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TRX Training Impact on Femur Neck Bone Density and Serum Leptin in Osteopenic Women: A Four-Month Study

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ABSTRACT

Introduction: Osteoporosis, characterized by diminished bone mass and increased fracture susceptibility, prompts the investigation into the impact of a four-month TRX training regimen on femur neck bone mineral density (BMD) and its correlation with serum leptin levels in women with osteopenia.

Material & Methods: In this quasi-experimental study, 30 women with osteopenia were purposefully selected and randomly assigned to TRX training (n = 15) or control (n = 15) groups. The intervention group underwent TRX exercises thrice weekly for 45-60 minutes per session for four months. Blood samples collected at baseline and post-intervention measured serum leptin levels via ELISA kit (Bio vendor, Czech Republic), while Dexa Lexxos Digital (2D model, USA) determined femur neck BMD. SPSS 20 software, dependent/independent samples t-tests, and Pearson correlation were used for data analysis.

Results: TRX training significantly increased femur neck BMD, reducing serum adiponectin levels versus the control group (P = 0.001 and P = 0.01, respectively). Compared to baseline, TRX training raised femur neck BMD and lowered serum leptin levels (P = 0.000 and P = 0.01, respectively). A significant inverse correlation emerged between femoral neck BMD and serum leptin levels in women with osteopenia (P = 0.00).

Conclusion: Findings suggest that TRX resistance training holds promise for enhancing the rehabilitation of women with osteopenia.

Keywords: Osteopenia, TRX Exercise, Femur Neck Bone Mineral Density, Leptin

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Introduction

Bone is a dynamic metabolic tissue constantly undergoing resorption and formation. An imbalance in these processes can lead to osteoporosis, elevating the risk of bone fractures (1). In Iran, approximately 70% of women and 50% of men aged 50 and above suffer from osteopenia or osteoporosis (2). Femoral neck fractures, known for their complexity, pose significant challenges in treatment and follow-up compared to other osteoporotic defects. The prevalence of these fractures is anticipated to rise from 1.7 million in 1990 to over 6.3 million in 2050, with one in five individuals experiencing femoral neck fractures succumbing within the first year (3). The incidence of hip fractures due to osteoporosis is projected to double over 50 years, assuming constant sex-related risk factors (3).

While therapeutic and pharmacological interventions exist for osteoporosis, their long-term use is limited due to side effects. Non-pharmacological strategies, such as physical activity, have shown promise in inducing bone regeneration, enhancing muscular strength, improving balance, and enhancing overall quality of life (1). However, the osteogenic response to mechanical stress diminishes with age (4), necessitating a closer examination of these processes in the elderly.

Research by Bamben et al. explored the effects of resistance training protocols with varying intensities on the bone mineral density (BMD) of the femoral neck and L4-5 vertebrae in elderly individuals, revealing intensity and frequency-dependent impacts (5). Despite extensive research, a consensus on the optimal exercise intervention for treating osteoporosis remains elusive. Khan et al. (2019) suggested that osteoanabolic exercises demonstrated more pronounced osteogenic effects compared to aerobic and resistance training (6). Additionally, Ahmadi-Kakavandi et al. (2019) highlighted the variability in exercise effects on different bones, with a six-month air-pump training improving L4-5 bone density but having no impact on femur and forearm BMD (7).

While resistance training has shown potential to stimulate the osteogenic response, variations in exercise protocols have led to conflicting results. Kemler et al. (2004) reported that resistance training targeting proximal femoral and trunk muscles preserved BMD in postmenopausal women with osteopenia (8). Laura et al. (2014) found that resistance training focused on areas of the body tolerating total body weight could promote osteogenic effects (9). Another study on elderly individuals comparing resistance training with different intensities demonstrated improvements in vertebrae and proximal femur BMD based on the program's intensity and frequency (10).

The femur neck and lumbar vertebrae, with their susceptible histological structure, are highly prone to osteoporosis. Review studies indicate that exercise protocols imposing mechanical loads on these bones can induce osteogenic effects. The site-specific nature of these effects suggests that exercise positively influences bones with mechanical loads (11).

