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The Importance of Sport and Physical Exercise in the Prevention and Therapy of Osteoporosis

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Osteoporosis is a systemic skeletal disorder involving low bone mass and micro-architectural deterioration of the bone tissue. Effective prevention of osteoporosis can primarily be expected from optimized nutrition and from increasing general physical exercise: “Food and exercise—equal attention to both is wise.” This article reviews the effects of sport and physical activity in the prevention and therapy of osteoporosis. The main aspects and conclusion are the following: (a) not duration, but rather frequency of exercise, combined with its intensity, seems to determine the level of the bone-anabolic effect; (b) training stimuli should become effective at those skeletal sites where an increase in bone mass is desired; (c) considerable evidence supports the importance of activity, especially activity initiated before puberty, for the development of peak bone mass; (d) even raised physical activity in daily life without any specific training of a certain body region may have a positive effect on total skeletal mass; (e) both general and specific strength are of great importance to bone mass to individual skeletal sections and to the entire skeleton; (f) non-specific variable strain with accordingly high peak strengths and various forces acting on the skeletal system are of enormous bone-stimulating importance; (g) in older adults, high-intensity resistance training, in contrast to traditional pharmacological and nutritional approaches for improving bone health, has the added benefit of influencing multiple risk factors for osteoporosis including improved strength and balance and increased muscle mass; (h) training adjustments of the bone in the sense of overcompensation can only be achieved if the “endocrine environment” and/or food-dependent parameters are not changed pathologically, and training is carried out according to individual load tolerance under scientific training aspects; (i) in the peri- and postmenopausal period, an actual increase in bone mass might be achieved by the combination of exercise and hormone replacement therapy; (j) physical activity may be a particularly promising preventive measure for hip fractures.

Key Words: osteoporosis, sport, physical activity, prevention, therapy

Key Points:

•Considerable evidence supports the importance of activity, especially activity initiated before puberty, for the development of peak bone mass.

•Even raised physical activity in daily life without any specific training of a certain body region may have a positive effect on total skeletal mass.

•Non-specific variable strain with accordingly high peak strengths and various forces acting on the skeletal system are of enormous bone-stimulating importance.

- Training adjustments of the bone in the sense of overcompensation can only be achieved if "endocrine environment" and/or food-dependent parameters are not changed pathologically, and training is carried out according to individual load tolerance under scientific training aspects.
- In older adults, high-intensity resistance training, in contrast to traditional pharmacological and nutritional approaches for improving bone health, has the added benefit of influencing multiple risk factors for osteoporosis including improved strength and balance and increased muscle mass.

1. Definition of Osteoporosis

Osteoporosis is a systemic skeletal disorder involving low bone mass and micro-architectural deterioration of the bone tissue. This results in increased bone fragility and proneness to fractures. Effective prevention of osteoporosis can primarily be expected from optimized nutrition and from increasing general physical exercise, with both aspects requiring similar attention: "Food and exercise—equal attention to both is wise."

This paper is intended to demonstrate the importance of physical exercise in the prevention and therapy of osteoporosis.

2. Introduction

Weight-bearing physical activities, including both job-related and daily routine activities as well as therapeutic, leisure, and competitive sports, are an essential precondition for bone health. As early as in 1683, Galileo Galilei was aware of a connection between body weight and bone size. By the end of last century, Wolff formulated the still valid law of bone transformation: Bone shape follows its function (145). Without the stimulating effects of the gravitational field or mechanical strain, both the axial and peripheral skeletons show a rapid and pronounced loss of bone mass. The total force acting on a certain skeletal part consists of the internal forces due to muscle contractions and the external forces due to the gravitational field and motion-induced compressive and tractive forces.

