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Review Article

Program design considerations for bone health in premenopausal women

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Abstract

The purpose of this literature review is to critique training studies that have examined the effects of jump-landing programmes on bone health parameters in premenopausal women. Activities such as jumping and hopping have been proposed to achieve the desired unusual or atypical strain distributions on the skeleton for women who are habitually inactive and not involved in high-impact sports, however specific protocols to optimise bone health are currently lacking. From this review, it can be concluded that jump-landing protocols that; utilise brief jumping episodes (10 - 100 jumps/day, 3 - 7 days/week), are 4 - 18 months duration, and present loading magnitudes of between 2 - 6 body weights (BW) and rates of >43 BW·s^{-1}, can result in significant gains in femoral neck bone mineral density of 0.6 – 3.4% in premenopausal women. Evidence from this review has the potential to inform future exercise recommendations used to improve bone health during the critical premenopausal period, and to both reduce and delay the incidence of osteoporotic fracture in the years post menopause.

Introduction

Osteoporosis is a disease where bone density and bone quality are reduced, leading to a weakness of the skeleton and a significantly increased risk of bone fracture [1]. This disease is recognized as a major public health issue in New Zealand and the developed world, with 59% of women and 29% of men over the age of 60 years suffering a fracture from this age [2,3]. The economic burden on the public health and social care system as a result of treatment and management of osteoporotic fractures is difficult to determine as often not diagnosed until a fragility fracture occurs [4]. An Australian study estimated the direct economic cost of osteoporosis in 2017 to be AUD$3.4 billion, which is three times higher than in 2007 [5]. Osteoporosis New Zealand estimated the total cost of the disease at a staggering $1 billion each year, with this figure predicted to increase rapidly if additional efforts are not made to address this disease [6].

Generally, women experience bone losses of approximately 1% per year after the fourth decade of life, however annual losses of 3% - 5% Bone Mineral Density (BMD) can be experienced during early post-menopause. The National Osteoporosis Foundation of America estimated that up to 20% of BMD can be lost in the 5 - 7 years after menopause, with lifetime bone losses estimated to be 30 - 40% of peak bone mass [7,8]. Researchers [9] have demonstrated that the hip and lumbar spine are fracture sites most frequently associated with postmenopausal osteoporosis, which is primarily a consequence of trabecular bone losses due to estrogen deficiency, however, the hip is considered the most severe osteoporosis complication [10].

Recommendations guiding exercise prescription for bone health have suggested moderate weight-bearing exercise, such as walking, as beneficial to these clinically relevant sites, however, this intensity of loading is insufficient and no longer

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consistent with the current evidence base [4,11,12]. It should be noted that although physical activity provides a multitude of health benefits, not all exercise is osteogenic. Therefore, in spite of the benefits aerobic activities such as walking, cycling and swimming may provide to body composition, strength, and balance, researchers have shown that these activities may have little or no effect on enhancing bone health [11,13-15]. Osteoporosis Australia (2013) has published recommendations for physical activity, based on an evidence-informed strategy to prevent osteoporosis. The key message was to optimize bone health throughout all stages of life and that high-impact loading appears to be the most beneficial approach in older women, however, the optimal loading prescription was still to be determined [4,16]. More recently, Exercise and Sports Science Australia published a position statement recommending that low-risk individuals, defined as healthy adults with normal BMD (T-score above -1.0 SD), need to perform 10 - 50 jumping exercises 4 - 7 times a week for the prevention of osteoporosis [17]. However, although the position statement identified the types of jumps to be performed, it lacked specific detail in terms of jump-landing technique, program design, and monitoring of the daily and weekly loading.

Thus although literature exists to support that a specific mode of impact exercise needs to be integrated into the lives of healthy adults and that well-designed exercise programs for enhancing and preserving BMD are required, current recommendations are outdated and need revision [16,18-22]. The current literature indicates that to provide an adaptive bone response the programme must consider: 1) GRF magnitude and rate of force development; 2) distribution patterns of loading; 3) duration of the programme; 4) number of loading cycles; 5) frequency and recovery between loading sessions; 6) age-specific response to loading; 7) bone-site specificity; 8) instructions provided; and, 9) jump-landing technique. In addition, the programme needs to adhere to best practice strength and conditioning principles such as; 10) progressive overload; 11) individualisation; and, 12) mesocycle design and periodisation.

The focus on premenopausal women represents a "window of opportunity" for premenopausal women to prevent or delay the time before the fracture threshold is surpassed in the postmenopausal years. Therefore, the purpose of this literature review is to critique training studies that have examined the effects of jump-landing programs on bone health parameters in premenopausal women. From this critique, those factors thought important for optimizing program design for improved bone health will be identified and discussed.

Literature search methods

This review evaluated and interpreted the current evidence base to provide researchers, primary health carers, sports scientists, and physical therapists alike, with an understanding of the rationale and application of osteogenic exercise as a preventative approach for osteoporosis and consequently the effects on reducing the risk of fracture. The conclusions and practical applications of this review were drawn from peer-reviewed journal publications. The databases searched were Academic Search Premier, SPORT Discus, PubMed, MEDLINE, and CINAHL. Literature searches were undertaken using several keywords including 'osteoporosis prevention', 'strength and conditioning, 'resistance training', 'premenopausal', 'impact exercise', 'periodization', 'exercise frequency', 'exercise loading', 'neural adaptation for exercise', 'exercise duration', 'contraindications to exercise, 'falls prevention', 'muscle reactivity', 'balance', 'body composition', 'jumping', 'ground reaction forces', 'bone mineral density, 'DEXA', 'bone geometry', 'jumping technique', 'plyometrics', and 'bone health'. Only English-language articles published in peer-reviewed journals were considered. Relevant literature was also sourced from searches of related articles and books arising from the reference list of those obtained from the database searches. The studies reviewed examined various recommendations from credible national organizations and 'best practice' strength and conditioning programs that could be integrated into an osteogenic exercise program for premenopausal women. Eleven studies (Table 1) were found that met the inclusion criteria which included; being female, premenopausal (< 51 years), utilizing dual-energy x-ray absorptiometry (DEXA) technology, and involving a jumping intervention lasting more than 3 months (minimum bone turnover cycle).