This study investigates the osteogenic effects of TRX training, a novel resistance exercise, in women with osteopenia. TRX has gained popularity due to its adaptability for various resistance exercises in limited spaces. The resistance intensity in TRX, adjustable through rope length, repetitions, and rest intervals, can impact osteogenic adaptation. The study focuses on distal trunk and proximal femur training, crucial areas affected by osteoporosis and fractures. Few studies have explored the osteogenic effects of TRX, highlighting the need for further research in this domain.

Bone mineral density (BMD), a quantitative bone mass index, is just one facet of bone health. Resistance against fractures depends on complex interactions among bone features, where factors affecting bone metabolism independently impact BMD. Adipose tissue, an endocrine organ, secretes hormones like leptin, influencing bone metabolism and health. Leptin, linked to body fat storage, plays a role in metabolic regulation. Studies show that bone metabolism is influenced by the body mass index, mediated by adipose tissue-derived molecules like leptin and adiponectin. Adipose tissue affects bone structure, density, and regeneration through various signaling pathways, with variable reported effects (12).

Leptin serum levels correlate positively with weight gain, decreasing with reduced body fat after exercise. Studies present conflicting results on resistance training's impact on serum leptin levels. While Munich et al. and Live et al. found no effect on men's serum leptin levels (15, 16), Piri et al. reported a decrease after resistance exercise (17). BMD, widely used for assessing exercise impacts on bone health, is a non-invasive indicator. However, to comprehend bone adaptation responses to exercise fully, investigating other components related to bone strength alongside BMD is advisable.

This study employs exercise protocols on the distal trunk and proximal femur through TRX training to evaluate site-specific effects on bone, focusing on the effects of four months of TRX training on femur neck BMD and its association with serum leptin levels in osteopenic women.

Materials and methods

The present study employed a quasi-experimental research design with a pre-test/post-test structure. The statistical population included osteopenic women aged 35 to 44 years, attending our clinic in Zahedan, Sistan and Baluchestan province, Iran. The sample consisted of 30 osteopenic women selected through purposeful accessible sampling. At the study's outset, participants provided demographic information, medical history, and consent to participate. A weekly food frequency questionnaire was also completed.

Inclusion criteria comprised a diagnosis of osteopenia or moderate risk for osteoporosis ($-2.5 \leq T \leq -1$), age within the specified range, lack of regular physical activity, non-consumption of dietary and pharmaceutical supplements, vitamins, or specific medications, non-smoking and non-alcohol consumption, no history of any specific disease, and no fractures in the target bone. After physician approval of these eligibility criteria, participants were randomly assigned to two groups: TRX training and control (n = 15 per group). Group allocation adhered to matching rules for features like age, height, weight, body mass index, and T score.

Study Design

Before initiating the 4-month training protocol (i.e., the pre-test phase), femur neck BMD was measured. Additionally, to assess serum leptin levels, 5 mL venous blood samples were collected from participants after a 12 to 14-hour fast. Sera were separated by centrifugation and frozen at -80 °C. Following 48 hours from baseline blood sampling, participants in the TRX group commenced the training protocols, conducted three days per week for 45-60 minutes per day, spanning four months. After the final training session, femoral neck BMD was reevaluated, and blood samples were withdrawn using the same fasting and separation procedures as before, to measure serum leptin levels. All laboratory tests and protocols in this study received approval from the institutional research council (No. 7924, dated March 5, 2019).

TRX Exercise Protocol

Participants in the control group were instructed to refrain from engaging in any specific sports activities and were asked to maintain their regular daily routine throughout the study. Before the intervention, an initial training session was conducted to familiarize the experimental group members with the TRX exercise method. This session included a 10-minute warm-up followed by 45 to 60 minutes of selected exercises under the researcher's supervision. All movements during the study were selected based on previously published materials on suspension TRX exercise (18, 19). The TRX suspension exercise protocol was designed by the researcher, who possessed one year of coaching experience in this field.