Besides purely mechanical influences, the skeletal system is subject to a variety of hormonal factors promoting osteogenic or degradative processes. Many of the bone-effective hormones show acute and/or chronic changes after physical strain. Serum levels of the osteo-anabolic hormones testosterone and estradiol, but also those of the catabolic hormone cortisol, increase after physical strain. However, too extensive or too intensive physical training may lead to a decrease in blood levels of the sexual steroids. The behavior of other hormones influencing bone metabolism (e.g., calcitonin, PTH, vitamin D, thyroid hormones) under different strain conditions is rather complex. Their importance as mediator of strain-induced adaptations is not clarified yet in many aspects. In summary, the sum of all endocrine and mechanical influential factors, under consideration of the individual genetic disposition, determines the current bone structure and the current bone metabolism at any specifically stressed site of the skeleton (Figure 1).

3. General Training Aspects

For the useful application of physical strain and of exercise programs for the prevention of osteoporosis, scientific training aspects have to be taken into consideration (51).

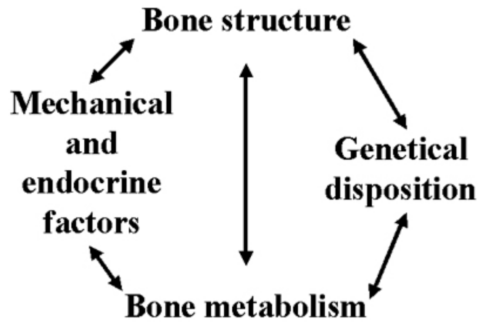

Figure 1 — Influences on bone structure and bone metabolism.

3.1 Specificity of the Training Effect

Training stimuli should become effective at those skeletal sites where an increase in bone mass is desired—that is, the regions of femur, spine, and distal lower arm, which are prone to fractures.

3.2 Extent of Strain

In order to achieve bone-effectiveness, the training stimuli have to be raised continuously. First and foremost, the exercise strain should clearly exceed the usual daily activities to yield an increase in bone mass.

3.3 Involution of Achieved Effects

The lesser the baseline values, the higher will be the percentages of bone mass increase when an exercise program is carried out. As these values increase, the gains that can still be achieved are diminished.

3.5 Individual Maximum

Each biological system has its genetic determination. This applies to both the achievable maximum physical performance in general and bone mass in particular. In this connection, the question emerges as to what increase in bone mass can be achieved by a fitness program in young women with values near the lower limit of normal.

3.6 Intensity, Frequency, or Duration?

It is still unclear today whether the strongest bone-anabolic effects can be achieved in humans by increasing the intensity, frequency, or duration of physical strain. However, if the results of animal-experimental studies are applied to the training programs in humans that aim to increase bone mass and bone strength, the following requirements become obvious (38). The training should: (a) be dynamic, (b) be conducted at the highest possible intensity and frequency, and (c) be composed of the greatest possible variety of exercises.

Frequency of exercise, not duration, combined with its intensity seems to determine the level of the bone-anabolic effect. Short, intensive strains seem to have a higher bone-anabolic effect than long-lasting ones of low intensity.

The simple prescription of “more exercise” for the prevention of osteoporosis does not meet today’s demands in sports medicine any more, although considerable demand for research still exists in many fields.

4. Studies on the Effects of Physical Exercise on Bone Density in Man

4.1. Methodological Considerations

The most frequently used method for the analysis of the influence of physical strain on the skeletal system is osteodensitometry for the determination of the bone mineral content (BMC). For a greater clarity, all measured values (of length, surface, and volume) obtained by different measuring methods (e.g., computerized tomography, photon absorption densitometry) will subsequently be referred to as *bone mass.*

4.2 Development of Bone Mass in Childhood and Adolescence

Total and volumetric bone mineral density increase with age in male and female children and adolescents, aged 4–20 years. During puberty, the age-dependent increment is highest (24). In adolescents, bone mass seems to be positively influenced by certain measures of physical fitness as well as by age, weight, and pubertal stage, while type of sport does not exert a significant influence on bone mass (35, 36). A longitudinal study showed that the most important factor affecting bone mass accretion in adolescents in both sexes is their pubertal stage (36). The authors conclude that to optimally increase bone mass in both sexes, and especially in girls, regular physical exercise programs should be instituted well before the onset of puberty rather than at or after it.

