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REVIEW

# The global approach to rehabilitation following an osteoporotic fragility fracture: A review of the rehabilitation working group of the International Osteoporosis Foundation (IOF) committee of scientific advisors

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## Abstract

**Purpose** To conduct a review of the current state of the evidence for rehabilitation strategies post-fragility fracture.

**Methods** Narrative review conducted by the Rehabilitation Working Group of the International Osteoporosis Foundation Committee of Scientific Advisors characterizing the range of rehabilitation modalities instrumental for the management of fragility fractures.

**Results** Multi-modal exercise post-fragility fracture to the spine and hip is strongly recommended to reduce pain, improve physical function, and improve quality of life. Outpatient physiotherapy post-hip fracture has a stronger evidence base than outpatient physiotherapy post-vertebral fracture. Appropriate nutritional care after fragility fracture provides a large range of improvement in morbidity and mortality. Education increases understanding of osteoporosis which in turn increases utilization of other rehabilitation services. Education may improve other health outcomes such as pain and increase a patient's ability for self-advocacy.

**Conclusion** Rehabilitation interventions are inter-reliant, and research investigating the interaction of exercise, nutrition, and other multi-modal therapies may increase the relevance of rehabilitation research to clinical care.

**Keywords** Education · Exercise · Fracture · Nutrition · Osteoporosis · Rehabilitation

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## Introduction

Osteoporosis is characterized by low bone mineral density and changes in bone structure resulting in an increased risk of fracture [1]. Approximately 30% of all postmenopausal women are reported to have osteoporosis. Of these, 40% will have an osteoporotic fracture, also known as 'fragility fracture' or low-energy fracture [2]. At the age of 50, lifetime risk of fracture is 40 to 50% for women; i.e., 1 out of 2 women is at risk of experiencing a fracture during her remaining life time [3], whereas 1 out of 5 men will experience a fragility fracture [4]. Fragility fractures result from mechanical forces that would not ordinarily result in fracture; the amount of force is commonly described as equivalent to a fall from a standing height or less [3]. Fractures associated with osteoporosis occur most often in the hip, wrist, proximal humerus, or vertebrae, with worldwide annual estimates of 9 million fragility fractures [2]. Due to the high incidence, the economic impact worldwide is substantial with estimates of treatment costs at $17 Billion (2005 USD) per annum in the US [5] and €37 Billion (2010 Euro) [6]. With the global growth of the elderly population, the economic burden is estimated to increase.

Fragility fractures are associated with pain, loss of bone mineral density (BMD) and muscle mass, disability, reduced quality of life, increased risk of subsequent fracture, and death. Nearly 40% of individuals who fracture their hip will be institutionalized or unable to walk independently within the year, 60% will require assistance a year later [7], and approximately one in four will die within a year [8]. Twenty percent of women who have a vertebral fracture will have another within a year, and the risk of death of those with a vertebral fracture is 2.7 times higher than those without [9]. Within the first year of a fragility fracture at any location, the risk of a future fracture is greater than double the risk for matched controls, and the risk remains higher for 10 years [10].

Guidance for the prevention, management, and treatment of osteoporosis has been developed by multiple national and regional organizations, and international campaigns exist to reduce the morbidity and mortality associated with osteoporosis [3]. The treatment of individuals post-fracture is multi-factorial. Pharmaceutical agents are often considered the first line of treatment for osteoporosis because future fractures can be reduced by approximately 20–60% [3]. In addition to improving bone health through medication, future falls and fractures can be decreased by addressing other fracture risk factors, such as sarcopenia, frailty, low supply of dietary protein, poor muscle strength and power, inadequate dynamic balance, and environmental risks, such as safe walking environments [11]. Unfortunately, fracture management frequently does not include comprehensive fracture prevention strategies that integrate falls and fracture risk factors; however, it is of utmost importance to optimize clinician and patient engagement in fracture preventive services to decrease morbidity and mortality. Depending on the jurisdiction, multiple clinicians (physicians, rehabilitation specialists, psychologists, dietitians, etc.) and agencies (home care agencies, nursing homes) are responsible for management of adults at risk of falls and fracture. The aim of this paper therefore is to summarize the global state of the evidence for the rehabilitation of patients post-fragility fracture without cognitive impairment and to suggest directions for future research.

## Methods

Members of the Rehabilitation Working Group of the International Osteoporosis Foundation Committee of Scientific Advisors proposed to address the broad topic of rehabilitation as an instrumental component of the treatment pathway post-fragility fracture. The goal of this narrative review is to serve as an overview and resource for the clinician seeking to support the rehabilitation of patients post-fragility fracture. Narrative reviews are ideally suited to this task [12]. This narrative review was developed independently by the authors, with funding sources having no role in the writing or editing of this document. Where available, systematic reviews, meta-analyses, and randomized controlled trials have been used to provide the evidence base. Searches were conducted in PubMed limited to English-language literature and studies conducted in humans from 2010 to August 2020 with primary sources being meta-analyses and systematic reviews of the post-fragility fracture rehabilitation literature and more recent trials not summarized in these reviews. Separate searches were conducted in the areas of exercise, physiotherapy, nutritional care, and patient education post-hip, vertebral, humeral, or wrist fragility fracture. The authorship team also searched health system factors relevant for understanding the episode of rehabilitation post-incident fracture including care transitions and care pathways post-fragility fracture.

