

REVIEW

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Exercise for fracture prevention - evidence and consensus-based practice guideline of the osteology umbrella association (DVO)

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Abstract

Exercise is considered a cornerstone of fracture prevention in people at increased risk of fractures. However the most effective exercise strategy for preventing fractures has yet to be determined. The primary aim of the present evidence- and consensus-based guideline was thus to derive practice recommendations for effective, feasible and safe training programs to prevent fractures in various cohorts. A novelty of our approach was the assignment of dedicated cohorts at risk for fractures to training objectives that prioritized bone strength or/and fall risk or/and fall impact reduction. In summary, bone strength exercise protocols should include periods of high loading magnitude and rate provided by impact loading and dynamic strength/power training. Fall risk should be addressed by an individualized mix of balance, perturbation, functional, stepping and interactive cognitive-motor exercises. Simple and low-risk strategies for safe landing can be advised unreservedly, however more sophisticated strategies derived from martial arts require close and experienced supervision and high safety standards. If the latter strategies are chosen in interventions, they should be reserved for dedicated training periods. Training frequency should be set at least 2 (bone strength) or 3 (fall risk) sessions/week, possibly with a (block) periodized approach with intense periods intermitted by low/regenerative phases, with varying training aims focusing on progression.

Clinical trial number

Not applicable.

Keywords Exercise, Low-trauma fracture, Bone mineral density, Fall risk, Practice recommendations, Consensus statement

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Introduction

Due to the profound individual consequences and considerable socioeconomic burden, low-trauma fractures, considered as fractures resulting from minor mechanical force, such as a fall from standing height or less, caused by low bone strength (i.e. osteopenia or osteoporosis [1]) represent a considerable challenge to healthcare systems in our aging societies [2]. Thanks to its favorable effect on bone strength [3] as well as the reduction of falls [4] and fall impact [5], exercise¹ might be the most promising intervention for preventing fractures related to osteoporosis [6]. Nevertheless, the most effective and feasible exercise protocol for people at increased risk for osteoporotic fractures has not yet been determined. This should not come as a surprise, because in the light of the varying individual risk factors, limitations, needs and requirements and safety aspects, a one-size-fits-all solution and a standard procedure for exercise training programs is not a viable option. Using an evidence- and consensus-based approach, the present DVO (Dachverband Osteologie e.V.) guideline on physical exercise for fracture prevention [7] aimed to address key research questions related to exercise-induced fracture prevention in women and men 45 years and older. However, the primary goal was to derive practical recommendations for effective, feasible and safe exercise training tailored to distinct risk categories among individuals susceptible to osteoporotic fractures. In detail, this includes people with low bone mineral density with and without present fractures and different degrees of fall risk.

Methods

The guideline on “physical exercise for fracture prevention” was initiated by the “Dachverband Osteologie e.V.” (DVO), a tri-national umbrella association (Austria, Germany, Switzerland) of 21 medical and scientific professional societies that focus on bone diseases. The project was registered (AWMF 183–02) according to the “Working Group of the Scientific Medical Societies” e.V. (AWMF). The guideline process was initiated and coordinated by the Institute of Radiology, University-Hospital Erlangen (UKER), Germany. Of note, in Germany guidelines must be registered with the AWMF via a professional association (here: DVO) and are subject to strict monitoring. Following the consensus conference and acceptance of the guideline by the involved professional associations and publication of the guideline, no further changes to the recommendations are possible until the next revision (every 5 years).

¹In contrast to physical activity that is any bodily movement produced by skeletal muscles that require energy expenditure, exercise is a subset of physical activity that is planned, structured, repetitive, and purposed for achieving physical fitness.

Scope and purpose of the guideline

Objectives of the guideline, research questions

The present guideline pursues various objectives in the field of physical training and fracture prevention in middle-aged and older people [7]. Briefly, this includes the research questions listed below. For a detailed listing and description of the research questions, the reader is referred to the guideline [7].

(a) Generating general evidence for the effect of physical exercise on

- incidence of low-traumatic and osteoporotic fractures
- bone mineral density (BMD) in postmenopausal women
- BMD in men 45 years and older
- BMD in people with glucocorticoid-induced osteoporosis
- fall risk
- fall impact

(b) Derivation of optimized training recommendations to prevent low-traumatic and osteoporotic fracture by different training strategies. The research topics addressed the following training dimensions

- training contents/types of exercise,
- exercise equipment,
- exercise components (synonym: exercise variable),
- training principles

Targeted patient groups

The present guideline targets community-dwelling men and postmenopausal women 45 years and older with normal bone mineral density (BMD), osteopenia and osteoporosis² and a normal or increased risk of falling. Children, adolescents, premenopausal women, younger men and individuals living in institutionalized settings were not addressed by the guideline.

Outcomes and operationalization

- Fracture incidence
 - Clinical low-traumatic fractures and main osteoporotic fractures (hip, lumbar spine, forearm and proximal upper arm [8])
- Bone strength

²Osteopenia: BMD reduction between -1.0 and -2.5 standard-deviation (SD) T-score (T-score compares individual BMD to the average BMD of a young, healthy adult of the same gender); Osteoporosis BMD reduction ≥ -2.5 SD T-Score.

- Bone density recorded via DPA, DXA or QCT on the lumbar spine and proximal femur region of interest (ROI)
- Fall risk
 - Number of falls
 - Number of falls with injuries
- Reduction in fall impact
 - Fall energy
 - Number of falls with injuries
- Surrogate parameters for the risk of falling
 - Strength abilities
 - Balance abilities

User target groups

The recommendations in the guideline are primarily intended for groups working in the field of osteoporosis and fracture prevention. Professionals involved in the practical implementation of physical exercise training such as physiotherapists/physical therapists, exercise therapists, sport scientists and exercise instructors are particularly addressed. The guideline is also aimed at people affected by or at an increased risk of fractures and their relatives. Political decision-makers should use the guideline as an orientation.

Participants and contributors in the development of the guideline

In accordance with the AWMF, which specifies and suggests potential specialist associations³ be involved in the guideline process, a large variety of associations were contacted. The respective professional societies were contacted by the guideline coordinator (WK) and provided mandate holders of their choice with experience in guideline development and expertise on the topic. Unfortunately only a limited response was received from non-German representatives. Of the five associations from Austria and Switzerland related to the DVO, lastly one Austrian association participated in the guideline development. Nevertheless, the expert group was formed on a multidisciplinary basis, taking into account all relevant expert groups, professional associations and stakeholders in the field of fracture prevention through physical exercise. This embraces expertise in endocrinology, osteology, orthopedics, geriatrics and gerontology, gynecology, nephrology, rheumatology, physical medicine

and rehabilitation, pain therapy, exercise science and physiotherapy. Stakeholders of patient organizations, educational bodies and institutional providers of preventive and rehabilitative exercise programs were closely involved in the development of the guideline. In summary, 14 appointed mandate holders with voting rights represented the 13 participating institutions and organizations. A list of the professional societies, associations, institutions and individuals involved can be found in the Acknowledgements section.

The scientific core team of three senior researchers (DS, SvS, WK) developed and prepared the clinical research questions addressed above. A board of five members (FJ, FT, KKS, SP, UL) of participating institutions and organizations complemented the core research team and advised them according to their expertise (exercise science, physiotherapy, osteology, radiology, biometry). Together with five affiliated researchers (EK, CB, HK, MS, SK) and 14 PhD and MD students, the core team prepared evidence for the dedicated research questions by reviewing and summarizing the available literature applying systematic searches and formed the first draft of recommendations according to scientific standards [9, 10] and the AWMF specifications (<https://www.awmf.org/>).

Guideline development process

Figure 1 illustrates the stepwise approach used to develop the present guideline “Exercise for Fracture Prevention” in more detail.

