Physical therapy approaches to reduce fall and fracture risk among older adults

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Abstract | Falls and fall-related injuries, such as fractures, are a growing problem among older adults, often causing longstanding pain, functional impairments, reduced quality of life and excess health-care costs and mortality. These problems have led to a variety of single component or multicomponent intervention strategies to prevent falls and subsequent injuries. The most effective physical therapy approach for the prevention of falls and fractures in community-dwelling older adults is regular multicomponent exercise; a combination of balance and strength training has shown the most success. Home-hazard assessment and modification, as well as assistive devices, such as canes and walkers, might be useful for older people at a high risk of falls. Hip protectors are effective in nursing home residents and potentially among other high-risk individuals. In addition, use of anti-slip shoe devices in icy conditions seems beneficial for older people walking outdoors. To be effective, multifactorial preventive programs should include an exercise component accompanied by individually tailored measures focused on high-risk populations. In this Review, we focus on evidence-based physical therapy approaches, including exercise, vibration training and improvements of safety at home and during periods of mobility. Additionally, the benefits of multifaceted interventions, which include risk factor assessment, dietary supplements, elements of physical therapy and exercise, are addressed.

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Introduction

Falls or more specifically fall-related injuries are a growing global problem among older individuals, as they often lead to pain, functional limitations, excess health-care costs and increased mortality.[1–4] In 2000, almost 10,300 fatal and 2.6 million medically treated, nonfatal fall-related injuries were reported in the US alone for individuals aged ≥65 years.[3] Moreover, in the same year, the worldwide prevalence of fragility fractures in adults aged ≥50 years was estimated at 9.0 million, of which 1.6 million were hip, 1.7 million forearm and 1.4 million clinically diagnosed vertebral fractures.[2]

In the broad field of preventive measures, physical therapy approaches are an essential part of the health and community services that help individuals to develop, maintain or restore movement and functional ability throughout their life. This therapeutic approach is particularly needed in circumstances in which movement and function are threatened by aging, injury, disease or environmental factors. Essential characteristics, such as an individual's functional ability and independence, are preserved or restored by providing both preventive actions and treatment interventions aimed at maximizing mobility and by removing and modifying the environmental barriers of independent movement.[5] The most important and promising fall and fracture prevention strategies are exercise training, vibration training and improvement of safety at home and during times of mobility. In addition, multifaceted interventions, which include some elements of physical therapy as well as other important preventive measures, such as supplementation of vitamin D and calcium, examination of a patient's medicines (medication review), cataract surgery, cardiac pacing and antiosteoporosis drugs, are of value.[6–9]

This Review aims to delineate the importance and complexity of fall and fracture prevention among older adults. Professionals working in different health-care fields should be made aware of the risk factors that predispose to falls and reduced bone strength, so that evidence-based methods to reduce the risk of fractures can be implemented.

Fall and fracture prevention

Only about 5% of all falls cause fractures;[1] however, the majority of all fractures occur as the consequence of a fall.[1,10] The occurrence of a fracture depends on the force of the fall and the strength of the bone (Figure 1).[10–13]

Noticeably, a great number of risk factors, such as advanced age, are related to both falls[1,14,15] and reduced bone strength.[16–20] These factors vary and interact individually,[12,21,22] and the risk of a fall increases rapidly as the number of risk factors rises. Thus, individuals of advanced age and with multiple risk factors for falls or low bone strength can be defined as the high-risk population for falls and fractures.

The strongest determinant of a fracture is the actual fall rather than bone fragility.[13,22,23] The key issue in fracture prevention, therefore, is to determine which

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individuals are at a high risk of falling and to tailor preventive actions first and foremost towards these individuals. Unfortunately, although assessment tools to screen people at high risk of fractures are available (for example, the WHO fracture risk assessment algorithm FRAX®), these programs have not included any, or only modest, efforts to address falls and their risk factors.[24,25] The interaction and apparent synergism between multiple risk factors make fall prediction difficult, and no single tool can be recommended for all subpopulations.[26,27]

Abnormalities in gait and balance are recognized as the most frequent and sensitive risk factors that predispose to falls[14,28–30] and fractures.[31] Aging and many diseases (for example, stroke and Parkinson disease) affect posture control via sensory and neuromuscular decline.[32,33] Immobilization and reduced physical activity, in turn, decrease muscle strength and the performance capacity of the cardiopulmonary system and are associated with cognitive decline, depression and reduced mental capacity.[15] Together, these changes cause difficulties in controlling balance and movements, such as gait.[32,33] In addition, physical limitations and physical inactivity reduce bone strength.[17,18] As a consequence, cohort studies in elderly populations, with adjustment for several risk factors for fractures at baseline, have shown that physical inactivity increases fracture risk,[34] whereas physical activity prevents fractures.[35] In addition to individual risk factors, 50–80% of patients treated in accident and emergency departments for falls report environmental home hazards as one of the causes of falling.[28,29]

Many studies on preventive interventions that aim to reduce falls and fractures among elderly individuals have been conducted, but not always with consistent results.[6,7,21] Nevertheless, the majority of the evidence supports the notion that falls and fractures can be prevented.[7,36–38] Studies on preventive programs have focused unselectively on older adults in general or more selectively on specific high-risk subpopulations, such as individuals with multiple falls or those aged ≥80 years.

Given the complexity of fall-related risk factors, any intervention program should simultaneously cover and treat a multitude of risk factors to be effective. Thus, ideal fall and fracture prevention strategies must consider both individual risk factors, such as functional limitations or reduced bone strength, and environmental hazards.

