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Systematic review

What is the effect of sensori-motor training on functional outcome and balance performance of patients' undergoing TKR? A systematic review

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Abstract

Objectives Total knee replacement (TKR) has a beneficial effect on patients' functional ability; however, incidence of falls and deficits on proprioception are not restored even 1-year after surgery. Early and intensive exercise post-TKR has received limited endorsement in the literature. The aim of this review was to systemically identify and critically appraise clinical studies investigating the effect of sensori-motor training on functional and balance performance in TKR patients.

Data sources The electronic databases Cochrane Library, MEDLINE, EMBASE, CINAHL, PEDro and the register of current controlled trials were searched up to September 2014.

Review methods Two independent reviewers used predefined inclusion and exclusion criteria to identify all eligible articles. Eligible articles were summarized and critically reviewed, using the PEDro scale.

Results Two hundred and seventy six articles were screened, six were included. The studies, presented the results of 409 patients (269 intervention, 140 control). A range of rehabilitation protocols were defined by components of proprioception, postural control, balance perturbation and coordination. All studies supported the use of sensori-motor training as an additional element in patients' rehabilitation protocols. Clinical performance-based tests (more than relevant patient-reported measures) showed that functional ability and balance were improved compared to controls. The robustness of evidence was compromised because most of the studies were underpowered.

Conclusions Limited robust (Ia) evidence supports the equal effectiveness of functional rehabilitation program as a functional rehabilitation enhanced with sensori-motor elements in patients post-TKR. However, dose-response parameters of exercise eliciting improvement warrant further investigation.

Keywords: Balance control; Balance training; Sensori-motor training; Proprioception training; Knee replacement; Systematic review

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Introduction

Approximately 60 to 80% of patients with osteoarthritis (OA) of the knee report knee instability, which affects sensori-motor and postural control, incidence of falls and ability to perform every-day life (ADL) activities [1–4]. Evidence from studies investigating the effect of total knee replacement (TKR), as a treatment to knee OA, showed gradual restoration of sensori-motor and functional abilities without however, reaching full recovery, even at 6-months postsurgery [5–11]. There is a 27% postsurgery reduction in patient' numbers exceeding cut-off criteria for falls-risk in the elderly (14 seconds, TUG test), indicating that falls-likelihood and restrictions to quality of life (QOL), is reduced but not eliminated [9–11].

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Studies investigating traditional 'cornerstones' of TKR recovery involving exercise programs with ROM and strengthening exercises, have shown small beneficial effects. Functional rehabilitation (exercises mimicking ADL mostly in weight-bearing positions) has shown better results, but the improvement has presented a plateau at 3 to 6 months [12,13]. Importantly, proprioception training demonstrated efficacy for balance performance in patients with OA of the knee [14,15]. Sensori-motor training has been found to improve proprioception, strength, and postural stability in lower extremity rehabilitation [3,15,16,20]. Balance and proprioception training has been characterized as sensori-motor training, first developed by Dr. Vladimir Janda, as part of a treatment approach to chronic musculoskeletal pain syndromes. Their role in rehabilitation is to challenge the sensori-motor system and restore normal motor programs. A recent systematic review investigating the effect of physical exercise after TKR included some of the studies with sensori-motor training [17]. The review showed that sensori-motor training could serve as a novel clinically appropriate rehabilitation refinement to traditional approaches in TKR patients [17]. Nevertheless, its dose-response characteristics, frequency and intensity/numbers of exercises have not been clarified.

A special form of therapeutic exercise designed to address, not only isolated strengthening of a group of muscles, but also enhances central nervous system (CNS). For example, function of the CNS in regulating movement in order to reach proper firing patterns for maintaining joint stability is characterized as sensori-motor training [18,19]. Sensori-motor training is thought to stimulate afferent information of joint sensors and therefore influence muscle activity and neuromuscular control scheme [18]. It is often used for the management of patients with chronic musculoskeletal pain syndromes and sports injuries [3,20,21]. Components of balance and proprioception usually include closed kinetic chain exercise aiming to challenge balance and knee stability such as retro-walking, side-walking, overcoming obstacles, exercise on wobble boards and generally weight-bearing tasks [3,21].

From the analysis of the available literature, it was evident that important questions, such as components of sensori-motor training added to the usual functional physiotherapy regime, timing of initiation, intensity/numbers of exercises and parameters influencing effectiveness, remained unanswered. The aim of the current systematic review was to analyze all published randomized controlled trials (RCTs) that have included sensori-motor components in TKR patients' physiotherapy rehabilitation program in order to assess the effect on physical function, performance tasks, pain relief and balance status. Moreover, potential answers in the aforementioned questions, such as the timing of when to best initiate such a program during the rehabilitation period, as well as the optimal frequency/number of balance exercises to be added to usual physiotherapy programs, was evaluated.

