

# Effect of Perturbation-Based Balance Training on Fear of Falling After Lower-Limb Orthopaedic Surgery

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**Abstract**—Fear of falling (FoF) is common after hip fracture and hip or knee arthroplasty and can restrict mobility during the very period in which rehabilitation depends on it. Perturbation-based balance training (PBT) trains reactive balance by exposing patients to repeated, unexpected, safely controlled losses of balance. It reduces falls in older adults, yet its effect on FoF is uncertain: it may build mastery and reduce threat appraisal, or it may provoke anxiety. This paper (i) synthesises current evidence on FoF and falls after lower-limb orthopaedic surgery and on PBT, (ii) proposes a mechanistic model of how PBT could alter FoF, and (iii) presents a registered-trial-ready protocol for an assessor-blinded randomised controlled trial (RCT) comparing six sessions of PBT with attention-matched conventional balance training (planned N = 152; primary outcome Falls Efficacy Scale-International, FES-I). The evidence reviewed shows a high burden of FoF and falls after surgery and a growing body of PBT trials in community-dwelling older adults, but no completed RCT in post-orthopaedic patients was identified, and the only trial reviewed that reported FES-I found no change. No participant data were collected for this paper; the results section therefore sets out testable hypotheses and interpretation rules rather than findings.

**Keywords**—perturbation-based balance training, fear of falling, falls efficacy, orthopaedic surgery, hip fracture, arthroplasty, rehabilitation.

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## 1. Introduction

Hip fracture, total hip arthroplasty (THA) and total knee arthroplasty (TKA) are among the most common lower-limb orthopaedic procedures in older adults, and hip fracture in particular carries a heavy burden of mortality, disability and social cost [1]. Recovery is not purely mechanical. Older adults waiting for or recovering from joint arthroplasty are at increased risk of falls, with reported prevalence ranging from 23–63% before and 13–42% after surgery [2]. Knee arthroplasty improves balance and fall status in many patients, yet deficits in knee extension strength, proprioception and postural strategy can persist after surgery [3].

Fear of falling (FoF) is a lasting concern about falling that leads people to avoid activities they are still capable of performing [4]. It is related to, but distinct from, falls self-efficacy, the confidence a person has in carrying out daily activities without falling [5]. Some studies indicate that half or more of patients after hip fracture experience FoF, and FoF has been linked with loss of mobility, institutionalisation and mortality [6]. In one cohort

of 100 patients in geriatric rehabilitation, 36% reported a little and 27% reported quite a bit or very much FoF [7]. Activity avoidance driven by fear is associated with physical frailty and subsequent falls [8], [9], creating a self-reinforcing cycle in which fear leads to inactivity, inactivity to weakness, and weakness to further falls.

Exercise is the best-supported strategy for preventing falls in community-dwelling older adults [10], but conventional balance and strength programmes may not be sufficiently specific to the rapid recovery actions needed after an unexpected slip or trip. PBT addresses this by repeatedly exposing the person to unexpected, externally induced loss of balance in a controlled setting so that reactive stepping and grasping responses can be practised and refined [11]–[13]. Randomised trials report improved compensatory stepping and grasping reactions [14], and perturbation training has been shown to lower the annual fall risk of community-dwelling older adults [15].

Whether PBT reduces FoF is much less certain. In a single-blind RCT of 82 community-dwelling

older adults with a recent fall, three 30-minute PBT sessions added to usual care did not change FES-I scores and did not differ from usual care [16]. Orthopaedic patients differ from that population in important ways: they are recovering from tissue injury, may have pain, weakness and weight-bearing precautions, and often report high FoF. Research in this group has only just begun; for example, a trial of perturbation-based training with pressure biofeedback after THA is registered [17]. This paper therefore aims to: (1) summarise what is known about FoF and falls after lower-limb orthopaedic surgery and the evidence for PBT; (2) propose a mechanistic model of how PBT might influence FoF; and (3) present a detailed, reproducible trial protocol to test the effect of PBT on FoF in this population.