Summary of the research

Participants: A total of 672 female participants subjects were involved in the research and comprised of 361 participants who performed a jump intervention and 311 controls. The average age for all participants was 34.6 years, which represented the premenopausal stage (post the attainment of peak bone mass and pre the hormonal changes associated with menopause) [23]. The population of interest was healthy premenopausal women who were not performing regular exercise (no more than 2.5 hours per week) and therefore representative of the general population.

Discussion

A discussion of the factors to be considered when designing an exercise program to optimally stimulate an adaptive bone response is detailed below. Please note that the findings of the training studies reviewed were combined with relevant acute research where appropriate, which has investigated osteogenic loading in pre-menopausal women.

1. GRF magnitude and rate of force development

Although the optimal dose of exercise is yet to be determined, it would seem from the research reviewed and other acute data that a Ground Reaction Force (GRF) magnitude of greater than 3-Body Weights (BW) and a rate of force development exceeding 43-body weights per second ($BW \cdot s^{-1}$) are needed for stimulating bone [26,35,36]. Bassey and colleagues [26], previously defined vertical osteogenic thresholds for GRF magnitude and rate (>3 BW and 4 $BW \cdot s^{-1}$, respectively), which they developed using bilateral jump-landings with premenopausal women [26]. The jumps utilized in this review reported GRFs ranging from 2.0 - 6.5 BW, using mostly bilateral jump-landings, which is in agreement with authors of meta-analyses that reported GRFs of 2 - 5 BW as being effective to stimulate bone and

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Table 1: Randomized controlled trials of jump-landing interventions in premenopausal women.

Authors	Age (year) (mean ± SD)	Sample size (n)	Jump-landing Intervention	Duration (months)	Change in BMD %
[24]	J = 32.0 ± 1.2 C = 29.8 ± 1.8	n = 14 J = 14 C = 13	50 vertical jumps/per day > 2 BW	6	FN: J = ↑2.4; C = ↓1.8 LS: J = ↑1.0; C = ↑1.5
[25]	J = 39.0 ± 3.0 C = 39.0 ± 3.0	n = 84 J = 39 C = 45	60 min session with 20 min high impact jumping 2.1 - 5.6 BW	18	€FN: J = ↑1.6; C = ↑0.6 LS: J = ↑2.2; C = ↑0.7
[26]	J = 38.4 ± 7.4 C = 36.4 ± 7.6	n = 55 J = 20 C = 35	5 x 10 vertical jumps 6 x week 3BW	5	€FN: J = ↑2.8; C = ↓0.3 €LS: J = ↑1.1; C = ↓1.1
[27]	J = 38.1 ± 1.7 C = 38.5 ± 1.6	n = 80 J = 39 C = 41	60 min session with 40 min high impact stamping, jumping & running 3 x week	12	€FN: J = ↑1.1; C = ↓0.4 *LS: J = ↑2.2; C = ↓0.4 * L1 only
[28]	J = 20.5 ± 0.6 C = 20.9 ± 0.8	n = 36 J = 18 C = 18	10 x maximal vertical jumps 3 x week 4.76BW (peak)	6	€FN: J = ↑2.6; C = ↓1.1 €LS: J = ↑2.4; C = ↓0.6
[29]	J1 = 38.3 ± 3.8 J2 = 41.3 ± 3.8 C = 40.5 ± 3.5	n = 59 J1 = 19, J2 = 16 C = 24	100 jumps + lower only (J1) or upper & lower (J2) body resistance exercises 3 x week 4 - 5BW	12	€FN: J1 = ↑1.0; J2 = ↑1.0; C = ↑0.1 €LS: J1 = ↓0.3; J2 = ↑1.1; C = ↑0.6
[30]	32.9 ± 2.4	n = 64 J1 = 16, J2 = 13 & J3 = 16 C = 19	5 x 10 multidirectional hops 2, 4, or 7x week 2.5 – 2.8BW	6	€FN: J1 = nc; J2 = ↑0.9 and J3 = ↑01.8; C = ↓1.2 * No changes in LS reported
[31]	J = 39.7 ± 1.2 C = 38.1 ± 1.2	n = 67 J = 34 C = 33	5 x 10 vertical jumps in an office setting 3 x week > 3.9g (2 - 3BW)	12	€FN: J = ↑0.6; C = ↓0.1 €LS: J = ↑0.8; C = ↓0.2
[32]	J = 22.8 ± 4.0 C = 21.7 ± 2.9	n = 96 J = 48 C = 48	10 x maximal vertical jumps 3 x week 4.56 BW (3.64 - 6.46)	6	FN: J = ↑3.7; C = ↓2.0 * using BUA (proposed to equal to ↑4.0 BMD in J group)
[33]	J1 = 41.0 ± 4.4 J2 = 39.8 ± 4.8 C = 37.6 ± 6.4	n = 60 J1 = 23 J2 = 14 C = 23	Jump 10 jumps, 2 x day (J1) Jump 20 jumps, 2 x day (J2) (8 hours between sessions) 6x week 3.8 - 4BW	4	Hip: J1 = ↑0.3; J2 = ↑0.2; C =↓0.9 * LS not reported
[34]	J = 43.0 ± 5.3 C = 41.5 ± 5.8	n = 57 J =32 C =25	32-42 max jump-landings 2-5 x week Bilateral and unilateral jumps (multiplanar) > 3BW	12	FN: ↑3.4; C = ↓0.2 LS: ↑0.4; C = ↓0.2

Key: BMD: Bone Mineral Density; FN: Femoral Neck; LS: Lumbar Spine; J: Jump group; C: Control group; BUA: Broadband Ultrasound Attenuation; BW: Body Weight € Significant change compared to the control group.

result in bone formation [12,26,34,37]. Interestingly, although Bailey and Brooke-Wavell [30], reported GRFs for vertical hops performed maximally that did not achieve the previously defined osteogenic threshold (> 3 BW), they reported femoral BMD gains of nearly 2% for the premenopausal participants. They speculated that the single-leg landing forces may be equivalent to a total landing force of 5 - 6 BWs due to forces being transmitted through one leg only, and therefore easily exceeded the bone stimulation thresholds previously defined. Although GRF magnitude is considered an important factor to influence the adaptation of bone, the rate of loading (rate of force development) is considered equally important [36,38,39]. Researchers have reported that if the peak rate of force production is sufficiently high, then bone adaptation can be stimulated without using high force magnitudes [36,38,40]. Thus, both peak magnitude and loading rate are considered important factors in achieving osteogenic thresholds.

