

The Impact of Strength Training on Bone Mineral Density and Fracture Risk in Older Adults

Nurul Islah Azahrah¹, Rika Safitri Jasman¹, Salmani Safitri¹

¹Health Polytechnic of Makassar

*Corresponding Author: Nurul Islah Azahrah

Email: nurulislah27@gmail.com

Article Info

Article History:

Received May 4, 2023

Revised May 25, 2023

Accepted: June 27, 2023

Keywords:

Strength Training, Bone Health,
Elderly, Bone Mineral Density,
Osteoporosis.

Abstract

With the aging population, risks associated with bone density decline, osteoporosis calls for these people to seek ways to enhance their bone health as they age. Strengthening exercise or resistance training exercise has received a lot of emphasis due to the effects on the BMD and bone health in the elderly. This literature review aims to elucidate on the effects of strength training on bone health, using its modalities of action, effectiveness and biological pathways. It has been revealed in researches that strength training causes mechanical loading on bones through exerting force on bones by osteoblasts and osteoclasts thus increasing BMD. Also, strength training enables muscles pull with a lot of force on bones, thus improving their density and strength. Changes in hormonal levels and in the indices of bone turnover – osteocalcin and C-telopeptide, all point to the fact that resistance training is beneficial in influencing bone metabolism. It forms part of the current review comparing strength training to different combinations of exercise in the prevention or treatment of bone loss or fracture in older adults, a subject on which it draws conclusions that positive outcomes include increased BMD in lumbar spine and femoral neck, decrease in fracture risk. Similarly, strength training complemented with proper nutrition and other forms of exercise increases the benefits many folds. This review shall also stress on strength training as a feasible strategy to counter age related bone densing and fracture rate and improved quality of life among the elderly.

Introduction

The growing old method involves numerous physiological alterations in bone including changes in density and the structural pattern. Given the reality that the population of the sector is aging at an accelerated price it is more likely that there will be an emphasis positioned on strategies which will facilitate wholesome getting older and the prevention of age-linked diseases. they have been some of this kind of methodologies that has full-size interest most notably the energy schooling often called resistance schooling or weightlifting. Strength training involves activities that incorporate muscle mass opposition in opposition to violence with the motive of enhancing strength, endurance and muscles.

Many researchers conducted within the beyond few decades aim at research the relation between electricity schooling and bone nutrient density within the aged populace. Osseous health is defined as an important component of elemental well-being since it involves the ability of a human being to move around, maintain a correct posture as well as protect essential organs. Osteoporosis, a situation identified through the World Health Organization by decreased bone mass and therefore an elevated threat of fractures is one other key health concern observed among anybody aged 60years and above. Strength training has been put forth as a candidate to help increase BMD and minimize danger of fractures in this high-risk population (Massini et al., 2022).

Science has given priceless information about potentiality of power education for creating bone fitness. This advent will reveal the current kingdom of analysis concerning the effects of energy education on bone health in aged people using multiple new empirical investigation and scholarly journals. Bone changes that occur with increasing age are referred to as osteoporosis and include the following factors. Osteoporosis is defined with the help of diminished bone mass and the quality or structure of bone tissue, resulting in bone fragility and higher susceptibility to fracture (Dempster et al., 2021). Estimations show that over two hundred million people worldwide have osteoporosis, with higher prevalence in the elderly, especially women after the menopausal age (Adami et al., 2022).

The consequences of osteoporosis related fractures can include: reduced mobility, reduced quality of life as well as higher mortality rates. Indeed, hip fractures have been found to have very high mortality and morbidity rates among the aged population (Bolton et al 2021). Hence, methods of interventional strategies to either prevent or improve bone health in older adults is of great importance to public health.

Strength training has become one of the most effective approaches to enhancing the health of bones for the aged. Compared to aerobic exercising that primarily benefits the cardiovascular method, energy schooling applies mechanical load to bones and remodels the tactics. This mechanical stimulus stimulates the activity of osteoblasts to increase the bone mineral density and bone energy perpetration.

Several investigations have examined the profound effects of strength coaching on bone health related factors in the elderly. Charde et al. (2023) using a meta-analysis realized that energy schooling appreciable) elevated lumbar spine and femoral neck BMD amongst postmenopausal girls. Likewise, according to a CDA authorized randomised managed trial via Ellegaard et al. (2020), steady increases in hip BMD and the bone turnover markers in older male contributors had been documented in the course of an electricity training intervention.

