Original Article

Association between selected trace elements and body mass index and waist circumference: A cross sectional study

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ABSTRACT

Background: The prevalence of obesity has increased worldwide. Abnormal plasma level of some trace elements may be associated with obesity. The present study was designed to compare the plasma level of zinc, phosphate, calcium and magnesium with the degree of body mass index and waist circumference.
Material and methods: In this cross sectional study 149 persons (20–60 years old) from March 2014 till April 2017 were included. Definition of central obesity was waist circumference (WC)$\geq$ 102 cm and $\geq$88 cm in men and women, respectively. Also BMI categorized to: normal weight: 18.50–24.99, over-weight: 25.00–29.99 and obese: $\geq$30 kg/m2 respectively.
Mg, Ca, P and Zinc in plasma was checked after12 h fasting in each persons. Comparison between the level of Mg, P, Ca and Zinc by three categories of BMI or waist circumference performed. The data were analyzed by independent T-test and one-way ANOVA. Scheffe method was used to determine post-hoc pair-wise comparisons. The relationship between BMI and concentration of elements was detected by linear correlation and Cubic model. A $p \leq 0.05$ were considered statistically significant. Statistical ana-lyses were executed by SPSS version 20.
Results: In this study, 32.2% male and remainder female, mean age of 42.26 ± 13.03 were participated. 40.9% were normal and 59.1% obese base on waist circumference. Also 24.8% normal,44.3% overweight and remainder was obese according to BMI. Obese subjects base on waist circumference had significantly lower serum Zinc(pvalue:0.002), Ca (pvalue:0.0001)and Mg(pvalue:0.042) concentration. Whereas, P concentration was significantly higher in obese cases in comparison with normal subjects(pvalue:0.012). Also normal cases had significantly higher serum Zinc (pvalue: 0.0001), Ca (pvalue:0.0001), and Mg(pvalue:0.006) concentration compared to overweight and obese subjects according to BMI categorizes.
Conclusion: Inverse correlation present between plasma zinc, calcium and magnesium level and BMI and waist circumference, but positive correlation seen between P level and waist circumference. Further studies are needed to evaluate the effect of dietary or supplemental interventions on obesity and central obesity.

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1. Introduction

Overweight and obesity has become one of the major risk factors for various chronic diseases, including diabetes, cardiovascular disease, and cancer [1]. Obesity has been identified as a medical problem that is caused by multiple factors such as environmental, genetics, cultural factors and lifestyle preferences factors [2]. A systematic review in 2014 has revealed the prevalence rates for overweight and obesity among Iranian adults as ranged from 27.0 to 38.5 and 12.6–25.9 respectively [3]. Also prevalence of over-weight and obesity were 29% and 9.5%, respectively in YAZD in study that published in 2013 [4].

Metallic elements in the human body are usually in small quantities, but some of them play important biological effects in enzymatic, hormonal and normal metabolism [5]. Deficiency in some trace elements may be associated with the incidence of

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obesity [6]. Also some studies have suggested the increasing rate of obesity in some regions of the world, concordance with micronutrient deficiencies in this regions than other area [7,8]. This maybe suggest association between micronutrient deficiencies and increase in obesity rates in this area [7,8].

Etiology of this phenomenon maybe explained by correlation between serum level of minerals and serum leptin concentrations [9].

Leptin regulate food intake and energy expenditure. Leptin also regulates components of the inflammatory response that are risk factors for obesity. Changes in leptin levels due to deficiencies in specific trace elements may cause increase in adipose tissue mass and obesity and inflammatory response activation [9]. Although now it is not clear the cause and effect of obesity and changes of trace elements, obesity cause micronutrient deficiencies or paradox [6].

Zinc is an essential micronutrient that plays an important metabolic function related to the metabolism of proteins, carbohydrates, lipids and nucleic acids. Zinc plays an important role in insulin action and carbohydrate metabolism [10]. In addition Zinc is an integral part of many anti-oxidant enzymes and Zinc deficiency impairs synthesis of this enzymes, resulting in increased oxidative stress [10].

Phosphate (P) plays a critical role in regulating many essential biological processes including carbohydrate metabolism, signal transduction, translation and saving of genetic information and maintenance of lipid membrane structure [11]. Plasma P level inversely was correlate to body weight [12].