Key points

- Regular multicomponent exercise is the most effective single physical therapy approach to reduce falls and fractures in older adults
- Exercise is also an important component of multifaceted intervention measures aimed at the prevention of falls
- Vibration training is a potential modality to improve muscle performance, balance and bone strength among older adults and might also reduce falls
- Home-hazard assessment and modification, including use of assistive devices, could potentially be helpful for people at a high risk of falling
- Hip protectors in nursing home residents and anti-slip shoe devices in older people walking outdoors in icy conditions are useful tools to prevent falls and fractures
- Multifactorial fall prevention programs have to be individually tailored to, and focused on, high-risk populations

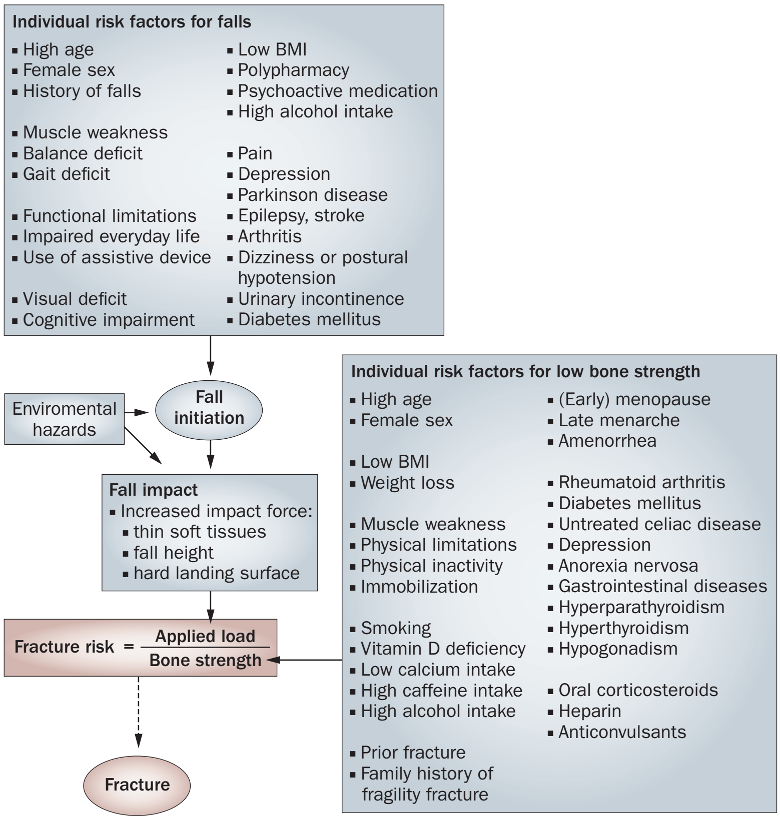

Figure 1 | Risk factors of falls and reduced bone strength that result in fractures. Factors for falls[1,14,15] and bone strength[16–20] were adapted from the literature and are not exhaustive. Bone strength is determined by bone geometry (size and shape) and structure (architecture) and material properties. Bones break when the applied load (the force that affects the bone) is greater than bone strength.[11]

Exercise training

Fall prevention by multicomponent exercise

With age, muscle mass, strength and balance decline, which predisposes to mobility problems, limitations in the performance of daily living activities and falls. Moreover, functional decline and fear of falling are severe threats towards the independence and quality of life of older individuals.[39,40] Regular exercise is needed to maintain physical functioning and to reduce the risk of falling. Additionally, exercise seems to be the most cost-effective strategy in preventing falls and fractures in community-dwelling older adults.[41–44]

Not all forms of exercise are equally effective in the reduction of falls. The most important components of exercise are balance and muscle-strength training, followed by flexibility and endurance training.[7] A Cochrane review by Gillespie and colleagues[7] on interventions to prevent falls in community-dwelling older adults showed that exercise which contains at least two of these components—typically balance and strength training—reduces both the risk of falls and the fall rate. In other words, the number of older adults who experience a fall is reduced by these exercise programs, and those who fall do not fall as often. Notably, exercise was the only intervention in the Cochrane review[7] that reduced both the risk of falling and fall rate. Other interventions, such as home-hazard modification, supplementation with vitamin D and calcium, medication review, cataract surgery, use of a cardiac pacemaker or multifaceted interventions, showed an effect only on one of these two variables.[7]

Exercise can be carried out as a group or individually in a home-based setting. According to Gillespie *et al.*,[7] supervised group exercise decreased the rate of falls by 22% (relative risk [RR] 0.78, 95% CI 0.71–0.86) and risk of falling by 17% (RR 0.83, 95% CI 0.72–0.97) in adults aged ≥60 years. Moreover, the group-based multicomponent exercise was efficient among both unselected and high-risk older adults. Individually prescribed exercise programs at home reduced the fall rate and risk of falling by 34% (RR 0.66, 95% CI 0.53–0.82) and 23% (RR 0.77, 95% CI 0.61–0.97), respectively. Tai chi exercise was analyzed separately and showed a 37% reduction in fall rate (RR 0.63, 95% CI 0.52–0.78) and 35% reduction in the risk of falling (RR 0.65, 95% CI 0.51–0.82).