Evidence generation

Systematic guideline search

In the first step of the evidence generation process (Fig. 1), a systematic guideline search was conducted to access existing evidence in the targeted area (fracture prevention). The rationale for the present systematic guideline search was the expectation that not only evidence on the effectiveness of physical training for bone strength in different groups but also concrete and sufficiently precise sports science recommendations for the practical implementation of physical training could be taken from existing guidelines.

In addition to querying the guideline databases of the GIN (Guideline International Network) and AWMF, a comprehensive search was conducted in electronic databases via PubMed, Scopus, and Cochrane for all current guidelines published between 2008 and June 2021. No restrictions were made based on language. The search strategy used the PICOS scheme. In detail, guidelines that focus on middle aged and older people (P), contain information on exercise interventions (I), that compared exercisers with active or inactive comparators, (C) addressed outcome on osteoporosis and fracture prevention, (O)

³In this context it is important to note that associations rather than individuals have to be contacted as part of the guideline development process.

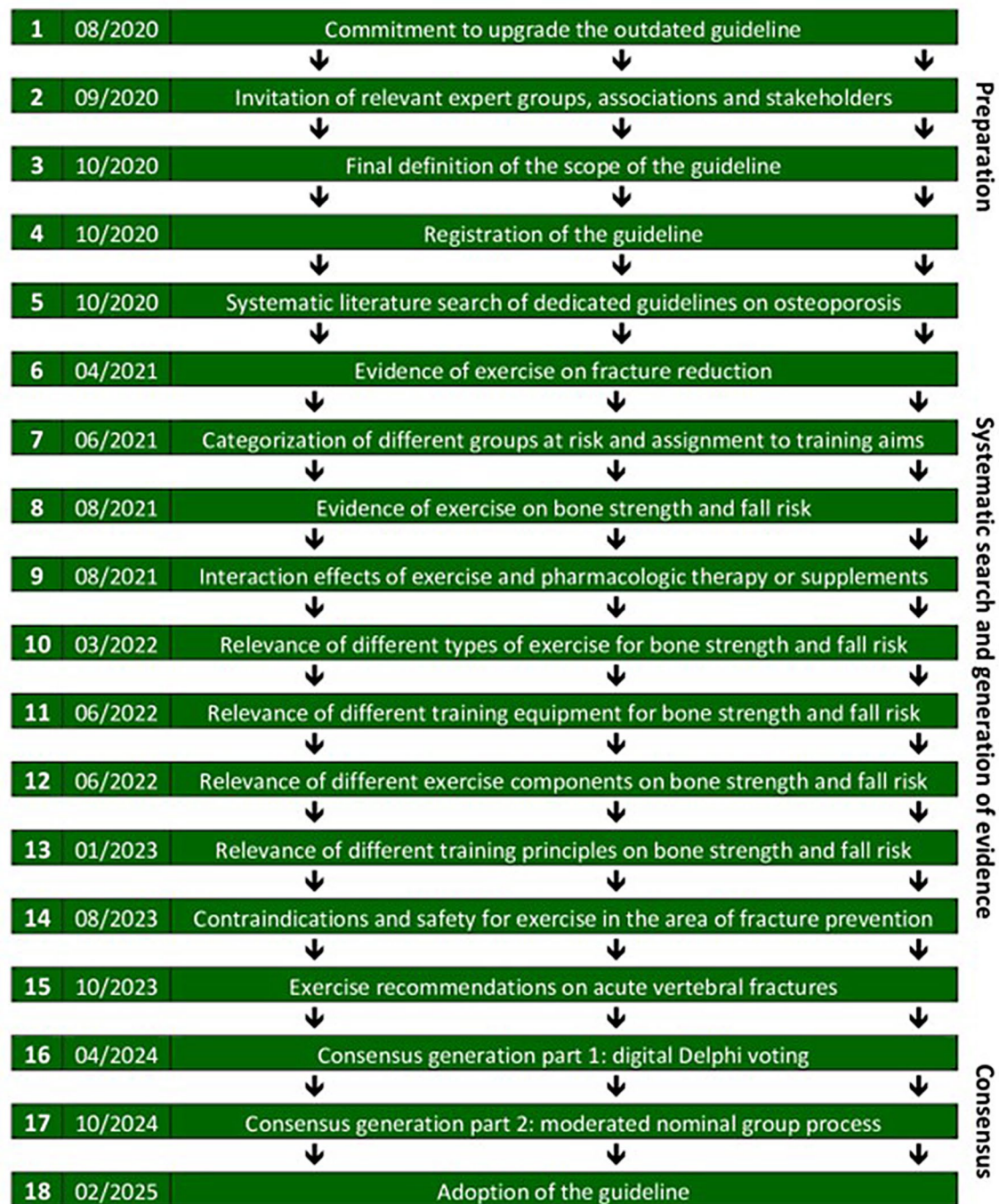


Fig. 1 Timeline (start date) and steps in the development of the present guideline. Sections 10, 12 and 15 are not covered by the present article

and were specifically designed as guidelines were eligible. The literature search was based around the English-language search terms “osteoporosis,” “exercise,” and “guideline.” A standard protocol was developed for this search and a controlled vocabulary (Mesh terms for MEDLINE) was used. The keywords and their synonyms for the specific guideline search were as follows: (Guideline OR management) AND (exercise OR exercise training)

AND (osteoporosis OR fracture). Duplicates were identified and excluded by comparing author names, titles, and publication dates. Two reviewers (SvS, WK) first independently assessed the full-text articles and then the extracted data from the included studies. If no consensus could be reached, a third reviewer (MS) was consulted. After reviewing the 51 eligible full-text articles, 41 articles were excluded, mainly due to their marginal

information content in the area of “physical exercise and osteoporosis”. Ten guidelines were analysed in more detail. In summary, although some guidelines provided useful information or provided dedicated recommendation on exercise in the area of osteoporosis or fragility fractures [11, 12], the guideline group finally considered these recommendations not sufficiently comprehensive or not up to date with the current literature.

Systematic literature searches

Due to the lack of transferable recommendations provided by available guidelines we focus on systematic literature searches to summarize present evidence in the different areas of the guideline. Using synergies between the research topics, not all recommendations were derived from dedicated literature searches, but were based on secondary analyses and manual searches of systematic searches that addressed more comprehensive topics. In summary, 21 standardized comprehensive searches in at least five important databases (e.g. Medline, CINAHL, Cochrane, Web of SPORT, SPORT-Discus) each of them applied a standard protocol with a controlled vocabulary without language restrictions. Eligibility criteria were applied according to PICO(S). Dependent of the topic addressed, eligibility criteria occasionally vary between the comprehensive literature searches particularly with respect to “outcomes”, but also for “intervention” and “participants”. In most cases only primary literature was considered, however in some cases with complex study situations meta-analyses were also accepted (e.g. [4]). Additionally, reference lists of included studies were screened manually to identify further potentially relevant articles. Identified references were saved in Endnote and duplicates were removed according to the method suggested by Bramer et al. [13]. Two reviewers each independently screened titles, abstracts, and full texts for eligibility. All disagreements were resolved by discussion. For details of the literature searches the reader is kindly referred to the respective publications [3, 14–24] which provide a general overview of our approach.

Systematic reviews, meta-analyses and meta-regressions

For particularly important cases, the literature searches were processed more intensively to provide evidence by meta-analyses and meta-regressions [16–31]. The reasons for this approach were quite diverse. In some cases, the relevant number of new publications required an update (e.g. [27, 28]), in other cases different eligibility criteria were applied (e.g. [21]) or the lack of studies that address this issue [20, 31] needed updated evidence. In two cases we applied [18, 24] a more reliable comparison approach from our point of view. For detailed information on search strategy, eligibility criteria, data extraction

and synthesis the reader is kindly referred to the respective publication [16–31] or the full text version of the guideline [7].