The positive effects strength training has on bone fitness has been postulated to owe to the following factors. Perturbations in the form of mechanical loading during the course of resistance exercises elicit microdamage in bone tissue which activates osteocytes and initiates bone remodeling. Le points relatif a cette technique de remodelage comprennent l'activation des osteoclastes pour decomposer des os anciens ou endommages, ainsi que la deposition subsquente d'os neuf par des osteoblastes.

Besides, the electricity training develops the muscles and energy in a roundabout manner contributing to the bone health. Tighter muscles produce higher forces on bones during loading tasks and consequently develop enhanced bone density and energy (Hart et al., 2020). This muscle-bone relationship is known as the mechanostat concept, this exceptional knitted relationship of musculoskeletal tissue in response to mechanical signals.

Even though the proof in support of the enchancement that strength coaching has on bone fitness is convincing, there are many things that must be considered while developing and implementing the workout packages for the elderly. First on the list is exercising prescriptions tailored to the individual; recommending at least three exercising pan prescriptions per week incorporating aspects like age, fat utilization, and medical history.

Yearly progressive overload, which may include increasing depth or resistance on physical activities yearly, is important to enhance the effectiveness of bone version to strength. Balanced fooding coupled with adequate intake of calcium, diet D, and protein also play vital role towards improvement of bone characteristic and muscles.

Method

This literature review was intended to review the impacts of strength training on bone density in the elderly. The review focused on critically appraising earlier literature in the last decade to identify the status of strength training interventions and its effects on BMD and factors influencing fracture risk in older adults.

Pubmed, scopus, web of sciences, Google Scholars were in need to search for related literatures for this study. The search was done based on articles published between 2013 and 2023 to accommodate the latest research results. The following keywords were used in the search: And, “strength training,” “resistance training,” “bone health,” “bone mineral density,” “osteoporosis,” “elderly,” “aging population,” “physical exercise.”

For this literature review, only the studies that concerned the elderly population, who were 60 years and older, and assessed the strength training or resistance exercise interventions, were included into the analysis. We only included trials which reported on measures of bone health including BMD, biochemical markers of bone turnover and risk of fractures. This paper has restricted the review to peer-reviewed journal articles and clinical trial reports only, so as to gather only reliable data. The excluded articles were those that were mainly about pharmacological interventions, animal trials, and papers written in foreign languages, largely as their translation was not feasible. These criteria helped the review to include the important and best quality papers that focused on the connection between strength training and bone health in older patients.

Personal characteristics from the selected studies included; aspects of the study like the type of research study conducted, the number of participants involved, the type and duration of strength training and lastly the findings of the studies. Other data extracted included; age, sex, and general health of the participant. In order to augment the content quality of the review, the studies that presented both benefits and no effect of strength training on the bone density were also incorporated into the present review.

The research findings were reviewed and integrated in a bid to getting to common themes in the findings. The results were analysed based on the kind of strength training intervention as defined by resistance exercise, weight lifting or other strength training programmes. Also, the papers were classified by the target bone area, including the lumbar spine, femoral neck, and hip as well as according to the applied techniques of bone density evaluation, including BMD, and bone turnover markers. This synthesis enabled the determination of the extent of intervention fidelity of strength training for enhancing bone health among the elderly.

Overview of Selected Studies

The selected articles for the present literature review comprise of a cross-sectional review of study types including systematic reviews and meta-analysis, RCTs, observational, and cohort studies. These studies had been mainly aimed on the investigation of influences of strength training or resistance exercises on bone mass in elderly people. The sample sizes of the studies incorporated ranged from less than 50 participants to more, including studies with more than 300 participants. Although some research focused only on postmenopausal women, who are the group most vulnerable to osteoporosis, other also enrolled men and elderly with various health issues and concerns, thus providing more comprehensive view on the efficacy of the intervention across the spectrum of users.