In contrast with community-dwelling older adults, the role of exercise training is less obvious in institutional settings. A Cochrane review by Cameron *et al.*[45] showed that supervised exercise training reduced the risk of falling by 56% (RR 0.44, 95% CI 0.20–0.97) in hospitalized patients aged ≥65 years. This result was obtained on the basis of three studies performed in subacute care hospitals. Two of these studies were conducted in rehabilitation wards. By contrast, pooled data on supervised exercise training from seven studies in nursing care facilities showed no reduction of the risk or rate of falls.[45] However, subanalyses of these trials were inconsistent. Two studies on gait, balance and coordination exercises that used a mechanical apparatus reduced the rate of falls (RR 0.45, 95% CI 0.24–0.85), whereas pooling of the results of four studies that used a different combination of exercises increased the rate of falls (RR 1.37, 95% CI 1.01–1.85). The subanalyses showed no effect on risk of falling.[45]

Sherrington and colleagues[37] used regression methods in their meta-analysis to determine whether particular features of the exercise program, study population or study design were more effective than others in reducing falls in older people living in the community or in residential care. The investigators concluded that the most effective exercise programs included physically challenging balance training and a high amount and frequency of exercise and did not include a walking program. The importance of the regular, challenging balance training was in line with previous findings.[46,47] Nevertheless, the conclusion that walking should not be included in the exercise program can be misleading. First, in the meta-analysis by Sherrington *et al.*,[37] studies in which older people were exclusively encouraged to walk outside were pooled with studies in which systematic, expert-supervised walking training was used. Second, walking was a more common exercise among the elderly individuals at risk of falls than in the general population. As falls occur mostly during periods of movement, such as walking, running or other physical activities,[48] training of mobility skills should be emphasized. However, encouragement to walk should not be the only method to improve performance, particularly in aged individuals at a high risk of falling.

In the analysis of Sherrington *et al.*,[37] muscle-strengthening exercise was not an effective exercise component in fall prevention, partly owing to limited numbers of studies with progressive, high-intensity strength training compared, for example, with studies using challenging, high-level balance training. Nevertheless, lower limb muscle strength is known to be essential for mobility and physical functioning, and evidence confirms that progressive resistance training can improve both of these factors.[49] Thus, strength training could potentially be a relevant component of multicomponent exercise strategies.[50,51] Exercises that increase muscle strength are typically part of the intervention programs that have proven effective in fall prevention.[7]

Fracture prevention and bone health

Contrary to fall prevention, experimental evidence to show that exercise can reduce fall-related and osteoporosis-related fractures is more controversial. In the Cochrane review by Gillespie *et al.*,[7] exercise resulted in a 64% reduction of fracture risk compared with no exercise (RR 0.36, 95% CI 0.19–0.70). However, this quite favorable result was obtained on the basis of only five randomized studies, including published and unpublished data, predominantly from a study by Korpelainen and colleagues.[52] In this study, after 30 months of group and home-based exercises that included jumping, balance and muscle strengthening, women aged 70–73 years who exercised sustained fewer fall-related fractures than did study participants who did not exercise (6 versus 16 fractures). In the other two published randomized, controlled studies[53,54] also included in the Cochrane review[7] and in a novel study by Kemmler *et al.*,[55] the total number of fractures was lower than in the study by Korpelainen and co-workers,[52] and the beneficial effect of exercise on fracture risk was, thus, less evident (Table 1).

Epidemiological evidence, nevertheless, indicates that exercise, or rather physical activity, is associated with a reduced risk of fall-related and osteoporosis-related fractures.[56] In a meta-analysis of 13 prospective cohort studies, moderate to vigorous physical activity was associated with a 38% and 45% reduction of hip fracture risk among women and men, respectively.[57] In particular, in the Nurses' Health Study,[58] which had a follow-up period of 12 years, each increase in physical activity equivalent to 1 h walking per week at an average pace, lowered hip fracture risk by 6% among postmenopausal American women aged 40–77 years. Moreover, women who walked at least 4 h per week had a 41% lower risk of hip fractures than sedentary women who walked less than 1 h per week. In the Uppsala Longitudinal Study of Adult Men,[59] Swedish middle-aged men were followed up over 35 years until the age of 82 years. Sedentary men had a 2.5-fold increased risk of hip fracture and a 1.5-fold higher risk of other fractures than men with high physical activity. The researchers estimated that if all men had participated in regular sporting activities

Table 1 | Prevention of fall-related and osteoporosis-related fractures and other fall-induced injuries by exercise