Methods

Search strategy

The electronic databases: the Cochrane Central Register of Controlled Trials (Cochrane Library), MEDLINE, EMBASE (via ProQuest), Biomed Central, Cinahl (via EBSCO host) and Physiotherapy Evidence Database (PEDro) were searched from 1995 to December 2014. The MEDLINE Mesh search strategy adopted for the study is displayed in Appendix I. Randomized controlled trials were only included if published in the English language. The reference lists of all eligible papers were also screened to identify any missing studies.

Eligibility criteria

Eligibility assessment was performed independently in a standardized manner and disagreements amongst reviewers were resolved by consensus. Therefore studies were included if they fulfilled the following five criteria:

1. Participants underwent primary TKR.
2. An exercise-based intervention incorporating sensori-motor components was involved compared or not with another therapeutic intervention, placebo or control.
3. Balance and/or functional performance was/were used as outcome measure/s.
4. Study design was a randomized design [22]
5. The full paper was published in the English language.

All cadaver or animal studies were excluded. Moreover, studies with samples involving patients with rheumatoid arthritis (RA) were excluded.

Study identification

Two evaluators independently selected the studies based on titles and abstracts, excluding those not related to the subject. The full text was obtained for all papers that were considered potentially relevant. Once collected, these were reviewed by both reviewers to determine if eligibility criteria were fulfilled. The studies finally included were analyzed according to a certain structure: author/year, sample, study design, assessment outcome measures, timeline, physiotherapy treatment, equipment and effects. Each reviewer assessed the methodological quality of the included studies independently using the PEDro criteria [23].

Critical appraisal

Studies were analyzed for methodological quality using the PEDro ten point scale [23] which assesses internal validity and interpretation of each trial.

Data analysis

In the first stage, the analysis involved a critical appraisal process of the studies according to the PEDro scale determining the methodological quality of the included studies (Table 1).

In the next stage, a descriptive review of studies incorporating a physiotherapy program with components of sensori-motor training in patients after TKR, was undertaken (Table 2).

All data extracted from the studies were analyzed independently by two reviewers (MM and RP) and were subsequently discussed. Disagreements were resolved by a third reviewer (NG).

Results

A total of 276 citations were identified from the search strategy, summarized in Fig. 1. In the initial search, 237 studies were excluded because the title, abstract or keywords did not match the proposed theme. Of the 39 that remained, nine were excluded due to the non-English language used, sample comorbidities such as RA and cadaver samples. Twenty studies were excluded as they had assessed balance and falls following a conventional physiotherapy program, but without incorporating sensori-motor training. Therefore six studies (five randomized controlled trials – RCTs – and one cohort study) were deemed eligible and were finally included in the review [23–30]. The results of the critical appraisal according to PEDro scale are presented in Table 1.

The quality of the studies was assessed in a first stage as although all studies satisfied a similar number of criteria for inclusion, their methodologies varied substantially.

Critical appraisal of studies' methodological quality

Table 2 presents critical appraisal of all studies (PEDro), except for the non-RCT study by Gauchard *et al.* [30]. All studies offered adequate robustness in methodology (PEDro: 5 to 7) with clearly defined research questions, population' characteristics and methods of assessing balance.

All included studies provided clear sampling descriptions (numbers, age, gender and pathology), acceptable recruitment methods and drop-out rates. A consistent limitation was that all, except for one study [29], had used experimental design sensitivity criteria to compute sample size' requirements. The studies by Liao *et al.* [28] and Gstoettner *et al.* [26] provided statistically significant improvement between groups in some of the outcome measures tested, without however, reporting effect sizes. The study by Piva *et al.* [27] was labeled as 'pilot', but lacked a significant treatment effect or had been underpowered. Similarly, the study by Fung *et al.* [25] offered high rates of retention of null-hypotheses (inflated type-II error).

Participants

Patients had primary OA (grade III–IV, Kellgren and Lawrence system) and fulfilled criteria to undergo TKR (same prosthesis; cemented; cruciate retention). The six studies included 409 subjects (269 randomized allocated to intervention; 140 to control group).

Outcome measures

All studies used validated measures [24] to assess balance despite the absence of 'gold standard' criteria. Parameters used were static or dynamic balance during either single or double leg stance, or during a functional task. Patient-reported outcomes including Activity-specific Balance Confidence Scale (ABCS) were used [25]. Sophisticated equipment (force plates; balance-platforms [Biodex stability system]) measuring postural sway, center of mass (COM) transference, bilateral dynamic stance [26], or center of pressure (COP), assessments of gait speed and function [WOMAC, Knee Society Score (KSS), Lower Extremity Functional Scale (LEFS), SF-36] [25–29], clinical functional outcomes Timed Up and Go test (TUG), functional reach test, single leg standing balance (SLSB), stair climb test [27,28], and dual platform posturography [30], were used.