The TRX training protocol targeted hip and trunk muscles, specifically focusing on the hip muscle, rectus abdominis, internal and external obliques, transversus abdominis, lumbar multifidus, and erector spinae. These regions were chosen due to their association with the highest rate of bone fractures. The exercise program's volume and intensity were adjusted in line with the FITT principles (frequency, intensity, time spent, and type of exercise) and were subsequently confirmed by a specialist physician.

Bone Densitometry

Femoral neck BMD was measured using the DEXA device (Digital 2D Densitometer, Lexxos, USA) at the Radiology Center of the Medical Imaging Clinic of Zahedan. The device demonstrated an accuracy of 99.5%.

Measuring Serum Leptin Level

Serum leptin levels were measured using an ELISA kit (Bio vendor, Czech Republic) with a sensitivity of 0.5 ng/mL.

Body Composition Assessment

To assess body composition and body mass index, all participants underwent body composition assessment using the bioelectric impedance method with the In Body device (Model 2016, South Korea), conducted 48 hours before initiating the training protocol. Height measurements were taken using the Seca device (Model 206, Germany), and body weight was measured using a standard medical scale (Seca Co., Germany).

Statistical Analyses

The results were presented as mean ± standard deviation. Data distribution and homogeneity of variances were assessed using the Kolmogorov-Smirnov (K-S) and Levin tests, respectively. Within-group and between-group comparisons were performed using paired and independent samples student t-tests, respectively. Pearson correlation was utilized to examine associations between variables. Data analysis was carried out using SPSS 20 software, with a statistical significance level set at P = 0.05

Results

The K-S test results indicated a normal distribution for all studied variables. Table 1 outlines the demographic features of participants in both study groups, revealing no statistically significant differences in age, height, weight, body mass index, and T score at the baseline.

Table 1. Physical and Anthropometric Measures, and T Scores of Participants in the Two Study Groups (n = 15 per group).

Features		Groups	
		TRX exercise (Mean ± SD)	**Control (Mean ± SD)**
Age (years)		40.53 ± 6.30	41.74 ± 5.30
Height (cm)		167.3 ± 35.12	158.6 ± 40.08
Weight (Kg)		74.59 ± 6.13	78.6 ± 8.17
Body mass index (Kg/m^2)		24.17 ± 5.84	24.65 ± 6.32
T-score	Pre-test	-1.59 ± 0.38	-1.63 ± 0.32
	Post-test	-0.94 ± 0.29	- 1.78 ± 0.36

As depicted in Table 2, four months of TRX training resulted in a noteworthy increase in femoral neck BMD (P = 0.000) and a significant reduction in serum leptin levels within the intervention group compared to pre-test values (P = 0.01). At the post-test phase, femur neck BMD was significantly higher (P = 0.001), and serum leptin levels were significantly lower (P = 0.01) in the TRX training group compared to the control group.

Table 2. Femoral Neck Bone Mineral Density and Serum Leptin Level in the Two Study Groups Before and After Four Months of TRX Training (n = 15 per group).

Variables	Groups	Pre-test (Mean ± SD)	Post-test (Mean ± SD)	Mean difference	P (within-group)
Femur neck bone mineral density (g/cm^2)	TRX training	0.93 ± 0.03	1.09 ± 0.06	-0.16	0.000*
	Control	0.92 ± 0.05	0.89 ± 0.07	0.03	0.2
	P (between-group)	0.83	0.001*	-	-
Serum leptin level (ng/mL)	TRX training	35.98 ± 4.80	28.08 ± 5.28	7.91	0.01*
	Control	34.49 ± 8.36	36.01 ± 3.30	-1.52	0.4
	P (between-group)	0.74	0.01*	-	-

*Statistically significant difference at P<0.05.

Table 3 presents the results of the Pearson correlation test, revealing a significant inverse correlation between femoral neck BMD and serum leptin levels after four months of TRX training (r = -0.689, P < 0.001).