## Overview of assessment

All postmenopausal women and men age ≥ 50 should be evaluated for osteoporosis risk to determine the need for BMD testing and vertebral imaging [3]. In clinical practice, osteoporosis is usually diagnosed by the BMD criteria or the occurrence of a fragility fracture. International guidelines recommend a comprehensive approach to risk assessment and diagnosis of osteoporosis which includes most of the following: a detailed history and physical examination, BMD assessment, vertebral imaging for vertebral fractures, and 10-year estimated fracture probability [3]. The diagnosis of osteoporosis requires the consideration of secondary causes. Many causes of bone loss and fractures can be grouped in the following broad categories: (1) Failure to develop a strong skeleton (genetics, nutrition, lifestyle), 2) loss of bone due to excessive breakdown (resorption), (3) failure to replace lost bone due to impaired formation, and (4) increased risk for falls (environmental, medical, and neuromusculoskeletal risk factors).

### Domains and sub-domains of assessment

Increased risk for falls can be assessed by considering psychosocial-emotional (including cognition), physical function, nutrition, medication history, and environmental safety domains using a combination of subjective and objective assessments. An exhaustive review of assessment measures is beyond the scope of this review; however, we highlight several sub-domains to illustrate best practices. The psychosocial domain should include assessments of cognition, depression, fear, self-efficacy, and pain. Physical function is a broad concept that includes sub-domains of strength, balance, and endurance. In addition to individual assessment of sub-domains, physical function can be assessed through the successful completion of complex tasks such as activities of daily living. Nutrition can be screened through self-report, BMI measurement, food intake, blood biomarkers, and weight loss. Finally, measures of health-related quality of life can be used to describe a person's health status as represented on multiple domains that are central to overall health which can be specific to osteoporosis and its consequence or represent general concepts of wellbeing. Interested readers are directed to a comprehensive review on assessment of fall risk in primary care by Phelan et al. [13] for many of these concepts and to a Supplementary Appendix with examples of measures for use in domains and sub-domains listed above.

## Care pathways

Treatment for osteoporosis should reflect the whole patient because declines in intrinsic capacity and functional ability are risk factors for fractures beyond bone mass [11]. The typical experience of an older adult with an extremity fracture begins with an emergency department presentation for acute medical management. The continuum of care for rehabilitation post-fragility fracture is complex, and improvements from rehabilitation can be realized as far out as 9- and 12-month post-fracture [14]. Common transitions from acute care include acute rehabilitation centers and typically a form of post-acute rehabilitation including inpatient rehabilitation, outpatient rehabilitation, sub-acute nursing facilities, or discharge home with supportive services. The form of post-acute rehabilitation depends in part on social support and the capacity to perform various intensities of daily rehabilitation [15]. It is common for patients to never return to pre-fracture levels of function, and as falls risks remain high, a secondary role of rehabilitation is to prevent falls and fall-related fractures in the post-acute phase [14].

### Models to address secondary fractures

Secondary fractures and subsequent morbidity and mortality can be magnified by system-level problems. Different models have developed to address this problem, including orthogeriatric units and fracture liaison services [16]. These models of care are often limited to the coordination of inpatient services, and despite increased attention in the acute phase of care, delays in the initiation of rehabilitation exist and increase the risk for in-hospital mortality (OR 2.2, 95% CI 1.06–4.42, $p$ value 0.034) [17].

Well-organized national and international campaigns have created robust fracture liaison services, such as Capture the Fracture® (https://www.capturethefracture.org) [18], where great emphasis is placed on case identification, pharmaceutical management to strengthen bones, and falls risk identification and education to prevent subsequent fractures [19]. Fracture liaison programs have improved case identification and are associated with a decrease in future fractures. Though these programs often include falls risk assessment and education, a distinction should be made between the assessment of falls risk and education and initiating a comprehensive exercise or rehabilitation program. As suggested by age UK's 2013 falls prevention exercise guidelines, falls prevention exercise programs should be tailored to each patient's falls risk profile [20].

Below we review distinct elements of a comprehensive approach to post-fracture management including current evidence for exercise, physiotherapy, education, and nutrition.

## Exercise principles and characteristics

Many studies describe exercise programs for the treatment and prevention of osteoporosis and its complications. The characteristics and principles upon which exercise studies are based for improving BMD are briefly described in Table 1. Mechanical load induced by exercise produces stress upon bones and enhances bone formation [21]. Figure 1 illustrates the interrelationship of BMD and loading principles. Progressive resistance exercise, weight-bearing impact training, and functional balance training are commonly prescribed modes of osteogenic exercise with