Sensori-motor interventions

Piva *et al.* and Liao *et al.* [27,28], implemented conceptually similar protocols of functional exercise training, which had previously been tested for their effectiveness [16] in enhancing sensori-motor training [4,31,32]. Protocols involved 6- and 8-weeks' supervised programs. However, Liao *et al.*'s study [28] also entailed a subsequent 4-month home program. These two studies [27,28] as well as the study of Gstoettner *et al.* [26] focused on balance exercise training involving agility and perturbation techniques (side walking, cross-over steps, single leg standing). Other studies have used relevant balance exercise in an aquatic environment using float cuffs [29] or Nintendo Wii-fit game platform-based exercises to engage lateral weight shifting, multidirectional balance and static/dynamic postural control [24], using full weight-bearing functional and proprioception exercises, mimicking ADL [26–28,30].

Timing of initiation

Some studies have started implementing the sensori-motor training at least 2-months postoperatively, in order to ensure pain and effusion elimination [29,31,32], others incorporated sensori-motor elements within days of surgery using land or aquatics programs [33,34] or even, preoperatively [30]. Notably, all pre and postsurgery TKR interventions were tolerated well by patients, with no adverse effects reported.

Table 1
Description of studies including Sensori-motor training in TKR patients.

Study	Sample	Age	Intervention	Dose	Intensity progression	Setting	Start of program	End of program	Main outcome measures	Final follow-up	Results	Treatment effect
Fung *et al.* 2012 [25]	IG $n = 27$ (19F); CG $n = 23$ (14F)	68	IG: Strengthening exercise + Wii-Fit balance challenging; CG: Strengthening, posture-balance exercise	60 minutes + 15 minutes Wii fit frequency/duration (weeks) NS	Exercise progressed	Outpatient clinic-supervised	Average 37 days after surgery	Average 54 days after surgery	Active ROM; 2MWT; NPRS; LEFS; ABCS; LOR	Average 54 days after surgery	Significant difference only for LEFS between groups favoring IG	Medium ES for LEFS
Gauchard *et al.* 2010 [30]	IG $n = 20$ (16F); TKR_1 posturography at 17 to 20 days post-op; TKR_2 posturography at 34 to 41 days post-op. CG $n = 10$ (8F) healthy	IG: 70; CG: 68	IG: Passive/active mobilization, quadriceps exercise + proprioceptive gait and functional exercise; CG: no PT	34 to 41days frequency/dose NS	NS	Inpatient clinic-supervised	1st post-op day.	34 to 41days	Static and dynamic posturography, SOT	34 to 41 days	TKR_1 IG statistically significant lower static balance performance at 17-20days compared to CG; Similar dynamic, not static balance IG TKR_2 to CG, at 34 to 41 days	NS
Gstoettner *et al.* 2010 [26]	IG $n = 18$ (16F); CG $n = 20$ (14F)	IG: 73; CG: 67	IG: Proprioceptive training and walking, stretching; CG: NS	Daily for 45 minutes (15 minutes standard + 30 minutes proprioceptive)	Exercise progressed	Home-based program; supervised once a week at clinic	6 weeks pre-op	At time of TKR	Balance (bilateral stance), Gait Speed Timed Stair test, WOMAC, KSS	6 weeks after surgery	Stat significant difference in balance in TG, no difference in CG. Stat significant difference between groups favoring TG	Small
Liao *et al.* 2013 [28]	IG $n = 58$ (46F); CG $n = 55$ (37F)	IG: 73; CG: 71	IG: Functional + balance training; CG: Functional training	90 minutes (30 minutes functional + 60 minutes balance; frequency NS	Exercise progressed	Outpatient clinic-supervised	At least 2 months after surgery	8 weeks	FRT; SLST; 10MW; TUG, 30 SCR, WOMAC	8 weeks after start program	IG more significant effects on physical performance and WOMAC than CG	IG better 20% SLST; 18% gait speed; 13% WOMAC; 31% FRT; 9% TUG than CG
Liebs *et al.* 2012 [29]	IG $n = 66$; CG $n = 69$	IG: 68.5; CG: 70.9	IG: early aquatic therapy; CG: late aquatic ther. Aquatic (proprioception, coordination, strengthening) + PT program	3/week for 30 minutes balance + daily PT	NS	Clinic-based supervised	IG: 6th Post-op day; CG: 14th Post-op day	Up to 5 weeks	WOMAC; SF-36	24 months	Mean outcomes better in the TG. Not statistically significant. Clinical significant WOMAC 24m- 6.9 units (with a MICD = 5.3)	ES = 0.2 to 0.3 in WOMAC
Piva *et al.* 2010 [27]	IG $n = 18$ (13F); CG $n = 17$ (12F)	IG: 70; CG: 67	IG: Functional + balance training; CG: Functional training	12 sessions of 90 minutes (30 minutes functional, 60 minutes balance) + home based program for 4months (2/week)	Exercise progressed	Clinic-based supervised	2 to 4 months after surgery	6 weeks after start program	Gait speed; SLST, 10MWT; TUG, 30SCRT, WOMAC, LEFS	6 months	Clinically significant effects in gait speed, SLST, WOMAC stiffness and pain favoring IG	IG: 8% gait speed, 24% SLST