Table 3. Correlation Between Femur Neck Bone Mineral Density and Serum Leptin Level After Four Months of TRX Training.

Variables	Serum leptin level (ng/mL)	
	Pearson correlation coefficient (r)	Sig.
Femur neck bone mineral density (g/cm^2)	-0.689	0.000*

*Statistically significant difference at P<0.05.

Discussion

The primary objective of this study was to evaluate the impact of four months of TRX training on femoral neck BMD and its correlation with serum leptin levels in osteopenic women. Our findings demonstrated a significant increase in femur neck BMD and a decrease in serum leptin levels with TRX training compared to the control group. These results differ from those of Kemler et al., who focused on the preservation, rather than enhancement, of BMD in the proximal femur and trunk in postmenopausal osteopenic women. Conversely, Laura et al. reported outcomes akin to our observations, suggesting that resistance training could induce osteogenic effects in regions capable of bearing the total body weight.

TRX training, as a novel resistance protocol, stands out due to its unique features and principles, distinguishing it from traditional dumbbell- or barbell-based exercises predominantly involving the upper and lower limbs. Leveraging gravity, body weight, wider angles, and movements, TRX training presents a more challenging exercise modality. Furthermore, by focusing on the body's mid muscles, TRX training protocols can apply greater mechanical loads to the proximal femur, trunk, and lumbar vertebra—sites particularly prone to fractures—through muscle contractions. The mechanical pressure exerted by sports activities ranks among the crucial factors facilitating skeletal tissue growth and development; however, the exact mechanisms underlying this phenomenon remain unclear (20).

It appears that the mechanical load placed on bones during physical activity results from tensions generated by muscle contractions, which, in conjunction with osteogenic effects, can enhance bone density and strength parameters (1, 20, 21). Some studies investigating the osteogenic effects of training interventions suggest that these effects can be site-specific, primarily manifesting in areas subjected to mechanical loads (11). Therefore, the TRX exercise employed in our study, with a focus on the distal trunk and proximal femur, likely provided the necessary mechanical load to stimulate the osteogenic response and foster local osteogenesis in the femur neck.

The unique characteristics of TRX exercise, utilizing a rope or strap, lead to muscle contractions occurring at a distance from the central axis of the rope, making movements more challenging compared to traditional dumbbell- or barbell-oriented exercises. Consequently, this form of resistance training may have favorable effects on femur neck BMD, a fracture-prone region, by increasing mechanical loads, especially in areas close to the trunk's center. Our findings differ from those of Khan et al. (2019), who demonstrated superior osteogenic effects of osteoanabolic exercises compared to aerobic and resistance exercises in osteoporotic women (6). This disparity may be partially explained by the results of Ahmadi Kakavandi et al. (2019), suggesting that the same exercise protocol can yield different impacts on distinct bones. In their study on postmenopausal women, six months of air-pump training had no effect on femur and forearm bone BMD but increased the density of L4-5 lumbar vertebrae (7).

On the other hand, our observation regarding the effectiveness of TRX training in improving femoral neck BMD, attributed to its adequate intensity and the appropriate mechanical load on the femoral region, aligns with the findings of Bamben et al. In their study, researchers reported that the effects of resistance training on the BMD of the proximal femur and lumbar vertebrae in older men and women depended on the intensity and frequency of the training program (5). Thus, local osteogenesis in areas bearing mechanical loads can explain the significant increase in femoral neck BMD observed in the TRX group.

It is noted that exercise-induced mechanical loads are more effective in inducing osteogenesis in trabecular compared to cortical bone, possibly due to the higher blood flow in metaphyseal spongy tissues, enhancing their metabolic activity and response to mechanical loads. As a result, metaphyseal spongy tissues may be more responsive to exercise compared to dense diaphysis tissues (22).