Methodological quality assessment, risk of bias

The methodological quality of systematic reviews and meta-analyses was rated separately by two independent researchers (corresponding PhD/MD student and either SvS, DS, EK or WK) each using the R-AMSTAR (Revised Assessment of Multiple Systematic Reviews) score [32]⁴. In cases of discrepancies, another senior researcher was consulted (SvS, DS, EK or WK). Briefly, R-AMSTAR includes 11 items, each scored from 1 to 4. Although, R-AMSTAR per se did not provide a categorization, we considered ≥ 37 score points for high-, 30 to 36 points for moderate -, and < 30 points for low study quality.

In parallel, randomized controlled trials were evaluated by two researchers applying the PEDro [33] and TESTEX score [34], both specifically dedicated to physiotherapy and exercise studies. Of note, in no case significant differences between the categories were found in any of the meta-analyses where sensitivity analyses for methodological quality (i.e. “low” vs. “moderate” vs. “high” [35]) were applied.

Categorization of evidence and evidence levels

Evidence levels were categorized according to the Agency for Healthcare Research and Quality (AHRQ):

- Ia: Evidence from meta-analysis of several randomized controlled trials
- Ib: Evidence based on at least one randomized controlled trial.
- IIa: Evidence based on at least one well-designed but non-randomized controlled trial.
- IIb: Evidence based on at least one well-designed, quasi-experimental study.
- III: Evidence based on well-designed, non-experimental descriptive studies, e.g. comparative studies or case-control studies.
- IV: Evidence based on reports from expert committees or on the clinical experience of recognized authorities.
- V: Evidence based on case series or multiple expert opinions.

Evidence levels were summarized to a three-stage categorization according to the suggestion to the program for national health care guidelines [36].

⁴In summary, R-AMSTAR results vary between 34 and 43 (of a maximum of 44) score points for the systematic reviews addressed.

- Grade A: At least one randomized controlled trial of overall good quality and consistency that relates directly to the recommendation in question and has not been extrapolated (evidence levels Ia and Ib).
- Grade B: Well-conducted clinical studies, but no randomized clinical studies, with direct reference to the recommendation (evidence levels II or III) or extrapolation from evidence level I if the reference to the specific research question is missing.
- Grade C: Reports from experts or expert opinion and/or clinical experience of recognized authorities (evidence category IV), extrapolation of evidence level IIa, IIb or III or animal studies that focus on the specific topic. This classification indicates that directly applicable clinical studies in humans of good quality were not available.

Grading of recommendations

Apart from evidence grades, particularly study results (effect size, homogeneity, sensitivity) were taken into account when formulating the recommendations. Clinical aspects, patients' risk/benefit ratio, the feasibility/applicability/cost-effectiveness and patients' preferences were also closely heeded when determining the recommendation grades. This includes the close discussion with stakeholders (e.g. Federal Patient Association for Osteoporosis, Germany), educational institutions (e.g. German Association for Health-Related Fitness and Exercise Therapy), rehabilitation providers (Bavarian Disabled and Rehabilitation Sports Association) and individuals of our local health sport club on osteoporosis (Bone Health Network Erlangen, Germany).

Recommendations were graded and formulated according to the AWMF system (<https://www.awmf.org/>):

- Degree A: Strong recommendation; "is recommended".
- Degree B: Moderate recommendation; "is suggested".
- Degree 0: Neutral recommendation; "may be considered".

The three core researchers were responsible for the proper preparation of the recommendations. Discrepancies were resolved through discussion or in a few cases voting.

Consensus process

After fixing the recommendations, the consensus process according to the AWMF procedure started in June 2024. Of importance, only mandate holders ($n = 14$) without any evidence for conflicts of interest according to the AWMF form "Declaration of interests and handling of conflicts of interest" were included in the consensus process using a modified Delphi approach. Applying the

AWMF procedures, briefly, consensus was reached in a two-stage process (Fig. 1). During the first stage, the 14 mandate holders of the participating societies and organizations were invited to participate in an online Delphi vote. In summary, the 73 recommendations of the guideline were released for an initial vote. Background information was provided by the long version of the guideline and the AWMF manual "Assistance for Delphi procedures for guidelines using digital voting". Mandate holders could either agree with the recommendations, reject them, or abstain. Only recommendations receiving unanimous (100%) approval were accepted directly. Forty-two or 58% of the recommendations were not approved by all mandate holders. Ten recommendations were rejected by two to a maximum of four voters. Recommendations not receiving unanimous approval were returned to the corresponding voters with the request to suggest alternative wording or modifications. Most frequently only alternative wording was suggested, only in three cases more profound changes are required (e.g. recommendation 7, 8). Results from the initial round, including all proposed changes and relevant comments, were then summarized and shared among all mandate holders.

In the second stage of the consensus process, recommendations that received less than 95% agreement (i.e. full consent) during the Delphi online voting were further discussed during the nominal group session, conducted online on 10/29/2024. This consensus conference was moderated by a neutral representative of the AWMF. Following an introduction to the (voting) procedure, each recommendation requiring further deliberation was briefly presented, along with its supporting evidence, rationale and in a few cases the wording of the recommendations and/or the level of recommendation was changed or recommendations were summarized. Finally, recommendations were voted by acclamation under the direction and documentation of the AWMF representative. In summary, all recommendations were accepted with full consent during the second consensus stage. The guideline was ultimately adopted by all participating professional societies, organizations and institutions on 02/10/2025.

Results

This article presents 45 (out of 73)⁵ recommendations considered most relevant for designing and implementing exercise training programs aimed at fracture prevention. Recommendations that refer to additive effects of

⁵as listed in Fig. 1, the recommendations not included in the present article refer to "relevance of different training equipment ..."; "interaction between pharmacologic therapy or supplements ..." and "exercise recommendation after acute vertebral fractures". Additionally some less(er) relevant recommendations regarding types of exercise, exercise components, or training principles were not addressed in this article.

combined exercise and pharmacologic therapy [16, 20, 25] or Vitamin D [26] and protein-supplementation [31] were not included. The same applies for exercise recommendation after acute osteoporotic vertebral fracture. This approach was taken due to the volume of the article, as neither topic fully aligned with the practical recommendations of the present work. Therefore, readers are referred to the relevant publication or the full text of the guideline.

General evidence of exercise effects on fracture prevention

Recommendation 1 summarizes the general evidence supporting physical exercise as an effective intervention for preventing low-trauma fractures.

Recommendation 1

Men and postmenopausal women 45 years and older with increased fracture risk are recommended to perform appropriate physical exercise training to prevent fractures.
Strong recommendation, (Evidence) Grade A [27, 28], 100% consensus

Explanation and conclusion

In summary there is considerable evidence for a positive effect of physical exercise on fracture reduction. Thus, in general, physical exercise is recommended as a core prevention strategy to reduce fractures in people 45 years and older.

Recommendation 2

Fracture prevention programs are recommended to be supervised by a qualified exercise professional.
Strong recommendation, Grade A [28], 100% consensus

There is some evidence that supervised protocols resulted in higher effect sizes for fracture reduction than predominately non-supervised protocols, although this finding may be influenced by the exercise setting, bearing in mind the fact that home-based exercise programs typically lack supervision. Although this guideline strongly recommends providing adequate supervision in the area of exercise and fracture reduction independently of the setting, we would like to emphasize that predominately non-supervised exercise programs also have a significant fracture-preventive effect [37].

Assignment of patient categories to dedicated training objectives

Although fracture prevention is the definitive endpoint of intervention programs in the field of osteoporosis, it is too vague for dedicated training methodological control and monitoring of the realization of individual training goals. Figure 2 shows the determinants of fracture risk, which should be targeted in terms of training goals, as starting points for the training regulation process [38].

