# Bone and Fall-Related Fracture Risk

13

Elisabeth Preisinger and Katharina Kerschan-Schindl

## Introduction

Accidental falls in the elderly are a major public health concern because they may result in fracture, loss of autonomy, and institutionalization. Additionally, falls are the second leading cause of accidental or unintentional injury deaths worldwide [1]. The fact that the mean age of the population is increasing almost everywhere in the world emphasizes the importance of prevention and management of falls.

Our sensory-motor control mechanisms are challenged several times a day because of some kind of perturbations. Usually we do not even recognize that. However, with increasing age the postural control system experiences a functional decline and the risk of stumbling and falling increases. An unintentional movement to the floor or lower level, not as a result of a major intrinsic event (such as stroke) or overwhelming hazard, may be defined as a fall [2]. A fall can be divided into three different phases: the initiation, the fall itself, and the impact on the ground.

## Epidemiology of Falls and Fall-Induced Injuries

Above the age of 65 years, about 30% of the self-dependent elderly and half of those living in residential care facilities or nursing homes fall at least once a year; the percentage increases further with increasing age, and about half of the fallers are

E. Preisinger, MD (✉)
Department of Physical Medicine and Rehabilitation, Hietzing Hospital and Neurology Center Rosenhuegel, Wolkersbergenstraße 1, 1130 Vienna, Austria
e-mail: elisabeth.preisinger@wienkav.at

K. Kerschan-Schindl, MD
Department of Physical Medicine and Rehabilitation, Medical University Vienna, Waehringer Guertel 18-20, 1090 Vienna, Austria
e-mail: katharina.kerschan-schindl@meduniwien.ac.at



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recurrent fallers [3]. The injurious outdoor fall rate is supposed to be similar in both genders; however, the rate of injurious indoor falls has been shown to be about twice as high in females compared to males [4]. Of course, the majority of falls do not lead to an injury, but in 20% some medical attention is necessary and 5% result in a serious injury, for instance, a fracture [3].

### Bone- and Fall-Related Fracture Risk

Except for most of the vertebral fractures, the nature of the fall and the bone structure are essential parts concerning the risk of a fragility fracture. A fracture occurs if the applied load during the impact of the fall is higher than the structural capacity of the bone. A 10% decrease of bone mineral density (BMD) increases fracture risk 2- to 2.5-fold [5], but most of the fragility fractures occur in subjects without osteoporosis. It is surprising that only 3% of elderly subjects attending an emergency department because of a fragility fracture have no other fracture risk factor than osteoporosis according to the WHO [1], 7% only have a bone-related risk factor, and the majority, one quarter, has one or more fall-related risk factors [6]. Fracture history, mother with fracture history, low body weight (<60 kg), immobility, and regular use of glucocorticoids are summarized as bone-related risk factors. Fall-related risk factors are described below.

The direction of the fall is another important point concerning the probability of a serious injury. Falling sideways increases the risk of a hip fracture fivefold and a fall directly on the trochanter even 30-fold [5]. Of course, the energy-striking bone also depends on the characteristics of the landing surface (e.g., forest soil vs pavement or street) and the thickness of the surrounding soft tissue absorbing some of the energy.

## Etiology of Falling

### Endogenous and Exogenous Risk Factors of Falling

The number of known risk factors is quite large, and most falls in the elderly are results of an interplay of predisposing and precipitating factors. Elderly subjects, female subjects, and white subjects are more prone to suffering from a fall-related fracture than their younger, male, or black counterparts.

