PART III

Physical activity

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Exercise and bone health

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KEY POINTS

1. Sufficient levels of physical activity in adulthood (pre-menopausal period) maintain bone strength and can prevent fragility fractures in later life.
2. The potential benefits of activity, in terms of fracture risk, are not restricted to increases in bone mineral density (BMD) alone. There are concomitant positive effects on other properties of bone, muscle mass, balance, risk of falling, morbidity, confidence and quality of life.
3. In order to achieve maximal benefit, regular physical activity (weight bearing, endurance and strength training) must target vulnerable bone sites (specificity) and be progressive in intensity (overload). Additionally, activities must be of sufficient duration and sustained over time (overload). BMD will return to previous levels if exercise is stopped (reversibility).
4. Regular loading of bones in vulnerable skeletal sites can, when of sufficient duration (1 year), increase BMD between 1 and 3% in post-menopausal women. Improvements may be even greater if the exercise is in addition to calcium supplementation or hormone replacement therapy.
5. Exercise among older adults with osteoporosis must be targeted within limitations of ability. Certain exercises in older people with osteoporosis can increase fracture risk (e.g. abdominal curls in vertebral osteoporosis). Guidelines detailing appropriate exercises for the management of such patients have been published.

Introduction

The purpose of this chapter is to review the role of physical activity and exercise in maintaining bone quality/strength, the potential adverse effects of excessive exercise and the beneficial effects of the reduction of the risk of osteoporosis and fragility fractures. Key examples of the type of exercise that might be most effective for reducing risk of fracture at different sites and exercise guidelines for those with osteoporosis are summarized. Most of the evidence for the benefits of physical activity and exercise for bone health in older adults accrues from research conducted among Caucasian post-menopausal women. However, more recent work with older men suggests that similar positive results can be achieved. There are few trials that specifically examine the influence of race or culture.

It is widely accepted that physical activity is vital in both the development of a healthy skeleton and in the maintenance of skeletal health in adulthood |1|. An important determinant of future fracture risk is the bone mass accrued prior to the third decade; regular physical activity early in life is most efficient at maximizing peak bone mass. There is a critical time during childhood when the skeleton is most responsive to bone loading and beyond this point of skeletal maturity BMD is not easily increased. Thus optimization of peak bone mass is important in minimizing the effects of age-related bone loss in older adults. However, an active lifestyle should be encouraged throughout the life span |2| as many epidemiological studies have shown that regular activity in adulthood reduces the risk of fractures. Care must be taken when increasing activity in those with osteoporosis but specific exercise can reduce pain, energy cost and improve quality of life, if undertaken safely.

Establishing a healthy skeleton in childhood

Physical activities involve the application of some degree of force on the bone. In response, the bone bends and is temporarily deformed. The extent of deformation is measured as strain and depends on the magnitude and direction of force; the distance from the point of application of force to the axis of bending (lever arm) and the moment of inertia |3|. Strain is considered as a functional variable, which contains all information necessary for the control of bone architecture in relation to bone loading |4|. Unusual strain distribution, high strains and high strain rates are effective in stimulating bone formation with only a few loading cycles needed |5|.

There is a window of opportunity for the greatest gain in bone with physical activity. This tends to be in early adulthood |1,2,6–8|. For example, the positive effects of tennis may be twice as great if training starts before rather than after menarche |7|. Bone appears more responsive to loading during active, growth-related modelling and remodelling.

Maintaining a healthy skeleton in adulthood

Body weight by itself is not sufficient to create the loading levels necessary for an osteogenic response. Some forms of exercise have been shown to be beneficial for slowing or reversing the age-related loss of bone. These include brief bouts of weight-bearing exercise such as intermittent jogging |9|, high-impact aerobic exercise classes |10| and also weight training using weights in excess of 80% of personal maximum (1 RM) |11|. However, walking alone does not increase bone

Table 9.1 Basic principles of training for bone health

Specificity (training effects are localized to sites loaded)
Overload (load must be greater than that seen during normal activities and must be progressed to maintain overload)
Reversibility (gains will be lost when exercise is stopped)
Initial values (lower starting BMD, greater response)
Diminishing returns (effects will eventually plateau)

Source: ACSM Position Stand 2004: Physical Activity and Bone Health |16|.

density, but merely helps maintain it |12|. Regular exercise could delay the point at which osteopenia progresses to clinically significant osteoporosis |10,13,14|. It must always be remembered that once exercise is stopped, normal bone loss continues and the benefits are not maintained |6,15|.