Following the exercise principle of individualization, we categorized cohorts at increased fracture risk according

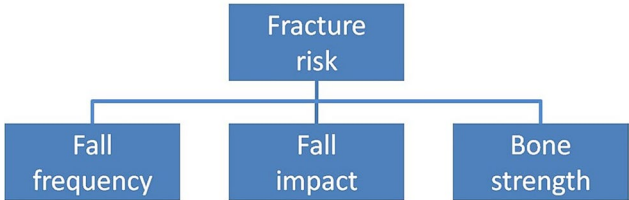


Fig. 2 Determinants of fracture risk

to bone strength, fall risk, physical fitness and eligibility for pharmaceutical therapy and assigned as their most relevant training objective i.e. (a) bone strength (b) falls and (c) fall impact (on bone) [39] (Table 1).

As shown in Table 1, training objectives vary in relevance across different risk categories. While maintaining or increasing bone strength is most important for physically fit individuals with increased bone loss but with limited eligibility for pharmaceutical therapy (e.g. early-postmenopausal women), this objective becomes largely obsolete for frail older people with multiple fractures and corresponding high-end pharmacologic therapy. Given the limited evidence for positive effects of pharmaceutical therapy on fall risk [40], exercise training should target fall frequency and severity in these individuals.

We agree that the categorization presented might be too vague to specifically classify individuals to their dedicated fracture risk. Nevertheless, we think it is suitable for the reliable allocation of cohorts to their most promising training strategies.

Table 1 Assignment of categorized groups to respective training objectives most relevant for fracture prevention

Patient risk category	Recommended key training aims
(1) Individuals with increased bone metabolism, moderate reduction in bone strength (in the sense of “osteopenia”) without relevantly increased risk of falls.	Maintain/increase bone strength
(2) Individuals with significant reduction in bone strength (in the sense of “osteoporosis”) without relevantly increased risk of falls.	Maintain/increase bone strength
(3) Individuals with significant reduction in bone strength (“osteoporosis”) without fractures but with significantly increased risk of falls.	Maintain/increase bone strength Reduce the number of falls Improve fall pattern to reduce impact
(4) Individuals with osteoporosis-associated fractures and multiple and/or pronounced fall risk factors	Reduce the number of falls Improve fall pattern to reduce impact Maintain/increase bone strength
(5) Frail individuals with multiple osteoporosis associated fractures, multiple and/or pronounced fall risk factors.	Reduce the number of falls Improve fall pattern to reduce impact

General evidence of exercise effects on bone strength

Bone strength is a major determinant of fracture risk, thus the second part of this guideline aimed to systematically evaluate and summarize the evidence of physical exercise on bone strength. Acknowledging that BMD does not entirely capture bone strength but remains the most reliable surrogate marker, we focused specifically on exercise trials that utilized BMD as a study outcome. Recommendations 3 to 5 summarize the overall evidence regarding the effectiveness of exercise interventions on BMD across different target populations.

Recommendation 3

Postmenopausal women who are at risk of or affected by osteoporosis are recommended to perform appropriate physical exercise training to improve bone strength.

Strong recommendation, Grade A [22], 100% consensus

Recommendation 4

Men who are at risk of or affected by osteoporosis are recommended to perform appropriate physical exercise training to improve bone strength.

Strong recommendation, Grade A [21], 100% consensus

Recommendation 5

People who are at risk of or affected by glucocorticoid-induced osteoporosis are recommended to perform appropriate physical exercise training to improve bone strength.

Strong recommendation, Grade A [17], 100% consensus

Explanation and conclusion

Addressing the most important groups at risk or concerned by increased bone loss, osteopenia or osteoporosis, considerable evidence for the positive effect of physical exercise on BMD was provided. Thus, in general, physical exercise is recommended as a core prevention strategy to positively affect BMD in people at increased risk for osteopenia or osteoporosis.

Exercise types or training contents to increase bone strength

Regardless the overall positive effects of exercise on BMD, results vary considerably between individual trials. Given the plethora of possible exercise protocols, differing in composition of training contents, exercise components/variables, exercise principles, and settings, many programs fail to significantly improve BMD. Thus, we systematically evaluated and reached a consensus on recommendations 6–12, which specifically address optimal exercise content and training types for enhancing bone strength.

Recommendation 6

It is recommended to include weight-bearing exercise and/or dynamic strength training in exercise training programs that focus on bone strength.

Strong recommendation, Grade A [3, 19, 41], 100% consensus

Recommendation 7

Walking as an intervention to improve bone strength may be considered for people with a severely reduced stimulation threshold¹.

Neutral recommendation, Grade A [42–45], 100% consensus

Recommendation 8

Swimming as an intervention to improve bone strength may be considered for people with a severely reduced stimulation threshold¹. More capable cohorts were recommended to add bone-specific exercise.

Neutral recommendation, Grade A [46–48], 100% consensus

Recommendation 9

Water-based exercise types are recommended as a training option to improve bone strength

Strong recommendation, Grade A [29], 100% consensus

Recommendation 10

When cycling is used as training content to improve cardiometabolic performance and physical fitness, suitable physical training for fracture prevention is suggested to be added.

Moderate recommendation, Grade A [49, 50], 100% consensus

Recommendation 11

Whole-body vibration is suggested as a training option to improve bone strength.

Moderate recommendation, la [51, 52], 100% consensus

Recommendation 12

Whole-body Electromyostimulation is suggested as a training option to improve bone strength for people with limited function and joint problems.

Moderate recommendation, Grade A [53], 100% consensus

¹i.e. people whose stimulus threshold is very low due to their low habitual mechanical stress and corresponding deconditioning and which can be exceeded even by low-intensity stimuli

Explanation and conclusion

In general, exercise types incorporating relevant weight bearing/impact loading (aerobic dance) and/or muscular tension (e.g. dynamic resistance training: DRT) have been demonstrated to positively impact BMD in people 45 years or older. In contrast, activities commonly preferred by older adults such as walking, cycling or swimming, activities, have minimal or no (osteogenic) effect, except potentially in individuals whose bone stimulation threshold is severely reduced due to extended periods of physical inactivity or bed rest. Aquatic exercises, more a vehicle rather than an exercise type per se, have been proven to be effective in increasing BMD. Nevertheless, land-based exercise generally produce greater bone-strengthening [54] thus aquatic exercise should be

primarily considered as an option for individuals with low physical function and/or joint problems. The same goes for Whole-Body Electromyostimulation, a rather novel closely supervised training technology [55]. Additionally positive evidence exists for Whole-Body Vibration (WBV), another training technology that is suggested as an option for increasing BMD, at least when other effective types of exercise are difficult to implement.

However, the effectiveness of training contents depends on the way it is applied. E.g. even types of exercise with high osteogenic potential (e.g. step aerobics or DRT) will fail if very rarely applied [56].

Relevance of selected exercise components on bone strength

Exercise induces specific mechanical stress (loading) that triggers bone adaptation. Figure 3 summarizes key mechanical (bone-)loading components associated with exercise-induced improvements of bone strength. Due to the close interaction between exercise components, it is difficult to derive recommendations for isolated loading components solely on comparisons between heterogeneous study protocols [57]. Nevertheless, the most critical loading components for effectively strengthening bone are addressed in recommendations 13 - 17.