Any acute or chronic disease like a neurologic disorder, rheumatic disease, or a cardiovascular problem raises the risk of falling. With advancing age, the likelihood of diseases or impairments in muscle or joint function, vestibular system, vision, etc. increases. All these factors negatively influence postural stability. Because of diseases and impairments, elderly subjects often have to take several medications. Unfortunately, “taking drugs” negatively influences the risk of falling to a high extent (OR 4.24) [7]. Especially, central nervous system-acting

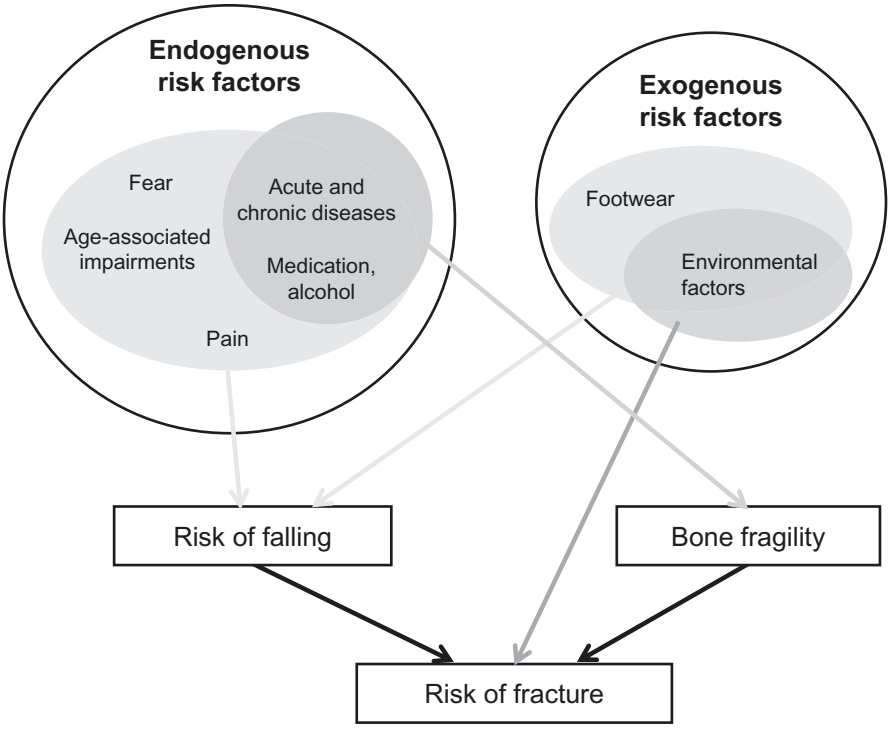


**Fig. 13.1** Risk factors for a fracture

agents are fall-risk increasing. Polypharmacy is a serious problem: The overall odds ratio of a hip fracture among patients using 10 or more agents is 8.42 compared to those taking no or just one compound per day [8]. Nevertheless, pain relieved—with or without medication—is indispensable not only to elevate psychological well-being and quality of life but also to reduce the risk of falling; a meta-analysis demonstrated that pain is associated with an increased odds ratio of falling (OR 1.56) [9]. Acute and chronic diseases, age-associated impairments, the intake of substances with a negative influence on postural stability, and psychological distress lead to a reduction in vigilance and can be summarized as endogenous risk factors. Environmental factors such as poor lightening, door sills, stairs, wet floors, or outdoor weather conditions further exacerbate the risk of falling. Of course, the footwear also is an important point in the phase of fall initiation (Fig. 13.1).

The risk of falling increases with the number of prevalent risk factors and with a history of previous falls. An important point is that half of the subjects who have fallen have fear to fall again, and one quarter reduces daily activities because of this fear [2, 10] which has a negative impact on social life and physical fitness which again increases the risk of falling and fall-related fractures (Fig. 13.2).