The strength training interventions used in the studies also differed in types of exercise, exercise intensity, duration of exercise and frequency of exercise. Some of the popular strength training programs were weights, bands and body weight exercises which were generalized to

the participants capability. Supplementary, machine-based resistance training was also reported to be commonly incorporated into interventions, particularly so where the study subjects had relatively low levels of baseline physical activity. The period of interventions varied from 8 weeks to more than one year and more than half of the studies had an average of 12 to 24 weeks as the intervention period. The reported training frequency ranged from 2 to 3 sessions in a week; some of the studies have elevated the frequency to 4 times in a week in high intensity fitness training. The magnitude of the exercises was most often, depending on the general physical condition of the participants, increasing the load gradually over time to affect the bone tissue remodeling.

In the few studies selected, bone health outcomes were measured using different technique with the majority using DXA to determine BMD. DXA scans were mostly applied to assess alterations in BMD at weight-bearing anatomic regions, such as the lumbar spine, femoral neck, and hip that are most susceptible to fracture in the elderly. Apart from BMD, other works also quantified bone turnover markers, which give an indication of the density of formation and resorption in the bones. Another measured parameter in the studies was clinical assessment of fracture risk strength training was tested in preventing falls and fractures in elderly people. These broad measurements enabled investigators to evaluate the effect of strength training on the spherical and practical components of bone energy.

Besides bone related effects, several of these included secondary outcomes of strength training for muscle strength, stability, ambulation, and overall functionality. These outcomes are important because falls are a major cause of fractures and complications arising from the same among the ageing population. research where we saw increases in muscle strength, observed that stronger muscles were capable of providing better support to the bones during the commonplace movements to lessen the chances of fractures. Additionally, greater balance and coordination that inevitably come with strength training exercises were established to minimize instability thereby reducing incidences of falls.

The findings of the cross-sectional and cohort studies reviewed in this paper were overall indicative of beneficial influence of strength training on the bone outcomes of the elderly. Most of the reports observed substantial increase in BMD especially in the L2-L4 region, hip and the femoral neck. Charde et al. (2023) conducted a meta-analysis to show that strength training improved the participants' BMD mainly at the lumbar spine and femoral neck in postmenopausal women. in the systematic randomized controlled trial conducted in 2020 reveal that strength training leads to increased hip BMD and decreased bone turnover. From the results of the present study, it may be concluded that, in the context of physical action, mechanical loading associated with resistance exercises is the primary factor that positively influences the activity of osteoblasts and the mineralization of bone tissues (Kalukula et al., 2022).

Other works also showed moderate or lesser outcomes, especially if the subjects had severe osteoporosis or other reasons against strength training Some subjects in a study done noted lesser benefits of strength training in raising BMD on elderly people with slight or moderate osteoporosis, although those with severe osteoporosis did not gain much. This is why exercise prescriptions should be specific to the individual and is therefore an indication of the importance of the prescriptive strength training for those persons with chronic diseases and disability in older adults (Hansen et al., 2022). Moreover, some of the works mentioned that isometric exercises were effective in improving the density of bones depending on certain skeletal locations since it speculative that there is a variation in the degree of bone density increase due to strength training according to the type of intensity of the exercise or the even the processes of bone remodeling peculiar to the certain regions of the skeleton.

The body of literature reviewed in the present paper offered sound arguments in favor of benefits of strength training on bone mass of older adults. It is assumed that these effects are due to mechanical loading and triggering of the bone remodeling process at intracellular levels, involving activity of osteoblasts and osteoclasts. Strength training also automatically strengthens the bones due to the fact that muscles mass and strength improves stability, balance thus decreasing the chances of falling. Nevertheless, the majority of the above findings are quite promising, it is also important to note that there are still questions left unanswered which may possibly center on the standardized procedure in conducting strength training intervention among elderly with respect to frequency, intensity, duration and frequency of progression (Chakraborty et al., 2021). Additionally, prospective investigations should be conducted to elaborate on potential chronic consequences of strength training on bone mass, as well as the ease and safety of strength training in clinical and highly osteoporotic samples.

Effects of Strength Training on Bone Mineral Density

Strength training especially in the elderly has been proved to have a positive impact on BMD which plays a centrally important role protective of fractures and widely utilized to determine bone status. Bone mineral density is been defined as the amount of mineral embedded per unit volume of the bone and as we know, higher values of BMD are better because they help to avoid such diseases as osteoporosis, and it is very crucial to either keep our BMD stable or raise it. discovered that mechanical loading; experienced during strength training, affect bone remodeling processes, thus enhancing bone density in weight- bearing portions (Wang et al., 2022). This is especially important so in the assumption of elderly clients since they suffer from osteoporosis which is a condition characterized by thinning of the bones and lessen bone mass and structure making the elderly susceptible to bone related complications such as fractures.