2. Distribution pattern of loading

Most of the studies included in this review utilized jumps in the vertical plane, and all studies represented GRFs in the vertical direction only. Bone adaptation has been shown to be blunted by habitual patterns of loading (e.g. walking and running), so novel or diverse loading patterns are required to stimulate an adaptive bone response [36,41]. Thus, exercises such as jumping and hopping in different directions, which are considered to provide 'unusual' or 'unfamiliar' patterns of loading have been shown to have a greater osteogenic effect than landing force magnitude alone, with bone adaptation being observed at much lower GRFs when these non-habitual strains are applied [36,38]. Furthermore the 'error strain distribution hypothesis' suggests that unusual or novel directions of force application may have a greater osteogenic effect than magnitude alone, and is therefore vital to osteogenesis [38,41]. Interestingly, the studies which utilized multidirectional

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jumps in this review [25,27,29], reported similar gains in BMD to those that utilized jumps in the vertical direction only. However, these multidirectional studies incorporated up to 200 jumps within a prolonged exercise session (60 minutes), which according to animal studies, may have saturated the optimal impact stimulus and consequently had a negative effect on bone mechanosensitivity [35,42]. In addition, the principle of variation may explain some of the findings in this review, whereby the changes in five months were similar to 18 months, as maybe not enough variation (i.e. multiplanar, unilateral vs bilateral) had been provided as a programming progression. The influence of loading variation is a particularly important consideration for osteogenic jump-landing programs and for special populations such as older adults unable to tolerate high magnitude and rate of GRF that warrants further investigation. Thus, future research is required to gain an understanding of the contribution of multi-planar GRFs (i.e. medio-lateral and anterior-posterior) in addition to vertical only, on the mechanosensitivity and subsequent adaptation of bone.

3. Number of loading cycles

The number of impacts (loading cycles) has been shown to affect the rate of bone formation, with animal studies demonstrating that a range of 5-100 loading cycles can stimulate bone formation and maintain the mechanosensitivity of bone [35,38,42]. Researchers using rats have shown that bone quickly becomes desensitized to impact exercise as the loading bout continues without interruption [35,42]. These researchers using animal models reported that skeletal tissue becomes desensitized after only 40 - 50 repetitive loading cycles, and furthermore recommended a rest period of 24 hours as sufficient to restore bone mechanosensitivity [35]. Interestingly, as few as 10 maximal vertical jumps (4.6 BW), achieved femoral neck gains equivalent to 4% (determined using broadband ultrasound attenuation), and thus fewer jump-landing repetitions (achieving osteogenic thresholds for magnitude and rate) may optimize the adaptive response of bone whilst reducing the risk of injury relating to fatigue. Studies which utilized longer duration exercise sessions (i.e. 60 minutes), including more jump-landing repetitions and additional resistance exercise [27,29], achieved similar (or lesser) increases in femoral BMD than studies lasting less than 5 minutes [34] (↑1.0 compared to ↑3.4%). This finding further supports the concept that GRF magnitudes exceeding > 3 BW are essential to bone adaptation. Although the optimal number of loading cycles for humans has not been determined, it appears from the current review that a similar, and potentially greater, the osteogenic effect occurred for the shorter exercise sessions (< 50 loading cycles), as compared to the longer exercise sessions (100 - 200 loading cycles). Thus, a shorter exercise session (< 10 minutes), would potentially be more beneficial to the bone, and more likely to positively influence exercise adherence, than exercise programs of extended duration.

4. Study duration

The jump-landing studies in this review ranged from 4 - 18 months, with an average intervention duration of 8.7 months. As one bone remodeling cycle (the complete cycle of activation, resorption, and formation of bone), is approximately 3 to 4 months, the program duration needs to be continued through several cycles in order to detect changes in BMD using DEXA [43]. Thus, a longer study duration (at least 12 months) has been suggested as providing a more valid representation of bone changes [12,17,44]. It appears that significant increases in femoral BMD (↑0.3 – ↑2.8%), have been achieved with jump-landing programs of only 4 - 5 months in duration, using vertical jumps (10 - 50 each session). Interestingly, studies of at least 12 months report a similar (and increased) benefit to femoral BMD (↑0.6 - ↑3.4%), using similar jump-landing protocols which indicates that longer studies may require loading to be progressively increased (periodised) or varied in some manner, to continue to satisfy bone mechanosensitivity requirements.

5. Frequency and recovery between loading sessions

The jump-landing protocols in this review utilized exercise session frequencies ranging from 3 - 7 times per week. One of these studies focused directly on the effect of frequency, reporting greater BMD gains when the jump-landing program was performed daily, compared to twice or four times (no change, ↑0.9 and ↑1.8%, respectively) [30]. These findings indicate that at least three sessions of a jump-landing program are required to achieve significant increases at the femoral neck, however, consideration may be needed for recovery and to reduce injury risk. Although the optimal frequency of loading bouts has not been established in humans, increases in BMD have previously been reported in premenopausal women using jumping interventions performed 3 - 7 times per week, thus further research is required regarding this variable. Interestingly, one study in the review, which used a multidirectional hopping intervention, concluded that hopping exercises need to be performed daily, when compared to other weekly frequencies, to increase femoral neck BMD [30]. Furthermore, two unrelated studies using young men and premenopausal women concluded that jumping twice daily (separated by 6 - 8 hours of recovery) was more osteogenic than the same number of jumps (40 - 60 jumps/day) carried out in a single session [33,45]. Adequate recovery between loading cycles and jumping sessions has been shown to maintain the mechanosensitivity of bone and optimize the osteogenic response by enhancing the surface area of bone actively forming new bone [46]. Researchers using animal models demonstrated that skeletal tissue became desensitized after 40 - 50 repetitive loading cycles, and a rest period of 24 hours was sufficient to restore bone mechanosensitivity [35]. Furthermore, rest periods between loading bouts of around 15 seconds and up to 4 hours, have been shown to increase bone formation outcomes by 65% to 100% [35,39,46,47]. Less than half of the studies in this review utilized rest intervals between jumps, and after sets of jumps, in spite of the recommendations indicated from these animal studies. Thus, the design of a jump-landing program needs to consider inserting appropriate rest periods within and between jump-landing sessions to optimize bone adaptation and reduce the risk of fatigue and bone damage [48,49].