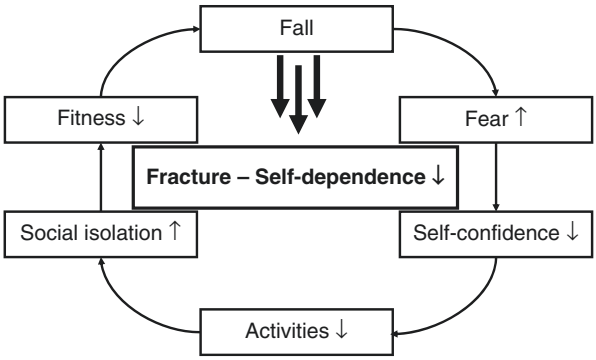


**Fig. 13.2** Consequences of a fall

## Physiology of Balance and Postural Strategies

To maintain balance during everyday activities, it is necessary to keep the body's center of gravity over its base of support during upright standing, movement, and walking. Balance is regulated and controlled via interplay of the sensory and motor systems. The central nervous system (CNS) steadily receives information from visual, acoustic, vestibular, and proprioceptive perceptions. This afferent component of the sensory-motor system leads the CNS to induce continuous reactive efferent mechanisms, changes of the motor system. Thus, postural control underlies a continuous feedback mechanism.

Since the regulation is very complex, it is susceptible to flaws. With increasing age we experience a decline in all components of this mechanism. Loss of vision and hearing and a decline in several peripheral receptors reduce the input to the CNS. The age-associated loss of muscle mass and function has an impact on the efficacy of the efferent part of this sensory-motor system. The CNS also underlies age-associated loss of function, and the vigilance of the superior management system is often reduced because of interfering factors like pain or fear. Additionally, an increase of the thoracic kyphosis, shortening or weakness of some muscles, and reductions in hip and knee extension lead to a displacement of the center of gravity; it is shifted forward. All these age-related changes lead to deficits in balance with increased swaying and to more complex postural reactions compared to subjects at younger age.

In young subjects, small disturbances of balance lead to an activation of the muscular activity in the ankle region (i.e., ankle strategy); older people tend to activate muscles in the hip region (i.e., hip strategy) [2, 10]. If it is not possible to regain balance with these postural strategies, one has to take a step. Elderly have to do so at a lower amount of perturbation, and older subjects have to take multiple smaller steps to restore balance, whereas younger subjects respond by a compensatory single step [10]. Apart from anterior-posterior perturbations, disturbances of the equilibrium in the lateral direction have been investigated [11]: Young subjects responded with large roll movements of the trunk in the opposite direction of the tilt platform and abduction of the ipsilateral arm to keep the center of gravity over their base of

support. In the elderly, trunk roll was in the same direction as support-surface motion with abduction of the arm in the direction "downhill," making elderly subjects more prone to losing control of their balance.

A large proportion of falls in the elderly occur while walking, a balance-displacement activity. Older adults may be less capable of weight shifting, and, thus, the gait tends to be stiffer with slower velocity, increased double support time, and smaller steps. Another important point leading to an increased risk of falling induced by an unevenness of the ground is that the minimum foot clearance (distance between lowest point of the foot of the swing leg and the ground) is lower and shows a higher variability during walking in elderly compared to younger men [12, 13].

## Screening and Fall Risk Assessment

A key component in preventing falls is the identification of important factors which may increase the risk of falls. An assessment of fall risk should be integrated into the history and physical examination of all geriatric patients, including those not specifically being seen for a problem with falling [14]: All older patients (65 years and more of age) should be asked at least once a year about falls, frequency and circumstances of falling. Older individuals should be asked about difficulties with walking or balance. Older persons presenting with a single fall should be evaluated for gait and balance. A multifactorial fall risk assessment should be performed for community-dwelling older persons who cannot perform a standardized gait and balance test or who report recurrent (two or more) falls in the past year or who report difficulties with gait or balance or who seek medical attention or present to the emergency department because of a fall.

### Multifactorial Fall Risk Assessment

The multifactorial fall risk assessment should be performed by a clinician (or clinicians) with appropriate skills and training. It should include a comprehensive history, a physical examination, a functional assessment, and an environmental assessment (Fig. 13.3).

Several studies report that the most important consideration in the history is a previous fall, which places the patient at increased risk of future falls. For patients presenting with a fall, important components of the history include the activity of the faller at the time of the incident; prodromal symptoms, like lightheadedness, imbalance, and dizziness; and where and when the fall occurred. Loss of consciousness is associated with injurious falls and may be caused by orthostatic hypotension, cardiac disease, or neurologic disease. Identification of underlying chronic diseases that increase fall risk is important. Examples of these age-related chronic conditions include Parkinson disease, chronic musculoskeletal pain, knee osteoarthritis, dementia, stroke, and diabetes.