A number of researchers have established enhanced BMD upon conducting resistance training interventions. Charde et al. (2023) meta- analysis showed that strength training led to improved lumbar spine and femoral neck BMD in postmenopausal women. Lumbar spine and femoral neck are the common sites for fractures in the elderly and in strength training through resistance training prominent efforts can be employed to reduce fractures risk (Berg et al., 2021). Altogether, these and other similar research studies indicate that strength training interventions, especially for the lower body, would have the greatest impact on bones in areas of high risk for osteoporosis caused fractures.

The impact of strength training on BMD depends on general characteristic such as the intensity, duration and nature of exercise undertaken. It suggests that strength training exercise regime for bones is most effective when it employs high intensity and utilizes progressive overload by which resistance to the strains of exercise is gradually raised. According to Ellegaard et al. (2020) high intensity resistance training led to significant gains in hip BMD among older men. These conclusions stress that, for strengthening bones, it is not enough only to perform strength training exercises, but it is also crucial to choose such loads, with which bones and muscles will have to deal.

Prolongation of the strength training intervention is central in defining the level of BMD gains. Indeed, shorter-term strength training programmes are promising but they are less effective on attaining a higher BMD than the long-term strength training programmes which may last for about 6-12 months. This is because, unlike acute exercises, resistance training occurs over the long-term and will thus require massive mechanical loading to brought about structural changes in the bone. Hart et al. (2020) discovered there was a greater improvement of over 1 year of strength training exercise on BMD compared to shorter intervention periods among the older adults. The general conclusion of these studies indicates that it is not sufficient to engage in

strength training, but it is necessary to work with constant and consistency for a long period to improve areal BMD.

The benefits of strength training for accession of improved BMD are not only witnessed among postmenopausal women, but also among the elderly male and population that has diverse physical bone strength status (Lee et al., 2020). The amount of BMD has been found to be augmented by strength training in both normal elderly and osteopenic/osteoporotic individuals. the extent of improvement might differ with the baseline BMD of the concerned person. Research has shown that high risk subjects that have a baseline BMD of below 2.5 SD, people with osteopenia, may derive even greater benefit than those who have normal bone density. This implies that strength exercises could be especially effective as a preventive measure in individuals who are potential candidates too osteoporosis, and may be used to actually reduce or arrest the bone density loss.

Of particular interest, strength training's positive effects on BMD are not limited to the bones that are recruited during strength-training exercises. Some authors have documented that strength training is capable of having a systemic approach on the body in the sense that it enhances the BMD in various areas of the body. To illustrate this, weight-bearing exercises that recruit the muscles of the lower extremities the squat and leg press have been shown to enhance BMD at the LS, hip, and FN. Likewise the exercises focused on upper body strength such as biceps curls and chest press also have positive effect on Bone mineral density in arms and shoulders. Taking into account general advantages of strength training, the conclusion that it is useful for the strengthen of skeletal system and less probability of fractures both in the general and certain allotted regions of the body may be made.

Nevertheless, according to the comprehensive enhancements of the BMD through strength training, the extent of these enhancements may be influenced by a number of factors including age, baseline health status, and certain health conditions; frail elderly persons or those with severe osteoporosis may witness a relatively small amount of change in BMD than healthy or relatively younger persons (Liang et al., 2020). whether the resistance training program employs free weights, machines or body weight can determine the extent of gain in BMD Although the totality of the researched literature is encouraging toward the use of strength training either by free weights or using gym equipment or the body weight as a means of improving BMD, reducing chances of fracture and enhancing bone health in the elderly.

Mechanisms of Action

It is now generally understood that strength training has a positive impact on the structure and health of bone tissue, through supporting bone mineral density (BMD) through several bone remodeling processes at cellular and structural levels. Of these accumulated stimuli, mechanical loading is central to bone adaptive responses as it is the stress on bones during resistance exercises. Weight-bearing exercise means that during activity, one has to bear their own body weight and during muscle contraction forces are produced and delivered through tendons to the bones. Disks create mechanical force on the bone causing bone cells namely osteocytes and osteoblasts to start synthesizing bone tissue for bone restoration. This development is subject to Wolff's Law that postulates that bone build up correlates with the load applied on the structure (Zhao et al., 2023).