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6. Age-specific response to loading

One study in this review investigated the effect of providing the same vertical jumping intervention in a cohort of premenopausal and postmenopausal women [26]. Bassey and colleagues [26], reported an increased femoral neck BMD gain of 2.8% in the premenopausal group, however, failed to achieve a significant difference for the postmenopausal group. This finding indicated that the loading forces required to achieve an osteogenic response in older (> 50 years) women may be higher than for younger women (< 50 years) [19,41,50]. If we consider the concept that post-menopausal BMD is a consequence of peak BMD (achieved at skeletal maturity), menopause, and the rate of bone loss as the women ages, then the period of bone growth during the pre-pubertal, pubertal and premenopausal years is the optimal time to focus on positive interventions for maximizing bone health. In a recent Exercise Sports Science Australia (ESSA) position statement, the key message was to optimize bone health throughout all stages of life, however high-impact loading (i.e. jumping and hopping) appeared to be the most beneficial approach in healthy premenopausal women [17].

7. Bone-site specificity

Cross-sectional studies have shown that athletes in weight-bearing sports (i.e. gymnastics, tennis, and volleyball) which involve high magnitude and rates of loading and novel or diverse loading patterns, have greater bone mass at loaded skeletal sites compared to non-athletes or athletes in non-weight-bearing or lower-impact sports [51-53]. These observations indicated that an osteoporosis prevention program needs to provide an appropriate osteogenic stimulus at clinically relevant bone sites related to osteoporotic fracture (i.e. femoral neck and lumbar spine), as the hip and lumbar spine are fracture sites most frequently associated with postmenopausal osteoporosis, although the hip is considered the most severe osteoporosis complication [10]. Evidence from all the studies in this review has shown that jump-landing exercises can provide osteogenic stimulus to the hip region (i.e. femoral neck), and the majority of studies also achieved significant BMD gains at the lumbar spine. The researchers from one study suggested that jump-landings would not provide an effective stimulus for individuals aiming to improve bone strength at the spine, and recommended upper-body resistance exercises as a better option [29]. These researchers suggested that jump-landing exercises fail to generate sufficient osteogenic stimulus for bone formation at the spine, as the mechanical load is attenuated before being translated to the lumbar area [27,29]. It is therefore of interest to determine whether jump-landings performed whilst utilising a reactive jump-landing, and 'stiff' landing mechanics, have the ability to stimulate the lumbar spine, in addition to the femoral region.

8. Instructions provided

Researchers have shown that we can successfully employ a specific jumping style after being instructed only once [54], which implies that once proficient, jumps do not need further coaching and can be performed in the home setting with the knowledge that the appropriate GRFs and subsequent osteogenic thresholds will be met. The studies in this review documented a variety of different instructions for arm position, effort during jumping, and most importantly, the technique utilized when landing. In addition, most of the studies in this review provided supervision during the jump-landing sessions. Therefore, future research is required to determine whether participants can achieve similar or greater jump-landing forces after only one instructed session, using specific cues to land stiffly with minimal knee flexion, due to learning or practice effects. This information would have clinical implications for osteogenic jump-landing programs to be effective when performed in a home-based unsupervised setting.

9. Jump-landing technique

Biomechanics researchers have indicated that jumping and hopping exercises may only be useful in terms of osteogenic benefit if the jump-landing technique is elucidated for this purpose. The important aspects of jump-landing include the cueing of participants to land stiffly and to minimize ground contact time, which has been shown to significantly influence this aspect of force attenuation, and therefore vital to osteogenesis [54-57]. Researchers from these biomechanical studies showed that the jump-landing technique utilized by participants is a major factor that can influence the osteogenic effectiveness of jumps and that repeated jump-landings have the potential to heighten bone stimulation. Although the studies included in this review have provided some information about the jumping technique, few have focussed on the jump-landing technique. Thus, future research is required to explore the effect of cueing participants to land 'stiffly', to utilize a flat-footed ground contact, and to employ repeated jump-landing for achieving osteogenic thresholds previously shown to increase bone mass in premenopausal women.

10. Progressive overload

In accordance with 'best practice' strength and conditioning, and physiotherapeutic programming, the first stage of a jumping or plyometric training program need to focus on developing competent movement patterns, general strength, and balance [58-60]. It is recommended that the successful completion of a progressive weight-bearing program, including strength and balance, will adequately prepare untrained individuals to tolerate the stresses involved with jump-landings to maximize benefits to bone health and reduce the risk of injury [59,61,62]. Only one study in this review provided a description of musculoskeletal and neural adaptation programming prior to participating in a jump-landing program [34]. It is therefore recommended that before an individual can undertake jump-landing exercises, pre-conditioning exercises may be needed to tolerate the stresses involved with jump-landing exercises to maximize benefits to bone health and reduce the risk of injury. It is recommended that this phase be performed in a supervised capacity, as the ability to provide instruction and demonstrate the proper technique is an important process for guiding exercise prescription and progression in a safe manner [63-65]. In addition, it is essential that participants are loaded and progressed within a jump-landing program according to

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several factors including; strength, balance, movement and technical proficiency, fitness level, injury status, and comfort, to maximize the potential for adaptation and minimize the risk of injury [59,61,62]. It is however evident that the jump-landing programs in this review are very basic in their design, with only one including a variety of multiplanar bilateral and unilateral jumps [34] and most utilizing only one exercise (i.e. vertical jump). In addition, most of these studies have provided a very basic understanding of the principle of progressive overload, with increased number and/or height of jumps described within the first 4 months only. Thus, further research is required to establish jump-landing programs that can continue to stimulate bone over long periods of time (i.e. greater than 1 year).