4.3 Peak Bone Mass

The maximal amount of bone mass gained during growth (peak bone mass) is an important determinant of bone mass in later life. Although genetic factors appear to be primary determinants of peak bone mass, environmental factors such as physical activity and nutrition also contribute (125, 137). Considerable evidence supports the importance of activity, especially activity initiated before puberty, for the development of peak bone mass (13). However, gene-environmental interactions are complex during childhood/adolescence, particularly in relation to menstrual history, exercise, and genetic factors like vitamin D receptor genotype (58). Recent reports investigating developmental changes in skeletal mass of adolescent girls and young women under different experimental or ecological conditions support the contention that modification of environmental factors, especially dietary calcium and physical activity, can favorably modulate bone mass and bone density compared to controls. The peri-pubertal period, starting as early as 10 years of age, seems to be most responsive to modification of environmental/lifestyle factors, whereas potential gains of bone mass during late adolescence and early adulthood, although smaller, may be more readily achieved through improved dietary calcium intakes and regular exercise programs (8). A recent longitudinal study in adolescent boys and girls revealed a 9% and 17% greater total body bone mineral content for active boys and girls, respectively, over their inactive peers 1 year after the individual age of peak bone mineral content velocity. The authors also estimated that, on average, 26% of adult total body bone mineral was accrued during the 2 years around peak bone mineral content velocity (11). Since bone mass of the lumbar spine and femur in children correlates with the level of activity of their mothers, the role of the parental example is of essential importance with regard to the activity behavior of the children.

In general, it can be assumed that more active children leave their youth with peak bone masses 5–15% higher than normal and thus reach the "critical fracture threshold" 10 years later than inactive children if this advantage is maintained until old age.

4.4 Activity During Adolescence and Later Bone Mass
All the caution for interpreting the results of retrospective studies provided, some investigations found positive correlations between the activities during adolescence or earlier years reported in questionnaires and the current bone mass of the radius or of the calcaneus (56, 76, 89), as well as at the lumbar spine (18), without specifying the activities in detail. One recent study suggested that classical ballet classes undertaken between the ages of 10 and 12 years are associated with higher hip BMD values in later life (74). These findings are consistent with the hypothesis that this age range identifies a stage of development when the proximal femur is particularly responsive to weight bearing exercise.

In summary, it can be assumed that a high activity level during childhood and adolescence not only results in a high peak bone mass but also has a lasting effect for later stages in life.

4.5 Immobilization
Numerous studies demonstrate that immobilization does not only cause muscular atrophy, but also a considerable decrease in the bone calcium content. This applies to both the immobilization of individual parts of the skeleton (e.g., plaster cast) and also to continuous bed rest and stay under weightless conditions (space travel; 49, 49, 59, 66, 68, 77, 88, 96, 109, 118, 119, 139, 148). With regard to extent and duration, the bone loss of man observed during space travel is similar to the bone loss observed during horizontal bed rest. Immobilization may lead to a loss of bone mass of 4–5% per month as compared with normal age-related atrophy of 1–2% per year!

4.6 General Level of Activity
A number of studies deal with the influence of the general level of activity on bone mass and on the total calcium content of the body (5, 37, 40, 72, 87, 92, 95, 102, 105, 111, 117, 134, 149, 150), prevailingly covering daily routine stresses like walking, climbing stairs, gardening, and housework. A recent study suggests that among all weight-bearing exercises, weight-bearing household and occupational activity also appears to be related to BMD (138). Sport-related stress such as jogging and cycling were weighted differently. Summing up, the results indicate that even raised physical activity in daily life without any specific training of a certain body region may have a positive effect on total skeletal mass. The low or lacking influence of daily activity on the radius emphasizes the assumption that physical strain acts prevailingly on the directly affected and stressed parts of the skeleton.