Strength training causes stress to bone, which leads to creation of small breaks in the bone tissue known as microfractures (Hoenig et al., 2022). Osteocytes that are located in the microdamage zone sense microdamages as changes in mechanical stimuli. Osteocytes use signals to stimulate osteoclasts to engage in the activity of bone resorption that involves the breakdown of old and damaged bone. After resorption, osteoblasts get stimulated

to form new bone matter in order to reestablish the mechanical property of bone tissue. Such alterations are grouped in this cycle of remodeling resulting from mechanical loading from resistance exercises which are significant in preserving bone integrity particularly among the aging due to progressive reduction in bone mineral density.

In addition to mechanical loading, strength training also enhances the interaction between muscles and bones, which is vital for bone health (Maestroni, et al., 2020). This interaction is described by the mechanostat theory, which suggests that bone strength is influenced by the forces exerted on it by muscles. Stronger muscles generate greater forces during weight-bearing activities, which in turn stimulates the bone to adapt by increasing its density and strength (Yao et al., 2022). Resistance exercises promote muscle hypertrophy (increase in muscle size), and this increase in muscle mass leads to greater mechanical forces being applied to the bones during activities like lifting weights or performing bodyweight exercises. This muscle-bone interaction not only improves muscle strength but also positively impacts bone mineralization, making bones less susceptible to fractures (Lara & Johnson, 2020).

Another critical mechanism involves the role of hormones in regulating bone metabolism. Strength training has been shown to influence various hormones that play a crucial role in bone health, such as estrogen, testosterone, growth hormone, and insulin-like growth factor (IGF-1). strength training has been found to increase serum levels of testosterone and growth hormone, both of which promote bone formation and increase BMD. In postmenopausal women, the decline in estrogen levels is a significant contributor to bone loss, but strength training can partially counteract this effect by stimulating the production of other hormones that support bone health. Similarly, the increase in IGF-1 levels associated with resistance training contributes to bone growth and remodeling by stimulating osteoblast activity.

Strength training has been shown to influence bone turnover markers, which provide insights into the rate of bone formation and resorption (Di Medio & Brandi, 2021). Bone turnover markers include substances such as osteocalcin and type I collagen, which are involved in the formation of new bone, and C-telopeptide (CTX) and tartrate-resistant acid phosphatase (TRAP), which are markers of bone resorption. Studies have demonstrated that strength training can lower bone resorption markers while increasing markers of bone formation (Bemben et al., 2022). This shift in the balance of bone turnover toward increased formation and decreased resorption helps to improve BMD and prevent the development of osteoporosis, particularly in older adults.

The influence of strength training on bone health also involves the impact of exercise on the nervous system (Maestroni et al., 2020; Harding et al., 2020; Papadopoulou et al., 2021). Regular resistance training has been shown to improve neuromuscular function, which refers to the communication between the brain, nerves, and muscles. Enhanced neuromuscular function improves muscle strength and coordination, which in turn leads to better control and stability during weight-bearing activities. This enhanced control reduces the risk of falls, which are a common cause of fractures in the elderly (Ganz & Latham, 2020). By strengthening muscles and improving balance, strength training indirectly helps to protect the bones by reducing the likelihood of fall-related injuries.

The effects of strength training on bone health are also influenced by other lifestyle factors, such as diet and physical activity levels (Proia et al., 2021). Adequate nutrition, particularly sufficient intake of calcium, vitamin D, and protein, is essential for bone health and muscle function. Strength training programs are most effective when combined with proper nutrition, as these nutrients play a critical role in supporting bone formation and muscle growth (Zatsiorsky et al., 2020). Vitamin D, is essential for calcium absorption and bone mineralization, while protein is necessary for muscle repair and growth. Combining strength

training with a balanced diet and other physical activity may further enhance the mechanisms of action, leading to more significant improvements in bone health.