11. Individualization

Although the studies reviewed stipulated that participants needed to be healthy and without current musculoskeletal injury to take part in the jump-landing programs, a limitation of current exercise recommendations for osteoporosis management and prevention, is the lack of consideration for individual differences, existing bone health, movement competency, and functional capacity. Therefore, a safe and effective osteogenic jump-landing program must consider risk factors that may compromise the safety of performing such a program such as; age, frailty, pre-existing osteoporosis, musculoskeletal pain or injury, osteoarthritis, and history of fractures or falls [23]. Authors of a recent position statement on exercise prescription for the prevention and management of osteoporosis, recommended that individuals were classified into three levels of risk for fragility fracture (low, moderate, and high), using the World Health Organisation (WHO) defined T-scores [17]. According to this classification, low-risk individuals were defined as having normal BMD (T-score above -1.0 SD), and no clinical risk factors for falls or fracture, and deemed safe to participate in a jump-landing program. Individuals classed as moderate and high risk (T-score -1.0 to -2.5 SD and less than -2.5 SD, respectively), were also recommended to perform jump-landings (2 - 3 BW), with an emphasis on conditioning the musculoskeletal system, gradual loading increments, pain-free competency and safety in terms of falls prevention [17].

12. Mesocycle design and periodization

Strength and conditioning training principles imply that a musculoskeletal exercise program needs to utilize a model of periodization to ensure that training principles are manipulated safely and effectively to achieve long-term benefits for the individual [66-68]. Thus, a jump-landing program needs to progress in volume and the technical difficulty over a 12-month period and its development should consider findings from previous studies which have achieved BMD gains in premenopausal women over similar time periods [17,66-68]. However, periodization and musculoskeletal programming principles, which may influence the long-term effectiveness and safety of these programs, are not currently reflected in the osteogenic jump-landing programs reviewed. Variables to be considered in a periodised training program for bone (adapted from musculoskeletal programming) include a progressively increased; magnitude, rate of strain, number of ground contacts, and technical difficulty (i.e. bilateral to unilateral) over at least a 12-month period. In addition, it would be of interest to utilize previously quantified GRF data for premenopausal women performing a variety of different jump-landings (i.e. multiplanar, bilateral, and unilateral), to determine the order these exercises should be introduced into an osteogenic jump-landing program.

Conclusion

The purpose of this review was to present a summary of the variables identified as integral in the development of a longitudinal periodised osteogenic jump-landing program for premenopausal women. Information regarding optimal jump-landing kinetics was identified whilst integrating current bone health guidelines, research, and concepts of best practice strength and conditioning.

From this review, it can be concluded that jump-landing protocols that; utilize brief jumping episodes (10 - 100 jumps/day, 3 - 7 days/week), are 4 - 18 months in duration, and present loading magnitudes of between 2 - 6 BW and rates of > 43 BW·s^{-}, can result in significant gains in femoral neck BMD of 0.6% – 3.4% in premenopausal women. Although these researchers have demonstrated that bone responds optimally to unusual or atypical mechanical forces applied to the skeleton for women who are habitually inactive and are not involved in high-impact sports, the aspects of the program design deemed important to the osteogenic potential of the exercise have not been clearly identified. In addition, only one study has attempted to incorporate all of the osteogenic loading (i.e. GRF magnitude, rate, and direction), and programming (frequency, intensity, duration, and type) variables, deemed important to musculoskeletal adaptation.

National and International Osteoporosis Organisations are now recommending that exercises, including jumping and hopping, should be utilized in an osteoporosis prevention program. However, currently, the peer-reviewed scientific literature on the use of exercise as a means of preventing osteoporosis is quite limited. While it would appear that jumping and hopping exercises are effective for this purpose, osteogenic programs specifically designed for premenopausal women are currently lacking [4,17,37,69]. Practitioners need to develop longitudinal periodised osteogenic jump-landing programs for healthy pre-menopausal women, which utilize quantified jump-landing force data (obtained from premenopausal women), whilst integrating current bone health guidelines, research, and concepts of best practice strength and conditioning. These programs need to utilize a model of periodization to ensure that training principles are manipulated safely and effectively to achieve long-term benefits to the bone whilst adhering to safe programming guidelines. In addition to participants developing adaptations to both generate and tolerate increased landing forces over time, multidirectional jumping and hopping interventions have the potential to achieve improvements in factors relevant to fall prevention, such as muscle strength and balance, in addition to enhanced BMD for premenopausal women at clinically relevant sites for osteoporosis prevention.