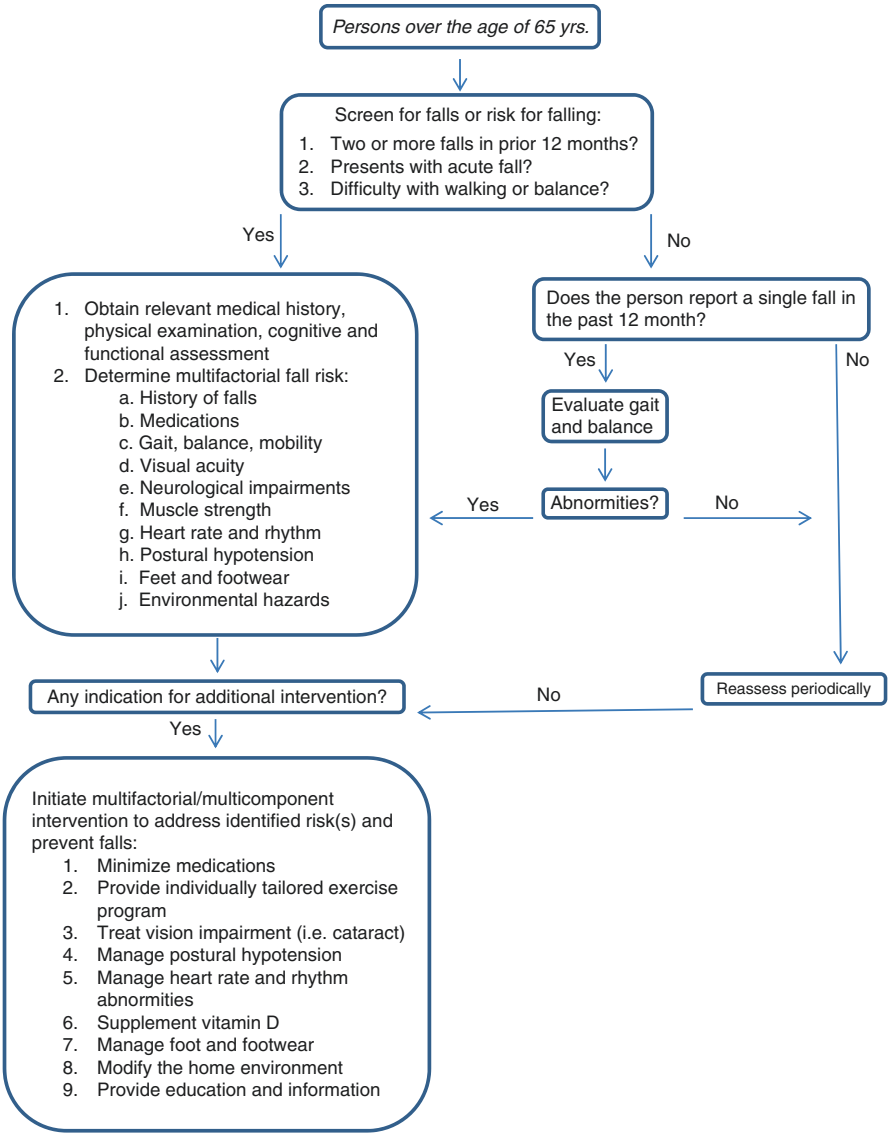


**Fig. 13.3** Prevention falls algorithm. Adapted from: The Prevention of falls in Older Persons: Clinical Practice Guideline from the American Geratrics Society. www.americangeriatrcs.org

Information on previous falls should be collected to identify patterns that may help target risk factor modification strategies. A complete medication history should be taken, with specific focus on psychotropic medications, sedative hypnotics, antidepressants, and antihypertensive medications. Timing of medication administration and alcohol use to past falls should be determined. Environmental factors that may have contributed to the fall should also be identified; information on lighting, floor covering, door thresholds, railings, and furniture may add important clues.