Recommendation 13
Dynamic strength training and weight-bearing exercise training are recommended to be performed with varying loading magnitude to avoid desensitization and overuse of the bone structure. Strong recommendation, Grade A [18, 58, 59], 100% consensus
Recommendation 14
Exercise training to improve bone strength is recommended to include training phases with high loading rates. Strong recommendation, Grade A [60], 100% consensus
Recommendation 15
Dynamic strength training and weight-bearing exercise training are suggested to be performed with varying loading rate to avoid desensitization and overloading of the bone structure. Moderate recommendation, Grade B [60, 61], 100% consensus
Recommendation 16
For people without relevant limitations, exercise is suggested to focus on low cycle number but high loading magnitude and/or rate. On the other hand, higher cycle number might compensate for moderate loading rate in people with limitation and or low tolerance for high intensity/velocity stimuli. Moderate recommendation, Grade B [18, 62–64], 100% consensus
Recommendation 17
Physical exercise to improve bone strength is suggested to be carried out in a dynamic mode. When applied in an isometric mode, short but intense stimuli should be preferred. Moderate recommendation, Grade C [65–67], 100% consensus

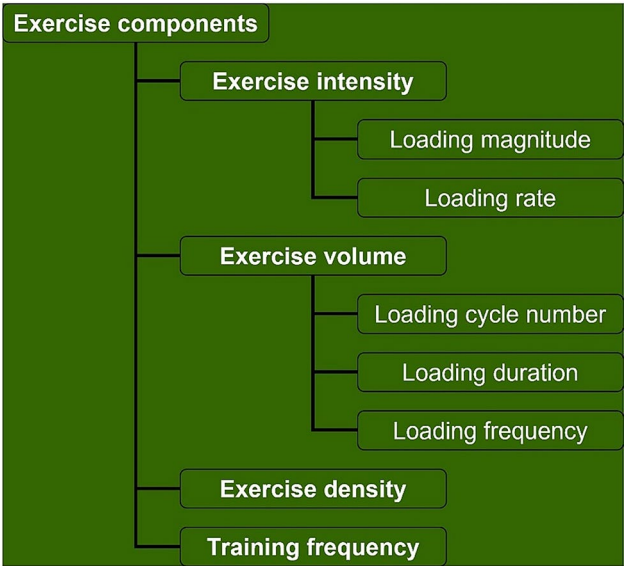


Fig. 3 Exercise components (synonym: exercise variables) related to bone adaptation [39] (Explanation on components see glossary)

Explanation and conclusion

Dedicated exercise strategies aimed at enhancing bone strengthening should focus on high loading magnitude and rate e.g. applied by high intensity/high velocity resistance exercise (DRT) and/or high impact aerobic dance and/or dedicated jumping exercises (if applicable). In contrast to the high ground reaction forces of high-impact weight bearing exercise, the high loading magnitude and rate generated by rapid movements (with focus on concentric range of motion) during DRT are generally feasible and well tolerated by older people or people with joint problems [68–70]. However, evidence suggests a variation of loading magnitude and rate, e.g. with periods of high intensity and/or high velocity WBE and DRT, intermitted by phases with lower loading magnitude and rate to avoid bone desensitization and allow adaptation and regeneration. When applying high stimulus intensity/rate, the cycle number is largely irrelevant, however when loading magnitude averages slightly below or around bone adaptive threshold, an increased number of cycles might trigger positive bone response [63, 71]. Of importance, in contrast to high loading magnitude (often considered as absolute exercise intensity) there is no evidence that exercise has to be applied with high “relative” exercise intensity i.e. work to fatigue or even muscular failure, to achieve bone-strengthening benefits. Further, exercises are recommended in a dynamic rather than an isometric mode [65–67], however this recommendation was based solely on animal data. Apart from bone specific loading parameters, other exercise components have to be considered when designing optimized exercise protocols for bone strengthening. This relates to exercise/loading density and in particular to training frequency.

Recommendation 18

Training periods with a high stimulus level are suggested to be intermitted by regenerative phases.

Moderate recommendation, Grade C [72, 73], 100% consensus

Explanation and conclusion

Due to bone desensitization resulting from prolonged loading [72], there is some evidence (albeit provided by animal studies) suggesting that frequent rest periods between intense phases of bone loading may produce superior results in bone strength compared to continuous loading [73]. The concept has been successfully applied in human exercise trials [74–76].

Recommendation 19

Exercise training programs to improve bone strength are recommended to be carried out at least twice a week

Strong recommendation, Grade A [24, 56], 100% consensus

Explanation and conclusion

To achieve meaningful improvements in bone strength, even optimized exercise training protocols should average at least two training sessions per week on an annual basis (i.e. net attendance), as lower frequencies have shown minimal or no positive effects on BMD [77–79].

General evidence of exercise effects on fall risk

Since sufficient high-quality evidence for positive effects of exercise on fall outcomes [4, 80] is provided, the issue of general evidence has not been evaluated further by own research. However, comparable to the bone strength, not each and every exercise protocol is adequately designed and aligned to positively impact fall risk. Thus, the present section focuses on evidence-based recommendations for exercise protocols in the area of fall prevention.

The most significant risk factor for fractures in older adults are falls [81]. Given the existence of sufficient evidence confirming the beneficial effects of physical exercise on fall-related outcomes [4, 80, 82–84], we did not further evaluate general effectiveness in this guideline. However, similar to interventions aimed at improving bone strength, not all exercise protocols are equally effective in reducing fall risk. Thus, the following section provides specific guidance on exercise components and protocols that have been shown to effectively reduce falls.

Training contents to reduce fall risk

Following a similar approach as for bone strength, we derived specific recommendations for effective training contents/exercise types aimed at reducing fall risk. Given the existing evidence in this area, we did not perform additional systematic reviews - with the exception of interactive cognitive-motor training (ICMT). Training components were categorized according to the suggestion of Lamb et al. [85] where applicable. Summarizing

the existing evidence in this area led to recommendations 20–32.

Recommendation 20

Depending on individual fall risk factors, multimodal training programs comprising various exercise types (see recommendation 21–32) are recommended to be included in optimized fall prevention programs.

Strong recommendation, Grade A [4, 86], 100% consensus

Recommendation 21

Challenging balance training is recommended as a central component of fall-prevention programs, including static and dynamic, reactive and proactive/anticipatory contents.

Strong recommendation, Grade A [87–91], 100% consensus

Recommendation 22

Exercises involving alterations or disruptions of normal gait patterns are recommended to be included as a component of balance training programs.

Moderate recommendation, Grade B [92, 93], 100% consensus

Recommendation 23

Perturbation-based balance training is recommended as a component of training protocols for fall prevention.

Strong recommendation, Grade A [92, 94], 100% consensus

Recommendation 24

Volitional stepping training is recommended as a component of training protocols for fall prevention.

Strong recommendation, Grade A [95–97], 100% consensus

Recommendation 25

Tai Chi is recommended as a component of training protocols for the prevention of falls, provided there is professional guidance.

Strong recommendation, Grade A [98–101], 100% consensus

Recommendation 26

Dancing and music-based exercise may be considered as a component of fall prevention training.

Neutral recommendation, Grade B [102–104], 100% consensus

Recommendation 27

Strength and power training for fall prevention are suggested to focus on functional exercises.

Moderate recommendation, Grade B [105, 106], 100% consensus

Recommendation 28

Endurance exercise may be considered as a component of fall prevention training.

Neutral recommendation, Grade A [107–110], 100% consensus

Recommendation 29

Flexibility exercise may be considered as a component of fall prevention training.

Neutral recommendation, Grade B [4, 111–116], 100% consensus

Recommendation 30

Interactive cognitive-motor training (ICMT) exercise is recommended as a component of fall prevention training.

Strong recommendation, Grade A [30], 100% consensus

Recommendation 31

Water-based gymnastics may be considered as a component of fall prevention training.

Neutral recommendation, Grade A [117, 118], 100% consensus

Recommendation 32

Whole-body vibration (WBV) is recommended as a component of fall prevention training.