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References

1. Kanis JA, Adachi JD, Cooper C, Clark P, Cummings SR, Diaz-Curiel M, Harvey N, Hiligsmann M, Papaioannou A, Pierroz DD, Silverman SL, Szulc P; Epidemiology and Quality of Life Working Group of IOF. Standardising the descriptive epidemiology of osteoporosis: recommendations from the Epidemiology and Quality of Life Working Group of IOF. Osteoporos Int. 2013 Nov;24(11):2763-4. doi: 10.1007/s00198-013-2413-7. Epub 2013 Jul 25. PMID: 23884436; PMCID: PMC5096926.
2. Lippuner K, Johansson H, Kanis JA, Rizzoli R. Remaining lifetime and absolute 10-year probabilities of osteoporotic fracture in Swiss men and women. Osteoporos Int. 2009 Jul;20(7):1131-40. doi: 10.1007/s00198-008-0779-8. Epub 2008 Oct 31. PMID: 18974918.
3. Osteoporosis New Zealand. Who is affected. 2018,https://osteoporosis.org.nz/osteoporosis-fractures/who-is-affected/ 2018.
4. Ebeling PR, Daly RM, Kerr DA, Kimlin MG. Building healthy bones throughout life: an evidence-informed strategy to prevent osteoporosis in Australia. Med J Aust. 2013 Oct 7;199(S7):S1-S46. doi: 10.5694/j.1326-5377.2013.tb04225.x. PMID: 25370432.
5. Tatangelo G, Watts J, Lim K, Connaughton C, Abimanyi-Ochom J, Borgström F, Nicholson GC, Shore-Lorenti C, Stuart AL, Iuliano-Burns S, Seeman E, Prince R, March L, Cross M, Winzenberg T, Laslett LL, Duque G, Ebeling PR, Sanders KM. The Cost of Osteoporosis, Osteopenia, and Associated Fractures in Australia in 2017. J Bone Miner Res. 2019 Apr;34(4):616-625. doi: 10.1002/jbmr.3640. Epub 2019 Jan 7. PMID: 30615801.
6. International Osteoporosis Foundation. (2015, January 29, 2016). National and Regional Osteoporosis Guidelines. https://www.iofbonehealth.org/facts-statistics
7. Consensus development conference: diagnosis, prophylaxis, and treatment of osteoporosis. Am J Med. 1993 Jun;94(6):646-50. doi: 10.1016/0002-9343(93)90218-e. PMID: 8506892.
8. Sipilä S, Poutamo J. Muscle performance, sex hormones and training in peri-menopausal and post-menopausal women. Scand J Med Sci Sports. 2003 Feb;13(1):19-25. doi: 10.1034/j.1600-0838.2003.20210.x. PMID: 12535313.
9. Drake MT, Clarke BL, Lewiecki EM. The Pathophysiology and Treatment of Osteoporosis. Clin Ther. 2015 Aug;37(8):1837-50. doi: 10.1016/j.clinthera.2015.06.006. Epub 2015 Jul 7. PMID: 26163201.
10. Kanis JA. Diagnosis of osteoporosis and assessment of fracture risk. Lancet. 2002 Jun 1;359(9321):1929-36. doi: 10.1016/S0140-6736(02)08761-5. PMID: 12057569.
11. Martyn-St James M, Carroll S. Meta-analysis of walking for preservation of bone mineral density in postmenopausal women. Bone. 2008 Sep;43(3):521-31. doi: 10.1016/j.bone.2008.05.012. Epub 2008 May 26. PMID: 18602880.
12. Zhao R, Zhao M, Zhang L. Efficiency of jumping exercise in improving bone mineral density among premenopausal women: a meta-analysis. Sports Med. 2014 Oct;44(10):1393-402. doi: 10.1007/s40279-014-0220-8. PMID: 24981245.
13. Ma D, Wu L, He Z. Effects of walking on the preservation of bone mineral density in perimenopausal and postmenopausal women: a systematic review and meta-analysis. Menopause. 2013 Nov;20(11):1216-26. doi: 10.1097/GME.0000000000000100. PMID: 24149921.
14. Martyn-St James M, Carroll S. Effects of different impact exercise modalities on bone mineral density in premenopausal women: a meta-analysis. J Bone Miner Metab. 2010 May;28(3):251-67. doi: 10.1007/s00774-009-0139-6. Epub 2009 Dec 15. PMID: 20013013.
15. Scofield KL, Hecht S. Bone health in endurance athletes: runners, cyclists, and swimmers. Curr Sports Med Rep. 2012 Nov-Dec;11(6):328-34. doi: 10.1249/JSR.0b013e3182779193. PMID: 23147022
16. Martyn-St James M, Carroll S. A meta-analysis of impact exercise on postmenopausal bone loss: the case for mixed loading exercise programmes. Br J Sports Med. 2009 Dec;43(12):898-908. doi: 10.1136/bjsm.2008.052704. Epub 2008 Nov 3. PMID: 18981037.
17. Beck BR, Daly RM, Singh MA, Taaffe DR. Exercise and Sports Science Australia (ESSA) position statement on exercise prescription for the prevention and management of osteoporosis. J Sci Med Sport. 2017 May;20(5):438-445. doi: 10.1016/j.jsams.2016.10.001. Epub 2016 Oct 31. PMID: 27840033.
18. Gómez-Cabello A, Ara I, González-Agüero A, Casajús JA, Vicente-Rodríguez G. Effects of training on bone mass in older adults: a systematic review. Sports Med. 2012 Apr 1;42(4):301-25. doi: 10.2165/11597670-000000000-00000. PMID: 22376192.
19. Guadalupe-Grau A, Fuentes T, Guerra B, Calbet JA. Exercise and bone mass in adults. Sports Med. 2009;39(6):439-68. doi: 10.2165/00007256-200939060-00002. PMID: 19453205.
20. Howe TE, Shea B, Dawson LJ, Downie F, Murray A, Ross C, Harbour RT, Caldwell LM, Creed G. Exercise for preventing and treating osteoporosis in postmenopausal women. Cochrane Database Syst Rev. 2011 Jul 6;(7):CD000333. doi: 10.1002/14651858.CD000333.pub2. PMID: 21735380.
21. Ilona I, Taina A, Mirela S, Eugenia R, Mihaela Z. The role of high impact exercise in improve bone mineral density in postmenopausal women with osteopenia or osteoporosis. Journal of Physical Education & Sport / Citius Altius Fortius, 2010;27(2):110-115.
22. Polidoulis I, Beyene J, Cheung AM. The effect of exercise on pQCT parameters of bone structure and strength in postmenopausal women--a systematic review and meta-analysis of randomized controlled trials. Osteoporos Int. 2012 Jan;23(1):39-51. doi: 10.1007/s00198-011-1734-7. Epub 2011 Aug 3. PMID: 21811864.
23. Tella SH, Gallagher JC. Prevention and treatment of postmenopausal osteoporosis. J Steroid Biochem Mol Biol. 2014 Jul;142:155-70. doi: 10.1016/j.jsbmb.2013.09.008. Epub 2013 Oct 29. PMID: 24176761; PMCID: PMC4187361.
24. Bassey EJ, Ramsdale SJ. Increase in femoral bone density in young women following high-impact exercise. Osteoporos Int. 1994 Mar;4(2):72-5. doi: 10.1007/BF01623226. PMID: 8003843.
25. Heinonen A, Kannus P, Sievänen H, Oja P, Pasanen M, Rinne M, Uusi-Rasi K, Vuori I. Randomised controlled trial of effect of high-impact exercise on selected risk factors for osteoporotic fractures. Lancet. 1996 Nov 16;348(9038):1343-7. doi: 10.1016/S0140-6736(96)04214-6. PMID: 8918277.
26. Bassey EJ, Rothwell MC, Littlewood JJ, Pye DW. Pre- and postmenopausal women have different bone mineral density responses to the same high-impact exercise. J Bone Miner Res. 1998 Dec;13(12):1805-13. doi: 10.1359/jbmr.1998.13.12.1805. PMID: 9844097.
27. Vainionpää A, Korpelainen R, Leppäluoto J, Jämsä T. Effects of high-impact exercise on bone mineral density: a randomized controlled trial in premenopausal women. Osteoporos Int. 2005 Feb;16(2):191-7. doi: 10.1007/s00198-004-1659-5. Epub 2004 Jun 17. PMID: 15221206.
28. Kato T, Terashima T, Yamashita T, Hatanaka Y, Honda A, Umemura Y. Effect of low-repetition jump training on bone mineral density in young women. J Appl Physiol (1985). 2006 Mar;100(3):839-43. doi: 10.1152/japplphysiol.00666.2005. Epub 2005 Nov 3. PMID: 16269526.
29. Winters-Stone KM, Snow CM. Site-specific response of bone to exercise in premenopausal women. Bone. 2006 Dec;39(6):1203-9. doi: 10.1016/j.bone.2006.06.005. Epub 2006 Jul 28. PMID: 16876495.
30. Bailey CA, Brooke-Wavell K. Optimum frequency of exercise for bone health: randomised controlled trial of a high-impact unilateral intervention. Bone. 2010 Apr;46(4):1043-9. doi: 10.1016/j.bone.2009.12.001. Epub 2010 Jan 6. PMID: 20004758.