CG, control group; IG, intervention group; TKR, total knee replacement; NS, not stated.

Table 2
Description of studies including Sensori-motor training in TKR patients.

Study	Sample	Age	Intervention	Dose	Intensity progression	Setting	Start of program	End of program	Main outcome measures	Final follow-up	Results	Treatment effect
Fung *et al.* 2012 [25]	IG $n = 27$ (19F); CG $n = 23$ (14F)	68	I	60 minutes + 15 minutes Wii fit frequency/duration (weeks) NS	Exercise progressed	Outpatient clinic-supervised	Average 37 days after surgery	Average 54 days after surgery	Active ROM; 2 MWT; NPRS; LEFS; ABCS; LOR	Average 54 days after surgery	Significant difference only for LEFS between groups favoring IG	Medium ES for LEFS
Gauchard *et al.* 2010 [30]	IG $n = 20$ (16F); TKR$_1$ posturography at 17 to 20 days post-op; TKR$_2$ posturography at 34 to 41 days post-op. CG $n = 10$ (8F) healthy	IG: 70; CG: 68	IG: Passive/active mobilization, quadriceps exercise + proprioceptive gait and functional exercise; CG: no PT	34 to 41 days frequency/dose NS	NS	Inpatient clinic-supervised	1st post-op day.	34-41days	Static and dynamic posturography, SOT	34 to 41 days	TKR$_1$ IG statistically significant lower static balance performance at 17 to 20days compared to CG; Similar dynamic, not static balance IG TKR$_2$ to CG, at 34 to 41 days.	NS
Gstoettner *et al.* 2010 [26]	IG $n = 18$ (16F); CG $n = 20$ (14F)	IG: 73; CG: 67	IG: Proprioceptive training and walking, stretching; CG: NS	Daily for 45 minutes (15 minutes standard + 30 minutes proprioceptive)	Exercise progressed	Home-based program; supervised once a week at clinic	6weeks pre-op	At time of TKR	Balance (bilateral stance), Gait Speed Timed Stair test, WOMAC, KSS	6 weeks after surgery	Stat significant difference in balance in TG, no difference in CG. Stat significant difference between groups favoring TG	Small
Liao *et al.* 2013 [28]	IG $n = 58$ (46F); CG $n = 55$ (37F)	IG: 73; CG: 71	IG: Functional + balance training; CG: Functional training	90 minutes (30 minutes Functional + 60 minutes balance; Frequency NS	Exercise progressed	Outpatient clinic-supervised	At least 2 months after surgery	8 weeks	FRT; SLST; 10MW; TUG, 30 SCR, WOMAC	8 weeks after start program	IG more significant effects on physical performance and WOMAC than CG	IG better 20% SLST; 18% gait speed; 13% WOMAC; 31% FRT; 9% TUG than CG
Liebs *et al.* 2012 [29]	IG $n = 66$; CG $n = 69$	IG: 68.5; CG: 70.9	IG: early aquatic therapy; CG: late aquatic ther. Aquatic (proprioception, coordination, strengthening) + PT program	3/week for 30 minutes balance + daily PT	NS	Clinic-based supervised	IG: 6th Post-op day; CG: 14th post-op day	Up to 5 weeks	WOMAC; SF-36	24 months	Mean outcomes better in the TG. Not statistically significant. Clinical significant WOMAC 24m-6.9 units (with a MICD = 5.3)	ES = 0.2 to 0.3 in WOMAC
Piva *et al.* 2010 [27]	IG $n = 18$ (13F); CG $n = 17$ (12F)	IG: 70; CG: 67	IG: Functional + balance training; CG: Functional training	12 sessions of 90 minutes (30 minutes functional, 60 minutes balance) + home based program for 4 months (2/week)	Exercise progressed	Clinic-based supervised	2 to 4 months after surgery	6 weeks after start program	Gait speed; SLST, 10 MWT; TUG, 30 SCRT, WOMAC, LEFS	6 months	Clinically significant effects in gait speed, SLST, WOMAC stiffness and pain favoring IG	IG: 8% gait speed, 24% SLST

CG, control group; IG, intervention group; TKR, total knee replacement; NS, not stated.