## 2. Background and Conceptual Framework

### 2.1 Falls and fear of falling after lower-limb surgery

Fig. 1 summarises published figures on the scale of the problem. Falls are frequent both before and after arthroplasty, and in a scoping review of five studies that examined FoF, pre-operative patients reported greater fear than post-operative patients, while FoF itself was identified as a modifiable risk factor for falls [2]. After hip fracture, however, high FoF appears to persist through rehabilitation, with mean FES-I scores of roughly 30 points reported across the first weeks after fracture in one cohort [7]. Because FES-I ranges from 16 to 64 and scores of 28 or more are commonly interpreted as high concern [18], this level of fear is clinically meaningful.

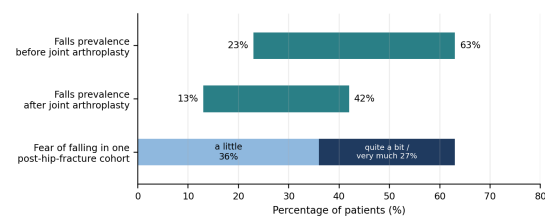


**Fig. 1. Reported burden of falls and fear of falling in the target population. Falls prevalence ranges (before and after total joint arthroplasty) are from the scoping review of Chen et al. [2]; fear-of-falling categories are from a cohort of 100 hip-fracture patients [7]. Different studies, instruments and populations are shown side by side for orientation only.**

### 2.2 Principles of perturbation-based balance training

PBT rests on task-specificity: because most falls in older adults follow an unexpected disturbance, such as a trip or slip, training should rehearse the recovery response itself [12], [13]. Perturbations can be delivered by treadmill belt accelerations, moving platforms, therapist-applied pulls or pushes, or slip and trip walkways, always with a safety harness. A review of clinical PBT concluded that treadmill-based systems and therapist-applied perturbations are likely the most practical in

clinical settings and that programmes combining several perturbation types and directions may be most beneficial [12]. Training is typically brief (a single session up to a few sessions) yet produces adaptations that are retained [15], [19], and it is conceptually related to, but different from, voluntary step training [20]. Recent work also compares the effects of PBT that targets both slips and trips [21].

### 2.3 How PBT could change fear of falling

Self-efficacy theory holds that mastery experiences are the most powerful source of confidence [22]. Within PBT, patients repeatedly lose balance and then recover successfully, which offers unusually direct mastery evidence that “I can recover if I stumble”. Three complementary pathways are proposed in Fig. 2: (a) motor learning that makes recovery objectively better; (b) mastery experiences that raise falls self-efficacy; and (c) graded exposure that reduces threat appraisal through habituation. A plausible adverse pathway also exists. Being deliberately destabilised could increase anxiety, particularly early after surgery or after a real fall. The net effect is therefore an empirical question, and moderators such as pain, surgery type and prior falls may determine its direction.

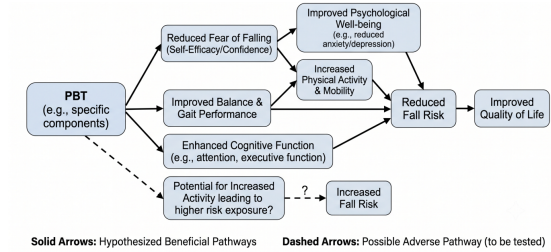


**Fig. 2. Proposed conceptual model linking PBT to fear of falling and downstream outcomes. Solid arrows show hypothesised beneficial pathways; the dashed arrow shows a possible adverse pathway. This model is a hypothesis to be tested, not an established result.**

## 3. Evidence Synthesis

This section is a structured narrative synthesis of key sources identified through targeted database searches and reference tracking in September 2026. It is not a full systematic review and no formal risk-of-bias rating was performed. Table I lists the evidence that most directly informs the research question.

**TABLE I. KEY EVIDENCE INFORMING THE RESEARCH QUESTION**

| Ref | Population and design                                             | Main finding (as reported)                                                                        | Relevance to this paper                  |
|-----|-------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|------------------------------------------|
| [2] | Older adults pre-waiting for or recovering from joint arthroplast | Falls prevalence 23–63% pre-operatively and 13–42% post-operatively; FoF higher before than after | Defines burden; supports FoF as a target |