The physical examination should include neurologic and joint functions, muscle strength, cardiovascular status, vision, the feet, and footwear. The most important aspect of the physical examination in the patient who has fallen is an assessment of integrated musculoskeletal function. This can be obtained by performing one or more tests of postural stability.

## Tests of Postural Stability

The "Get Up and Go" test is one of the best known tests. A 2013 meta-analysis of 53 studies ($n$ = 12,800) showed a mean difference of 3.59 s between institutionalized fallers and non-fallers [15]. However cutoff points distinguishing fallers from non-fallers showed considerable variation between the studies. The test is best used as part of a global assessment of an individual's fall risk. In practical terms, the observation of deficiencies in various individual components may isolate areas for targeted intervention. The test is performed by observing the subject rising from a standard arm chair, walking a fixed distance of 10 ft. (3 m) across the room, turning around, walking back to the chair, and sitting back down. Observation of the different components of this test may help to identify deficits in leg strength, balance, vestibular dysfunction, and gait. The timed part of the test records the mean time (in seconds) from initial getting up to reseating. Patients are compared to the mean time of adults in their age group [16] (Table 13.1).

The "Performance Oriented Mobility Assessment tool (POMA or Tinetti Assessment Tool)" is a scored instrument that assesses balance and gait, using an ordinal scale from zero to two ("0" for the most impaired performance, "1" if slight impairment, and "2" if independent) [17]. The items range from being able to maintain balance when someone slightly pulls on an individual to walking normally with assessment of step continuity and path deviation. No reliable cut point has been established for the POMA score in the prediction of falls.

The "Functional Reach" test is another practical approach to testing integrated neuromuscular base of support that has predictive validity for falls [18]. Functional reach is the maximal distance one can reach forward beyond arm's length while maintaining a fixed base of support in the standing position. The individual makes a fist and extends the arm forward as far as possible without taking a step or losing balance. The total reach is measured along the yardstick and recorded. In its original description, the functional reach correlated with other physical performance measures, including walking speed, tandem walking, and standing on one foot.

**Table 13.1** Reference values for the Timed Up and Go Test

| Age (years) | Mean time (s) |
|---|---|
| 60–69 | 8.1 (7.1–9.0) |
| 70–79 | 9.2 (8.2–10.2) |
| 80–99 | 11.3 (10.0–12.7) |

Bohannon RW. Reference Values for the Timed Up and Go Test: A descriptive metaanalysis. J Geriatr Phys Ther 2006; 29(2):64–8 [16]

The "Short Physical Performance Battery (SPPB)" characterizes lower extremity function [19]. It includes measures of standing balance (timing of tandem, semi-tandem, and side-by-side stands; four-meter walking speed and ability; and time to rise from a chair five times). The SPPB captures a wide range of functional abilities, and summary scores <9 have independently predicted disability in ADL and mobility at one to 6 years of follow-up and are also predictive of falls.

Other tests are the "Berg Balance test." It is performed easily in the rehabilitation setting or outpatient clinic [20]. The scale predicted risk of multiple falls in older patients in one study. A more comprehensive performance-oriented assessment of balance includes measures of sitting and standing balance, ability to withstand a nudge on the sternum, and ability to reach up, bend down, and extend the back and neck. Each of these performance measures attempts to identify components of postural stability that complement the standard physical examination. Difficulty in performing divided attention tasks such as "walking while talking" may also identify individuals at high risk for falling. A preliminary study in 60 older people found that those who had difficulty walking while reciting the alphabet or walking while reciting every other letter of the alphabet were at significantly increased risk for falls (odds ratio [OR] 7.02 and 13.7, respectively) [21].