**Table 1** Loading characteristics and training principles to optimize bone health

| Key considerations | Description | Example |
|---|---|---|
| Loading characteristics | • Dynamic > static loads<br>• High intensity – function of strain (magnitude of deformation and frequency of loading)<br>• Diverse load patterns<br>• Rest intervals | • Drop landings > static stretching<br>80–85% 1RM, high velocity<br>• Multi-directional loading patterns<br>• 1–2-min rests between sets |
| Specificity | Bone adaptation to loading is specific to the site under mechanical strain | High impact jumping improves BMD at proximal femur, but not lumbar spine |
| Progressive overload | Bone has a threshold level of adaptation, loads (strains) above this level will stimulate bone formation | The threshold value for osteogenic overload is proposed at around (1500 micro strains), but it varies by individual and between bone regions<br>Shifting from habitual walking ~ 4 km/h (~ 2.5 mph/h) to brisk walking 5–6 km/h (3–4 mph/h) |
| Reversibility | Bone formation resulting from exercise training will be slowly lost once the stimulus is discontinued | Reduction in physical activity is associated with bone loss |
| Initial Values | Greatest changes in BMD will occur in those with the lowest initial BMD* | Starting with lower BMD values produces greater improvement hip BMD |
| Diminished Returns | Bone cells will respond strongly to a given load with sufficient magnitude, but response will eventually phase out with accommodation to the load | Bone loses more mechanosensitivity after only a relatively small number of loading cycles, ~ 20 |

*If relative intensity or pattern of loading is of a sufficient magnitude and rate or differs from everyday movement patterns, then bones should adapt accordingly, regardless of the initial values

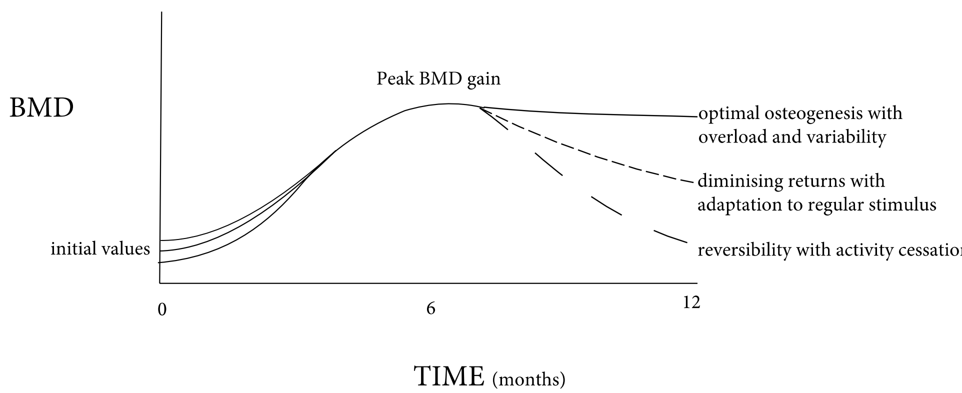


**Fig. 1** Illustration of exercise principles in relation to exercise induced gains in BMD

resistance exercise and impact training promoting the greatest bone formation.

Table 2 suggests general recommendations for osteogenic exercise prescription. It should be noted that the majority of evidence supporting these recommendations has been developed in a pre-fragility fracture population [22]; however, these criteria are being increasing applied to post-fracture populations with growing evidence for their principled use post-fracture [23]. Clinicians should consider applying these principles in the post-fragility fracture population, emphasizing correct technique, gradual loading increments, and avoidance of activities that might increase falls [24]. All clinicians prescribing exercise programs should consider the potential to load too aggressively increasing the likelihood of fracture [25]. All patients post-fragility fracture require initial focus at the level of transfer and mobility impairments prior to weight-bearing and standing balance activities. Slow progress or plateaus in rehabilitation [14] can be considered against meaningful exercise progression as suggested by these principles.

## Exercise post-fragility fracture of the vertebra

Individuals with vertebral fractures may have a number of challenges including kyphosis, alterations in trunk muscle control, and pain which affects their participation in exercise, daily activities, and reduces quality of life. Randomized controlled trials (RCT) and meta-analyses have demonstrated that exercise improves quality of life, reduces pain, and improves physical function

**Table 2** Exercise parameters for managing patients at high risk of fragility fracture

| Training type | Dose | Recommendations | Precautions |
|---|---|---|---|
| Progressive resistance training | • ≥ 2 days/ week<br>• ≥ 2 sets of 8–12 repetitions<br>• 1–3-min rest between sets<br>• ≥ 8 exercises targeting major muscle groups and common fracture sites | • Slow progression with emphasis on correct lifting technique | • Consider vulnerable tissue when training, e.g., the rotator cuff with overhead lifting<br>• Use caution with trunk bending or twisting for patients with low spine BMD |
| Weight-bearing impact training | • 4–7 times per week<br>• 5–50 jumps per session (Build capacity over time)<br>• 5 sets<br>• 1–10 repetitions<br>• 1–2-min rest between sets | • Increase jump and step height<br>• Change movement direction | • Consider comorbid conditions affected by impact exercises, e.g., patients with incontinence or arthritic joint pain |
| Functional balance, agility, and coordination training | • 30 min, 4 times/week<br>• Examples include weight shifting, single leg balance, turning and stepping on and over objects. Can manipulate vision, speed, direction, multi-limb movements and cognitive tasks | • Must be progressive, challenging and supervised | • Start with static and progress to dynamic balance for patients with impaired balance or with high risk of fracture |

Adapted suggested exercises from Beck et al. [24] and Daly et al. [22]

post-vertebral fractures [26]. However, the quality of the evidence is low, and little research exists for the effect of exercise in men with vertebral fractures [26].