|      |                                                                             |                                                                                                                                 |                                                                          |
|------|-----------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------|
|      | y; scoping review (12 studies)                                              | surgery; FoF a modifiable fall risk factor                                                                                      |                                                                          |
| [3]  | TKA patients; systematic review (13 studies)                                | Balance and FoF improve after TKA, but strength, proprioception and postural strategy deficits persist                          | Residual impairments justify balance training                            |
| [6]  | Hip fracture; systematic review (15 studies)                                | FoF in 50% or more in some studies; linked with loss of mobility, institutionalisation and mortality                            | Establishes prognostic importance of FoF                                 |
| [11] | Older adults and neurological groups; meta-analysis of preliminary RCTs     | Assessed effect of PBT on falls in daily life                                                                                   | Supports PBT as a fall-prevention approach                               |
| [15] | Community-dwelling older adults; RCT                                        | Perturbation training lowered annual fall risk                                                                                  | Shows durable transfer to daily life                                     |
| [12] | Older adults and clinical groups; systematic search                         | Falls incidence reduced in healthy older adults and some patient groups; treadmill and therapist-applied methods most practical | Guides feasible delivery mode                                            |
| [16] | 82 older adults with recent fall; single-blind RCT; 3 × 30-min PBT sessions | No difference from usual care in Mini-BESTest; FES-I unchanged in either group                                                  | Only reviewed trial reporting FES-I; cautions against assuming an effect |
| [17] | Patients after THA; registered RCT (30 planned)                             | PBT with pressure biofeedback versus control; results not available                                                             | Confirms an emerging, unresolved question                                |

### 3.1 Synthesis and evidence gaps

Three patterns emerge. First, FoF and falls are common in exactly the patients who need to

mobilise early [2], [6]. Second, PBT has a credible mechanism and supportive fall-prevention data in healthy and clinical older adults [11], [12], but FoF is seldom the primary outcome. Third, the one reviewed trial that measured FES-I found no change, and its authors called for work on how to adjust training dose [16]. No completed RCT of PBT for FoF in post-orthopaedic patients was identified among the sources reviewed, which leaves three open questions: whether PBT is acceptable and safe soon after surgery, whether it reduces FoF beyond conventional balance training, and whether any change is mediated by improved reactive balance or by greater confidence.

### 4. Proposed Trial Protocol

The protocol below follows the SPIRIT guidance for trial protocols [23]. Fig. 3 gives the overall flow.

#### 4.1 Design and setting

A two-arm, parallel-group, assessor-blinded, superiority RCT with 1:1 allocation, stratified by surgery type (hip fracture or hip arthroplasty versus knee arthroplasty), conducted in an outpatient orthopaedic rehabilitation service. Allocation will be concealed using sequentially numbered opaque envelopes or a central web-based system.

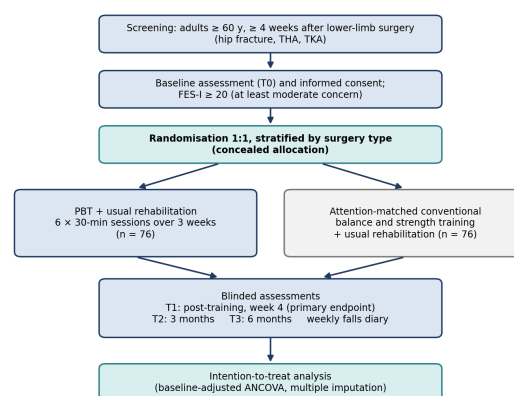


Fig. 3. Planned participant flow. PBT, perturbation-based balance training; T0–T3, assessment time points; THA/TKA, total hip/knee arthroplasty; ANCOVA, analysis of covariance.

#### 4.2 Participants

**Inclusion:** age 60 years or older; at least 4 weeks after hip fracture surgery, THA or TKA; cleared by the surgeon for full weight-bearing; able to walk 10 m with or without a walking aid; FES-I of at least 20, indicating moderate or high concern about falling [18]. **Exclusion:** cognitive impairment that prevents following instructions or giving consent; neurological disorder affecting balance; unstable cardiovascular disease; unresolved surgical complication, infection or uncontrolled pain; body mass exceeding the harness rating. Written informed consent will be obtained from all participants.