## General Physical Examination

Other aspects like orthostatic hypotension should be excluded. The blood pressure and heart rate should be taken supine and after one and 3 min of standing. Some information may be derived from sitting vital signs if the patient is unable to stand. An assessment of visual acuity should be performed. Hearing may be assessed using the whisper test or a handheld audiometer. Eighth cranial nerve deficits may be associated with vestibular dysfunction. Examination of the extremities may uncover deformities of the feet that contribute to the risk of falling, such as bunions, callouses, arthritic deformities, and sensory neuropathies. A targeted neurologic examination including evaluation of lower extremity strength, gait, and postural stability may identify persons with an increased risk of falls. Individuals who report a history of falls in the past year tend to have a greater number of abnormalities on a neurologic examination [22]. Leg weakness may increase the risk of falling by more than fourfold.

## Diagnostic Testing

Diagnostic testing may be indicated based upon the history and physical examination, including evaluation of postural stability, gait, and mobility. There is no standard diagnostic evaluation of an individual with a history of or at high risk for falls. Only balance problems can be tested by posturography. Laboratory tests such as a hemoglobin concentration and serum urea nitrogen, creatinine, and glucose concentrations can help to rule out causes of falling such as anemia, dehydration, and

neuropathy related to diabetes. Serum 25-hydroxyvitamin D levels can identify individuals with vitamin D deficiency who will benefit from vitamin D supplementation. There is no proven value of routinely performing ambulatory cardiac monitoring in individuals who have fallen. Similarly, the decision to perform echocardiography, brain imaging, or radiographic studies of the spine should not be considered routine, but should be driven by findings during the history and physical examination.

## Preventing Falls

In general, evidence suggests that interventions individually tailored to target risk factors and impairments are more effective than those applied as a standard package [23].

In reviewing the studies of fall prevention, many trials use the number of fallers in active versus placebo groups, whereas other studies use the rate of falls in the active versus placebo groups. Since individuals who sustain multiple falls have a different risk profile than individuals who sustain a single fall, it seems more relevant to clinical practice to favor those studies that examined fall rates as the outcome [24]. A 2012 systematic review evaluated 159 randomized trials of interventions to reduce the incidence of falling and involved 79,193 older persons living in the community [25]. Authors concluded that group- and home-based exercise programs and home safety interventions reduce rate of falls and risk of falling in community-dwelling elderlies. Exercise both reduces risk of falls and prevents injuries related to falls. In care facilities, mostly vitamin D supplementation is effective in reducing the rate of falls [26]. Exercise in subacute hospital settings appears effective, but its effectiveness in care facilities remains uncertain due to conflicting results, possibly associated with differences in interventions and levels of dependency. There is evidence that multifactorial interventions reduce falls in hospitals, but the evidence for risk of falling was inconclusive. Evidence for multifactorial interventions in care facilities suggests possible benefits.

### Exercise Programs

Multiple meta-analyses of randomized trials conducted in various populations, nursing home patients, as well as community-dwelling older adults find that various exercise regimens tend to reduce the risk of falls and that exercise programs that include balance components are most effective [25]. Exercise both reduces risk of falls and prevents injuries related to falls. Exercise interventions can be grouped into different categories: (a) strength training or resistance training exercise, (b) endurance training, (c) flexibility training or range of motion exercises or stretching exercises, and (d) motor control exercises or complex exercises such as gait training, balance training, Tai Chi, dancing, and general physical activity.

Exercise classes incorporating multiple categories of exercise both reduced the rate of falls (rate ratio, RaR, 0.71, 95% CI 0.63–0.82) and risk of falling (risk ratio,

RR, 0.85, 0.76–0.96). Home-based exercises that included more than one type of exercise also decreased the fall rate and fall risk [25]. In one trial involving subjects 70 years and older with a history of a significant fall in the past year, a program that integrated balance and resistance training into everyday home activities resulted in a 31% decrease in the rate of falls (RaR 0.69, 95% CI 0.48–0.99) compared to sham control and was more effective than a structured exercise program done three times a week. Tai Chi, which contains elements of motor control exercise, flexibility, and balance training, was found effective in the systematic review and other studies, although may be less effective in frail older adults at high risk for falls. In one meta-analysis, greater relative effects of exercise in decreasing fall rates were seen for exercise programs that incorporated balance challenges and used a higher dose of exercise. A large trial conducted in New Zealand compared Tai Chi to low-level exercise that did not incorporate any exercise specifically targeted to balance and found that both the Tai Chi and the low-level exercise reduced the risk for falls by 58% [27].