4.7 Influence of Muscular Strength and Muscle Mass
Through their origins and attachments, muscles transmit the contractile forces directly to the corresponding skeletal sections. Thus it can be assumed that there is a correlation between muscular strength, or muscle mass and bone mass. Moreover, high muscle mass can be considered as an expression of high physical activity, which in turn has bone stimulating effects due to the external forces (see above). Numerous studies show that both general and specific strength are of great importance to bone mass to individual skeletal sections and to the entire skeleton (17, 55, 85, 104, 110, 121, 122, 129, 132, 133, 149). However, some weight-bearing

loading seems to be essential for gaining bone mass, as horseback riding in young females is associated with high muscle strength of the thigh but not with a high bone mass (2), and as the loading pattern and muscular contractions associated with kayaking result in site-specific adaptations of the skeleton (57). Furthermore, high physical activity seems to weaken the relationship between BMD and muscle strength. Hence, impact forces may be of greater importance in regulating bone mass than muscle strength in itself in highly trained athletes (101).

4.8 Specific Training Effects

If already daily activities contribute to the development and maintenance of bone mass, what effects can then be expected from intensive, partly yearlong training stress? Evidence in human studies of the association of long-term habitual exercise with bone mineral density largely comes from studies in athletes (3, 4, 6, 21, 22, 25, 26, 34, 42, 45, 54, 65, 67, 79, 91, 97, 101, 116, 136). In young adults, the highest BMD values have been found in strength and power-trained athletes, as well as in team sports, while endurance activities such as long-distance running and swimming seem less effective with regard to peak bone density. However, BMD at the focus of strain for running (i.e., the legs) is higher in endurance runners when compared to matched controls (25). After menopause, female athletes show greater bone mass, indicating that they do not share the accelerated decline in BMD observed in a non-athletic population. Middle-aged and elderly male athletes from various sports have significantly higher BMD than controls, especially in trabecular bone sites, but higher cortical BMD has also been found in the dominant/non-dominant arm comparisons with unilateral exercises such as tennis and volleyball. Although the interpretation of results of cross-sectional studies should be treated with caution, studies in athletes serve as an economical alternative approach to experimental trials, with their long-term follow-up and exercise compliance problems. The differences found in BMD between those who have devoted themselves to life-long training and those who have been much less active should not be underestimated (135). In our own cross-sectional study, we investigated a total of 382 competitive athletes (aged 18–30 years) from different sports branches (long-distance running, team sports, cycling, triathlon, power sports, and ballet), non-specifically trained sports students and untrained controls, applying the DEXA technique on the lumbar spine and the femur (34). In the region of the lumbar spine, the strength athletes and team sports athletes, as well as the non-specifically trained sports students, showed highest density values (Figure 2). In the region of the hip, most obvious results in women were obtained from the team-sports athletes in particular and to some extent also from the strength athletes. Men demonstrated a graduation from team-sports athletes and strength athletes, sport students, runners, and triathletes to cyclists and untrained people (Figure 3). All caution for the interpretation of cross-sectional comparisons provided, the results of this study and of others demonstrate, on the one hand, the great importance of strength-emphasized training and high muscle mass for the bone mass of the lumbar spine and femur in men and women. Mere endurance training (running, cycling, triathlon), on the other hand, has no bone-stimulating effects in the region of the lumbar spine, and some bone-stimulating effect in the region of the femur only in men in branches of running. The high bone masses of team sports athletes and sports students, however, indicate that non-specific variable strain with accordingly high peak strengths and various forces acting on the skeletal system (e.g., jumps, sprints and stops, changes of direction during running, rotational movements, etc.) are of enormous bone-stimulating importance.

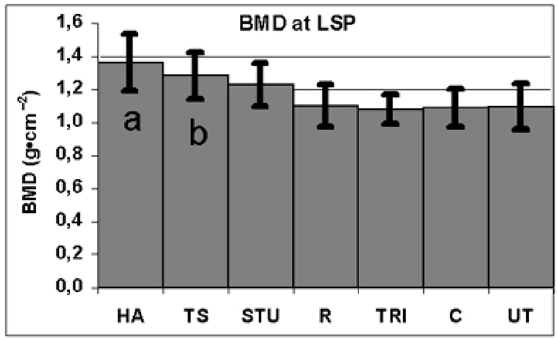

Figure 2 — Bone mineral density (BMD) at lumbar spine (LSP) in male athletes from different sports. HA: strength athletes; TS: team sports; STU: sport students; R: runners; TRI: triathletes; C: cyclists; UT: untrained non-athletes. a. Significantly higher compared to STU, R, TRI, C, and UT. b. Significantly higher compared to R, TRI, C, and UT.