#### 4.3 Intervention

Participants in the PBT arm will receive six 30-minute sessions over three weeks, in addition to

usual rehabilitation. The dose is deliberately double that of a three-session programme reported earlier [16] because that trial found no change and recommended examining dose. Perturbations will be applied in a full-body safety harness using treadmill belt accelerations or, where a perturbation treadmill is unavailable, therapist-applied waist pulls and shoulder pushes, as these are considered the most practical clinical methods [12]. Sessions progress from predictable to unpredictable and from low to high intensity (Table II). A fear-specific component (brief education, a 0–10 “fear thermometer” before and after each block, and guided reflection on successful recoveries) is embedded to support mastery [22]. Sessions stop if pain exceeds a pre-set threshold, if the participant asks to stop, or if a safety criterion is met.

**TABLE II. PLANNED PROGRESSION OF THE PBT PROGRAMME**

| Session | Perturbation type and direction                                                                                 | Intensity and predictability                            | Fear-specific component                                                          |
|---------|-----------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|----------------------------------------------------------------------------------|
| 1–2     | Standing: therapist-applied pulls and pushes (forward, backward); walking: low-magnitude belt accelerations     | Low; announced direction and timing                     | Education on harness safety; first mastery experience; baseline fear thermometer |
| 3–4     | Standing and walking: multi-directional (including lateral) perturbations; belt accelerations and decelerations | Moderate; direction unannounced, timing partially known | Reflection on successful recoveries; graded increase in challenge                |
| 5–6     | Walking with dual task; simulated trips and slips; surgical-side leading and trailing limb                      | Moderate to high; fully unpredictable                   | Confidence review; plan for transfer to daily activities                         |

#### 4.4 Comparator

The control arm will receive six attention-matched 30-minute sessions of conventional balance and lower-limb strengthening exercise (e.g., weight-shifting, tandem stance, sit-to-stand, stepping) in the same harness and setting but without unexpected perturbations, in addition to usual rehabilitation. This isolates the specific contribution of perturbation from general exercise, therapist attention and harness exposure.

#### 4.5 Outcomes and assessments

The primary outcome is FES-I total score (16–64; higher scores mean greater concern) [18], [24] at T1 (week 4). Secondary outcomes are balance confidence (Activities-specific Balance Confidence scale) [25], balance performance (Mini-BESTest) [26], mobility (Timed Up and Go) [27], falls recorded prospectively by weekly diary, activity level, adverse events and attendance. Table III shows the schedule. Assessors will be blinded to allocation; participants cannot be blinded to the nature of the training.

**TABLE III. OUTCOMES AND ASSESSMENT SCHEDULE**

| Measure                                | Role      | T0 | T1 | T2 | T3 |
|----------------------------------------|-----------|----|----|----|----|
| FES-I                                  | Primary   | ✓  | ✓  | ✓  | ✓  |
| Activities-specific Balance Confidence | Secondary | ✓  | ✓  | ✓  | ✓  |
| Mini-BESTest                           | Secondary | ✓  | ✓  | ✓  | ✓  |
| Timed Up and Go                        | Secondary | ✓  | ✓  | ✓  | ✓  |
| Falls diary (weekly)                   | Secondary |    | ✓  | ✓  | ✓  |
| Adverse events, attendance             | Safety    |    | ✓  | ✓  | ✓  |

T0, baseline; T1, week 4 (post-training); T2, 3 months; T3, 6 months.

#### 4.6 Sample size

Sample size is based on a planning assumption, not on published effect estimates: a between-group difference of 4 FES-I points and a standard deviation of 8 points (standardised effect  $d = 0.5$ ). With a two-sided  $\alpha$  of 0.05 and 80% power, 64 participants per arm are required (Fig. 4). Allowing for 15% attrition, 76 per arm ( $N = 152$ ) will be recruited. These assumptions should be revisited against pilot data and the anchor-based minimal important difference for the chosen population before the trial is finalised.

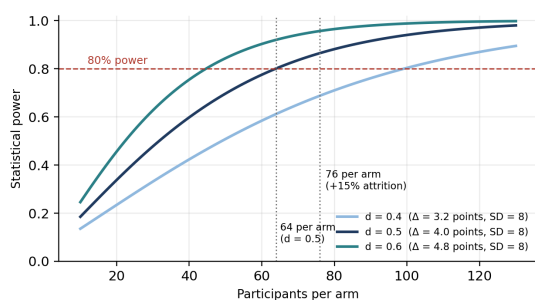


**Fig. 4.** Statistical power for a two-sample comparison of FES-I change at  $\alpha = 0.05$  (two-sided), for standardised effects of 0.4–0.6. Values were computed from the noncentral t distribution.