Study	Population	Intervention and duration	Control	Main result*,‡	Other essential results‡
McMurdo *et al.*[53] RCT	118 community-dwelling women from the UK (mean age 64.5 years)	Weight-bearing exercise with music plus calcium supplement (1,000 mg daily) Duration: 2 years	Calcium supplement	Fractures: 2 vs 0 (statistical significance not tested)	Fallers: 21 vs 13 (NS) Falls: 31 vs 15 (NS) Ultradistal forearm BMC change –2.5% vs +1.14% (*P*=0.009)
Ashburn *et al.*[54] RCT	142 independent patients with Parkinson disease and a history of falling from the UK (mean age 72 years)	Daily personalized home-exercise program (strength, balance, flexibility and walking) plus weekly visits by a physical therapist over 6 weeks. Monthly telephone call Duration: 6 months	Standard care	Fractures: 6 vs 2 (NS)	Fallers: 49 vs 46 (NS) Near falling: 57 vs 50 (*P*=0.048) Maintained functional reach and QoL§ in exercise group (*P*=0.009) No difference in BBS and SAS
Korpelainen *et al.* [52,128] RCT	160 community-dwelling women from Finland (aged 70–73 years) with a low BMD (T-score <–2 SD)	Combination of group and home-based exercise (balance, jumping and strength). Group exercise supervised by a physical therapist for a 6-month period each year Duration: 30 months	No exercise	Fractures: 16 vs 6 (*P*=0.019)	Falls: 101 vs 88 (NS) Trochanter BMC decreased less in exercise group compared with controls (*P*=0.001), not seen in BMD Postural sway more stable, greater leg strength, walking speed and endurance and TUG in exercise group (for all *P*<0.001)
Kemmler *et al.*[55] RCT	246 independently living women from Germany (mean age 69 years)	Supervised, progressive and high-impact group exercise plus home training sessions (aerobic, balance, strength, weight-bearing and stretching) Duration: 18 months	Wellness program	Fractures: 12 vs 6 (NS)	Fall rate (overall): 1.66 vs 1.00 (*P*=0.002) BMD change in LS 0.3 % vs 1.8% (*P*<0.001) and in FN –1.1% vs 1.0% (*P*<0.001)
Sinaki *et al.*[80] Prospective follow-up after RCT	50 community-dwelling, white women from the US (mean age 55.6 years)	Progressive, resistive back-exercise training using backpack Muscle strength, posture and physical activity evaluation every 4 weeks Duration: 2 years	Muscle strength, posture and physical activity evaluation every 4 weeks	Radiographic compression fractures at 10 years: 4.3% vs 1.6% (*P*=0.029)	Increased back extensor strength at 2 years (*P*<0.001) in exercise group Group difference partly maintained at 10 years (*P*=0.036) Less bone loss in exercise group at 10 years (*P*<0.001)
Campbell *et al.*[129] RCT	233 community-dwelling, independently living women from New Zealand (mean age 84 years)	Individually tailored program of physical therapy at home (Otago program: strength, balance and walking) Duration: 12 months	Standard care and equal number of visits at home	Injurious falls: HR for a first fall with injury 0.61 (95% CI 0.39–0.97) in exercise group RR for a fall with injury 0.67 (0.45–1.00) in exercise group	Falls (at 1 year): 152 vs 88 Fall rate per year: 1.34 vs 0.87, ADL and FoF‖ (at 1 year): no difference in ADL scales, FoF decreased more in exercise group
Campbell *et al.*[130] Continued RCT	Continued study of Campbell *et al.*[129] (see above)	After 1-year Otago program, participants were asked to continue home-exercise for another year Duration: 12 months	None	Injurious falls: HR for a fall with injury 0.63 (95% CI 0.41–0.9) in exercise group	Falls (at 2 years): 220 vs 138 Fall rate (overall): 1.19 vs 0.83 HR for falls 0.69 (0.49 to 0.97) in exercise group
Robertson *et al.*[131] RCT	240 community-dwelling, independently living women and men from New Zealand (mean age 81 years)	Otago program and walking plan carried out by a trained district nurse Duration: 12 months	None	Injurious falls: 9 vs 2 serious injuries RR 4.6 (95% CI 1.0–20.7) in control group	Falls: IRR 0.54 (0.32 to 0.90) in exercise group Subanalysis: decreased number of falls in those aged >80 years in exercise group (*P*=0.007), but no group-difference in participants aged 75–79 years
Robertson *et al.*[132] CT in multiple centers	450 community-dwelling, independent women and men from New Zealand (mean age 83 years)	Otago program plus walking plan carried out by a trained district nurse Duration: 12 months	None	Injurious falls: IRR (moderate and serious injury) 0.72 (95% CI 0.62–0.82) in exercise group, no difference in moderate injuries (40 vs 40)	Falls: IRR 0.70 (0.59–0.84) in exercise group

*According to fracture and injury prevention. ‡Control vs exercise group if not otherwise stated. §Evaluated by SF-12. ‖Evaluated by the falls efficacy scale. Abbreviations: ADL, activities of daily living; BBS, Berg balance scale; BMC, bone mineral content; CHD, coronary heart disease; CT, controlled trial; FN, femoral neck; FoF, fear of falling; IRR, incidence rate ratio; HR, hazard ratio; ITT, intention to treat; LS, lumbar spine; NS, no statistical significance; QoL, quality of life; RCT, randomized controlled trial; RR, relative risk: SAS, self-assessment Parkinson disease disability scale; SD, standard deviation; TUG, timed up and go-test; vs, versus.

for ≥3 h per week, one-third of hip fractures could have been prevented.[59] In addition, both studies indicated that the risk of hip fracture decreased if a sedentary individual became physically active, and, conversely, giving up a physically active lifestyle led to increased hip fracture risk.[58,59]

Another aspect of exercise and bone health is the effect of exercise on BMD, as low BMD is associated with an increased risk of fractures.[60,61] Notably, the majority of so-called fragility fractures occur among individuals whose BMD is not osteoporotic (T score ≥–2.5).[23,62] More than 90% of hip fractures and almost all wrist fractures are caused by a fall,[63,64] as well as about one-third of all vertebral fractures.[65,66] Weight-bearing exercise and proper nutrition are vital for the development of a strong skeleton during childhood and adolescence; during the long period of adulthood, these factors are essential for maintaining or further strengthening the skeleton.[67] With age, exercise can slow down the age-related decline in bone mass and strength. Meta-analyses of randomized and nonrandomized, controlled studies show that high-intensity resistance training is especially beneficial for maintaining lumbar spine BMD,[68] whereas walking seems to be effective for the preservation of femoral neck BMD among postmenopausal women.[69] In a meta-analysis, Martyn-St James *et al.*[70] analyzed trials of various exercise programs. Combined exercise seemed to be beneficial for both lumbar spine and femoral neck BMD. The most effective program was jogging combined with other low-impact exercise, such as walking or stair climbing, and high-impact exercise, such as jumping, in combination with resistance training. However, this conclusion was not confirmed when nonrandomized studies were excluded from the analysis. In addition, in some exercise studies of postmenopausal women, changes in bone structure have been seen with or without a change in BMD, indicating that exercise can also modify postmenopausal bone geometry.[71] The substantial influence of exercise on bone structure is further apparent from cross-sectional studies of athletes.[72–75]

In light of these findings, the fact that bone and fall studies have most often been conducted separately is unfortunate. However, one study by Kemmler *et al.*[55] showed that, compared with a low-frequency wellness program, an 18-month high-intensity aerobic, balance, strength and weight-bearing exercise program increased femoral neck and lumbar spine BMD and decreased the fall rate among independently living German women aged ≥65 years (Table 1). In future studies, the twofold effect of exercise on bone health and fall risk should specifically be examined among individuals with poor functional ability and advanced age, that is, in those not capable of performing high-impact exercise.