Resistance training can enhance bone mineral density (BMD) through several potential mechanisms, including the reduction of bone resorption (by decreasing the number of osteoclasts), the stimulation of bone formation by increasing the number of osteoblasts, and the optimal distribution of mechanical loads on the bone (1). In our study, the significant increase in femoral neck BMD in the TRX group supports the notion of site-specific effects of exercise. It appears that this type of exercise, which targets the core muscles of the body, may both quantitatively and qualitatively improve osteogenesis in fracture-prone areas, thereby promoting femur neck BMD through the imposition of optimal mechanical load and pressure.

While Dual-Energy X-ray Absorptiometry (DEXA) is considered a gold standard and non-invasive method for assessing bone health, it provides a quantitative measure of bone condition. However, bone is a complex structure, and its resistance to fractures is influenced by the interaction of various functional parameters (20). BMD, though widely used for bone health assessment, is just one determinant of bone strength. Therefore, it is essential to explore other factors influencing bone metabolism and understand their relationships with BMD. It's crucial to note that these factors, independently of BMD, can impact the risk of bone fractures.

The findings from our study indicate that four months of TRX training led to a significant reduction in serum leptin levels in women with osteopenia. Furthermore, there was a significant and inverse correlation observed between serum leptin levels and femur neck BMD after the TRX training period. Adipocytes, acting as secretory cells, not only synthesize estrogen in postmenopausal women but also produce adipokines such as leptin (13). Apart from the mechanical load imposed on bones by adipose tissue, adipokines play a role in regulating energy metabolism and bone regeneration. However, the practical applicability of plasma levels of adipokines as indicators of bone health remains unclear (23, 24).

In clinical studies, serum leptin concentration has been linked to BMD, suggesting it as a potential biochemical predictor of bone density. However, the underlying mechanisms of this relationship are still a subject of discussion. Body mass index, either directly or indirectly through adipose-derived molecules like leptin and adiponectin, can impact bone metabolism (13). Studies reveal complex patterns in the effects of adipocyte-derived secretions on bone, where leptin has a negative impact on BMD, while adiponectin positively influences bone regeneration and formation. The adipose tissue's involvement in the pathophysiology of osteoporosis is also highlighted (25). Adipocytes and osteoblasts both originate from mesenchymal stem cell precursors, and their functions are influenced by inflammatory and hormonal regulatory factors (25).

The relationship between bone and fat tissues involves several mechanisms. Our findings align with those of Chanperasertiotin et al., Oha et al., and Contogiani et al., who all reported a significant and inverse correlation between serum leptin levels and the BMD of L2-4 lumbar vertebrae (26-28). Moreover, our study results are consistent with Sofilo et al.'s observations regarding the reduction of serum leptin levels after exercise (29). Studies indicate that leptin can inhibit bone formation partly by influencing the hypothalamus (26), with other research suggesting a role for hypothalamic neurons in promoting the anti-osteogenic actions of leptin (30).

During the early years of life, leptin promotes bone growth through its angiogenic properties and osteogenic effects on dense bones. However, in later years, leptin has been observed to decrease bone regeneration (31). Since serum levels of adipokines, such as leptin, increase with weight, the continuous 4-month exercise program employed in this study may have led to a reduction in adipokines, including leptin, by modulating the body weights of the participants. This, in turn, could contribute to the improvement in femoral neck BMD observed in our study.

Conclusion

In conclusion, the results of our study suggest that four months of TRX training demonstrated osteogenic effects, as indicated by an increase in femur neck BMD along with a reduction in serum leptin levels, serving as a biomarker for fat and bone metabolism. Consequently, this form of exercise appears to be beneficial for stimulating osteogenesis, particularly in individuals at risk of osteoporosis. Further research is warranted to address unanswered questions and gain a deeper understanding of the role of TRX training in enhancing bone health.

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Conflict of interest

There are no conflicts of interests in the present study.

Authors' contributions

FP designed the study, contributed to data acquisition and interpretation, and drafted the manuscript. **AS** contributed to the study's conception, interpretation of data, and drafted the manuscript. **MB** participated in drafting and critically revising the manuscript. **ZR** abstracted and analyzed data.