## International recommendations/guidelines

Clinicians often prescribe walking as a weight-bearing exercise for individuals with fractures; however, this does not specifically target vertebral BMD and risk for fracture. The Too Fit To Fracture recommendations [26] have stressed the importance of individuals with vertebral fractures to engage in a multi-component exercise program, including resistance training and balance training. A number of online resources are available; examples include those available at www.iofbonehealth.org and www.osteoporosis.ca. Due to the importance of a broad assessment of movement related impairments, a large international consensus has recommended that physical therapist consultations guide exercise prescription after a vertebral fracture, particularly for those with multiple vertebral fractures. Other recommendations include teaching of spine sparing techniques and daily balance training as well as endurance training for spinal extensors. Activities that involve rapid, repetitive, weighted, or end-range twisting or flexion of the spine, or that have high fall risk should be avoided; and the benefits from higher impact exercise may be outweighed by the risks of further injury [26].

## Supervised exercise

A recent single-blinded RCT including women with a vertebral fracture focused on investigating the effects of a multi-component balance and resistance training program on walking speed as a primary outcome with secondary outcomes focused on quality of life, fear of falling, and other functional outcomes [27, 28]. A physiotherapist led a group of 8 to 10 women twice weekly for an hour for a total of 12 weeks. No statistically significant differences in walking speed were found, but significant improvements were found across all other functional outcomes [27, 28].

In a recent three-arm RCT including post-menopausal women with vertebral fracture, investigators compared a supervised program of back strengthening versus home-based program of back strengthening versus control. Groups of five participants under "full supervision of physiatrist" completed trunk extension exercises three times per week and performed 3 sets of 8 repetitions in weeks 1–2 and increasing by two repetitions at 2-week intervals until study completion at 6 weeks. The supervised exercise group had significantly lower spinal pain, greater muscle strength and endurance, and improved functional mobility and quality of life relative to home-based exercise program and control ($p < 0.01$) [29].

### Home-based exercise

Few controlled trials have investigated home-based programs since the Too Fit To Fracture recommendations. A large feasibility multi-site RCT was undertaken to address the ability to recruit individuals with vertebral fracture and adherence to exercise. The build better bones (B3E) trial was a home-based exercise intervention that included resistance, balance, and posture exercises, and recommendations to perform daily moderate to vigorous aerobic physical activity for a minimum of 30 min on a daily basis over 12 months supervised by a physiotherapist (six visits). Typical prescriptions were 5–8 exercises with a minimum of 2 sets of 8–10 repetitions. Adherence to the intervention was 66% with falls and fractures not significantly different between groups [30].

A recent Cochrane review [31] found insufficient evidence for the effects of exercise on incident vertebral fractures or adverse events. Despite improvement in pain and disease-specific quality of life in individual trials, the findings were limited by low-quality evidence and imprecision [31]. Recommendations for future research include exercise interventions in males as few male participants have been included in trials to date.

## Exercise post-fragility fracture of the hip

The main causes of morbidity post-fracture are a result of decreased mobility, impaired balance, and fear of falling [32], resulting in an increased risk of falls. Altogether, these causes prevent approximately 40% of older people from returning to pre-fracture daily activity, which are required for independence and safety [7]. The recuperation time of pre-fracture skills and capabilities can last up to 9 months for balance deficits and approximately 1 year for gait and walking speed. Exercise programs seek to address impairments related to mobility loss and reduced function.

## Intervention programs

### Supervised exercise

Systematic reviews and meta-analyses of progressive resistance exercise [33], balance training [34–36], and structured exercise [37] interventions all show moderate to large improvements in physical function compared with control groups in people post-hip fracture. Consistent with expectations from exercise training principles, structured exercise trials focusing on progressive resistance exercises had larger treatment effects on overall mobility (SMD = 0.58, 95% CI 0.17 to 0.98, $p = 0.008$) [37], and balance training at high frequency was more effective for improving overall function than balance training at low frequency [35]. The LIFTMOR randomized trial is notable for including 28% of participants with a history of osteoporotic fracture when assessing a high intensity resistance training and impact training program, though exclusion criteria prohibited participation within the first year of fracture [38]. Impact loading consisted of jumping chin-ups with drop landings where participants were instructed to jump "as high as possible while simultaneously pulling themselves as high as possible with their arms. At the peak of the jump, the participant dropped to the floor, focusing on landing as heavily as comfortably possible." The study participants performed 30 min of exercise, twice weekly for 8 months. Relative to control, the high intensity and impact training group showed significant improvements in bone mass, femoral neck geometry, and physical function and reported no major adverse events. Auais, Eilayyan, and May performed a systematic review and meta-analysis on exercise programs that were longer-term or "extended" relative to traditional rehabilitation post-hip fracture and found a moderate improvement on physical performance-based tests (ES = 0.53, 95% CI = 0.27–0.78) [39].

### Home-based exercise

Reviews of home-based exercise interventions show mixed results [34, 40, 41]. Two meta-analyses report mean improvement in function, and a third reported no difference using home-based exercise programs. Latham et al. showed significant, between-group improvements in performance-based and self-reported function at 9-month follow-up when adding a home exercise program to conventional rehabilitation relative to rehabilitation care alone [42].