Strong recommendation, Grade A [119, 120], 100% consensus

Explanation and conclusion

The highest level of evidence for reducing fall incidence exists for multimodal training protocols [4, 121–124]. This aligns with the typically multifactorial risk profile of older adults. However, clear classification of these components is often daunting (e.g., functional strength training vs. functional training). A key component is to provide balance training [107, 124] at a challenging level. Training elements that combine specific elements of balance training (i.e. anticipatory responses, reactive balance ability, dynamic stability, balance control near the limits of stability), and flexibility form an especially effective combination [124]. Perturbation-based balance training (PBT) represents a particularly effective type of balance training, applying external stimuli that trigger compensatory motor responses to either prevent a fall or restore balance [94, 125]. PBT uniquely provides realistic, task-specific fall prevention by safely exposing individuals to simulated falls, directly training the motor responses needed to react effectively in real-life balance loss situations [126]. Another highly effective form of balance training is volitional step training, which is particularly relevant as most falls among independently living older adults occur while walking [92, 95]. This training involves modifying gait and stepping patterns (=gait adaptability) in response to environmental cues such as colors or music, requiring quick and precise step execution. Stepping programs enhance reaction speed and cognitive-motor abilities, which are essential for safely navigating dynamic environments in daily life. Balance training, including step training, can be delivered as interactive cognitive-motor training, as it replicates the complex demands of real-life tasks. This training paradigm takes place in enriched environments, where participants interact with a computer through movement, integrating sensory processing, cognition (particularly executive functions), and motor control. ICMT encompasses virtual reality applications and exergames [127]. An effective form of fall prevention is Tai Chi, originally developed as a martial art, but characterized by slow, continuous, and multidirectional movements that make it a valuable method for balance and strength training. It positively influences multiple fall risk factors, including static and dynamic balance [128–130], proprioception, particularly in the foot and knee joints [131, 132], gait mechanics and walking speed [133], reaction time [134], fear of falling [135], and executive function [136]. Isolated strength training alone, however, has not been shown to significantly reduce fall incidence; nevertheless, it is a key component in many effective fall prevention programs applying functional training, i.e. tasks of daily living (e.g. sit to stand) [4]. Power (explosive strength) plays a more critical role in physical functionality than maximal strength [137, 138], making power training particularly

effective for improving functional performance [139] and for enhancing reactive balance [140]. In frail individuals, the protective ability to break a fall using the upper limbs is often diminished [141, 142]. While lower-extremity strength is frequently emphasized in training, fall prevention programs must also include power training for the trunk and upper extremities to enhance overall protective responses. If available, whole-body vibration (WBV) can serve as a low-threshold, time-efficient complement to conventional training methods. While evidence suggests little to no effect of isolated endurance, flexibility, standard/folk dance, or aquatic exercise programs on fall incidence, these activities remain valuable as components of multimodal programs—such as the Otago Exercise Program—where they contribute to fall risk factor modification and overall functional improvements.

Relevance of selected exercise components for fall risk

Due to the highly faceted character of falls, it is much more difficult to identify promising constellations of exercise components, at least compared to the continuous scored BMD. Nevertheless a few recommendations (33–35) on key exercise components could be derived.

Recommendation 33

Optimum training frequency of a fall prevention exercise program is recommended to average about three sessions/week.

Strong recommendation, Grade A [86, 107, 143], 100% consensus

Recommendation 34

Perturbation training is recommended to involve sufficiently intense stimuli that trigger compensatory motor responses necessary for fall prevention

Strong recommendation, moderate-quality Grade B [94], 100% consensus

Recommendation 35

During functional strength training, periods of fast movement against moderate to high resistance are suggested to be applied.

Moderate recommendation, Grade B [139, 144], 100% consensus

Explanation and conclusion

Recommendations for optimized training programs for fall prevention focus on training frequency and exercise intensity. In summary, exercise training programs involving three or more sessions per week (N.B.: not adjusted for attendance) were superior to lower training frequencies [86, 107]. Additionally, higher exercise intensity (functional strength training) or greater levels of challenge (balance training) are preferable for enhancing skills directly related to falls [88, 94, 139, 144]. Considering the inherent higher fracture risk when applying high velocity movements against moderate to high loads (e.g. body weight), emphasis must be placed on appropriate exercises, safe positioning, and, if necessary, higher levels of supervision.

General evidence and recommendations for fall impact reduction

Although critical for fracture prevention, few exercise studies have specifically addressed safe landing strategies (i.e. falling without injury). It is noteworthy, however, that training protocols designed for fall prevention also positively influence fall-related injuries, including fractures [82, 83], especially when programs incorporate fast reaction, including cognitive information processing speed and rapid and powerful movements. A potentially more effective option for preventing fractures, particularly those close to the hip, would be the reduction of mechanical forces exerted on bones during a fall. Correspondingly, it might be important to practice suitable mechanisms that reduce the fall impact, particularly during sideways falls. Based on existing evidence, recommendations 36 and 37 outline targeted exercise strategies to mitigate the impact forces on bones during falls.

Recommendation 36

Low-risk strategies for safe landing after a fall are recommended in fracture reduction programs

Strong recommendation, Grade B [141, 145, 146], 100% consensus

Recommendation 37

More complex fall/arrest techniques are suggested to be part of training programs for fracture prevention if close and competent supervision can be ensured.

Moderate recommendation, Grade B [5, 147, 148], 100% consensus

Explanation and conclusion

Low-risk strategies for safe landing i.e. rapid squatting, elbow flexion, forward rotation, rolling during the fall or stride strategies [145], i.e. exercises that could be easily, safely and time effectively applied are recommended for fall prevention programs.

More complex fall and landing techniques, predominately derived from martial art exercises, significantly decrease bone impact forces [5] and were reported to be feasible and safe in community-dwelling older adults [147]. Nevertheless, the need for (very) close and competent supervision limits their widespread application in conventional exercise training programs.

Although it remains unclear as to what extent fall techniques are effectively applied in real-life falls, whether they help prevent fall-related injuries, and given that impact forces during an unexpected fall are significantly higher than in self-initiated practice falls [146], techniques aimed at reducing impact forces could still be considered as part of fracture prevention training for individuals without functional limitations. A key prerequisite for such training is the ability to practice safely on the floor.

Relevance of dedicated training principles for fracture prevention programs

Training principles are insufficiently addressed in most health-related exercise guidelines. However, the close adherence to basic training principles is crucial, particular for sustainable effects of exercise on fracture risk. Here, we focus on the key (health-related) training principles [149] i.e. (a) overload, (b) progression, (c) specificity, (d) individualization, (e) variation, (e) optimal relationship between exercise and recovery and (f) periodization. Recommendations 38–44 summarized important aspects that should be considered when designing or applying exercise programs.

Recommendation 38

Training stimuli are recommended to exceed corresponding mechanical, physiological and functional load level that occurs in everyday life.

Strong recommendation, Grade A [4, 22], 100% consensus

Recommendation 39

Progressive overload is recommended when applying long-term or continuous exercise protocols.

Strong recommendation, Grade B [27, 80, 150], 100% consensus

Recommendation 40

Training stimuli are recommended to be applied in a targeted manner in order to realize the desired, specific adaptive responses.

Strong recommendation, Grade B [151, 152], 100% consensus

Recommendation 41

Exercise training programs are recommended to be individualized as far as possible and applicable.

Strong recommendation, Grade A [4, 27, 86], 100% consensus

Recommendation 42

Exercise training programs are recommended to be continuous without longer periods of inactivity in order to prevent detraining effects on bone and physical function.

Strong recommendation, Grade A [153, 154], 100% consensus

Recommendation 43

In the long-term training process, training contents, exercises, training equipment and exercise components are suggested to be varied frequently to prevent homeostasis of the addressed system.

Moderate recommendation, Grade B [4, 22] 100% consensus

Recommendation 44

Exercise training programs are suggested to be periodized, in order to increase the variability of the training stimulus, provide regular relief phases and avoid monotonous training.