References

1. Saiem Aldahr MH. Bone mineral status response to aerobic versus resistance exercise training in postmenopausal women. World Appl Sci J. 2012;16(6):806-13. http://www.idosi.org/wasj/wasj16(6)12/5.pdf .
2. Khorsandi J, Shamsi M, Jahani F. The survey of practice about prevention of osteoporosis based on health belief model in pregnant women in arak city. J Rafsanjan Univ Med Scie. 2013; 8(1):35-46. http://journal.rums.ac.ir/article-1-1661-fa.html.
3. Hernlund EA, Svedbom M, Ivergård J, Compston C, Cooper J, Stenmark EV, et al. Osteoporosis in the european union: Medical management, epidemiology and economic burden. 2013; 8: 136. dio:10.1007/s11657-013-0136-1.
4. Chen H, Zhou X, Fujita H, Onozuka M, Kubo KY. Age-related changes in trabecular and cortical bone microstructure. Int J Endocrinol. 2013; 213234. https://doi.org/10.1155/2013/213234.
5. Bemben DA , Bemben MG. Dose-response effect of 40 weeks of resistance training on bone mineral density in older adults. Osteoporos Int. 2011 ;22(1):179-86. https://doi.org/10.1007/s00198-010-1182-9.
6. Khan AA, Farhad A, Siddiqui PQR, Ansari B. Effects of osteoanabolic exercises on bone mineral density of osteoporotic females: A randomized controlled trial. Int J Health Sci. 2019;13 (1):9-13. PMID: 30842712; PMCID: PMC6392486.
7. Ahmadi Kakavandi M, Alikhani S, Azizbeigi K. The Effect of body pump training on bone mineral density and balance in postmenopausal women. Iran J Health Educ Health Promot. 2019; 7 (3):316-327. http://journal.ihepsa.ir/article-1-1160-en.html.
8. Kemmler W, Lauber D, Weineck J, Hensen J, Kalender W, Engelke K. Benefits of 2 years of intense exercise on bone density, physical fitness, and blood lipids in early postmenopausal osteopenic women. Arch Intern Med. 2004; 164(10):1084-1091. doi:10.1001/archinte.164.10.1084.
9. Laura AG, Armas R. Pathophysiology of osteoporosis. Endocrinol Metab Clin.2014; 41(3):475–486. doi: 10.1016/j.ecl.2012.04.006.
10. Bemben DA , Bemben MG. Dose-response effect of 40 weeks of resistance training on bone mineral density in older adults. Osteoporos Int. 2011 ;22(1):179-86. https://doi.org/10.1007/s00198-010-1182-9.
11. Winters-Stone KM, Snow CM. Site-specific response of bone to exercise in premenopausal women. Bone. 2006; 39(6):1203-1209. https://doi.org/10.1016/j.bone.2006.06.005.
12. Tavakkoli Darestani A, Hosseinpanah F, Tahbaz F, Amiri Z, Tavakkoli Darestani R, Hedayati M. Effects of conjugated linoleic acid supplementation on body composition and leptin concentration in post-menopausal women. Iran J Endocrinol Metab. 2010; 12(1): 48-59. http://ijem.sbmu.ac.ir/article-1-787-en.html.
13. Reid IR. Relationships among body mass, its components, and bone. Bone J. 2012; 31: 547-555. https://doi.org/10.1016/S8756-3282(02)00864-5.
14. Roux S. New treatment targets in osteoporosis. Joint Bone Spine. 2010;77:222-8. https://doi.org/10.1016/j.jbspin.2010.02.004.
15. Moonikh K, Kashef M, Azad A, Ghasemnian A. Effects of 6 weeks resistance training on Body Composition, serum Leptin and muscle strength in non-athletic men. Horizon Med Sci. 2015; 21(2): 135-40.dio: 10.18869/acadpub.hms.21.2.135.
16. Lau PWC, Kong Z, Choi CR, Yu CCW, Chan DFY, Sung RYT, et al. Effects of short-term resistance training onserum leptin levels obese adolescents .J Exerc Sci Fit. 2010; 8(1): 54-60. https://doi.org/10.1016/S1728-869X(10)60008-1.
17. Peeri M, Zamani M. Comparing the effect of 8-weeks resistance training with different patterns of movement on the levels of adiponectin, leptin, testosterone and cortisol in sedentary men. Iran J Endocrinol Metab. 2016; 17(6):448-56.
18. Golara K. Suspension training total body resistance exercise. Federation of sport for all Tehran. 2016; 15-9.
19. Dawes J. Complete guide to TRX suspension training. Champaign, Illinois: Human Kinetics; 2017.
20. Fonseca H, Moreira-Gonçalves D, Coriolano HJ, Duarte JA. Bone quality: the determinants of bone strength and fragilit. Sports Med. 2014; 44(1):37-53. DOI: https://doi.org/10.1007/s40279-013-0100-7.
21. Allison SJ, Folland JP, Rennie WJ, Summers GD, Brooke-Wavell K. High impact exercise increased femoral neck bone mineral density in older men: a randomised unilateral intervention. Bone J. 2013; 53(2):321-328. https://doi.org/10.1016/j.bone.2012.12.045.
22. Hagihara Y, Nakajima A, Fukuda S, Goto S, Iida H, Yamazaki M. Running exercise for short duration increases bone mineral density of loaded long bones in young growing rats.