Despite overall positive effects of exercise interventions, trials tend to be relatively small. and exercises are poorly described [33, 34] making reproducibility difficult. Exercise interventions are important tools in recovery post-fracture. We recommend clearer reporting and improving the research base of studies investigating exercise parameters on future falls, physical function, and bone formation post-fragility fracture, administered at different points in the post-operative continuum of care.

## Physiotherapy post-fragility fracture

Physiotherapists employ a variety of strategies post-fragility fracture in addition to exercise including functional mobilization, transfer training, safety training, patient education, postural taping, manual therapy, and use of assistive devices [43, 44]. To avoid duplication of previous sections focusing on exercise, this section highlights investigations of physiotherapy related to dosage, intensity, or multi-modal physiotherapy interventions that employ non-exercise modalities used in rehabilitation.

## Dosage, intensity, and setting

High intensity physiotherapy for patients post-hip fracture has shown mixed results and has been defined in varying ways in the literature [45, 46]. Kimmel et al. investigated the effect of three daily physiotherapy, 30-min visits versus one daily 30-min visit in acute rehabilitation. The intervention group experienced a significant improvement in level of assistance required ($p = 0.04$) and reduced hospital stay by over 10 hospital days [45]. Moseley, et al. [46] randomized individuals post-hip fracture to high intensity versus low intensity physiotherapy. The intervention began in the inpatient setting and progressed to the outpatient setting. No differences were found in the primary outcomes of walking speed or muscle strength; however, the main difference between high intensity and low intensity groups in the inpatient phase was time spent in treadmill walking, and the total difference between groups in the outpatient phase was a median of 4 days [46]. Physiotherapy services are administered in multiple settings, and no strong consensus exists for outpatient versus home setting in the management of hip [47] or wrist fracture [48].

## Behavioral approaches

Multi-disciplinary rehabilitation programs have included behavioral approaches within the context of physiotherapy, such as the use of counselling sessions [49], workbooks and goal setting [50, 51], motivational interviewing [52], and cognitive behavioral therapy [53]. In these examples, behavioral approaches were employed to support patient self-management [49–52] and decrease fear of falling [51, 53]. The motivational interviewing intervention increased objective physical activity versus usual care [52], and the psychologically-informed rehabilitation program improved patient participation (primary outcome) [51]. Unfortunately, no other approach showed significant differences in their main analyses. However, secondary analyses of physiotherapy employing counselling sessions increased physical activity [54] and improvements in physical disability [55] at 1-year follow-up.

## Manual therapy, taping, and orthoses

Few studies have investigated the use of taping modalities and manual therapy in the post-fragility fracture population. Bennell et al. conducted a single blind, randomized controlled pilot trial assessing taping, manual therapy (soft tissue massage and joint mobilization), and exercise versus control in people with a history of painful vertebral fracture. Significant improvements were found in pain during movement and at rest and in physical function, quality of life questionnaire (QUALEFFO) physical function ($-4.8$ ($-9.2$ to $-0.5$)) and the timed loaded standing test (46.7 (16.1 to 77.3) s) [56]. Barker et al. published an adaptive single-blinded randomized controlled trial assessing exercise therapy versus manual therapy approaches [57]. Participants were included if they had a diagnosis of primary osteoporosis, at least one previous vertebral fracture, with the ability to walk at least 10 m independently. This three-arm trial assessed seven individual physiotherapy sessions over 12 weeks for either manual therapy or home exercise versus one session of physiotherapist delivered education. At 4 months, significant improvements over education were found in the manual therapy and exercise groups, respectively, for the time loaded standing endurance test and functional reach test, but these improvements did not persist to 1-year follow-up [57]. The study suffered from low adherence to protocol: only 60% of exercise sessions and approximately 70% of manual therapy sessions were attended, and only 40% and 50% of the exercise and manual therapy groups fully complied with the protocol. Additionally, 25% of education participants engaged in therapy outside of the trial [57].

Rehabilitation often includes coordinated assistive device management to support limited mobility. Assistive devices can serve as short-term or long-term measures of improving balance, activity level, and overall independence depending on potential for functional recovery. Key considerations in prescribing assistive devices are to prevent further complications by appropriately fitting the device to the patient and providing proper education and assessment of understanding for their use [58]. As instruments in the rehabilitation process, systematic reviews have investigated the use of spinal orthoses for vertebral osteoporosis including strategies assessed post-vertebral fracture [59]. Few studies have compared spinal orthoses with usual care despite their common use in clinical management. Spinal orthoses appear safe as a means to treat acute and sub-acute vertebral fracture, but there is no clear evidence of superiority for rigid versus soft braces [59]. A recent multi-center, RCT compared soft versus rigid bracing strategies with acute vertebral fracture and found no difference in anterior vertebral body compression at 48 weeks [60]. A recent feasibility study of taping relative to usual care showed a promising reduction in pain and improvement in function and quality of life [61].

Most reviews assessing the effects of physiotherapy report low quality of evidence mainly due to high risks of bias and small sample sizes. Several interventions currently used by physiotherapists have not been properly evaluated and warrant future randomized trials including orthoses, taping, and manual therapy. It is recommended that investigators of physiotherapy seek to identify optimal combinations of interventions, modalities, dosage, and setting.