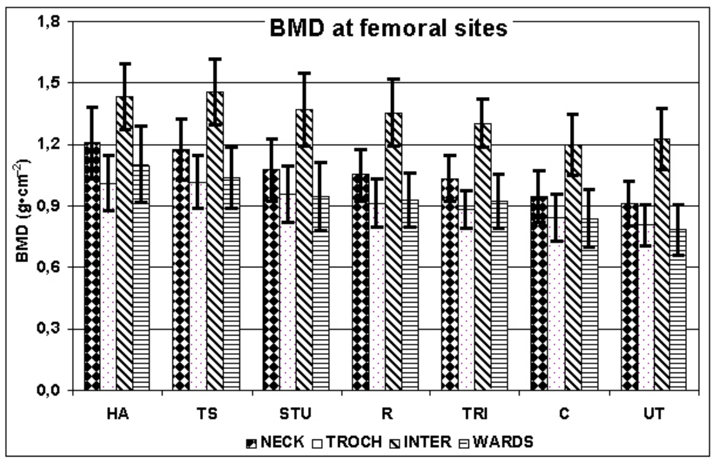

Figure 3 — Bone mineral density (BMD) at the femoral sites of male athletes from different sports. HA: strength athletes; TS: team sports; STU: sport students; R: runners; TRI: triathletes, C: cyclists; UT: untrained non-athletes.

4.9 Training Studies: Endurance Training

Studies of the influence of endurance training on bone mass have usually investigated walking, dancing/aerobic, jogging, or an extensive run training (6, 23, 71, 75, 94, 106, 117, 127, 141, 143). Summing up, it became obvious that moderate walking alone is not sufficient to stop the age-dependent loss of bone mass. The minimum strain required to achieve bone-stimulating effects in untrained people seems to be intensive walking or aerobic/dancing (60–80% of the maximum heart rate) 3–4 times per week, 45–60 min each, if possible with additional weight-bearing load. The increases in bone mass yielded by such a training program, however, are only minor but at least reduce the expected age-dependent loss.

4.10 Training Studies: Strength Training

Some specific strength-training studies have been conducted in both young men and pre-menopausal as well as postmenopausal women (1, 16, 20, 50, 60, 81, 86, 108, 115, 123, 126). The bone mass increases that can be achieved by "common" strength training programs are supposed to be about 1% per year at most and should thus compensate for the "physiological" annual bone mass loss. Even a short-term high-intensity resistance exercise program can either maintain or improve the BMD of the femoral neck and lumbar vertebrae in pre-menopausal women (50). Postmenopausal bone loss is unaffected, however, by an only modest exercise program despite an increase in muscle strength. Non-loading muscle exercise may therefore be ineffective in retarding vertebral bone loss in healthy postmenopausal women (123). A recent study suggests that site-specific moderate physical exercises have very little effect on bone mass. However, it appears that some exercises may reshape the bone segment under stress by increasing both the cross-sectional area and the density of the cortical component. These structural changes are theoretically associated with increases in the bending strength (1). These suggestions may explain why in some intervention studies, gain in bone mass is only small despite a significant increase in muscle strength (20). Comparing different kinds of strength training, eccentric muscle training seems to be more osteogenic than concentric muscle training (63).

Altogether, many studies have shown a direct and positive relationship between the effects of resistance training and bone density. In older adults, high-intensity resistance training, in contrast to traditional pharmacological and nutritional approaches for improving bone health, has the added benefit of influencing multiple risk factors for osteoporosis including improved strength and balance and increased muscle mass (80).