Tohoku J Exp Med. 2009; 219(2):139-43. https://doi.org/10.1620/tjem.219.139.
23. Mitsui Y, Gotoh M, Fukushima N, Shirachi I, Otabe S, Yuan X, et al. Hyper adiponectinemia enhances bone formation in mice. BMC Musculoskelet Disord. 2011; 12(18): 1-6. dio: https://doi.org/10.1186/1471-2474-12-18.
24. Liu Y, Song CY, Wu Sh, Liang QH, Yuan LQ, Liao EY. Novel adipokines and bone metabolism review article. Int J of Endocrino. 2013; 8(4):1-9. https://doi.org/10.1155/2013/895045.
25. Reid IR. Relationships between fat and bone. Osteoporos Int. 2008; 19(3):595– 606. Doi: : https://doi.org/10.1007/s00198-007-0492-z.
26. Chanprasertyothin S, Piaseu N, Chailurkit L, Rajatanavin R. Association of circulating leptin with bone mineral density in males and females. J Med Assoc Thai. 2005;88(5):655-9. http://www.medassocthai.org/journal.
27. Oh KW, Lee WY, Rhee EJ, Baek KH, Yoon KH, Kang MI, et al. The relationship between serum resistin, leptin, adiponectin, ghrelin levels and bone mineral density in middle-aged men. Clinical Endocrinology.2005; 63(2):131-8. doi/abs/10.1111/j.1365-2265.2005.02312.x.
28. Kontogianni MD, Dafni UG, Routsias JG, Skopouli FN. Blood leptin and adiponectin as possible mediators of the relation between fat mass and BMD in perimenopausal women. J Bone Miner Res 2004; (19):546-51. doi/abs/10.1359/JBMR.040107.
29. Tsofliou F, Pitsiladis YP, Malkova D, Wallace AM, Lean ME. Moderate physical activity permits acute coupling between serum leptin and appetite-satiety measures in obese women. Int J Obes Relat Metab Disord. 2003;27(11):1332-9. https://doi.org/10.1038/sj.ijo.0802406.
30. Elefteriou F, Karsenty G. Bone mass regulation by leptin: a hypothalamic control of bone formation. Pathol Biol .2004;52(3):148-53. https://doi.org/10.1016/j.patbio.2003.05.006.
31. sCaro JF, Kolaczynski JW, Nyce MR, Ohannesian JP, Opentanova I, Goldman WH, et al. Decreased cerebrospinal-fluid/serum leptin ratio in obesity: a possible mechanism for leptin resistance. Lancet .1996; 348:159–61. https://d1wqtxts1xzle7.cloudfront.net.