The National Osteoporosis Foundation suggests that weight-bearing exercises (e.g. weight training, stair climbing, walking, running, jogging, dancing, aerobics, racquet sports, court sports and field sports), three times per week, for 20–30 min are required to help maintain a healthy bone mass. In all activities, it is important to consider the basic principles of training for bone health |16|, as summarized in Table 9.1. The ideal types of exercise, duration and intensity of bone loading in adulthood are summarized in Table 9.2 |16|.

What is the evidence behind the National Osteoporosis Society |17| and American College of Sports Medicine |16| recommendations?

Sporting activities

Different sports load the bone in different ways and it has been shown convincingly that adaptations occur only at sites that are stressed: exercise is therefore site specific |11,13,18|. Strength sports produce a high magnitude loading on bones, for example weight lifters have up to 30% better BMD than sedentary adults at

Table 9.2 Exercise prescription for bone health

Mode	Weight-bearing activities (greater than normal load on the body during habitual physical activities)
Intensity	Moderate to high, in terms of bone-loading forces
Frequency	Weight-bearing endurance activities 3–5 × per week
	Resistance exercise 2–3 × per week
Duration	30–60 min of a combination of weight-bearing endurance and resistance exercise targeting all muscle groups

Source: ACSM Position Stand 2004: Physical Activity and Bone Health |16|.

maximally loaded sites [19]. Compared with controls, the femoral neck BMD has been found to be 17% greater in squash players [20] and 22% greater in gymnasts [21]. Sports involving repetitive loading, such as running, show only modest benefits to BMD [20,22]. Cyclists and swimmers, non-weight bearing, do not have greater BMD and female athletes with amenorrhoea have significantly lower BMD, especially in the spine [23,24].

Of course, high bone density in athletes may simply reflect a genetically determined strong musculoskeletal system, which favours the participation of these individuals in high-level sports rather than the training itself leading to an increase in BMD. However, an argument against this criticism comes from studies of unilateral-loading activities, such as tennis, where the playing arm has a larger bone mass than the non-playing arm [25,26].

Strength training

High intensity strength training improves the BMD of the trochanter, intratrochanteric area, and Ward's triangle of healthy post-menopausal women [11,27] and these improvements correlate with increased muscle strength. Similarly, BMD of the lumbar vertebra improves in lung transplant recipients after 6 months of exercise on a lumbar extensor machine [28], further supporting the notion that progressive mechanical loading is effective at reducing osteoporotic symptoms.

High-impact exercise

A 1-year study incorporating jumping, stepping, marching and side stepping in an exercise class [10] for the over 50s showed that there were significant increases (approximately 2%) in BMD at the hip, but not spine. Some of the subjects continued for a second year in which the spine BMD increased significantly and the changes in hip BMD were maintained. This type of exercise also considerably reversed the age-related loss of muscle strength. Urinary excretion of pyridinoline and deoxypyridinoline were measured to assess the impact of the exercise on bone resorption [10]. Both markers significantly decreased during the first 6 months of exercise and then returned to baseline values. This suggests that the exercise was suppressing osteoclastic bone resorption. It remains to be seen whether exercise may promote osteogenic responses. Similar findings on the response to high-impact work have also been obtained in younger adults [13,29].

Microvibration interventions

Whole body vibration (WBV) has recently been considered as a possible candidate for skeletal loading. In older adults, WBV at 30 Hz for <20 min for 12 months [30], or at 35–40 Hz three times weekly for 24 weeks [31], has been linked with increased bone strength. However, at 20 Hz for 4 min once a week for 12 months, microvibrations appeared to have no additional positive bone strength effect (compared with a course of 5 mg daily of alendronate), in post-menopausal women |**32**|. More work is needed on this type of bone loading, not least on the potential side effects that may occur from the vibration to the head and neck region |**30**|.

Walking

Supervised walking for a year showed no effect on trabecular bone density in the spine |**12**|. In a 7-month trial, Hatori *et al.* |**33**| compared walking above (high intensity) or below (low intensity) the anaerobic threshold on spine BMD. The moderate intensity group showed a similar loss of bone to the controls, whereas the high intensity group showed a small improvement. It is unlikely that the general population will be prepared to walk at anaerobic levels.