4.11 Training Studies: Combined Trainings

Some intervention studies partly examined extremely different training programs, among them combined endurance and strength training or endurance and strength training in comparison (39, 46, 62, 90, 100, 113, 114, 130). In elderly and very old, untrained people, already a moderately dosed, but regular training (e.g., 3 times per week, 30 min each, training around a chair; 3 times per week, 20 min each, easy physical exercises) a slight increase in bone mass or a reduction of the age-dependent bone mass loss at least, and thus the maintenance of bone mass, could be achieved (114, 128). A meta-analytic review of studies suggests that exercise may slow the rate of bone loss in postmenopausal women (73). Another recent meta-analysis on the effects of exercise training programs on bone mass, measured as bone mineral density or bone mineral content, of the lumbar spine and the femoral neck in pre- and postmenopausal women showed very consistently that the different exercise training programs prevented or reversed almost 1% of bone loss per year in both skeletal sites for both groups of women (144). However, it is premature to form strong conclusions regarding the effects of exercise on regional bone mineral density in postmenopausal women. A need exists for additional, well designed studies on this topic before a recommendation can be made regarding the efficacy of exercise as a non-pharmacological therapy for maintaining and/or increasing regional bone mineral density in postmenopausal women (73). Altogether, the regular and long-term conduct of a training program is of great importance. Independent of whether a training-induced increase in bone mass was achieved by endurance or strength training, it will be lost as soon as the physical exercise is reduced or discontinued.

4.12 Overload Responses

A number of investigations in female competitive athletes and Army recruits could demonstrate that sport-induced disorders of the menstrual cycle with their associated low sexual steroidal hormone levels and/or eating disorders lead to pathologically low bone density values and to a raised incidence of stress fractures, despite the very high training loads and the associated high mechanical stimulation (28, 30, 32, 41, 43, 52, 53, 64, 70, 82–84, 93, 103, 107, 146, 147). In one of our previous investigations, we found dramatically reduced bone density values in amenorrheic and oligomenorrheic female athletes (Figure 4; 83). Decreased bone density values have also been described for male long-distance runners (19). This decline in BMD may possibly also be connected with reduced sexual hormone levels. Stress fractures are observed in both sexes independent of the degree of mineralization also with purely mechanical overload, in particular with unusually high training loads or unusual techniques (112). The risk of stress fracture seems to be increased in athletes with menstrual disturbances and with lower bone density (14). A very high risk for osteoporotic stress fractures exists in females with anorexia nervosa, an eating disorder that may also be present in female athletes (78). With full recovery from eating disorders, however, teenage girls can achieve normal bone mass and body composition (33).

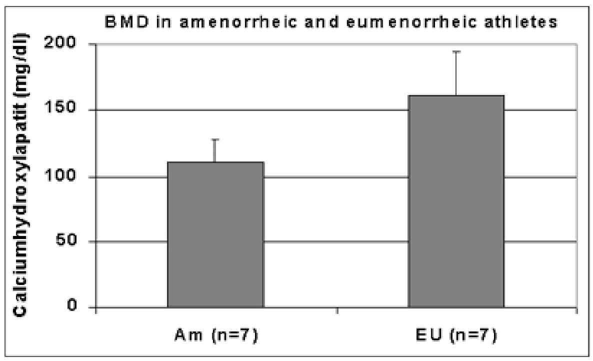

Figure 4 — Bone mineral density in eumenorrheic (EU) female athletes as compared with amenorrheic (AM) female athletes.

All these findings demonstrate that training adjustments of the bone in the sense of overcompensation can only be achieved if: (a) "endocrine environment" and/or food-dependent parameters are not changed pathologically, and (b) training is carried out according to individual load tolerance under scientific training aspects.

4.13 Physical Activity During Menopause

Due to the lacking bone-stimulating effect of the gonadal steroids, a clear increase in trabecular and cortical bone loss occurs during menopause (131). The available cross-sectional and longitudinal studies in women of this age group provide contradictory results with regard to the protective effects of physical strain on the enhanced bone loss. However, there is no evidence yet that physical activity alone could stop the enhanced postmenopausal bone mass loss, but some reduction of the loss rate seems possible (7). An actual increase in bone mass, however, could be achieved by the combination of exercise and hormone replacement therapy (12, 98, 106). A very recent study showed that more physically active postmenopausal women had higher hip BMD at baseline compared to inactive women, but the response to hormone replacement therapy was greater in the less physically active women. The difference in response between groups may be due to physically active women having lower resorption at the hip and hence reduced response to anti-resorptive effects of hormone replacement therapy (27).