Exercise training is useful not only for the prevention of osteoporosis but also for the treatment of this condition.[76,77] A systematic review of 28 exercise interventions in individuals with low BMD concluded that exercise can reduce falls, fall-related fractures and several risk factors for falls in this group.[78] Regular weight-bearing activities combined with resistance exercises are useful for bone strength and improve lower extremity muscle strength. The inclusion of balance exercises in training to improve balance and prevent falls is similarly important.[78] Older women with osteoporosis have reduced balance and lower limb strength compared with age-matched healthy individuals,[79] which emphasizes the role of retraining these components. Strength training of trunk muscles, especially back muscles, improves posture and might possibly protect the axial skeleton.[77,78] No clear evidence to support the suggestion that trunk exercise can prevent vertebral fractures among patients with osteoporosis is currently available;[78] however, Sinaki *et al.*[80] observed a reduced incidence of vertebral fractures 8 years after completion of a 2-year back-strengthening exercise program among healthy postmenopausal women (Table 1).

The most efficient approach to prevent fractures is apparently twofold: the risk of falls is reduced by improvement of physical functioning and mobility, whereas bone strength is maintained by adequate exercise loading. Multicomponent exercise, including balance, strength, endurance and flexibility training, has shown the most promising results and is, therefore, recommended for community-dwelling older adults and those who are hospitalized for more than a few weeks. In nursing home populations, exercise alone seems to be insufficient, and thus should be integrated with other preventive actions, as discussed in detail in the section on multifaceted interventions in this Review. In institutional settings, exercise training should be supervised and preferably tailored to the individual.

Vibration training

Vibration training has been used as a training modality for athletes since the mid-1980s,[81] but its real breakthrough has occurred over the past few years. Vibration training is typically performed as whole-body vibration, in which the individual stands on a side-alternating or vertical-oscillating platform of the training device over a certain period of time—from minutes to tens of minutes, consecutively or in intermittent periods—while potentially practicing some additional exercises (for example, squats). Depending on the device, the vibration frequency (oscillations per second) can vary from 10–90 Hz and the amplitude (displacement of oscillation) from hardly perceptible (~0.05 mm) to quite intensive (~10 mm).[81–86] Vibration training can thus differ markedly in terms of vibration frequency, amplitude, type of vibration, duration of a single exercise, number of weekly exercise periods and the activities performed during the vibration exercise, let alone the total duration of the training intervention.

Depending on the amplitude and frequency used in vibration training, reaction forces generated by the oscillating platform can vary from 0.1–10 G (gravitational constant). In other words, besides static body weight, tens of momentary loads (impacts) of a magnitude ranging between 0.1 and 10 times an individual's body weight can be delivered to the body through the contact between foot and oscillating platform every second.[87] For comparison, during normal physical activity only a couple of loads of this magnitude can be imposed on the body per second. Vibration training could, therefore, be a more efficient training form than conventional physical activities—at least in theory.

To date, several randomized, controlled trials on vibration training have been carried out in different target groups (from athletes to frail elderly adults), but the results and conclusions have varied substantially.[81–86] Obviously, the large variance in results is attributable to the great disparity in vibration training regimes. Moderate to strong evidence suggests that long-term, whole-body vibration exercise over several months can improve muscle performance (strength and power) of lower extremities in individuals of advanced age.[81,82,86,88,89] Vibration training also has the potential to improve balance among fall-prone elderly individuals[81,90,91] and in the long term can increase BMD at the femoral neck, lumbar spine or both.[81,84,85,92] Importantly, results of one randomized, controlled trial suggest that long-term vibration training may reduce the number of falls among older women besides having positive effects on BMD.[92]

Given the large number of high impacts that can be delivered to the body within seconds, safety issues must be carefully considered before starting vibration training.[81,84–87] Common contraindications include prostheses and implants, previous fractures, history of high risk of acute thrombosis, kidney and bladder stones, previous surgery, hernia, acute rheumatoid arthritis, serious cardiovascular disease and severe diabetes mellitus with neuropathy. Although severe adverse effects have not reportedly occurred with vibration training in randomized, controlled trials, minor yet mainly transient adverse effects, such as headache, dizziness, groin pain, tingling of the lower limbs and erythemia, have been reported in some individuals.[85,86,90]

Vibration training simultaneously affects muscular, skeletal, endocrine, nervous and vascular systems of the body, and the specific mechanisms to explain how whole-body vibration affects different physiological systems remain undetermined, as are the optimal vibration training regimens.[84] Neither has it been established whether vibration training *per se* is essentially more beneficial than conventional exercise.[81,83,88,89] However, vibration provides an intriguing training option with proven potential to improve muscle performance, balance and bone strength in older adults. Vibration training may be particularly attractive for those who are unable or reluctant to do conventional exercise owing to, for example, pain, functional limitation or illness. Obviously, more systematic studies are required before specific benefits (prevention of injurious falls and fractures) and risks of vibration training can be unraveled and definitive recommendations provided.