Intracellular calcium plays an important role in the regulation of lipid metabolism and insulin sensitivity. Serum calcium (Ca) had positive correlations with metabolic syndrome in the general population [13]. Also higher prevalence of adult obesity is correlated with higher serum Ca level in the chinese population [14].

Intracellular magnesium (Mg) plays a critical role in regulating insulin action, insulin dependent glucose uptake and vascular tone [15]. Serum Mg levels in overweight and obese children are lower than normal weight children [16].

Due to high prevalence of obesity in our region, the present study was designed to compare the plasma level of zinc, P, Ca and Mg with the degree of body mass index and waist circumference.

2. Methods

2.1. Subjects

This cross-sectional study designed to evaluate and compare the plasma Mg, Ca, P and zinc levels in patients with different degree of body mass index and waist circumference. In this study 149 patients (20–60 years old) who were came to Yazd diabetic research center and Khatamol-Anbia speciality clinic from March 2014 till April 2017 were included. Patients with Ma, Ca, P, and Zinc supplements as well as those with diuretic use, people with severe hyperglycemia, severe hypertension, pregnancy, lactation, thyroid disease, vitamin D deficiency, decreased kidney function (estimated glomerular filtration rate <60 mL/min/1.73 m2), cancer, acute infection or under special diets excluded from the study.

2.2. Definitions of variables

We used definition of central obesity according to the WHO criteria: waist circumference (WC)$\geq$ 102 cm and $\geq$88 cm in men and women, respectively. Also BMI categorized to: normal weight: 18.50–24.99, overweight: 25.00–29.99 and obese: $\geq$30 kg/m2 respectively [17].

2.3. Clinical and anthropometric measurements

A checklist consisted age, gender, height, weight, BMI, WC was completed for each patient. Height, weight, and WC were measured in standing position and BMI was calculated according the following formula; weight (kg)/height (m) ^{2}.WC was measured to the nearest 0.5 cm at the superior border of the iliac crest with a non-stretchable tape in late expiration in standing position.

2.4. Laboratory measurements

A 10 mL sample of venous blood (after 12 h fasting) was taken from each participant to measure level of Mg, Ca, Ph and Zinc in plasma. The level of Mg, Ca, P and Zinc were measured with Biosystem kits (Spain, European), using the enzymatic methods (BA400 Biosystem, Spain).

2.5. Research ethics

This research was presented to the ethics committee of Shahid Sadoughi University of Medical Sciences and approved by the internal medicine department. The ethics committee approved the study with the number 17/198313 on December 22, 2014. The patients were informed about the objective and nature of the study, and each participant provided written consent prior to the study.

2.6. Statistical analysis

The sample size was calculated by two mean comparison formula. Considering, type one error 0.05, effect size (d: 0.55) and power 90%, the calculated sample size was 149 participants. For the comparisons between the level of Mg, P, Ca and Zinc by three categories of BMI (normal, overweight and obese) or waist circumference (normal or obese), the data were first analyzed by independent T-test and one-way ANOVA. Given that we found some interaction effects of sex with BMI or WC categories and concentration of elements, we conducted the ANOVAs separately for men and women. In addition to this, Scheffe method was used to determine post-hoc pair-wise comparisons. The relationship between BMI and concentration of elements was detected by linear correlation and Cubic model. A p-value less than 0.05 were considered to indicate statistical significance. Statistical analyses were executed by the programs SPSS version 20.

3. Results

The present study was conducted on 149 healthy participants. Demographics and clinical characteristic of participants are summarized in Table 1. Mean body mass index (BMI) was significantly higher among women than men(28.97 ± 5.74 versus 26.70 ± 3.78,

Table 1
The baseline characteristics of studied patients.

Variables	Mean $\pm$ SD
Gender	
Male (N %)	48(32.2%)
Age	42.26 ± 13.03
Weight(kg)	74.38 ± 13.86
Height (cm)	162.56 ± 10.34
BMI(kg/m^2)	28.24 ± 5.29
WC(cm)	95.35 ± 12.81
Zinc(µg/dL)	86.89 ± 16.66
P(mg/dL)	3.75 ± 0.55
Ca(mg/dL)	9.44 ± 0.71
Mg(mg/dL)	1.86 ± 0.40

p-value: 0.005). In this study, 40.9% were normal and 59.1% obese base on waist circumference. 24.8% normal BMI,44.3% overweight and remainder was obese according to BMI. Women BMI were normal in 29.2%, 60.4% overweight, and 10.4% obese. Among men, 22.8% were normal, 36.6% overweight and 40.6% obese.