Volume–duration of exercise

In the previously described studies by Piva *et al.* [27] and Liao *et al.* [28] that had shared a common format of delivery, the volume of exercise implemented in control and intervention groups was not equal, with the intervention group receiving 30 minutes more training in each session. By contrast, the study by Fung *et al.* [25] was iso-volumetric across groups but did not report the frequency of sessions undertaken by each group. Non iso-volumetric conditioning was noted in the study by Gstoettner *et al.* [27], in which the intervention group's training consisted of a 6-week, 6-session prehabilitation program (45 minutes session duration), which had not been matched with the program of the control group. Similarly, the study by Liebs *et al.* [29] reported earlier initiation (by several days) of post-TKR sensori-motor conditioning for the intervention group, compared to controls (6th vs 14th post-operative day). The time-line of each of the included studies, in terms of baseline measurement, intervention period and follow-up are presented in Fig. 2.

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Progression

Criteria for patients' progression (via re-assessment) were not detailed within the manuscripts. Progression for patients in the study by Fung *et al.* [25], that implemented sensori-motor training with the Wii-Fit, had been regulated according to similar exercises already performed successfully in physiotherapy treatment [25], without experiencing increased pain, effusion, giving away and decreases in ROM [23], or by clinical review of their capabilities [22]. In several studies [28–30], no progression was reported throughout the rehabilitation period.

Follow-up

Most of the studies followed-up patients for 2 to 6 months after surgery [25–28,30], apart from the study by Liebs *et al.* [29] that had followed-up patients for up to 2-years post-operatively.

Effects on pain and function

The study by Liebs *et al.* [29], showed that early compared to late initiation (6th vs 14th postoperative day) of aquatic sensori-motor training led to superior improvements in function and quality of life (mean scores in WOMAC at 2-year follow-up; and although these results were not statistically significant, they exceeded minimal clinical important criteria for WOMAC across publications. Liao *et al.* [28] showed statistically significant change in scores (between 36 and 50% in WOMAC and functional tests such as TUG, stair-climb test, functional reach test) for an 8-week program ($n = 113$) of the group with the additional balance exercises to functional training compared to functional training group alone. Over a shorter intervention (6-weeks), Piva *et al.* [26] in a study using the same intervention groups as the study by Liao *et al.* [28], yielded no statistical change in scores ($n = 43$). Similarly, Gstoettner *et al.* [26] showed no across group (proprioception training vs control group) differences on function (WOMAC and KSS) after prehabilitation but improvement across groups was shown after TKR. Fung *et al.* [25] showed equivalent improvement in pain and functional performance (Numeric Pain Rating Scale and LEFS) between the usual care group and the group with the additional Wii-Fit training 2-months after TKR.

Effects on balance

Augmentation with balance exercises elicited approximately 25% postsurgery improvements in SLSB compared to baseline [27,28], 15% gains in patients' balance confidence compared to controls [25], and statistically significant ($P = 0.045$) postsurgery gains in bipedal stance performance with prehabilitation compared to controls [26]. Posturographic testing in the study by Gauchard *et al.* [30] showed improvements ($P = 0.07$) similar to that of age-matched controls. In the open-eyes' condition of the dynamic tests s, although improvement did not reach statistical significance ($P = 0.07$), it was clearly more than that of controls, at 6-weeks post-TKR [30].

Discussion

Functionally intensive rehabilitation programs have elicited enhanced physical performance outcomes post-TKR [12,13], but deficits in movement control and balance remain [7–15]. In order to address these deficits exercise programs that include activities that challenge knee stability may be more appropriate [20,21]. Functional rehabilitation augmented by targeted sensori-motor conditioning (i.e. weight-bearing exercises involving twisting, changing direction, sudden start-stops, negotiation of unstable surfaces and obstacle) could potentially address these deficits and offer improved physical activity, postural control and prevent falls. Improving postural control and lowering falls-related injuries will reduce health-care costs. However, there is no available information on the costs associated with sensori-motor program replication or the cost-effectiveness of exercise programs aimed ta preventing falls in TKR patients. Results from this systematic review suggest that sensori-motor training induces equivalent improvement between intervention and control group [25,27], indicating that sensori-motor training is an acceptable adjunct to usual care in physiotherapy. The studies by Liao *et al.* [28] and Gstoettner *et al.* [26] favored sensori-motor training; both studies showed a greater effect of additional sensori-motor training on the usual care on these persisting deficits, bridging a potential gap in rehabilitation programs. Moreover, studies report sensori-motor conditioning interventions as a therapeutic means which is entertaining for patients [29], is independent of specialized equipment (e.g. Wii fit) and environment (e.g. land or water-based), has the capability of producing movements with less energy expenditure [6,32] and importantly, offers no adverse effects to patients in any study reviewed. Moreover, the inclusion of dynamic stabilization exercises and eyes-closed exercises was highlighted as important [30].