The downside of over-exercise

With up to 17% decrement in bone quality after extreme endurance cycle training |**34**|, we are increasingly becoming aware that some types of exercise may not be optimal for bone health or reduction of falls. Another limitation of extreme levels of exercise is that increased incidences of menstrual disorders have been observed in athletic women and infertility has been reported in amenorrhoeic athletes. This is a condition known as the athlete triad |**35**|. It describes the simultaneous presence of eating disorders, amenorrhoea/oligomenorrhoea (i.e. 0–9 menses per year), and decreased BMD (osteoporosis and osteopenia) in athletic females |**35–37**|. Many of the women who develop such disorders have a later than average puberty, which may be associated with the adoption of intense exercise early in life |**35,36**|. In addition, injuries to the musculoskeletal system are much more common in amenorrhoeic athletes, in particular the development of stress fractures |**37**|. It is important that athletes are aware of the potential risks to the skeleton of extended periods of menstrual irregularities, as it remains to be shown whether these skeletal deficits can be reversed by the resumption of menses or hormone replacement |**23**|. In males, a study has found that testosterone levels are significantly lower in triathletes |**38**|. In addition, these athletic males did not have increased BMD at the spine or total body compared with sedentary controls, despite their high levels of activity |**38**|. This would suggest that disturbances in the male hypothalamic–pituitary–gonadal axis also occur in highly active males.

Exercise and physical activity in preventing fractures and osteoporosis

Age-adjusted risk of hip fractures is up to 40% lower in the most active compared with the least active adults [39]. Indeed, epidemiological studies have shown that a lifetime's history of regular physical activity can reduce the risk of hip fracture by up to 50% and much of this benefit is thought to result from a reduction in falls [40]. Most of the evidence for the benefits of physical activity and exercise for bone health in older adults comes from research conducted among Caucasian, post-menopausal women. However, more recent work with older men suggests that similar positive results can be achieved. There are few trials that specifically examine the influence of race or culture. Almost 90% of hip fractures result from the impact of a fall [41]. Wrist fractures become less common in the very old, because of slower reaction times and inability to extend an arm in time to break the fall. A lack of vigorous exercise in the preceding 2 weeks has been associated with increased risk of wrist fracture [42].

Simple squeezing of a tennis ball for 30 seconds a day has significant benefits in the non-injured forearm of women who had already sustained a Colles' fracture [43]. In addition, a set of dynamic bone-loading exercises for the distal forearm results in increased bone strength at the wrist [44]. Total body calcium is improved in post-menopausal women training at a repetitive low force, as well as in those who train at a similar level with the addition of light weights attached to their wrists and ankles during the exercise classes [45]. In post-menopausal women, Tai Chi Chun exercise has been linked with a three- to fourfold slowing down in the rate of bone loss in both trabecular and cortical compartments of the distal tibia compared with a sedentary lifestyle [46], as well as reducing fall risk [47]. In patients with rheumatoid arthritis, a long-term high intensity weight-bearing exercise programme has been associated with slowing down the rate of decrease in hip BMD, but not in lumbar spine BMD, which is another argument both for the effectiveness of exercise but also on the limitation of the extent of the benefits [48]. Finally, there is evidence that male heart transplant patients following a 6-month strength training programme have greater relative gains in BMD than age-matched controls [49].

A number of studies have shown an increased benefit to bone by adding dietary supplementation with an exercise regimen [50,51]. Despite significant improvements in aerobic capacity, a year-long investigation of treadmill walking at 70–85% of maximum heart rate together with calcium supplementation found no effect at the spine or forearm in post-menopausal women [50]. A 1-year study [51] of combined walking, running and stair climbing with calcium supplements given at a dose of 1500 mg/day showed a 6% increase in spine bone mineral content (BMC). Those who had stopped training after the initial 12 months of exercise returned to their baseline BMC, whereas those who carried on training maintained their BMC gain without further improvements.

Similarly there is an added benefit to exercising while taking hormone replacement therapy (HRT) [52]. Post-menopausal women exercising three times per week for a year saw benefits of 1–2% in spine BMD, but the group exercising while on HRT treatment had improvements of about 8% over the year [52].

When immobilized, bone is not loaded and some degree of bone loss occurs: 27 days of bed rest has led to the loss of 0.9% of bone mineral per week [53,54]. High rates of inactivity in older people, especially those in residential or nursing accommodation will lead to an increased loss of bone with increasing age. Nursing home residents spend up to 90% of their time either sitting or lying down [55]. There are, of course, many factors, other than bone strength that may increase the likelihood that a person will fall and that a fracture will ensue. Slow reaction time and decreased functional ability owing to lack of practice and/or physical pain, inadequate strength of the muscle–tendon complex, decreased joint flexibility, lower limb asymmetry in strength and power, are considered the main muscle factors involved [56–58]. Falls in the home-dwelling elderly take place during periods of maximal activity [59], so there may be a U-shaped relationship between the amount of physical activity and the number of falls, with a higher incidence of falls in the least active and the most active as suggested in one study [39]. Indeed, one walking intervention in patients with a previous Colles' fracture actually increased the risk of fractures compared with normal activity [60].