The waist circumference ≥102 cm was present in 29.2% of male, and waist circumference ≥88 cm was present in 73.3% of female.

Mean serum Zinc, P, Ca and Mg levels in normal and obese waist circumference are shown in Table 2. As shown in this table, there is a significant difference in Zinc, P, Ca and Mg levels between normal and obese waist circumference. Compared to the obese subjects, the normal cases had significantly higher serum Zinc, Ca and Mg concentration. Whereas, P concentration was significantly lower in normal cases in comparison with obese subjects.

Table 3 shows the mean serum Zinc, P, Ca and Mg levels in normal, overweight and obese groups according BMI categorizes. There is a significant difference in Zinc, Ca and Mg levels in normal, overweight and obese groups. According to the post hoc analysis, compared to the overweight subjects, the normal cases had significantly higher serum Ca (p-value: 0.04) and Mg (p-value: 0.04) concentration. Compared to the obese subjects, the normal cases had significantly higher serum Zinc (p-value: 0.0001) Ca (p-value: 0.0001) and Mg (p-value: 0.012) concentration.

The mean level of Zinc, P, Ca and Mg levels in normal and obese waist circumference by gender segregation were shown in Table 4. In men there are no significant different between levels of elements and waist circumference. But in women there is a significant difference in P and Ca levels between normal and obese groups according to waist circumference. There are the significant negative linear correlation between Mg, Zinc and Ca with BMI according to linear and cubic Models ([zinc linear R square: 0.071, p-value: 0.001, Cubic; R square: 0.113, p-value: 0.001], [Ca linear R square: 0.075, p-value: 0.001. Cubic R square: 0.089, p-value: 0.004], [Mg linear R square: 0.054, p-value: 0.005. Cubic R square:0.057, p-value: 0.039]), but there is a positive linear correlation between BMI and serum P level (Linear R square: 0.038, p-value: 0.017, Cubic R square: 0.039, p-value: 0.125).

4. Discussion

The possibility that micronutrient deficiencies may be linked to obesity is of great interest in area with a high prevalence of micronutrient deficiencies(7,8). In this study, there was inverse correlation between trace elements such as zinc, Ca and Mg levels and BMI and waist circumference, but positive correlation between P and waist circumference. Although positive trend between P and BMI was seen but it is not significant.

Zinc deficiency increased oxidative stress [10]. Results in the field of association between plasma zinc status and body composition are controversial. Some studies reported inverse correlation

Table 3
Mean serum Zinc, P, Ca and Mg levels in normal, overweight and obese BMI.

	BMI	Mean ± SD	p-value
Zinc	Normal	92.91 ± 17.64	0.0001
	Overweight	89.91 ± 13.32	
	Obese	78.00 ± 17.01	
P	Normal	3.58 ± 0.47	0.059
	Overweight	3.76 ± 0.62	
	Obese	3.86 ± 0.46	
Ca	Normal	9.79 ± 0.80	0.0001
	Overweight	9.43 ± 0.66	
	Obese	9.17 ± 0.57	
Mg	Normal	2.03 ± 0.52	0.006
	Overweight	1.81 ± 0.36	
	Obese	1.77 ± 0.29	

Data are expressed as mean ± standard deviation.
Statistical analysis by: *t*-test for independent samples.

[18–22] and some reported no association [23,24].

The association between zinc status and obesity may be due to the relationship between zinc metabolism and leptin. Decreased Zinc concentrations leads to reduced serum leptin level in rats and humans and reduced leptin secretion by rat adipocytes [9,25–27] Reduced phosphorus status potentiate the development of obesity [12,28]. Also subjects with metabolic syndrome show decreased phosphate level compared with healthy individuals [29]. We did not this phenomenon in our study with no explanation. But it may be due to consumption of high-protein diet that is enriched with high P in obese subjects of our participants. Another study showed that a high phosphate level was correlated with cardiovascular risk factors such as total cholesterol, LDL cholesterol but a lower phosphate level was correlated with metabolic syndrome risk factors such as waist circumference, triglyceride level, lower HDL level, systolic blood pressure, diastolic blood pressure, and fasting blood glucose [30].

Therefore, It is important to maintain normal level of serum P for preventing cardiovascular disease and metabolic syndrome [30]. The mentioned study emphasized that abnormal level of phosphate is risk factor for cardio-metabolic syndrome.