Exact mechanisms underpinning how TKR impacts on mechanoreceptors remains elusive. The reviewed studies suggested mild improvements in balance following TKR [26,28,30]. These kinds of additional sensori-motor interventions activate proprioceptors in the ankle and hip joint, as well as proprioceptors in muscular, tendon and ligament tissues (e.g. posterior cruciate ligament) at the knee, since articular proprioceptors have been resected during TKR. These improvements may also result from retensioned capsuloligament structures (e.g. collateral ligaments), reduced pain and inflammation in the knee joint following the surgery [29]. Moreover, gradual functional and sensori-motor training after TKR induces restoration to intra-sensory proprioceptive compensation either at knee or other joints (hip/ankle) [30]. Therefore, corrective compensatory strategies regulate better postural control through neuroplasticity, involving improved muscle activation synergies, movement patterns, joint torques and contact forces that are disturbed during OA degeneration [30,34]. As a result, sensori-motor training potentially influences central mechanisms and motor responses that promote physical function, and potentially sensory function and stability [34,35].

Observation studies have showed that muscle coordination and proprioception is deficient even 6-months after TKR [10,11,36]. Two-month postsurgery period was considered sufficient to avoid pain and effusion exacerbation for the safe initiation of sensori-motor training [25,27,28], and to have provoked no adverse effects. Therefore, given the clinically important results by the studies by Liebs, Piva and Liao [27–29], it can be understood that the initiation of sensori-motor training within the first 2-months post-surgery, is acceptable and essential. Thus, any compensatory protective strategies in proprioceptive and gait control, already learned and established in patients with knee OA, that had been associated with the pathway leading to TKR [1,2,31], would be eliminated. However, studies that had initiated programs early (6th day post-TKR) vs late (14th day) offered marginal patient-reported gains (WOMAC, medium effect size [29,30]. Interestingly, total hip replacement patients showed that early vs late training can give opposite outcomes compared to TKR patients, suggesting surgery-specific mechanisms of recovery [29]. The study by Gauchard *et al.* [30] investigated recovery of posturo-motor strategies post-TKR at two stages: firstly, after the elimination of pain and secondly, after a 6-week enhanced sensori-motor rehabilitation program (started within a few days after TKR), also showed that postural regulation (posturography analysis) required approximately 1-month to reach that of age-matched controls. Thus, a safe time for clinicians to initiate sensori-motor training seems to be within 2 weeks from TKR.

Regarding duration of the sensori-motor rehabilitation, most of the studies reviewed had implemented 6 to 8 week programs of supervised exercise (>1 session/week; 45 to 90 minutes). Nevertheless, optimal frequency, time and progression of dosage remain elusive due to methodological heterogeneity. Intervention groups in all studies offered improved functional and balance outcomes compared to controls when functional rehabilitation had been augmented with sensori-motor conditioning. No study had reflected an iso-volumetric comparison (between usual care and usual care enhanced with sensori-motor elements), hindering evaluation of any possible advantages by sensori-motor conditioning. Dose–response effects may therefore have been implicated in any gains that had been observed.

It was notable that patient-reported outcome measures (e.g. LEFS, ABCS, WOMAC) could not always detect the changes identified by objective functional and balance measures, such as TUG test and SLSB, known for their good clinimetric responsiveness and prognostic validity of falls-likelihood [25,27].

Underpinning the points for discussion in this review, was evidence from RCTs (except one [30]), offering Level Ia robustness (PEDro scale 5 to 7), sound methodologies and minimal patient' numbers lost-to-follow-up.

Limitations

This review has identified six studies investigating the effects of sensori-motor training when these are added to the physiotherapy regime post-TKR surgery. PEDro scoring suggested adequate robustness of methodological approaches in the five studies that were scored. Nevertheless, the experimental design of most studies was underpowered and had shunned iso-volumetric comparisons, precluding robust interpretation of the contribution of balance and proprioception conditioning, and also the generalization of outcomes. Heterogeneity of outcome measures, timing of conditioning initiation, and intensity/frequency of exercise, precluded meta-analytical approaches for the synthesis of evidence. Therefore, this systematic review offered novel qualitative data on the effect of sensori-motor training and speculation on its optimal implementation. The inclusion of only English language studies might have introduced bias, while the exclusion of patients (from the sample) with co-morbidities such as rheumatoid arthritis, limited the generalization of findings. All studies in this review offered critical discussion of findings, description of potential clinical impact, and contextualization within contemporary literature. However, although the sample recruitment and selection was acceptable, generalization of findings should be made with caution, and was only feasible in patients with knee OA undergoing primary TKR.