Safety at home and during mobility

Home hazard modification

The majority of fragility fractures occur indoors, especially among individuals aged ≥80 years.[93] Improving safety by home hazard modification, therefore, seems a very logical approach to prevent falls. Nonetheless, according to Gillespie *et al.*,[7] home hazard modification was inefficient for the prevention of falls among unselected community-dwelling older adults. Some evidence does, however, point to the fact that home hazard modification for people at a high risk of falling, reduces the rate of falls (RR 0.56 95% CI 0.42–0.76).[7] Findings from a previous meta-analysis by Clemson *et al.*[94] suggest a modest but statistically significant effect of home hazard assessment on fall prevention. The strongest evidence comes from the study by Campbell *et al.*,[95] in which a home safety assessment and modification program was implemented among individuals aged ≥75 years who had severe visual impairments. The majority of the study participants (90%) partially or completely followed the recommendations to remove or change loose floor mats, paint the edges of steps, reduce glare, install grab bars and stair rails, remove clutter and improve lighting where needed. As a result of these modifications, falls were reduced by 41% in the home safety group compared with study participants who followed an exercise program or received social visits (RR 0.59, 95% CI 0.42–0.83). Thus, home hazard assessment and modification should be recommended for those individuals at a high risk of falling. Furthermore, older adults who are at the highest risk of losing their independence are most likely to accept preventive measures.[96]

Use of assistive devices and footwear

Somewhat surprisingly, the effect of assistive devices, such as canes and walkers, on fall prevention has been studied sparsely, and according to our knowledge no randomized, controlled trials have been performed to date. In some multifaceted interventions, assessment and modification of assistive devices have been used as a part of the intervention (Tables 2 and 3). Nevertheless, its independent role is impossible to evaluate. Common sense, however, dictates that inappropriate or lack of assistive devices can predispose frail older adults to falls and, therefore, appropriateness of assistive devices should be assessed.

The type of footwear an individual wears influences balance and might increase the risk of falls in older adults.[97,98] However, the independent association of footwear with risk of falling is not clear, as shoes can be changed many times during the day depending on the location or activity. Individuals of very advanced age who have the highest likelihood to sustain spine, pelvis or hip fractures are prone to fall inside their home.[93] Thus, their falls are more probably associated with an intrinsic risk of falling, such as severe medical problems and poor functional ability, whereas fit individuals frequently move outdoors and are thus more prone to slips, traffic accidents and high-energy falls related to environmental hazards.[93,99]

Slips and fall accidents (even on icy, snowy or wet surfaces) are attributed not only to footwear properties but also to several other factors, such as underfoot surface characteristics, friction between sole of footwear and surface, human gait biomechanics, human physiological aspects and other environmental factors such as temperature, snowfall and lighting.[100] One randomized, controlled trial showed that anti-slip shoe devices reduced the rate of falls (RR 0.42, 95% CI 0.22–0.78) and injurious falls that did not require hospitalization (RR 0.13, approximately 95% CI 0.03–0.66) in fall-prone older individuals during icy conditions.[7,101] For every prevention of one nonserious, injurious fall by anti-slip shoe devices,

Table 2 | Examples of successful multifactorial fall-prevention interventions

Study	Population (UK)	Intervention and follow-up	Results*	Comments
Close *et al.*[111]	397 community-dwelling, independent and cognitively intact individuals (mean age 78.2 years, 68% women) who attended the A&E department after a fall	Medical and occupational assessment after a fall with referral to relevant services Advice and education about safety within the home Assessment and supply of assistive devices Follow-up: 1 year	Falls: 510 vs 183 (P=0.0002) Risk of falling: OR 0.39 (95% CI 0.23–0.6) in intervention group Risk of recurrent falling: OR 0.33 (95% CI 0.16–0.68) in intervention group Injurious falls: fewer serious injuries (fall-fractures) in intervention group (8% vs 4%, NS)	Secondary prevention ITT analysis was not always used (n=304) 23% drop-out rate in both groups
Davison *et al.*[28]	313 community-dwelling, independent and cognitively intact individuals (mean age 77 years, 72% women) who attended the A&E department after a fall and with a history of at least one more fall in the past year	Medical, gait, balance and home environmental assessment followed by individual-based intervention Two hospital attendances and two therapy visits Management of medical problems Review of medication Home hazard modification Supervised home-based exercise for 3 months Follow-up: 1 year	Number of falls: 617‡ vs 387 Fall rate reduced in intervention group (RR 0.64, 95% CI 0.46–0.90) Risk of falling NS Fracture rates NS Fall-related hospitalization admissions NS Days in hospital: 688 vs 131 Mean length of fall-related hospitalizations (in days) reduced in intervention group FoF§ increased in control group and decreased in intervention group	Secondary prevention for recurrent fallers ITT analysis was performed Fall diaries were kept and assessed every 4 weeks Drop-out rate was 11% in intervention group and 8% in control group The adherence and progression in physical training was not described The duration of exercise remained short

Both trials were randomized controlled trials. Control groups received standard care. *Control vs intervention if not otherwise stated. ‡Exclusion of two radical outliers. §Determined by the activities-specific balance confidence scale. Abbreviations: A&E, accident and emergency; FoF, fear of falling; ITT, intention to treat; NS, no statistical significance; OR, odds ratio; RR, relative risk; SD, standard deviations; vs, versus.

six patients needed treatment. Because these devices are inexpensive, and user compliance was high (78%), they can be recommended to ambulatory older adults who live in areas with icy conditions—especially if the device can be put on and off without assistance.

Injury site protection (hip protectors)

As the majority of hip fractures in older adults are caused by a sideways fall with direct impact to the greater trochanter of the proximal femur, one option for preventing fractures is to use biomechanically effective external hip protectors.[36,102] Combined findings for all different types of hip protectors suggest that especially in institutions, the use of hip protectors can reduce the risk of fracture by 20–60%,[36,102,103] particularly among nursing home residents with a history of falls and a BMI ≤19 kg/m^2.[104] However, hip protectors have not been found effective in all randomized, controlled trials implemented in nursing home settings.[104,105]

No evidence exists to date that hip protectors are effective in home-dwelling older individuals,[36,102] and the evidence for elderly adults living in care homes is scarce.[106] Nevertheless, hip protectors may be effective in community-dwelling, frail older adults at particularly high risks of falls and fractures.[107]

Hip protectors are effective only if they are worn, preferably, all day, every day.[102,107] The use of protectors does not result in any major adverse effects, but the acceptance and compliance level of these devices is often low.[36]