Study in the association of calcium with BMI and waist circumference are different results. Low plasma Ca level lead to calcitriol mediated increase in intracellular ionized Ca concentrations. High ionized Ca stimulate the fatty acid synthesis and inhibit lipolysis [31–33]. Serum Ca had positive correlations with

Table 2
Mean serum Zinc, P, Ca and Mg levels in normal and obese waist circumference groups.

	Waist circumference	Mean ± SD	P-value
Zinc(μg/dL)	Normal	92.13 ± 15.65	0.002
	Obese	83.34 ± 16.47	
P(mg/dL)	Normal	3.62 ± 0.48	0.012
	Obese	3.84 ± 0.58	
Ca(mg/dL)	Normal	9.69 ± 0.77	0.0001
	Obese	9.26 ± 0.61	
Mg(mg/dL)	Normal	1.94 ± 0.45	0.042
	Obese	1.80 ± 0.35	

Data are expressed as mean ± standard deviation.
Statistical analysis by: *t*-test for independent samples.

Table 4
Mean Serum Zinc, P, Ca and Mg levels in normal and obese waist circumference by gender segregation.

Sex		Waist circumference	Mean ± SD	P-value
Male	Zinc	Normal	96.88 ± 14.30	0.051
		Obese	87.42 ± 15.68	
	P	Normal	3.65 ± 0.51	0.539
		Obese	3.55 ± 0.51	
	Ca	Normal	9.80 ± 0.92	0.130
		Obese	9.39 ± 0.56	
	Mg	Normal	2.00 ± 0.54	0.210
		Obese	1.79 ± 0.37	
Female	Zinc	Normal	86.06 ± 15.46	0.355
		Obese	82.52 ± 16.61	
	P	Normal	3.58 ± 0.45	0.006
		Obese	3.90 ± 0.57	
	Ca	Normal	9.55 ± 0.52	0.014
		Obese	9.24 ± 0.61	
	Mg	Normal	1.86 ± 0.29	0.445
		Obese	1.80 ± 0.35	

Data are expressed as mean ± standard deviation.
Statistical analysis by: *t*-test for independent samples.

metabolic syndrome in the general population [13]. Also higher prevalence of adult obesity is correlated with higher serum Ca level in the chinese population(14).

No correlation was seen between baseline serum calcium levels and incident risk of metabolic syndrome in a longitudinal study by 34. Baek et al. [34]. But there was an association between higher serum calcium levels and decreased incident metabolic syndrome in individuals with central obesity or two components of metabolic syndrome at baseline in subgroup analysis [34].

Further studies are required to see the effect of supplementation of diet with this essential micronutrient on the BMI and waist circumference.

Inverse correlation was seen between plasma magnesium level and BMI, insulin resistance in adult and adolescent [16,35,36]. This study are agreement with our results.

The mechanism by which low Mg level lead to insulin resistance and obesity is not clear. Mg is a cofactor for enzymes involved in carbohydrate metabolism(15). Adipocytes in low-Mg media show decreased insulin-stimulated glucose uptake [37]. Also tyrosine kinase activity is decreased in insulin receptors of muscle rats in a state of low Mg diet [38]. These findings indicate possible effect of Mg on insulin signaling.

Our study showed that women with central obesity(base on waist circumference) had lower Ca and higher P level than normal women. Finding of Gozde Aritici and coworker suggest that high serum Ca level among turkish premenopausal women are associated with decreasing risk of metabolic syndrome[39].

Low serum P levels were associated with increased risk of metabolic syndrome and waist circumference in men but not in women among the japanese population [40]. Future studies with large sample size in men and women for explaining this findings is recommended.

However, there are some limitations to our study. Firstly, due to the cross-sectional design, determining the cause and effect of the observed associations is impossible. Other limitations are small sample size and lack of dietary data to assesse amount of these mineral intake.

As a conclusion, this study suggests that an effective approach to the reduction of obesity may be focus on dietary therapy. In addition, improving the nutritional status of minerals could be a low-cost preventive measure to reduce the high prevalence of obesity and adiposity.

Future studies to explore the association between intake of these minerals, either through diet or supplementation and central obesity maybe necessary.