Exercise to prevent falls could involve Tai Chi and other dynamic balance exercises, chair exercises and floor work for strength, local muscular endurance, bone loading, power, flexibility, postural and gait training, supported endurance work and tasks to improve visual, vestibular and sensory input [61]. See Fig. 9.1 for

Fig. 9.1 Sample of exercise interventions for older adults. Illustrations of balance, muscle strengthening, and low impact aerobic exercises in older men and women.

Table 9.3 Types of exercise and evidence of effectiveness

Type of activity	Skeletal site	Effectiveness
Walking	Spine	Absent unless at anaerobic levels
	Hip	Absent
Mixed aerobic	Spine	Present
	Hip	Present
	Wrist	Contradictory
Strength	Spine	Present
	Hip	Present
	Wrist	Present
High impact	Spine	Absent
	Hip	Present
Low impact	Total body	Present
Whole body vibration	Hip	Contradictory
	Forearm	Contradictory
Exercise + calcium	Spine	Present
Exercise + hormone replacement therapy	Spine	Present
	Total body	Present
	Wards triangle	Present
	Distal tibia	Present

examples of these exercises. Table 9.3 gives a summary of the general evidence for/against the effectiveness of various exercise activities on different skeletal sites.

Exercising with osteoporosis

Even frail older patients with osteoporosis gain benefit from exercise. However, when working with these patients, exercise must be low risk and low impact for safety. For example, patients with kyphosis/vertebral fractures are likely to have reduced strength of the back extensor muscles and therefore must start with very low workloads and progress slowly |**62**|. It is important for people with a previous history of vertebral fractures to avoid unsupported spinal flexion and abdominal curls |**62**|. It is possible to reduce the incidence of future fractures with emphasis on back extensions |**62**|. The overall emphasis should be on fall prevention. Several studies have shown good benefits of individualized exercise for osteoporosis patients, such as improved balance and strength after 20 weeks |**63**|, reduced pain and improved muscle function after only 6 weeks |**64**|. One large population-based trial, over 10 years, has seen a reduction in fracture rate |**65**| by advocating increased physical activity and other lifestyle changes.

The American College of Sports Medicine has issued general guidelines for exercise instructors working with older adults |**66**|, and adults with osteoporosis |**16**| (Table 9.4). Specific guidelines for physiotherapists on exercise for patients with osteoporosis |**67**| are summarized in Table 9.5.

Table 9.4 Guidelines on exercise for osteoporosis patients

Mode	Goals	Loading
Strength: dumbells, machines and floor calisthenics	Improve strength in arms, shoulders, legs and hips. Emphasize hip flexors/extensors and back extensors	50% of 1 RM or 70% of 3 RM 2–3 sets of 8 repetitions 2 days/week for 20–40 min
Endurance: walking, cycling, swimming	Improve and maintain work capacity	40–70% peak heart rate 2–5 days/week for 20–30 min
Flexibility: stretching, chair exercises	Increase/maintain range of movement, especially pectorals	5–7 days/week
Functional: activity-specific exercises	Increase/maintain daily living activities	

RM, repetition maximum (the maximum amount that can be lifted once).

Source: Chartered Society of Physiotherapists 1999 [67].

Table 9.5 Physiotherapy osteoporosis prevention and management guidelines

Severe osteoporosis—BMD <2.5 + previous fracture

Targeted gait and postural balance training

Functional local muscular endurance and strength training (e.g. sit to stand, stairs)

Functional range of movement and flexibility training

Osteoporosis—BMD <2.5 without previous fracture

Targeted postural, gait and low impact endurance training (e.g. stepping)

Functional and open chain strength and bone-loading training

Functional range of movement and flexibility training

Osteopenia—BMD <1 to <2.5

Targeted low–medium impact and endurance training (post-menopausal)

Targeted medium impact and endurance training (pre-menopausal)

Normal—BMD >1

Medium–high impact endurance training

Open/closed chain strength training

Complex challenging balance training

Flexibility

(BMD measured by DXA)

Source: Chartered Society of Physiotherapists 1999 [67].

Conclusion

There is strong evidence that physical activity across the life span is important in preserving good skeletal health [68] and preventing fractures [15,69]. However, for the greatest benefit, the activities have to be weight bearing (above loads that the skeleton normally carries), involve strong muscle contractions or involve strains in a variety of planes.

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