Overall, hip protectors are highly recommended for frail and fall-prone older adults.[102] They should be considered especially for those elderly individuals who are transferred into a long-term care facility, as the incidence of hip fractures is highest during the first months after admission.[108]

Multifaceted interventions

Age-related physiological changes, medical problems and other risk factors of falling are cumulative, which leads to a decreased ability to intrinsically regulate movements and to compensate for external stress that disturbs balance during basic everyday tasks.[109] With increasing age, the risk of falling rises rapidly with each added risk factor.[14,15] Thus, falling can be viewed as an indicator of a complex system failure caused by several factors that require multifaceted attention and intervention.[109,110]

Multifaceted interventions can either be implemented by multifactorial or multiple approaches.[7,45] In a multifactorial intervention trial, the fall and fracture risk profile of each person is assessed first, then individual interventions and treatments are implemented as appropriate. By contrast, a multiple intervention approach comprises a fixed combination of two or more major components of intervention, such as exercise and supplementation of vitamin D, which are delivered to all participants. The components of interventions in multifactorial trials have varied. In addition to risk factor assessment, they typically include exercise, care planning, medical and/or diagnostic approaches, changes in physical environment, education programs, calcium and vitamin D supplementation, medication review, hip protectors and removal of physical restraints (for example, bedside rails).[7,45,106] Both multifactorial and multiple interventions have been shown to be effective in some studies but ineffective in others.[7,45]

Multifactorial interventions

Overall evidence from 15 trials with 8,141 participants showed that multifactorial interventions reduced the rate of falls in community-dwelling older adults (RR 0.75, 95% CI 0.65–0.86), but their effectiveness in reducing the number of individuals who fall or fall-related fractures is

Table 3 | Examples of successful community-dwelling multiple and community-based fall-prevention interventions

Study	Population	Intervention and follow-up	Results*	Comments
Day *et al.*[117] RCT	1,090 community-dwelling adults from Australia (mean age 76.1 years, 60% women), randomly allocated to either exercise, home hazard and/or vision assessment, different combinations of these interventions or no intervention	Exercise: weekly strength and balance exercise class for 15 weeks plus daily home exercises Home hazard: removal or modification of hazards and home visit by home maintenance staff plus free labor and materials up to €60 Vision: assessment and intervention if necessary by existing providers Follow-up: 18 months	RR of a first fall was lowest (0.67; 95% CI 0.51–0.88) in study participants who exercised and received both vision and home hazard assessment, as was the NNT to prevent one fall	Primary prevention Fall diaries were kept and a phone call made if a study participant had fallen Transport to exercise classes if necessary Adherence: 61% participates attended at least 50% of the exercise sessions, 76% got help in home modification Drop-out rate: 11% Reassessed at follow-up: 442 out of 1,090 (41%)
Clemson *et al.*[115] RCT	310 community-dwelling, independent and cognitively intact individuals from Australia (mean age 78.4 years, 74% women) with previous falls or concerned about falling[§]	Education on how to improve balance and lower-limb strength (home exercise), on home and community environment and behavioral safety (including hip protectors, vitamin D, footwear, home hazards) and encouragement of vision assessment and adaptations to low vision as well as medication review Follow-up: 14 months	Fall rates (all falls): RR 0.69 (95% CI 0.50–0.96) in intervention group FoF[‡] maintained in intervention group and decreased in control group (P=0.042)	Secondary prevention ITT analysis was used Postal questionnaire every month (pre-addressed and stamped) Adherence of exercise at 14 months: 59% Drop-out rate in intervention group 6% and in control group 10% The support of spouse might have influenced the results, especially in men
Ytterstad *et al.*[121] Population-based CT	Individuals aged >65 years Intervention community: City of Harstad, Norway, with a population of 22,500 Control group community: City of Trondheim, Norway, with a population of 135,000	WHO-designed safe community program Local media coverage of program Educational talks to older adults Home visit by health-care professionals to high-risk individuals Promotion of safe footwear Promotion of physical exercise Engagement with local community agencies and services Follow-up period: 1989–1993 (Harstad: 14,850 person–years; Trondheim: 101,097 person–years)	Fracture rate in Harstad decreased by 14.7% (NS) Fracture rate in Trondheim increased by 31% (P<0.001, baseline versus follow-up)	Primary prevention Physical exercise was not described in detail The participation and adherence to offered interventions was not reported

*Intervention compared to control if not otherwise stated. ‡Determined by the mobility efficacy scale. Abbreviations: FoF, fear of falling; ITT, intention to treat; NNT, number needed to treat; NS, not statistically significant; RCT, randomized controlled trial; RR, relative risk.

unevidenced.[7] Two well-conducted programs successful in preventing falls and injurious falls,[28,111] and included in the Cochrane review by Gillespie *et al.*,[7] are presented in Table 2 as examples.

Cameron and colleagues[45] showed that multifactorial interventions reduced both rate (RR 0.69, 95% CI 0.49–0.96) and risk of falling (RR 0.73, 95% CI 0.56–0.96) in hospital settings. However, this effect was not seen in nursing care facilities when all studies were included. A subanalysis of the Cochrane review[45] showed that the rate and risk of falling decreased in trials having multidisciplinary team and exercise training components (RR 0.60, 95% CI 0.51–0.72, and RR 0.85, 95% CI 0.77–0.95, respectively). Also, reduction of hip fractures was seen in pooled data of three studies (RR 0.48, 95% CI 0.24–0.98).[29,112,113] Interestingly, all these three studies were conducted as multidisciplinary team work and included exercise in the intervention protocol.[45] Successful results were also obtained in a psychogeriatric nursing home, in which preventive actions were carefully tailored to the individual by a multidisciplinary team.[114]