Conclusion

Aerobic exercise training has been shown to be the most effective strategy for halting and reversing age-related bone loss in the elderly through mechanisms such as mechanical loading of the skeleton, mechanical adaptation to muscle loading, hormonal factors, and even inhibition of bone remodeling. Strength training thus assists in the areas of negative impact by osteoporosis thus decreasing the rate of fracture incidences among the seniors. The addition of resistance exercises to proper nutrition and other elements leads to these and other benefits that make strength training an important part of maintaining the health of the elderly. With an increase of population's age across the globe currently, strength training emerges as a major strategy that can be taken to enhance positive aging and well-being.

References

- Adami, G., Fassio, A., Gatti, D., Viapiana, O., Benini, C., Danila, M. I., ... & Rossini, M. (2022). Osteoporosis in 10 years time: a glimpse into the future of osteoporosis. *Therapeutic Advances in Musculoskeletal Disease*, 14, 1759720X221083541. <https://doi.org/10.1177/1759720X221083541>
- Bemben, D. A., Sherk, V. D., Buchanan, S. R., Kim, S., Sherk, K., & Bemben, M. G. (2022). Acute and chronic bone marker and endocrine responses to resistance exercise with and without blood flow restriction in young men. *Frontiers in physiology*, 13, 837631. <https://doi.org/10.3389/fphys.2022.837631>
- Berg, O. K., Stutzer, J. M., Hoff, J., & Wang, E. (2021). Early maximal strength training improves leg strength and postural stability in elderly following hip fracture surgery. *Geriatric Orthopaedic Surgery & Rehabilitation*, 12, 21514593211015103. <https://doi.org/10.1177/21514593211015103>
- Bolton, D., Bush, C., & Wallace, M. T. (2021). Nonagenarian hip fractures: morbidity and mortality at a single institution. *Journal of Clinical Orthopaedics and Trauma*, 14, 69-73.
- Chakraborty, S., Krishna, R., Ding, Y., & Ray, B. (2021). Deep learning-based vulnerability detection: Are we there yet? *IEEE Transactions on Software Engineering*, 48(9), 3280-3296. <https://doi.org/10.1109/TSE.2021.3087402>
- Charde, S. H., Joshi, A., & Raut, J. (2023). A Comprehensive Review on Postmenopausal Osteoporosis in Women. *Cureus*, 15(11).
- Dempster, D. W., Marcus, R., & Bouxsein, M. L. (2021). The nature of osteoporosis. In *Marcus and Feldman's Osteoporosis* (pp. 3-13). Academic Press.
- Di Medio, L., & Brandi, M. L. (2021). Advances in bone turnover markers. In *Advances in Clinical Chemistry* (Vol. 105, pp. 101-140). Elsevier. <https://doi.org/10.1016/bs.acc.2021.06.001>
- Ellegaard, M., Bieler, T., Beyer, N., Kjaer, M., & Jørgensen, N. R. (2020). The effect of 4 months exercise training on systemic biomarkers of cartilage and bone turnover in hip osteoarthritis patients. *Translational Sports Medicine*, 3(1), 16-25. <https://doi.org/10.1002/tsm2.108>