Moderate recommendation, Grade C [73, 76, 155], 100% consensus

Explanation and conclusion

Overload and progressive overload are fundamental components of each and every exercise program and thus have to be considered with very high priority. Overload can be achieved by manipulating intensity and volume parameters or by increasing the complexity and demands of the exercises themselves. The latter strategy is particularly relevant for fall-prevention training [80]. The relevance of specificity applies to the aspect of site specific bone adaptations [151], for example, or the varying effects of balance training on different balance skills

[156]. Nevertheless, the available transfer effects of exercise to favorably affect more than one fracture-related outcome [151, 152] should be leveraged to create time-efficient training protocols. Individualized exercise programs should at least prioritize individual training aims under consideration of the most relevant fracture determinants and the individuals' physical status (Table 1). The principle of reversibility highlights the risk of maladaptation during prolonged inactivity. Although detraining effects probably vary between different outcomes related to fracture prevention [153, 154, 157], we recommend avoiding exercise interruptions > 6 weeks so as to prevent detraining effects. This recommendation does not conflict with a periodized exercise training approach. Considering that more than one training objective is usually specified (Table 1), block periodization, e.g. with regularly applied short periods of fall/arrest techniques or machine-based perturbation training that intermitted bone-strengthening or fall prevention periods, helps prevent desensitization or overuse while allowing for a more specified training process. In addition, linear or non-linear periodization with exercise intensity as a reference size contributes to greater variation and prevent an early levelling-off effect.

Analyses and monitoring of training effects

Finally, it is important to determine the results of training periods in order to rate, or better quantify, the intended changes of the specified outcomes. Based on recurring test results, the training should be continued largely unchanged (if effective), gradually adapted or, in cases of ineffectiveness, partially or completely revised.

Recommendation 45

Individual changes in fracture risk factors are suggested to be determined at regular intervals using appropriate methods.

Moderate recommendation, Grade C [1, 158], 100% consensus

Explanation and conclusion

Frequent and reliable assessments of outcomes related to fall risk, strength or power can easily be implemented into the training process [158]. Mobility, as determined by the "timed up and go test" (TUG [159]; is considered an independent fall risk factor [160], for this reason, (upon others) the DVO guideline "Prevention, Diagnosis, and Treatment of Osteoporosis in Adults" [1] recommends performing this test, an approach we endorse here. While strength and power might not be established fracture risk factors used for assessment in clinical practice, they allow the effectiveness of the exercise program per se to be estimated and, with some limitations, also the effects on parameters related to bone strength.

However regular tests of bone strength changes due to monitor effects of the exercise program are questionable. Despite the high reproducibility of x-ray-based bone

densitometry, limited training-induced BMD changes and the long duration of a remodeling cycle usually prevent their frequent application. Although biomarkers of bone metabolism might offer rapid (but imprecise) information on current bone formation or resorption, the guideline consortium does not recommend their application for monitoring exercise-induced effects.

In summary, recommendation 45 should be considered as a request to monitor the training process using suitable tests in order to identify any stagnation in performance development at an early stage and adjust the training program if necessary.

Box 1 Contraindications and precautions for exercise in the area of fracture prevention

Considering the multitude of options, there are no contraindications for exercise as long as an adequate selection of training contents and an individually adapted load are achieved. While no special precautions for physically fit people with low fracture risk (i.e. group 1, Tab. 1) are required, in cohorts with considerably decreased bone strength (i.e. advanced osteoporosis) or vertebral fractures, high axial impact or high compression load on the spine (e.g. depth jumps, deadlifts) is contraindicated. This particularly includes back extension exercises from a flexed position with high resistance. The same applies to trunk flexion under high resistance, while exercises with flexion/extension of the spine without loading are advisable. In parallel, abrupt rotation of the trunk particularly under load must be avoided.

While fall prevention training should not cause falls, adequate challenge is necessary, e.g. in to improve stability and reaction skills. To ensure safety while maintaining training effectiveness, appropriate precautions should be taken, such as securing the individual with trainer assistance, partner support, stabilization equipment (e.g. harness, or simply a fixed chair) or, when appropriate, training on a soft surface

Condensed recommendations for fracture prevention in different cohorts at risk

Due to different individual, logistical and organizational conditions, no single universally applicable, effective and safe training protocol exists. The recommendations listed below should therefore be regarded as an evidence- and consensus-based guidance for compiling individualized training programs, but not as binding instructions for training adults at increased fracture risk.

General recommendations

Largely independent of an individual's fracture risk profile (Table 1), we recommend a cautious and progressive approach during the first 3–6 months of the exercise training, focusing on physical, cognitive, and psychological conditioning. Exercises with low ground reaction forces and/or moderate-intensity resistance exercise (<70% one-repetition maximum (1RM)) should be applied carefully to prevent overload. Explosive or high-velocity movements (i.e. power), should be avoided during the initial training period, even when using resistance devices. Due to their lower risk of injury, balance (e.g. gait training, stepping exercises, ICMT, perturbation training), functional training,

3D training, (exercises that utilize the full range of motion in multiple planes of movement e.g. Tai Chi, Qi Gong) can progress more rapidly to definitely over-threshold stimuli. Before introducing dedicated fall training/fall schooling programs, foundational improvements in strength, speed, flexibility and relevant coordinative skills are necessary to provide a functional basis and to reduce injury risk. Once familiarization and conditioning are achieved, progressively increasing the stimulus to over-threshold levels is crucial. This includes periods of high loading magnitude and rate, generated by intense ground reaction forces and moderate-to-high intensity DRT (70–85%, 1RM), incorporating periods of higher movement velocity during the concentric phase, intermitted by (re)sensitizing periods of low mechanical demands and focus on other fracture-related outcomes (Table 1). Simultaneously, more complex exercises with higher demands on balance skills and functional abilities should be introduced progressively to enable a sustainable increase in performance. We advise a (block) periodized approach, with alternating phases of varying intensity and training objectives, with a net training frequency of at least two, preferably three, sessions per week.

Individuals with increased bone metabolism, moderate reduction in bone strength (“osteopenia”) without relevantly increased risk of falls

The primary training aim for this group is to maintain or increase bone strength (Table 1). This includes training contents with increased ground reaction forces (GRF) such as running, step aerobics/high impact aerobics preferably provided in an interval mode (HIIT) or appropriate games with jumping components, rapid acceleration and stops. Jumping exercises (e.g. 4–6x 8–12 repetitions, 2Hz, 30–45 s rest/set) with a progressive increase in ground reaction forces definitely exceed bones adaptation threshold, but should be introduced carefully. Periodized DRT targeting large muscle groups (10–13 exercises) with variable stimulus intensity (60 to 85% 1RM) and movement speed (4s-1s-4s to “explosive”-1s-2s) can be performed as single- or multi-set protocols, with or without strength equipment. Although emphasis is placed on bone strength, this multimodal training approach that includes aerobic dance, games and functional strength/power training will trigger synergistic effects on types of exercise (e.g. “balance” [161]), closely related to fall risk factors.

Individuals with significant reduction in bone strength (“osteoporosis”) without relevantly increased risk of falls

The previous recommendations also apply to women with osteoporosis without an increased fall risk, albeit with some restrictions. Training content such as e.g.

running, aerobic dance or appropriate forms of non-contact games with moderate GRF (e.g. tennis) can be recommended without restriction. Strength and particular power training also remain beneficial; however emphasis should be placed on safe positioning and guided movements. Dynamic exercises that impose high back extension/flexion loading are contraindicated to prevent vertebral fractures. Additionally, we recommend progressively integrating fall prevention-related stimuli by increasing movement complexity and incorporating coordinative challenges within primarily bone-strengthening activities, (e.g. aerobic dance)

Individuals with significant reduction in bone strength (“osteoporosis”) without fractures but with significantly increased risk of falls

For this group, fall prevention must become a primary focus. Training should now incorporate specific fall prevention components, including challenging balance training with continuous, reactive and proactive training contents, perturbation, multidirectional stepping, Tai Chi components and ICMT, where applicable. Resistance training should target all major muscle groups, with an emphasis on functional strength exercises for the hip and lower extremities, incorporating periods of rapid movement against high resistance (60–80% 1RM) to enhance fall-related motor skills. All exercises should be carried out in a safe, non-fall prone position to minimize risk. This also applies to aerobic dance variations or game-based activities, which should be modified in terms of rules and/or execution to further reduce fall risk while maintaining effectiveness.