## Fall prevention programs post-fragility fracture

Fall prevention programs for community dwelling older adults are effective at reducing falls, hospitalizations, and associated medical costs [62] and are recommended for community implementation to improve public health [63]. Fall prevention programs typically include multi-modal exercise approaches and may include behavioral strategies and other forms of task training, such as transferring from the floor to upright stance [62]. Many of the components of falls programs have been described in previous sections of this paper; however, Tai Chi as a movement warrants further description given its popularity as a falls prevention intervention. Tai Chi was developed over 300 years ago in China, beginning as a form of martial arts, but today is mostly employed as a mind–body practice with three basic components: (1) body position should be extended and relaxed, focusing on awareness and alignment; (2) the mind should be alert but calm, increasing awareness of bodily movement in space; and (3) body movements require coordinated sequencing of segments from trunk and hips to extremities [64]. Tai Chi has been shown to be effective for decreasing falls in older adults [62]. Unfortunately, few fall prevention programs have been explicitly studied in the post-fragility fracture population with future fractures reported as an outcome. Likewise, despite evidence as a means to decrease falls in community dwelling older adults, little evidence exists for the use of Tai Chi in patients post-fragility fracture, and there are mixed results as a means to improve bone health [65].

## Nutritional care post-fragility fracture

Malnutrition, in particular protein and caloric under-nutrition, are considered fracture risks by impairing muscle strength and function, thereby increasing the risk of falling. Compromised bone strength results in increased bone fragility and reduced soft tissue protection around the hip [66]. Malnutrition can also negatively influence fracture healing (mostly in animal studies) and rehabilitation by slowing down independence restoration, which increases risk of complications and disabilities and increases the risk of subsequent fracture.

## Nutritional status

Pre-fracture nutritional status is predictive of functional status at discharge, of admission into nursing homes at 6 months [67], and of mortality at 6 months [68] and later [68, 69]. Mortality is increased more than twofold with malnutrition in patients with hip fracture [70]. The prevalence of malnutrition using weight loss, food intake, and BMI-based instruments depends on the age of the patients and the type of fracture. In patients attending a trauma ward, and with a mean age of 55 years, malnutrition prevalence was around 20% [71]. Prevalence increases to 40% in 65 years and older patients in an orthopedic clinic and more than 85% in elderly patients with hip fracture when both malnourished and at risk of malnutrition are analyzed together [68].

## Nutritional interventions (dietary, supplements)

Controlled trials, which have investigated the influence of nutritional intervention after fracture (Table 3), include dietary counselling [72, 73], energy [74–76], protein supplements [77–87] such as casein or whey protein based [88], or protein enriched with hydroxymethyl butyrate, a metabolite of the amino acid leucine which has been shown to favorably influence muscle function by acting on the target of rapamycin (TOR) enzyme [89, 90]. In a small pilot trial, essential amino acids were evaluated [91]. The doses of protein were between 17 and 40 g/day, correcting or overcoming protein intake deficiency. It appears that muscle protein synthesis requires more substrate in old as compared with young individuals [66]. Under these conditions, higher amounts of protein are recommended in older subjects, from a recommended daily allowance of 0.8 /kg body weight to up to 1.3–1.5, in situations of stress or inflammation, where the needs are higher. Indeed, the PROT-AGE study group recommends 1.0 to 1.2 g protein per kilogram of body weight per day to help older adults maintain and regain lean body mass and function, and ≥ 1.2 g/kg body weight/day is recommended for older adults who are exercising, and 1.2–1.5 g/kg body weight/day is recommended for those with chronic disease[92].

## Dietary/supplements intervention post-fragility fracture

Protein supplements increase insulin-like growth factor, IGF-I [79], which is considered as a marker of malnutrition. By 4 weeks of supplementation, it appears that maximal effects could be reached [93]. Regarding trials with clinically relevant outcomes, the trials have included hip fractured patients with a mean age above 80 years, representing thereby typical hip fractured patients. The number of patients varied between 23 and 420, with durations between 1 week and 12 months (Table 3). Some studies have shown a decrease in medical complications [77, 78, 80, 84] such as