#### 4.7 Statistical analysis

All analyses will follow the intention-to-treat principle. The primary comparison will use analysis of covariance on T1 FES-I, adjusted for baseline FES-I and the stratification factor, with the between-group difference reported with a 95% confidence interval. Missing data will be handled by multiple imputation, with a sensitivity analysis using complete cases. Longitudinal outcomes (T1–T3) will be analysed with mixed-effects models. Falls will be analysed as counts using negative binomial regression with exposure time. Exploratory mediation analyses will test whether changes in Mini-BESTest or balance confidence account for changes in FES-I. Secondary analyses will not be adjusted for multiplicity and will be labelled exploratory.

#### 4.8 Ethics and safety

The trial would require approval from an institutional ethics committee and prospective registration in a public trial registry before enrolment. Surgeon clearance for full weight-bearing, harness use, a trained physiotherapist and an independent safety monitor are required. Adverse events, including any fall during training and any surgical-site problem, will be recorded and reported.

### 5. Anticipated Outcomes and Interpretation Framework

No participants have been enrolled and no trial data exist; accordingly no results are reported here. This section fixes hypotheses and interpretation rules in advance to limit bias when the trial is run.

#### 5.1 Hypotheses

- **H1 (primary):** at week 4, FES-I will be lower in the PBT arm than in the conventional balance training arm after adjustment for baseline.
- **H2:** balance confidence and Mini-BESTest will improve more with PBT, consistent with the motor-learning and mastery pathways in Fig. 2.
- **H3:** any fear reduction will be at least partly mediated by improved reactive balance or confidence rather than by attention or exercise alone.

- **H4:** PBT will be feasible and safe, with attendance of at least 80% of sessions and no serious training-related adverse events.

#### 5.2 Interpreting possible findings

A clinically important reduction in FES-I, together with adequate safety, would support PBT as an add-on to orthopaedic rehabilitation. A null result would be informative given the earlier null FES-I finding in older fallers [16], and would direct attention to dose, timing after surgery and participant selection. A transient early rise in FES-I would be consistent with the adverse pathway in Fig. 2 and would prompt review of progression and the fear-specific component. Effects will be judged against a pre-specified minimal important difference, not by statistical significance alone.

### 6. Discussion

#### 6.1 Why the question matters

Rehabilitation after hip fracture or arthroplasty relies on early, repeated mobilisation. FoF is associated with poorer rehabilitation outcomes [6] and with avoidance behaviour that promotes frailty [8]. A treatment that directly addresses both the physical and the psychological side of recovering from a loss of balance would therefore be attractive. PBT is especially interesting because it manufactures the exact experience patients dread, but under conditions in which success is likely.

#### 6.2 Relation to existing evidence

The proposed protocol is designed to respond to what earlier work suggests. The null FES-I result in older fallers [16] may reflect dose, population or outcome sensitivity; these possibilities cannot be separated from the available data, and the present protocol addresses them by raising the dose, selecting participants with at least moderate FoF, and using an attention-matched comparator. Selecting patients with elevated baseline concern also gives the primary outcome room to change. Delivery by therapist-applied perturbations keeps the programme feasible in services without a perturbation treadmill, which may matter in resource-limited settings [12].

#### 6.3 Limitations

This paper does not report primary data, and the evidence synthesis was narrative rather than systematic; relevant studies may have been missed and no formal quality appraisal was undertaken. The evidence for PBT comes mainly from community-dwelling older adults and neurological populations, so extrapolation to surgical patients is uncertain. Sample-size inputs are assumptions. Participants and therapists cannot be blinded, which may favour a more novel intervention. Follow-up to six months will not show whether FoF changes translate into fewer fractures or better long-term function.

### 7. Conclusion

Fear of falling is prevalent after lower-limb orthopaedic surgery and can slow recovery. Perturbation-based balance training offers a task-

specific way to improve reactive balance and, in theory, to build confidence through mastery and graded exposure, but direct evidence on fear of falling in surgical patients is lacking and the closest available trial did not show an effect on FES-I. The trial protocol presented here provides a rigorous, feasible route to answering the question. Until such evidence exists, PBT after orthopaedic surgery should be regarded as promising but unproven for reducing fear of falling.

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