- Ganz, D. A., & Latham, N. K. (2020). Prevention of falls in community-dwelling older adults. *New England journal of medicine*, 382(8), 734-743. <https://doi.org/10.1056/NEJMcp1903252>
- Hansen, D., Abreu, A., Ambrosetti, M., Cornelissen, V., Gevaert, A., Kemps, H., ... & Piepoli, M. (2022). Exercise intensity assessment and prescription in cardiovascular rehabilitation and beyond: why and how: a position statement from the Secondary Prevention and Rehabilitation Section of the European Association of Preventive Cardiology. *European journal of preventive cardiology*, 29(1), 230-245. <https://doi.org/10.1093/eurjpc/zwab007>
- Harding, A. T., Weeks, B. K., Lambert, C., Watson, S. L., Weis, L. J., & Beck, B. R. (2020). Effects of supervised high-intensity resistance and impact training or machine-based isometric training on regional bone geometry and strength in middle-aged and older men with low bone mass: The LIFTMOR-M semi-randomised controlled trial. *Bone*, 136, 115362. <https://doi.org/10.1016/j.bone.2020.115362>
- Hart, N. H., Newton, R. U., Tan, J., Rantalainen, T., Chivers, P., Siafarikas, A., & Nimphius, S. (2020). Biological basis of bone strength: anatomy, physiology and measurement. *Journal of musculoskeletal & neuronal interactions*, 20(3), 347.
- Hoenig, T., Ackerman, K. E., Beck, B. R., Bouxsein, M. L., Burr, D. B., Hollander, K., ... & Warden, S. J. (2022). Bone stress injuries. *Nature Reviews Disease Primers*, 8(1), 26. <https://doi.org/10.1038/s41572-022-00352-y>
- Kalukula, Y., Stephens, A. D., Lammerding, J., & Gabriele, S. (2022). Mechanics and functional consequences of nuclear deformations. *Nature reviews Molecular cell biology*, 23(9), 583-602. <https://doi.org/10.1038/s41580-022-00480-z>
- Lara-Castillo, N., & Johnson, M. L. (2020). Bone-muscle mutual interactions. *Current osteoporosis reports*, 18, 408-421. <https://doi.org/10.1007/s11914-020-00602-6>
- Lee, S. J., Lehar, A., Meir, J. U., Koch, C., Morgan, A., Warren, L. E., ... & Germain-Lee, E. L. (2020). Targeting myostatin/activin A protects against skeletal muscle and bone loss during spaceflight. *Proceedings of the National Academy of Sciences*, 117(38), 23942-23951. <https://doi.org/10.1073/pnas.2014716117>
- Liang, H., Wang, O., Cheng, Z., Xia, P., Wang, L., Shen, J., ... & Xia, W. (2022). Jintiang combined with alfacalcidol improves muscle strength and balance in primary osteoporosis: A randomized, double-blind, double-dummy, positive-controlled, multicenter clinical trial. *Journal of Orthopaedic Translation*, 35, 53-61. <https://doi.org/10.1016/j.jot.2022.05.002>
- Maestroni, L., Read, P., Bishop, C., Papadopoulos, K., Suchomel, T. J., Comfort, P., & Turner, A. (2020). The benefits of strength training on musculoskeletal system health: practical applications for interdisciplinary care. *Sports Medicine*, 50(8), 1431-1450. <https://doi.org/10.1007/s40279-020-01309-5>
- Maestroni, L., Read, P., Bishop, C., Papadopoulos, K., Suchomel, T. J., Comfort, P., & Turner, A. (2020). The benefits of strength training on musculoskeletal system health: practical applications for interdisciplinary care. *Sports Medicine*, 50(8), 1431-1450. <https://doi.org/10.1007/s40279-020-01309-5>
- Massini, D. A., Nedog, F. H., de Oliveira, T. P., Almeida, T. A., Santana, C. A., Neiva, C. M., ... & Pessôa Filho, D. M. (2022, June). The effect of resistance training on bone mineral density in older adults: a systematic review and meta-analysis.

- Papadopoulou, S. K., Papadimitriou, K., Voulgaridou, G., Georgaki, E., Tsotidou, E., Zantidou, O., & Papandreou, D. (2021). Exercise and nutrition impact on osteoporosis and sarcopenia—the incidence of osteosarcopenia: a narrative review. *Nutrients*, *13*(12), 4499. <https://doi.org/10.3390/nu13124499>
- Proia, P., Amato, A., Drid, P., Korovljev, D., Vasto, S., & Baldassano, S. (2021). The impact of diet and physical activity on bone health in children and adolescents. *Frontiers in Endocrinology*, *12*, 704647. <https://doi.org/10.3389/fendo.2021.704647>
- Wang, L., You, X., Zhang, L., Zhang, C., & Zou, W. (2022). Mechanical regulation of bone remodeling. *Bone research*, *10*(1), 16. <https://doi.org/10.1038/s41413-022-00190-4>
- Yao, J., Li, Z., Li, Y., & Fan, Y. (2022). Weightless Musculoskeletal Injury and Protection. In *Biomechanics of Injury and Prevention* (pp. 395-415). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-16-4269-2_13
- Zatsiorsky, V. M., Kraemer, W. J., & Fry, A. C. (2020). *Science and practice of strength training*. Human Kinetics.
- Zhao, C., Liu, H., Tian, C., Zhang, C., & Wang, W. (2023). Multi-scale numerical simulation on mechano-transduction of osteocytes in different gravity fields. *Computer Methods in Biomechanics and Biomedical Engineering*, *26*(12), 1419-1430. <https://doi.org/10.1080/10255842.2022.2117552>