Individuals with osteoporosis-associated fractures and multiple and/or pronounced falls risk factors

In this cohort, fall prevention takes precedence over bone strengthening (Table 1), particularly given the prescribability of pharmacological therapies with significant effects on BMD but little or no effects on fall risk. Nevertheless, a short bone-strengthening warm-up sequence is recommended incorporating e.g. aerobic dance, appropriate Polka variations and/or safe game-based exercises. Additionally, functional strength and power training dedicated to falls should also embrace trunk and upper body exercises enhance postural stability and protective responses. Trunk extension and flexion exercises are recommended to be applied with low stimulus levels (50–60% 1RM) and low-moderate movement speeds (≥ 2 s-1s-2s) to minimize the risk of vertebral body fractures. It is suggested that resistance training be initially carried out on devices to achieve safe positioning and movement control and thus allow higher intensity and speed without increased risk of injuries and falls. Machine based-perturbation training is recommended

due to its high time efficiency (but low availability) applying a block-periodized approach e.g. every 4–6 months for 2–4 sessions. Additionally (preferably) side-alternating vibration training is recommended as a supplementary intervention.

Frail individuals with multiple osteoporosis-associated fractures, multiple and/or pronounced falls risk factors and very low physical fitness.

Individuals with multiple vertebral and extra-vertebral fractures and poor physical performance are recommended to exercise in closely individualized and supervised settings. We recommend using the algorithm suggested by Jansen et al. [158] and Gross et al. [162] to check whether group training is still possible. Overall, exercise should aim to maintain or restore a level of physical performance sufficient to address key fall risk factors. Structured and well-introduced home training programs (e.g. Otago Exercise Program [163]), with a focus on functional balance and strength can complement supervised training sessions. Bone strengthening plays a negligible role for this cohort, since poor performance and functional status may prevent the safe application of appropriate training stimuli and due to the pharmaceutical osteo-anabolic therapy mandatorily prescribed.

Limitations of the present guideline

Beyond the exclusion of relevant cohorts (e.g. institutionalized persons), several other limitations of the guideline should be considered.

- (a) Due to the high complexity and heterogeneity of exercise, evidence synthesis did not always yield conclusive results, even when sophisticated biometric methods were applied.
- (b) Related to the lack of human studies in some areas, we also considered animal studies to derive recommendations by expert opinion (e.g. recommendation 18). Although there is some evidence that basic mechanical principles are transferable to our targeted cohorts, their findings however cannot be consistently generalized due to different site-specific loading and adaptation processes.
- (c) Although we usually checked for overlap of primary studies when using multiple systematic reviews for processing evidence, in at least one case, (recommendation 33), recommendations were based on two systematic reviews with overlapping studies [86, 107] which might have led to inaccurate interpretation.
- (d) Particularly in the area of training principles, recommendations were interpolated from results of systematic reviews or clinical trials. In a few

cases (e.g., “progression”) evidence in this area was generated by expert rating, as no study addresses these biologically self-evident aspects.

- (e) Due to the length of a remodeling process, we excluded exercise studies on BMD shorter than 6 months. However, even in adult humans it remains unclear whether each and every loading constellation necessarily triggers bone adaptation via remodeling. Bone modeling certainly enables faster bone adaptation, nevertheless the rationale for the 6-month eligibility criteria of exercise studies was that the full extent of bone adaptation to exercise will not be achieved much earlier than after 6 months. Nevertheless, the length of most of the studies included was too short to derive meaningful recommendations for key exercise principles (e.g. progression, periodization).
- (f) We applied the AHRQ grading of evidence, which is considered less precise and informative compared e.g. with the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) [164]. This particular refers to the concept of “certainty” that its application might have provided a more precise estimation of the “quality” of the present evidence. However, we freely admit that we did not apply the elaborate GRADE procedure due to limited resources in the face of the large number of topics that have to be addressed by a comprehensive guideline on exercise and fracture prevention. Another reason was that the precision with which the quality of the evidence could be assessed was only one aspect of the decision-making process, which was ultimately condensed to the rough AWMF’s three-tiered recommendation approach (i.e. strong – moderate - neutral).
- (f) Even though a 100% consensus was not a prerequisite, the intention was to formulate the recommendation in such a way that all mandate holders could support it. While this ultimately resulted in 100% approval, it also led to the recommendation being somewhat diluted in a few cases predominately due to the different professional backgrounds of the voters. Nevertheless, once again, it should be explicitly pointed out that none of the individuals involved in developing the guidelines had a conflict of interest.
- (g) Another limitation is the limited diversity of the consensus group in terms of both geographic location (13 Germans, one Austrian, no Swiss associations) and sex (with few exceptions male authors and mandate holders).

Conclusion

Undoubtedly exercise training significantly reduces fracture risk by addressing all major determinants. To maximize effectiveness, individualized exercise protocols should be tailored to the specific fracture risk profile, ensuring that training aims align with appropriate exercise components and content. Regular assessment of exercise effects on bone health and fall risk is essential to allow for necessary adjustments and optimization of the training process. Beyond its effectiveness, individualized exercise is both safe and feasible for all at-risk populations, including frail individuals with manifest osteoporosis, who require greater individualized support and supervision during training.

Abbreviations

1RM	one repetition maximum
AHRQ	Agency for Health Care Policy and Research
AWMF	Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften
BMD	Bone Mineral Density
DRT	Dynamic Resistance Training
DVO	Dachverband Osteologie e.V.
GRADE	Grading of Recommendations, Assessment, Development and Evaluation
ICMT	Interactive Cognitive-Motor Training
N.B.	nota bene
PBT	Perturbation-based Balance Training
PEDro	Physiotherapy Evidence Database
R-AMSTAR	Revised Assessment of Multiple Systematic Reviews
TESTEX	Tool for the assessment of Study quality and reporting in EXercise
UKER	University Hospital Erlangen (Germany)
WBE	Weight Bearing Exercise
WBV	Whole Body Vibration

Glossary

1-repetition maximum (1RM):	Maximum weight or resistance that can be moved exactly once over the specified range of motion with maximum voluntary effort. %1RM is widely used to specify loading intensity of resistance exercise.
AWMF:	Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachgesellschaften e. V. Among other activities, the AWMF coordinates the development of medical guidelines for diagnostics and therapy and publishes them via the AWMF guideline register.
Delphi survey:	A catalogue of issues that is presented to and rated by a group of experts.

DVO:

Dachverband Osteologie. Tri-national (Austria, Germany, Switzerland) umbrella association of currently 21 medical and scientific professional societies which deal with bone diseases.

Exercise components

(synonym exercise variables): Specific components of an exercise program that are manipulated to create a training stimulus and to realize a given training aim.

PEDro:

Physiotherapy Evidence Database Scale. The scale consists of a checklist of 11 items that score methodologic quality of physiotherapy and exercise studies.

TESTEX:

Tool for the assessment of study quality and reporting in exercise training studies. Checklist of 15 items that score methodological and exercise specific quality criteria

Training content:

Refers in general to the type of training (e.g. endurance or resistance) and in detail to the dedicated exercise (e.g. leg press, leg extension etc.)

Loading magnitude:

represents the level of the maximum force acting on the bone (in Newtons [N]). In animal studies, load magnitude is measured as the resulting deformation of bone (strain [ε]).

Loading rate:

Is specified either in force per time [N/s] or as a deformation rate in strain per second [ε /s]. It is the second parameter that determines the stimulus intensity

Loading cycle number:

Number of individual mechanical stimuli or repetitions.

Loading frequency:

Number of individual mechanical stimuli or repetitions per time (Hz; 1 Hz represents one repetition/cycle/oscillation per second).

Loading duration:

Exposure time of the single mechanical stimuli/loading cycle

Exercise density:

Ratio between loading and rest periods in different time dimensions (s/min/d/w/m)

Training frequency:

Number of training sessions over a period of time (week/month)

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