Acknowledgments

References

[1] Pi-Sunyer X. The medical risks of obesity. PGM (Postgrad Med) 2009;121(6): 21–33.
[2] Krebs NF, Jacobson MS. Prevention of pediatric overweight and obesity. Pediatrics 2003;112:424–30.
[3] Jafari-Adli S, Jouyandeh Z, Qorbani M, Soroush A, Larijani B, Hasani-Ranjbar S. Prevalence of obesity and overweight in adults and children in Iran; a systematic review. J Diabetes Metab Disord 2014;13(1):121.
[4] Ghadiri-Anari A, Jafarizadah M, Zare A, Mozaffari-Khosravi H, Afkhami-Ardekani M, Shojaoddiny-Ardekani A. Prevalence of obesity and overweight among adults in Iranian population (Yazd province). IJDO 2013;5(2):67–70.
[5] Fraga CG. Relevance, essentiality and toxicity of trace elements in human health. Mol. Asp. Med. 2005;26:235–44.
[6] Garcia OP, Long KZ, Rosado JL. Impact of micronutrient deficiencies on obesity. Nutr Rev 2009;67:559–72.
[7] Monteiro CA, Moura EC, Conde WL, Popkin BM. Socioeconomic status and obesity in adult populations of developing countries: a review. Bull World Health Organ 2004;82:940–6.
[8] Monteiro CA, Conde WL, Popkin BM. Income-specific trends in obesity in Brazil: 1975–2003. Am J Public Health 2007;97:1808–12.
[9] Chen MD, Lin PY. Zinc-induced hyperleptinemia relates to the amelioration of sucrose induced obesity with zinc repletion. Obes Res 2000;8:525–9.
[10] Ranasinghe P, Wathurapatha WS, Ishara MH, Jayawardana R, Galappatthy P, Katulanda P, Constantine GR. Effects of Zinc supplementation on serum lipids: a systematic review and meta-analysis. Nutr Metab 2015;12(1):26.
[11] Ellam TJ, Chico TJ. Phosphate: the new cholesterol? The role of the phosphate axis in non-uremic vascular disease. Atherosclerosis 2012;220(2):310–8.
[12] Obeid OA. Low phosphorus status might contribute to the onset of obesity. Obes Rev 2013;14(8):659–64.
[13] Saltevo J, Niskanen L, Kautiainen H, Teittinen J, Oksa H, Korpi-Hyövälti E, Sundvall J, Männistö S, Peltonen M, Mäntyselkä P, Vanhala M. Serum calcium level is associated with metabolic syndrome in the general population: FIN-D2D study. Eur J Endocrinol 2011;165(3):429–34.
[14] Ren XH, Yao YS, He LP, Jin YL, Chang WW, Li J, Chen Y, Song XL, Tang H, Ding LL, Guo DX. Overweight and obesity associated with increased total serum calcium level: comparison of cross-sectional data in the health screening for teaching faculty. Biol Trace Elem Res 2013;156(1–3):74–8.
[15] Barbagallo M, Dominguez LJ. Magnesium metabolism in type 2 diabetes mellitus, metabolic syndrome and insulin resistance. Arch Biochem Biophys 2007;458(1):40–7.
[16] ul Hassan SA, Ahmed I, Nasrullah A, Haq S, Ghazanfar H, Sheikh AB, Zafar R, Askar G, Hamid Z, Khushdil A, Khan A. Comparison of serum magnesium levels in overweight and obese children and normal weight children. Cureus 2017;9(8).
[17] WHO. Obesity: preventing and managing the global epidemic.Report of a WHO consultation. World Health Organ Tech Rep Ser 2000;894:1–253.
[18] Selva DM, Lecube A, Hernandez C, Baena JA, Fort JM, Simo R. Lower zinc-alpha2-glycoprotein production by adipose tissue and liver in obese patients unrelated to insulin resistance. J Clin EndocrinolMetab 2009;94:4499–507.
[19] Di Martino G, Matera MG, de Martino B, Vacca C, Di Martino S, Rossi F. Relationship between zinc and obesity. J Med 1993;24:177–83.
[20] Marreiro DN, Fisberg M, Cozzolino SM. Zinc nutritional status in obese children and adolescents. Biol Trace Elem Res 2002;86:107–22.
[21] Marreiro DN, Geloneze B, Tambascia MA, Lerario AC, Halpern A, Cozzolino SM. Effect of zinc supplementation on serum leptin levels and insulin resistance of obese women. Biol Trace Elem Res 2006;112:109–18.