Conclusion

The review's findings provide encouraging qualitative data on the incorporation of sensori-motor training into the usual functional physiotherapy programs. This approach offers an acceptable and targeted intervention in improving functional performance and balance in patients after TKR. Sensori-motor training implemented for 6 to 8 weeks and initiated two weeks post-TKR, may be effective and tolerated well by patients, with no fear of adverse effects in physical function. However, a lack of acceptable effect size in some studies, combined with underpowered experimental designs, suggested both the possibility of either a lack of potency of intervention or a compromised capability to detect subtle gains that might have been offered by the intervention. Both aspects threaten what might be generalized from the findings in this population. Optimal intensity/frequency of exercise and criteria of progression warrant further investigation.

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Conflict of interest: No conflict of interest.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.physio.2015.11.001.

References

[1] Lytinen T, Liikavainio T, Bragge T, Hakkarainen M, Karialainen PA, Arokoski JP. Postural control and thigh muscle activity in men with knee osteoarthritis. J Electromyogr Kinesiol 2010;20(6):1066–74.

[2] Messier SP, Ryer TD, Craven TE, O'Toole ML, Burns R, Ettinger Jr WH. Long-term exercise and its effect on balance in older, osteoarthritic adults: results from the Fitness, Arthritis, and Seniors Trial (FAST). J Am Geriatr Soc 2000;48(2):131–8.

[3] Fitzgerald GK, Piva SR, Gil AB, Wisniewski SR, Oddis CV, Irrgang JJ. Agility and perturbation training techniques in exercise therapy for reducing pain and improving function in people with knee osteparthritis: a randomized control trial. Phys Ther 2011;91(4):452–69.

[4] Schmitt LC, Fitzgerald GK, Reisman AS, Rudolph KS. Instability, laxity, and physical function in patients with medial knee osteoarthritis. Phys Ther 2008;88:1506–16.

[5] Swanik CB, Scott LM, Harry EM. Proprioception, kinesthesia and balance after total knee arthroplasty with cruciate-retaining and posterior stabilized prostheses. J Bone Joint Surg Am 2004;86-A(2): 328–34.

[6] Viton JM, Atlani L, Mesure S, Massion JP, Franceshi JP, Delarque A, *et al.* Re-organisation of equilibrium and movement control strategies after total knee arthroplasty. J Rehabil Med 2002;34:12–9.

[7] Wada M, Kawahara H, Shimada S, Miyazaki T, Baba H. Joint proprioception before and after total knee arthroplasty. Clin Orthop Relat Res 2002;(403):161–7.

[8] Mandeville D, Osternig L, Chou LS. The effect of total knee replacement surgery on gait stability. Gait Posture 2008;27:103–9.

[9] Schwartz I, Kandel L, Sajina A, Litinezki D, Herman A, Mattan Y. Balance is an important predictive factor for quality of life and function after primary total knee replacement. J Bone Joint Surg Br 2012;94-B:782–6.

[10] Swinkels A, Newman J, Allain T. A prospective observational study of falling before and after knee replacement surgery. Age Ageing 2009;38:175–81.

[11] Swinkels A, Allain T. Physical performance tests, self-reported outcomes, and accidental falls before and after total knee arthroplasty: an exploratory study. Physiother Theory Pract 2013:1–11.

[12] Moffet H, Collet JP, Shapiro SH, Paradis G, Marquis F, Roy L. Effectiveness of intensive rehabilitation on functional ability and quality of life after first total knee arthroplasty: a single-blind randomized controlled trial. Arch Phys Med Rehabil 2004;85:546–56.

[13] Bade MJ, Stevens-Lapsley JE. Early high-intensity rehabilitation following total knee arthroplasty improves outcomes. J Orthop Sports Phys Ther 2011;41(12):923–41.

[14] Silva A, Serrao PR, Driusso P, Mattielo SM. The effects of therapeutic exercise on balance of women with knee osteoarthritis: a systematic review. Rev Bras Fisioter 2012;16(1):1–9.

[15] Mat S, Tan MP, Kamaruzzaman SB, Ng CT. Physical therapies for improving balance and reducing falls risk in osteoarthritis of the knee: a systematic review. Age Ageing 2015;44(January (1)):16–24.