Citation: Clissold T, Cronin JB, De Souza MJ, Winwood PW (2022) Program design considerations for bone health in premenopausal women. Arch Sports Med Physiother 7(1): 007-015. DOI: http://dx.doi.org/10.17352/asmp.000015

31. Niu K, Ahola R, Guo H, Korpelainen R, Uchimaru J, Vainionpää A, Sato K, Sakai A, Salo S, Kishimoto K, Itoi E, Komatsu S, Jämsä T, Nagatomi R. Effect of office-based brief high-impact exercise on bone mineral density in healthy premenopausal women: the Sendai Bone Health Concept Study. J Bone Miner Metab. 2010 Sep;28(5):568-77. doi: 10.1007/s00774-010-0163-6. Epub 2010 Mar 30. PMID: 20349354.

32. Babatunde O, Forsyth J. Effects of lifestyle exercise on premenopausal bone health: a randomised controlled trial. J Bone Miner Metab. 2014 Sep;32(5):563-72. doi: 10.1007/s00774-013-0527-9. Epub 2013 Nov 8. PMID: 24202061.

33. Tucker LA, Strong JE, LeCheminant JD, Bailey BW. Effect of two jumping programs on hip bone mineral density in premenopausal women: a randomized controlled trial. Am J Health Promot. 2015 Jan-Feb;29(3):158-64. doi: 10.4278/ajhp.130430-QUAN-200. PMID: 24460005.

34. Clissold T. The Quantification and Development of an Osteogenic Jump-landing Program and Its Chronic Effects on Bone Health in Premenopausal Women. Auckland University of Technology. 2021.

35. Robling AG, Burr DB, Turner CH. Recovery periods restore mechanosensitivity to dynamically loaded bone. J Exp Biol. 2001 Oct;204(Pt 19):3389-99. doi: 10.1242/jeb.204.19.3389. PMID: 11606612.

36. Turner CH, Robling AG. Designing exercise regimens to increase bone strength. Exerc Sport Sci Rev. 2003 Jan;31(1):45-50. doi: 10.1097/00003677-200301000-00009. PMID: 12562170.

37. Babatunde OO, Forsyth JJ, Gidlow CJ. A meta-analysis of brief high-impact exercises for enhancing bone health in premenopausal women. Osteoporos Int. 2012 Jan;23(1):109-19. doi: 10.1007/s00198-011-1801-0. Epub 2011 Sep 28. PMID: 21953474.

38. Lanyon LE. Functional strain in bone tissue as an objective, and controlling stimulus for adaptive bone remodelling. J Biomech. 1987;20(11-12):1083-93. doi: 10.1016/0021-9290(87)90026-1. PMID: 3323200.

39. Robling AG, Castillo AB, Turner CH. Biomechanical and molecular regulation of bone remodeling. Annu Rev Biomed Eng. 2006;8:455-98. doi: 10.1146/annurev.bioeng.8.061505.095721. PMID: 16834564.

40. O'Connor JA, Lanyon LE, MacFie H. The influence of strain rate on adaptive bone remodelling. J Biomech. 1982;15(10):767-81. doi: 10.1016/0021-9290(82)90092-6. PMID: 7153230.

41. Lanyon LE. Using functional loading to influence bone mass and architecture: objectives, mechanisms, and relationship with estrogen of the mechanically adaptive process in bone. Bone. 1996 Jan;18(1 Suppl):37S-43S. doi: 10.1016/8756-3282(95)00378-9. PMID: 8717546.

42. Umemura Y, Sogo N, Honda A. Effects of intervals between jumps or bouts on osteogenic response to loading. J Appl Physiol (1985). 2002 Oct;93(4):1345-8. doi: 10.1152/japplphysiol.00358.2002. PMID: 12235034.

43. Kenkre JS, Bassett J. The bone remodelling cycle. Ann Clin Biochem. 2018 May;55(3):308-327. doi: 10.1177/0004563218759371. Epub 2018 Mar 4. PMID: 29368538.

44. Hart NH, Nimphius S, Rantalainen T, Ireland A, Siafarikas A, Newton RU. Mechanical basis of bone strength: influence of bone material, bone structure and muscle action. J Musculoskelet Neuronal Interact. 2017 Sep 1;17(3):114-139. PMID: 28860414; PMCID: PMC5601257.

45. Erickson CR, Vukovich MD. Osteogenic index and changes in bone markers during a jump training program: a pilot study. Med Sci Sports Exerc. 2010 Aug;42(8):1485-92. doi: 10.1249/MSS.0b013e3181d0fa7a. Erratum in: Med Sci Sports Exerc. 2012 Apr;44(4):770. PMID: 20139789.