**Table 3** Effects of nutritional supplements on clinical outcomes after hip fracture (selected controlled trials)

| Author year (ref) | *N* mean age | Duration (months) | Supplements | Outcome |
|---|---|---|---|---|
| Delmi, 1990 [77] | 59, 81.6 years | 1 | Prot 20 g/day<br>254 kcal/day | Complications: 16 vs 37% (6 Mo)<br>Median LoS: – 40%<br>Mortality: 24 vs 37% (6 Mo) |
| Tkatch, 1992 [78] | 62, 82 years | 1.3 | Prot 20 g/day | Complications and deaths: 52 vs 80% (7 Mo)<br>Median Los: – 32% |
| Schürch, 1998 [79] | 82, 80.7 years | 6 | Prot 20 g/day | LoS (Rehab.): – 39%<br>∂ Femoral neck BMD: 2.4% (12 Mo)<br>∂ IGF-I: 51% (6 Mo) |
| Espaulella, 2000 [80] | 171, 82.6 years | 2 | Prot 20 g/day | Complications (6 Mo): 55 vs 70% (in-hospital and at 6 Mo) |
| Houwing, 2003 [81] | 103, 81.0 years | 1 | Prot 40 g/day<br>500 kcal/day | Pressure ulcers stage II: – 9% |
| Sullivan, 2004 [74] | 57, 79.0 years | 6 | 1375 kcal/d<br>nasogatric, orally | No ∂ complications nor mortality |
| Tidermark, 2004 [82] | 60, 82.9 years | 12 | Prot 20 g/day<br>200 kcal/day | ∂ ADL (6Mo) |
| Hommel, 2007 [75] | 420, 81.0 years | 0.3 | 250 kcal/day | Pressure ulcers: 9 vs 18.6% |
| Tengstrand, 2007 [83] | 60, 82.9 years | 6 | Prot 20 g/day | ∂ BMD (12 Mo) |
| Gunnarsson, 2009 [76] | 100, 81.0 years | 0.17 | 30 kcal/kg/day<br>Nasogastric | Pressure ulcers: 18 vs 36% |
| Botella-Carretero, 2010 [84] | 60, 83.6 years | 0.33 | Prot 40 g/day | Complications: – 7.5% |
| Myint, 2013 [85] | 121, 81.3 years | 1 | Prot + 18–24 g/d ay | Maintained body mass index<br>Infections: – 52%<br>LoS: – 13% |
| Li, 2013 [73] | 162, 78.2 years | 12 | Diet counselling | Better ADL and walking capacity |
| Flodin, 2015 [86] | 79, 81.0 years | 6 | Prot 40 g/day<br>600 kcal/day | No ∂ in lean mass nor EQ-5D |
| Ekinci, 2016 [89] | 62, 82.6 years | 1 | Prot 36 g/day<br>HBM 3 g/day | Shorter wound healing period<br>Mobility: 81 vs 27% (1 Mo)<br>Higher muscle strength |
| Niitsu, 2016 [88] | 38, 79.7 years | 0.5 | Whey prot 32.2 g/day | Higher lower limbs muscle strength<br>Better Barthel index |
| Malafarina, 2017 [90] | 107, 85.4 years | 1.5 | Prot 40 g/day<br>HBM 3.1 g/day | Maintained body weight and appendicular lean mass |
| Wyers, 2018 [87] | 152, 78.5 years | 3 | Prot 40 g/day<br>500 kcal /day | No ∂ in LoS nor in clinical outcomes |
| Invernizzi, 2018 [91] | 32, 79.0 years | 2 | EAA 8 g/day | No ∂ in functional outcomes (grip strength, time-up, and go test) |

*ADL* activities of daily living; *BMD* bone mineral density; *EAA* essential amino acids; *EQ-5D* EuroQol instrument for quality of life evaluation; *IGF-I* insulin-like growth factor; *LoS* length of stay

fewer pressure ulcers and shorter wound healing times [75, 76, 81], fewer infections [85], reduced length of stay [77–79, 85], lower mortality [77, 78], a preservation of BMD [79, 83], improvements in ADLs [82], and better muscle function [73]. The results are heterogeneous with a low consistency, likely in relation to the small number of patients in some trials, different follow-up durations, variability in outcomes, and differences in interventions. The effects of nutritional supplements in hip fractured patients have been evaluated in 2 meta-analyses including different numbers of studies (Table 4) [94, 95]. Medical complications, wound, respiratory, and urinary infections were significantly reduced [94], as well as overall unfavorable outcomes including both deaths and medical complications [95].

## Fracture liaison services (FLS) support nutritional management

To manage the correction of malnutrition in fractured patients, a critical pathway aimed at detecting malnutrition and offering re-nutrition either through dietary changes or supplements should be a full part of fracture liaison services, not only to improve short- and middle-term rehabilitation

**Table 4** The role of perioperative oral nutritional supplementation in elderly patients after hip surgery

| Ref | Outcome | Trials (*n*) | Oral nutritional supplements (*n*) | Controls (*n*) | Relative risk with oral nutritional supplements | 95% CI |
|---|---|---|---|---|---|---|
| [94] | Complications* (e.g. all infections, bed sores, cardiac disease, cognitive impairment) | 6 | 55/220 | 97/243 | 0.49 | 0.32–0.73 |
| | Wound infection" | 3 | 1/97 | 10/102 | 0.17 | 0.04–0.79 |
| | Respiratory infection" | 3 | 2/100 | 10/100 | 0.26 | 0.07–0.94 |
| | Urinary infection" | 3 | 2/100 | 10/100 | 0.22 | 0.05–0.90 |
| | Mortality* | 5 | 35/198 | 39/218 | 1.02 | 0.62–1.70 |
| [95] | Mortality* | 15 | 24/486 | 31/82 | 0.81 | 0.49–1.31 |
| | Complications* (pressure sore, infections, venous thrombosis, pulmonary embolism, confusion) | 11 | 157/367 | 123/370 | 0.71 | 0.59–0.86 |
| | Unfavorable outcome* (deaths or complications) | 6 | 58/176 | 67/158 | 0.67 | 0.51–0.89 |
| | GI side effects** (vomiting and diarrhea) | 6 | 18/231 | 11/211 | 0.99 | 0.47–2.05 |

*Follow-up: 1–12 months. "Follow-up: 1 month or until hospital discharge. **Follow-up: during supplementation period

outcomes, but also as an integrated component of secondary fracture prevention [18, 19, 96]. Future investigations in the role of nutritional management within FLS are encouraged.