[16] Pavlu D, Novosadova K. [Contribution to the objectivization of the method of sensorimotor training stimulation according to Janda and Vavrova with regard to evidence-based-practice]. Rehabil Phys Med 2001;8(4):178–81 [Translated from Czech].

[17] Pozzi F, Snyder-Mackler L, Zeni J. Physical exercise after knee arthroplasty: a systematic review of controlled trials. Eur J Phys Rehabil Med 2013;49(6):877–92.

[18] Riemann BL, Lephart SM. The sensorimotor system. Part I: The physiologic basis of functional joint stability. J Athlet Train 2002;37(1):71–9.

[19] Riemann BL, Lephart SM. The sensorimotor system. Part II: The role of proprioception in motor control and functional joint stability. J Athlet Train 2002;37(1):80–4.

[20] Zech A, Hubscher M, Vogt L, Banzer W, Hansel F, Pfeifer K. Neuromuscular training for rehabilitation of sports injuries: a systematic review. Med Sci Sports Exerc 2009;41(10):1831–41.

[21] Ahmed AF. Effect of sensorimotor training on balance in elderly patients with knee osteoarthritis. J Adv Res 2011;2:305–11.

[22] Supplementary guidance for authors undertaking reviews with the cochrane consumers and communication review group, p. 14. Available from: http://cccrg.cochrane.org/sites/cccrg.cochrane.org/files/uploads/Study_design_guide2013.pdf [updated June 2013, accessed 04.07.15].

[23] Pedro Physiotherapy Evidence Database. Available from: http://www.pedro.org.au/english/faq/#question_five [updated 3 July 2015, accessed 04.07.15].

[24] Sibley KM, Beauchamp MK, Van Ooteghem K, Straus SE, Jaglal SB. Using the systems framework for postural control to analyze the components of balance evaluated in standardized balance measures: a scoping review. Arch Phys Med Rehabil 2015;96(January (1)):122–32, e29.

[25] Fung V, Ho A, Shaffer J, Chung E, Gomez M. Use of Nintendo Wii Fit platfrom in the rehabilitation of outpatients following total knee replacement: a preliminary randomized controlled trial. Physiother 2012;98:183–8.

[26] Gstoettner M, Raschner C, Dirnberger E, Leimser H, Krisme M. Preoperative proprioceptive training in patients with total knee arthroplasty. Knee 2010;18(4):265–70.

[27] Piva SR, Gil AB, Almeida GJ, DiGioia AM, Levison T.J., Fitzgerald GK. A balance exercise program appears to improve function for patients with total knee arthroplasty: a randomized clinical trial. Phys Ther 2010;90(6):880–94.

[28] Liao C, Liou TH, Huang YY, Huang YC. Effects of balance training on functional outcome after total knee replacement in patients with knee osteoarthritis: a randomized controlled trial. Clin Rehabil 2013: 1–13.

[29] Liebs TR, Herzberg W, Rüther W, Haasters J, Russlies M, Hassenpflug J. Multi-center randomized controlled trial comparing early versus late aquatic therapy after hip and knee arthroplasty. Arch Phys Med Rehabil 2012;93:192–9.

[30] Gauchard GC, Vançon G, Meyer P, Mainard D, Perrin PP. On the role of knee joint in balance control and postural strategies: effects of total knee replacement in elderly subjects with knee osteoarthritis. Gait Posture 2010;32(2):155–60.

[31] Valtonen A, Pöyhönen T, Heinonen A, Sipilä S. Muscle deficits persist after unilateral knee replacement and have implications for rehabilitation. Phys Ther 2009;89(10):1072–9.

[32] Levinger P, Menz HB, Wee E, Feller JA, Barlett JR, Bergman NR. Physiological risk factors for falls in people with knee osteoarthritis before and early after knee replacement surgery. Knee Surg Sports Traumatol Arthrosc 2011;19:1082–9.

[33] Cho SD, Hwang CH. Improved single-limb balance after total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2012;21(12):2744–50.

[34] Ageberg E, Bjorkman A, Rosen B, Lundborg G, Roos E. Principles of brain plasticity in improving sensori-motor function of the knee and leg in healthy subjects: a double-blind randomized exploratory trial, 10; 2009. p. 99.

[35] Ageberg E. Consequences of a ligament injury on neuromuscular function and relevance to rehabilitation—using the anterior cruciate ligament-injured knee as model. J Electromyogr Kinesiol 2002;12(3):205–12.

[36] Bascuas I, Tejero M, Monleón S, Boza R, MunIesa JM, Belmonte R. Balance 1 year after TKA: correlation with clinical variables. Orthopedics 2013;36(1):6–12.

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