46. Srinivasan S, Weimer DA, Agans SC, Bain SD, Gross TS. Low-magnitude mechanical loading becomes osteogenic when rest is inserted between each load cycle. J Bone Miner Res. 2002 Sep;17(9):1613-20. doi: 10.1359/jbmr.2002.17.9.1613. PMID: 12211431; PMCID: PMC1435731.

47. Burr DB. Introduction--Bone turnover and fracture risk. J Musculoskelet Neuronal Interact. 2003 Dec;3(4):408-9. PMID: 15758334.

48. Burr DB. Why bones bend but don't break. J Musculoskelet Neuronal Interact. 2011 Dec;11(4):270-85. PMID: 22130136.

49. Burr DB. The complex relationship between bone remodeling and the physical and material properties of bone. Osteoporos Int. 2015 Mar;26(3):845-7. doi: 10.1007/s00198-014-2970-4. Epub 2014 Dec 20. PMID: 25526711.

50. Gómez-Cabello A, Ara I, González-Agüero A, Casajús JA, Vicente-Rodríguez G. Effects of training on bone mass in older adults: a systematic review. Sports Med. 2012 Apr 1;42(4):301-25. doi: 10.2165/11597670-000000000-00000. PMID: 22376192.

51. Alfredson H, Nordström P, Lorentzon R. Bone mass in female volleyball players: a comparison of total and regional bone mass in female volleyball players and nonactive females. Calcif Tissue Int. 1997 Apr;60(4):338-42. doi: 10.1007/s002239900239. PMID: 9075629.

52. Kontulainen S, Sievänen H, Kannus P, Pasanen M, Vuori I. Effect of long-term impact-loading on mass, size, and estimated strength of humerus and radius of female racquet-sports players: a peripheral quantitative computed tomography study between young and old starters and controls. J Bone Miner Res. 2003 Feb;18(2):352-9. doi: 10.1359/jbmr.2003.18.2.352. PMID: 12568413.

53. Snow CM, Williams DP, LaRiviere J, Fuchs RK, Robinson TL. Bone gains and losses follow seasonal training and detraining in gymnasts. Calcif Tissue Int. 2001 Jul;69(1):7-12. doi: 10.1007/s00223-001-0014-5. Epub 2001 Jun 5. PMID: 11685427.

54. Bobbert MF, Huijing PA, van Ingen Schenau GJ. Drop jumping. I. The influence of jumping technique on the biomechanics of jumping. Med Sci Sports Exerc. 1987 Aug;19(4):332-8. PMID: 3657481.

55. Bobbert MF, Mackay M, Schinkelshoek D, Huijing PA, van Ingen Schenau GJ. Biomechanical analysis of drop and countermovement jumps. Eur J Appl Physiol Occup Physiol. 1986;54(6):566-73. doi: 10.1007/BF00943342. PMID: 3948851.

56. Lees A. Methods of impact absorption when landing from a jump. Engineering in Medicine. 1981; 10(4): 207-211. doi: 10.1243/emed_jour_1981_010_055_02

57. Lees A, Vanrenterghem J, De Clercq D. Understanding how an arm swing enhances performance in the vertical jump. J Biomech. 2004 Dec;37(12):1929-40. doi: 10.1016/j.jbiomech.2004.02.021. PMID: 15519601.

58. Kritz MMC, Cronin JPHD, Hume PP. The Bodyweight Squat: A Movement Screen for the Squat Pattern. Strength and Conditioning Journal. 2009; 31(1): 76-85.

59. Mothersole G, Cronin JB, Harris NK. Jump-landing program for females: Development of a systematic progression model. Strength and Conditioning Journal. 2014; 36(4): 52-64. doi: 10.1519/SSC.0000000000000078

60. Stone MH, Pierce KC, Sands WA, Stone ME. Weightlifting: Program Design. Strength & Conditioning Journal. 2006; 28(2): 10-17.

61. Davies G, Riemann BL, Manske R. CURRENT CONCEPTS OF PLYOMETRIC EXERCISE. Int J Sports Phys Ther. 2015 Nov;10(6):760-86. PMID: 26618058; PMCID: PMC4637913.

62. Mansfield EM. Designing exercise programs to lower fracture risk in mature women. Strength and Conditioning Journal. 2006; 28(1): 24-29.

63. Ashley CD, Weiss LW. Vertical jump performance and selected physiological characteristics of women. Journal of Strength & Conditioning Research. 1994; 8(1): 5-11.

64. Wang L, Xu X, Zhang Y, Hao H, Chen L, Su T, Zhang Y, Ma W, Xie Y, Wang T, Yang F, He L, Wang W, Fu X, Ma Y. A model of health education and management for osteoporosis prevention. Exp Ther Med. 2016 Dec;12(6):3797-3805. doi: 10.3892/etm.2016.3822. Epub 2016 Oct 19. PMID: 28105113; PMCID: PMC5228464.

Citation: Clissold T, Cronin JB, De Souza MJ, Winwood PW (2022) Program design considerations for bone health in premenopausal women. Arch Sports Med Physiother 7(1): 007-015. DOI: http://dx.doi.org/10.17352/asmp.000015

65. Young WB, Pryor JF, Wilson GJ. Effect of instructions on characteristics of countermovement and drop jump performance. The Journal of Strength & Conditioning Research. 1995; 9(4): 232-236.

66. Bompa TO, Haff GG. Periodization: Theory and methodology of training: Human Kinetics Publishers. 2009.

67. Fleck SJ, Kraemer W. Designing Resistance Training Programs, 4E: Human Kinetics. 2014.

68. Haff GG, Triplett NT. Essentials of Strength Training and Conditioning 4th Edition: Human kinetics. 2015.

69. Weaver CM, Gordon CM, Janz KF, Kalkwarf HJ, Lappe JM, Lewis R, O'Karma M, Wallace TC, Zemel BS. Erratum to: The National Osteoporosis Foundation's position statement on peak bone mass development and lifestyle factors: a systematic review and implementation recommendations. Osteoporos Int. 2016 Apr;27(4):1387. doi: 10.1007/s00198-016-3551-5. Erratum for: Osteoporos Int. 2016 Apr;27(4):1281-386. PMID: 26935424; PMCID: PMC4969869.

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