Multiple interventions

All trials included in the Cochrane meta-analyses by Gillespie *et al.*[7] and Cameron *et al.*[45] had an exercise component. A substantial reduction in the rate of falls was achieved in two out of six studies implemented in community-dwelling older adults,[7] but not in a study conducted in an institutional setting.[45] In community-dwelling settings, Clemson and co-workers[115] were able to reduce the rate of falls by 31% by using a combination of exercise, education and home safety intervention (Table 3). In their small, pilot randomized, controlled trial of women with osteopenia or osteoporosis, Swanenburg and colleagues[116] found that 81% fewer falls occurred in the patients who were allocated to exercise as well as vitamin D, calcium and protein supplementation compared with patients who only received vitamin D and calcium supplementation.[7,116] In addition, a notable reduction in the rate of the first fall was achieved in all groups with an exercise component in a randomized, controlled trial by Day *et al.*[117] (Table 3). In this study, falls were reduced most effectively when exercise, home hazard reduction and visual correction were combined (33% versus 18% for patients who were prescribed exercise alone).

Community-based intervention programs

Even though multifactorial and multiple interventions may reduce the rate of falls in predefined groups of older individuals, less evidence is available on their effectiveness in the general community. Some community-based intervention programs, defined as coordinated, community-wide and multistrategy initiatives, have been implemented for the prevention of falls, fall-related injuries and fractures among the older population.[118,119] In these programs, one or more health-promotion strategies have focused on their use by the whole community.

In their Cochrane review, McClure and co-workers[118] assessed the effectiveness of six controlled, population-based, multifactorial interventions for the reduction of fall-related injuries on a community level among people aged ≥60 years. Despite some design limitations in the included studies (that is, no randomization), a substantial decrease or trend for decrease in fall-related injuries was achieved in all studies. The reduction in injury risk ranged from 6–33% for some subpopulations. Two of the three programs successful in preventing fractures used physical activity in combination with home hazard reduction.[120,121] As an example, the intervention implemented in Harstad, Norway,[121] is described in Table 3.

A study by Tinetti *et al.*[119] showed promising results in reducing fall-related injuries and use of medical services in persons aged ≥70 years. In this nonrandomized study, the clinicians and facilities in the intervention regions (that is, home-care agencies, senior centers, outpatient rehabilitation and primary care offices) used evidence-based, fall-prevention interventions. During a 2-year follow-up period, serious fall-related injuries were 9% lower and fall-related use of medical services was 11% lower in intervention regions compared with regions where the older adults were treated with standard care. However, the study raised the issue of cost-effectiveness of multifaceted interventions, which result in higher costs per prevented falls compared with single component interventions.[41,43,44] On the other hand, the potential of multifaceted interventions for saving health-care costs at the community level in the long term cannot be ignored.[119,121]

Challenges of fall prevention measures

Problems remain especially in the efficiency of referral-based fall preventive measures for individuals receiving standard care. Strong evidence indicates that referral of persons at risk of falls to their health-care providers or to existing community programs is ineffective, either because of poor adherence to recommended interventions or because the individual does not receive appropriate preventive measures.[122,123] Older adults have several competing medical problems, and, apparently, the participation in fall prevention programs is not always their highest priority,[123,124] although individuals with previous falls, indicative of the need for preventive measures, are often willing to participate in such programs.[96,123] Thus, all intervention methods should be tailored to the individual with their cooperation, and that of their caregivers and health-care providers.[122,125] One such approach is the introduction of so-called falls clinics, which provide a detailed multidisciplinary assessment of fall risk factors on an individual basis, followed by recommendations or implementations of targeted falls and injury prevention strategies.[126,127] Whether falls clinics will prove effective in fall prevention remains to be determined.

Conclusions

The prevention of falls is of primary importance for the reduction of fall-induced injuries and fractures, and several physical therapy components have been shown to be efficacious in this respect. The most effective approach to reduce both the risk and rate of falls in older, community-dwelling adults is multicomponent exercise, which is also beneficial for bone health and maintaining functional ability. In institutional settings, exercise training alone does not appear to be sufficient to prevent falls and fractures, although in a subacute care hospital setting supervised exercise training seems to be effective. Multifaceted interventions should also include an exercise training component, which is potentially the most cost-effective single component for the prevention of falls and fractures.

Whole-body vibration training has shown potential to improve muscle performance, balance and bone strength, but more studies are needed before any specific recommendations for its use among older adults can be given.

Home hazard assessment and modification and use of hip protectors have proven efficient for frail older adults at the highest risk of falling. For those individuals who walk outdoors in icy conditions, the use of anti-slip shoe devices also seems beneficial.

With regard to multifaceted interventions, multifactorial programs, which include several individually tailored preventive components, are especially beneficial for those at the highest risk of falls. Although these multifactorial interventions are often expensive and require multidisciplinary team cooperation, they may provide additional health and functional benefits for older adults.

In conclusion, many risk factors of fractures are related to both falls and reduced bone strength, but the strongest determinant of a fracture is the actual fall rather than bone fragility. Ideally, the most effective approach for the prevention of fractures in older adults will be tailored to the individual. Physicians, therefore, need to acknowledge the complexity of fall prevention and be aware of the various risk factors that predispose older individuals to falls and fractures.

Review criteria

Articles for this Review were selected using PubMed searches of all full-text English language articles (and one article in German with an English abstract) from all years using the following search terms: "accidental falls", "falls", "osteoporosis", "physical therapy modalities", "equipment and supplies", "self-help devices", "protective devices", "orthopedic equipment", "hip protector", "environment design", "environmental intervention", "home modification", "exercise", "exercise therapy", "physical education and training", "whole body vibration" including randomized, controlled trials, clinical trials, reviews and meta-analyses. Reference lists of identified papers were also reviewed to identify additional relevant publications. Meta-analyses and systematic reviews were chosen to use as primary references, followed by single randomized, controlled trials.

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