoperative care.

By identifying common trends or best practices in antigravity treadmill training protocols following knee surgery, the present scoping review can inform the development of evidence-based rehabilitation protocols for clinicians, potentially leading to improved patient outcomes and faster recovery times.

Based on the gathered evidence, clinical recommendations favoring antigravity treadmill training cannot be made at this stage as evidence from different studies failed to prove its superiority over other, more cost-effective treatment modalities. Consideration of cost-effectiveness is paramount. A thorough cost-benefit analysis will help elucidate the economic implications of incorporating antigravity treadmill training into rehabilitation protocols, ensuring that interventions are not only clinically effective but also financially sustainable in the long term. By adhering to these discussions and guidelines, clinicians can navigate the complexities surrounding antigravity treadmill training post-knee surgery, offering personalized and evidence-based care to their patients.

Limitations

The main limitations of this study consisted of the number of databases that were searched. Also, the search was limited to articles in English, French, German, Polish, and Arabic. Some studies might have been missed due to this limitation. Another limitation concerns the JBI appraisal, as the authors failed to identify some aspects not explicitly mentioned in the included studies. One systematic review on the effect of antigravity treadmill training was excluded as the study could not be found in full text, and the authors did not reply to the request.

Conclusions

The antigravity treadmill is a valuable device that allows the rehabilitation of patients who have restricted weight-bearing capabilities. Whether it is used in terms of gait or run training or for other purposes like balance exercises, it improves patients' outcomes after knee surgery. Compared with procedures not involving an antigravity treadmill, its beneficial effect was not shown; however, taking into account the low evidence of the analyzed studies, definitive conclusions cannot be made at this point.

Therefore, future high-quality RCTs should investigate the effect of antigravity treadmill training due to the low quality of provided evidence. Also, a cost-effectiveness analysis is required to determine whether the investigated intervention fits the purpose.

Data availability

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics approval

No ethical approval was deemed necessary as this paper only provides a review of already conducted research. The individual studies were all compliant with relevant local ethical guidelines, as approval was provided by the relevant institutions.

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