5. Physical Activity and the Risk of Fractures

Osteoporosis-induced fractures are associated with low bone mass, with a clear and continuous increase in the frequency of such fractures being observed in women over 45 years of age (9, 15). Factors that influence the risk of hip fracture have been identified, many of which can be eliminated or modified. Bone mineral density is the major measurable determinant of the risk of fragility fractures. Skeletal factors other than BMD that may increase the risk of hip fracture in women include hip geometry and height (tallness; 124). Besides the instability of the bone, the elevated risk of falling is another factor of the increased bone fracture risk in old age (31). Balance disorders, low muscle strength in the lower limbs, poor coordination and flexibility, decreased visual acuity, neuromuscular impairment, cognitive impairment, residence in a nursing home, poor general physical health, use of medications that diminish alertness, low body weight secondary to poor appetite or poor health, and a low amount of soft tissue in the hip region are contributing factors for bone fractures due to falling (120, 124). Fall mechanics also play an important role in the etiology of hip fractures. Falls to the side, particularly those with impact on the hip or side of the leg, more often result in hip fractures than do other falls. Protection of the hip with external padding offers great promise in the prevention of hip fracture in patients with very low bone mass or with conditions that make falls almost inevitable (124).

Although the role of exercise in the prevention of osteoporosis and hip fracture has not yet been proven, there is evidence of independent protective effects of both past physical activity and moderate levels of recent physical activity on the risk of hip fracture. Physical activity may therefore be a particularly promising preventive measure (61, 69). The association is strong and consistent with physical activity in leisure, and weaker with respect to physical activity at work. The association is present for physical activity from childhood to adult age, and it is consistent in study populations from the U.S., Australia, Asia, and Northern and Southern Europe, in spite of very different hip fracture incidences in these populations. The magnitude of the association is difficult to assess because of varying criteria for exposure, but to be among the physically active seems to reduce the risk of later hip fracture by up to 50%. It seems that even daily chores, such as climbing stairs and walking, protect against hip fracture.

Regular physical training or physical strain do not only improve cardiovascular health, coordination, and flexibility as well as balance, but also muscle strength and load tolerance. The prophylactic effect of physical activity on osteoporosis-induced fractures is not only achieved by increased bone mass or a reduction of the age-dependent bone mass loss but also, in particular in older age, prevailingly, by the other factors mentioned, which are typical of high general fitness. These associations have been demonstrated by several studies that report a higher general activity level of women without femoral neck fractures as compared with women with femoral neck fractures (10, 44, 99, 142).

6. Physical Training in the Therapy of Osteoporosis

Regular physical training in the sense of a controlled exercise therapy, or—in accordance with the respective individual clinical picture—a controlled physical therapy (29), has been established as an important component of the overall therapeutic program (47, 140). Whether this leads to an increase in bone mass, however, has not been demonstrated yet. It seems rather improbable, since the strain stimuli that would be required for some bone-anabolic effect often cannot be reached because of the reduced load tolerance and the poor general fitness frequently found in this age group (51). Exercise therapy, though, can have many beneficial effects that do not only imply a gain in quality of life, but also a certain protection against further fractures (Table 1). After rehabilitation and regaining of a minimum of mobility and self-assurance, the following types of exercise seem useful if the respective clinical picture is taken into account: (a) strength-emphasized physical exercises, (b) well-dosed and specific strength training on apparatus and, moreover, (c) all exercises that train coordination and flexibility, make possible easy dosing, and facilitate controllable performance.

Table 1 Essential Objectives of Exercise Therapy in the Treatment of Osteoporosis
• promotion of flexibility and tensibility • improvement of motoricity in everyday life • reduction of the risk of falls, which imply the risk of further fractures • strengthening of the static postural muscles in particular (trunk bending, reduction of a kyphotic mal-posture) • relief for the small vertebral joints mal-positioned and irritated due to vertebral fractures • long-term pain reduction

Sports involving higher risks of falling and compression, such as cycling, horse-back riding, and gymnastics, should not be done any longer, especially in cases of inadequate practice. Sufficient experience in the respective sport provided, however, training can be continued if well dosed and if the risk of falling or compression is minimized (e.g., tricycle for the elderly, smooth road tires for cycling).