[22] Fan Y, Zhang C, Bu J. Relationship between selected serum metallic elements and obesity in children and adolescent in the US. Nutrients 2017;9(2):104. Feb 3.
[23] Obeid O, Elfakhani M, Hlais S, Iskandar M, Batal M, Mouneimne Y, Adra N, Hwalla N. Plasma copper, zinc, and selenium levels and correlates with metabolic syndrome components of lebanese adults. Biol Trace Elem Res 2008;123(1–3):58–65. Jun 1.
[24] Weisstaub G, Hertrampf E, Lopez de Romana D, Salazar G, Bugueno C, Castillo-Duran C. Plasma zinc concentration, body composition and physical activity in obese preschool children. Biol Trace Elem Res 2007;118:167–74.
[25] Tallman DL, Taylor CG. Effects of dietary fat and zinc on, serum leptin and adipose fatty acid composition in C57BL/6J mice. J Nutr Biochem 2003;14: 17–23.
[26] Chen MD, Song YM, Lin PY. Zinc may be amediator of leptin production in humans. Life Sci 2000;66:2143–9.
[27] Ott ES, Shay NF. Zinc deficiency reduces leptin gene expression and leptin secretion in rat adipocytes. Exp Biol Med 2001;226:841–6.
[28] Blaak EE, Antoine JM, Benton D, et al. Impact of postprandial glycaemia on health and prevention of disease. Obes Rev 2012;13:923–84.
[29] Kalaitzidis R, Tsimihodimos V, Bairaktari E, Siamopoulos KC, Elisaf M. Disturbances of phosphate metabolism: another feature of metabolic syndrome. Am J Kidney Dis 2005;45(5):851–8. May 1.
[30] Park W, Kim BS, Lee JE, Huh JK, Kim BJ, Sung KC, Kang JH, Lee MH, Park JR, Rhee EJ, Oh KW. Serum phosphate levels and the risk of cardiovascular disease and metabolic syndrome: a double-edged sword. Diabetes Res Clin Pract 2009;83(1):119–25. Jan 1.
[31] Zemel MB. Regulation of adiposity and obesity risk by dietary calcium: mechanisms and implications. J Am Coll Nutr 2002;21(Suppl):S146–51.
[32] Gruff JL, Gropper SS. Advanced nutrition and HumanMetabolism. Belmont, CA: West/Wadsworth; 2000.
[33] Jones BH, Kim JH, Zemel MB, et al. Upregulation of adipocyte metabolism by agouti protein: possible paracrine actions in yellow mouse obesity. Am J Physiol 1996;270:E192–6.
[34] Baek JH, Jin SM, Bae JC, Jee JH, Yu TY, Kim SK, Hur KY, Lee MK, Kim JH. Serum calcium and the risk of incident metabolic syndrome: a 4.3-year retrospective longitudinal study. Diabetes & metabolism journal 2017 Feb 1;41(1):60–8.
[35] Rosolova H, Mayer Jr O, Reaven GM. Insulin-mediated glucose disposal is decreased in normal subjects with relatively low plasma magnesium concentrations. Metabolism 2000;49(3):418–20. Mar 1.
[36] Huerta MG, Roemmich JN, Kington ML, Bovbjerg VE, Weltman AL, Holmes VF, Patrie JT, Rogol AD, Nadler JL. Magnesium deficiency is associated with insulin resistance in obese children. Diabetes Care 2005;28(5):1175–81. May 1.
[37] Kandeel FR, Balon E, Scott S, Nadler JL. Magnesium deficiency and glucose

metabolism in rat adipocytes. Metab, Clin Exp 1996;45(7):838—43. 1.

[38] Suarez A, Pulido N, Casla A, Casanova B, Arrieta FJ, Rovira A. Impaired tyrosine-kinase activity of muscle insulin receptors from hypomagnesaemic rats. Diabetologia 1995;38(11):1262—70. Nov 1.

[39] Aritici G, Bas M. Metabolic syndrome and calcium: the effects on body composition and biochemical parameters among premenopausal women.

Prog Nutr 2018;2:220—8.

[40] Shimodaira M, Okaniwa S, Nakayama T. Reduced serum phosphorus levels were associated with metabolic syndrome in men but not in women: a cross-sectional study among the Japanese population. Ann Nutr Metab 2017;71: 150—6.