Programs that include multitasking exercises during balance/gait interventions have shown some benefit. One trial compared a walking intervention termed "trail walking exercise" with regular walking, both in combination with a standard exercise program [28]. The trail walking procedure is a complex task walking exercise in which an individual walks sequentially from one numbered flag to another, thereby incorporating the dual task of walking and being challenged with an "executive" function. After a six-month period, incidence of falling showed an 80% reduction in the trail walking group. A trial among community-dwelling older adults of a dual task exercise done to rhythm from piano music improved balance and functional test results and decreased risk of falling and number of falls by about 50%; the benefit persisted 6 months after the intervention [29].

## Medication Modification

One placebo-controlled trial found that gradual withdrawal of psychotropic medications reduced the rate of falls (RaR 0.34, 95% CI 0.16–0.73), but not the risk of falling [25]. Risk of falling was decreased (RR 0.61; 95% CI 0.41–0.91) in one trial that evaluated medication review combined with multiple other physician-focused interventions (academic detailing, provider feedback on prescriptions, and financial reward). However, there is no evidence that medication assessment and withdrawal in the absence of other management interventions will reduce the risk of falling.

## Vitamin D

Although the evidence is not definitive, because of low risk of harm, we suggest that older patients be given cholecalciferol (vitamin D3) supplements for fall prevention, which can be given daily, weekly, or monthly with the dose adjusted to achieve the dosing equivalence of at least 1000 units daily, in agreement with 2014 guidelines

from the American Geriatrics Society for fall prevention [30]. Men and women over age 65 years with low serum 25-hydroxyvitamin D concentrations (<10 ng/mL [25 nmol/L]) are at greater risk for loss of muscle mass, strength, and hip fractures [31]. Vitamin D supplementation may improve bone mineral density and muscle function. However, the effect of vitamin D on risk of falls remains unclear. A 2012 meta-analysis of trials of interventions to prevent falls showed that vitamin D supplementation in community-dwelling adults did not reduce risk of falling (risk ratio 0.96, 95% CI 0.89–1.03, 13 trials) or the rate of falls (rate ratio 1.00, 7 trials), but may have had some effect in people with lower pretreatment vitamin D levels [25]. It is important to ask about dietary supplements (some of which contain vitamin D) that patients may be taking, as well as assessing other contributors to vitamin D status such as dietary intake, the presence of obesity, and sun exposure before prescribing extra vitamin D, since the amount of supplemental vitamin D should take these factors into account.

### Multiple and Multifactorial Interventions

In a meta-analysis of six studies, home safety assessment and interventions decreased the rate (RaR 0.81, 95% CI 0.68–0.97) and risk (RR 0.88, CI 0.80–0.96) and were most effective for individuals at higher fall risk and when delivered by an occupational therapist [25]. In a subsequent cluster randomized trial, a standardized set of home safety interventions, installation of stair handrails, grab rails in bathrooms, improved lighting, slip-resistant deck surfacing, nonslip bathmats, etc., resulted in a 26% decline (RR 0.74, 95% CI 0.58–0.94) in injuries caused by falls over a 3-year period, compared with study of households that were wait-listed for the intervention. Vision assessment and correction did not reduce risk or rate of falls in four trials. One randomized trial found that substituting single lens for multifocal glasses during outdoor and walking activities decreased the rate of falls in active older adults. Nonslip devices worn on shoes in winter weather conditions decreased the rate of falls in the outdoors (RaR 0.42, 95% CI 0.22–0.78). Educating older people about fall prevention as a sole intervention did not reduce the rate or risk of falls in a systematic review [25]. A systematic review of "cognitive motor interference" (CMI) interventions (practicing a simultaneous cognitive and motor task) to prevent falls concluded that CMI training reduced falls and improved gait, balance, and reaction time [32].