Exercise therapy should be carried out daily as a regular program. In addition, for further physical training, local osteoporosis sports groups may be available that offer physical activities under instruction of specialized therapists (48).

7. Recommendations for the Avoidance of Injuries and Overload Risks Due to Sport

The following recommendations have been compiled by the author, together with members of the German Osteoporosis Working Group (DAGO; 47).

Sports and exercise are today undisputed in general health promotion. The training program should be adapted to individual load tolerance. As with any medication, dosage is decisive. The inner organs, in particular the cardiovascular system, have so many reserves that their failure cannot be induced even by extreme loads. Problems may occur with pre-existing damage (e.g., coronary arteriosclerosis) or diseases (e.g., infections).

Overloads with acute and intense forces (e.g., falls) may cause a variety of injuries. Minor, repeated damages (e.g., wrong lifting, carrying, or exercise techniques) may add up to overload damages.

In order to avoid risks due to pre-existing disease and to prevent overloads and injuries, the following basic rules should be observed.

Medical Check-Up

Before starting regular physical training, the middle-aged and elderly, the untrained and those with an elevated risk of organic diseases in particular, should go for a medical check-up including an exercise test and electrocardiogram.

Choice of Sport and Consideration of the Individual Abilities

There are kinds of sport with an elevated risk of injuries (e.g., alpine skiing, team games) and those with a lower risk to get injured (e.g., swimming). However, the risk of injury of a sport is determined by the individual ability and the realistic assessment of one's own capability to a considerable extent.

Warming Up and Cooling Down

Each training unit should be preceded by a warming-up phase and followed by a cooling-down phase. The elasticity of the muscles and in particular of the tendons is dependent on a sufficient temperature. Thus, warming up increases flexibility. Depending on the kind of sport, a warm-up period of 10 to 15 min is required, including an exercise program. Active cooling down after a training program (running out, stretching) keeps metabolism up and accelerates the removal of waste products from muscles, thus enhancing the regenerative processes.

Specific Training Build Up

In the long run, a specific build up training should be carried out according to current capability and load tolerance. Duration and intensity of strain, however, should be raised only in the course of the training process, which helps avoid overloading and injuries at the beginning of a training phase.

Sportswear and Equipment

Suitable equipment is essential. Besides adequate sportswear, which should be comfortable and not restrict movement, particular attention should be paid to proper shoes. They should be specific to the respective sport (e.g., hiking shoes, running shoes, special shoes for indoor games). The selection of sports equipment (e.g., alpine and cross-country skis, tennis rackets) should match the individual capability. If required, proper protective gear should be worn (e.g., helmets for cycling; guards for knees, elbows, and wrists for roller skating).

8. Practical Recommendations

Both healthy and the sick men and women should move and get exercise as much as possible in daily life, at work, and in leisure, depending on their individual capabilities. As early as in childhood and adolescence, a wide range of exercise and regular sports should be an undisputed constituent of the daily routine. Optimal nutrition provided, for healthy children and adolescents a lot of exercise and skeletal load are useful as long as overloading damages—and with girls in particular, disturbed menstrual cycles due to overloading—are being avoided. During early and middle adult age as well, sufficient load stimuli should be applied to the bones. Even in the elderly, individual sport and exercise therapy with specific muscular build up programs promotes bone maintenance.

Basically, a minimum training amount of 120–150 min per week, adjusted to individual capability, should be distributed over three or more training units. Exercise and aerobic programs with their combinations of extension, motion, and strengthening exercises for the muscles of the limbs and trunk are particularly recommendable for those who re-enter sports life and for older people. With previously untrained people, minor loads can already induce positive effects. A variety of different loads and movements as they occur, for example, in sports games have a particularly beneficial effect on bone mass.

Exercise programs for people with manifest osteoporosis do not primarily aim at bone formation, but mainly at improving quality of life and load tolerance in everyday activities, and at achieving some protection from further fractures by the effects of physical exercise.

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