## Patient education

Patient education is a recognized component to the management of many chronic diseases, and its role in post-fracture management has been reviewed in two systematic reviews [97, 98]. In the first, published in 2014 by Jensen and colleagues [97], the authors report on the results of 7 studies (2 observational studies and 5 randomized controlled trials) published between 1993 and 2011 that included patients with osteoporosis with or without fractures who were involved in group education packages. There was good geographic representation, with studies originating from Europe (*n*-=3), North America (*n*=3), and Australia (*n*=1). Participants were recruited from outpatient clinics (*n*=5), a retirement community (*n*=1), and an emergency department (*n*=1). The sample size of each study ranged from 50 to 300 participants; 849 women but only 74 men were recruited. Group sizes, where stated, ranged from 4 to 20 individuals; programs lasted from 5 to 27 h, running 1–2 times per week for 4–5 weeks, with the number of educators ranging from 1 to 4.

The content of the schemes was similar, and consisted of three overall themes: knowledge of osteoporosis, medication, and diet and exercise. Activities of daily living, pain management, and fall prevention also were featured in some. In five of the included studies, theories of empowerment, self-management, action planning, self-efficacy, and coping were used. Heterogeneity in the outcome measures used made overall assessment challenging, but the authors concluded that multi-faceted osteoporosis group education can increase a patients' knowledge of osteoporosis, health-related quality of life, physical activity, and psychosocial functioning, and may also be a way to increase adherence to both pharmacological and non-pharmacological treatments, as it was reported that participants who attended a four-session group adhered better to medication subsequently, although calcium intake was no different between the two groups. There was also some evidence of benefit with regard to pain and physical activity outcomes. Interestingly, only two studies considered knowledge as an outcome, and in both cases, this improved with education. Hence, in this review, there was evidence of benefit in group education sessions, but varying methodology made it difficult to synthesize evidence, and the few data available in men was a significant limitation. Qualitative studies were excluded from this report, but their potential contribution to the topic was acknowledged.

In the second more recent systematic review by Morfeld and colleagues [98], limitations of methodology were highlighted, with the need for further research acknowledged. They reviewed randomized controlled trials published between 2001 and 2013, identifying 15 articles (of 13 studies), that included 7 considering group-based education, 5 that considered individual education and one that considered both. The general risk of bias was considered as moderate to high, and the authors report that differences between the intervention and control groups with regard to pharmacological therapy, medication adherence, physical activity, fractures, and quality of life were found to be statistically significant in less than 50% of the trials. Once again, there was evidence of recruitment worldwide, with men and women participating. As in the previous systematic review, a wide variety of outcome tools and measures were reported, making comparisons difficult. When comparing adherence rates across trials, substantial variation was apparent with proportions of adherent patients varying between 16 to 92% in the intervention group and 22% to 80% in the control group.

Patient education appears to be an attractive tool in the management of osteoporosis and has been highlighted as an area of unmet need among patients with osteoporosis and fragility fracture [99]. However, the two available systematic reviews have highlighted the need for randomized controlled trials that clearly report education packages and randomize interventions appropriately, and for researchers to find consensus on outcomes measures, and how they might be assessed. The potential for benefit in placing the patient at the center of their management is very considerable, as demonstrated by a randomized controlled trial, the PREVOST study, where this approach, coupled with a case manager, led to a 20% uplift in BMD measurement in patients who had sustained a humeral fracture [100]. In addition, education is mandatory for patient engagement with physiotherapy and dietary changes.

## Recommendations for future research

This paper reviews current evidence for rehabilitation following a fragility fracture. The areas of rehabilitation highlighted above are each a group of complex interventions, built up from a number of components that may act independently and inter-dependently. Together, they serve to build functional capacity and decrease the risk of future fracture. Research investigating these relationships will reinforce a comprehensive approach to clinical management. Gaps in the literature of complex interventions have been identified including clinical trial methodology and gaps between research evidence, clinical practice, and health policy. These gaps continue to exist in rehabilitation post-fragility fracture, particularly with respect to gaps between evidence and practice. We would like researchers to consider features of participatory research processes and the importance of implementation during intervention development.

Specific areas that we believe need further study are:

- Development of individualized exercise approaches considering patient preferences and integrating factors associated with patient adherence
- Trials to define the exercise regimens that create the greatest reduction in kyphosis and pain after vertebral fracture
- Trials to define the exercise regimens using multi-disciplinary/collaborative approaches to ensure the best recovery and the lowest length of stay in rehabilitation units, including formal incorporation of psychosocial constructs such as fear and self-efficacy
- A greater understanding of the specific educational needs of patients and caregivers, which may require the employment of qualitative approaches
- Study of rehabilitation strategies across the continuum of care including characterization of rehabilitation dosage and transition between rehabilitation settings
- Characterization of the relationship between malnutrition, fracture healing, rehabilitation, and future fracture risk
- Trials of rehabilitation implementation strategies associated with fracture liaison services for secondary fracture prevention

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## Declarations

**Conflict of interest** The authors declare no competing interests.

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