### Several Interventions Targeting Patients with Specific Morbidities

For fallers with carotid sinus hypersensitivity, insertion of a cardiac pacemaker decreased the rate of falls (RaR 0.42, 95% CI 0.23–0.75) [25]. For patients with cataracts, expedited surgery for the first eye reduced the rate of falls (RaR 0.66, 0.45–0.95), but cataract surgery for the second eye was not associated with a

decrease in the rate of falls [25]. Data from a Medicare database comparing hip fracture rates in patients with cataract who did or did not undergo cataract surgery found a 16% decrease in the adjusted odds ratio for hip fracture within 1 year in patients who had surgery and a 23% decrease for patients with severe cataract. Compared with usual care, oral nutritional supplementation for 3 months for malnourished older patients (BMI <20 kg/m$^2$ or significant recent unintentional weight loss) who had been recently hospitalized decreased the number of falls and number of fallers. The intervention included vitamin D, a protein supplement, and nutritional counseling. Postural hypotension is a fall risk, and treatment has shown benefit [14]. Treatment may include medication reduction, fluid optimization, elastic stockings, or medications such as fludrocortisone or midodrine. For community-dwelling older patients with disabling foot pain, a multifaceted podiatry intervention (podiatry care, orthotics, footwear subsidy, foot and ankle exercises, and falls education) led to a 36% reduction in the incidence of falls compared to patients who received usual care.

## Preventing Complications of Falls

The above measures can reduce a large number of falls, but do not prevent them entirely. Additional aids should be considered for preventing fall complications.

### Hip Protectors

Hip protectors have been studied as a method of preventing hip fractures. A meta-analysis of randomized trials that included both community-dwelling and nursing home patients found no evidence that they were effective in reducing hip fractures in studies in which randomization was by individual patient within an institution or among patients living at home [33]. Hip protectors may fail to prevent injury because they are often not worn, or injury occurs in circumstances that would have precluded use of hip protectors.

### Assistive Devices

Providers are often motivated to recommend assistive devices (walkers or canes) to their aging patients with gait and balance impairments related to decline in neuromuscular function with aging and/or chronic disease. Some individual patients are obviously benefited by such devices, in terms of mobility. However, evidence that assistive devices reduce the risk of falls is lacking. There are no randomized placebo-controlled trials of assistive devices to prevent falls. Observational studies have noted an association between the use of assistive devices and increased risk for falls. This most likely represents an inherent bias because individuals with the most impaired gait and balance are most likely to be prescribed these devices. It should

be possible that using a walker or cane can interfere with compensatory stepping, which may result in an increased risk for falling.

## Time on Floor

A study of 1100 individuals over age 72 found that 47% of the 313 who experienced non-injurious falls were unable to get up for at least 1 h after falling [34]. Prolonged time on the floor was associated with serious injury, hospital admission, and move to long term care. Call alarm systems have been promoted to prevent "long lies" after falls. These systems may include alarm buttons worn on the person or in the room. Their effectiveness is uncertain. Sometimes very old fallers who could not get up and had some type of call alarm system did not use it.

## Anticoagulation

A decision analysis has concluded that a predisposition to falls, with potential head trauma, is rarely a contraindication to the use of anticoagulants in older adult patients with atrial fibrillation (AF) [35]. Even when taking anticoagulants, the risk of subdural hematoma is so low that persons with an average risk of stroke from AF must fall approximately 300 times in a year for the risks of anticoagulation to outweigh its benefits.

**Conclusion**

With advancing age the risk of falling and fall-related injuries increases. Most fragility fractures are caused by falling from a standing or sitting position. The sensory-motor system is complex, and many age- and disease-associated changes have a negative impact on balance. Thus, a fall risk screening or assessment has to be performed in older patients with osteoporosis. Multifactorial/multicomponent interventions have to address identified risk factors in order to effectively prevent falls.

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