



Bioavailability

Body mass index, iron absorption and iron status in childbearing age women

María Fernanda Mujica-Coopman^a, Alex Brito^{a,b}, Daniel López de Romaña^{a,c}, Fernando Pizarro^a, Manuel Olivares^{a,*}^a Micronutrients Laboratory, Institute of Nutrition and Food Technology, University of Chile, Chile^b United States Department of Agriculture, Western Human Nutrition Research Center, University of California, Davis, USA^c The Micronutrient Initiative, Ottawa, ON, Canada

ARTICLE INFO

Article history:

Received 10 January 2014

Accepted 26 March 2014

Keywords:

Obesity

Body mass index

Iron absorption

Hemoglobin

Women

ABSTRACT

Background: The prevalence of obesity has increased at an alarming rate worldwide. Some studies have observed an association between iron (Fe) deficiency (ID) and obesity, however more research is needed. **Objective:** To assess whether body mass index (BMI) is associated with both Fe absorption and Fe status. **Methods:** A cross sectional sample of 318 Chilean childbearing age women was studied. The women received either a single dose of 0.5 mg of Fe ($n = 137$, group 1) or 3 mg of Fe plus ascorbic acid (1:2 molar ratio) ($n = 181$, group 2), both as FeSO₄ with labeled radioisotopes. Fe absorption was assessed through radio Fe erythrocyte incorporation. Fe status was determined by hemoglobin (Hb), mean corpuscular volume, serum Fe, total iron binding capacity, transferrin saturation, erythrocyte Zn protoporphyrin and serum ferritin (SF).

Results: 29%, 47% and 24% of the women were classified as normal, overweight or obese, respectively. Fe absorption was significantly lower in obese women ($p < 0.05$). In group 1, the geometric mean and range ± 1 SD of the percentage of Fe absorption for normal-weight women was 32.9% vs. 19.7% in obese. For group 2, this percentage was 36% vs. 30%, respectively (2-way ANOVA: BMI classification and Fe dose $p < 0.05$; interaction $p = 0.34$). Although Fe absorption was lower in obese women, they had higher SF ($p < 0.01$) and Hb ($p < 0.05$) concentrations.

Conclusion: Although we did not observe a relationship between BMI and Fe status, obese women displayed lower Fe absorption compared with overweight and normal weight women, possibly due to subclinical inflammation associated with obesity.

© 2014 Elsevier GmbH. All rights reserved.

Introduction

The nutritional status of populations in countries undergoing economic transition is changing rapidly due to diet and lifestyle changes [1–3]. These populations display a high prevalence of chronic disease associated with obesity, such as cardiovascular disease, type 2 diabetes and cancer. These populations continue to have high rates of micronutrient deficiencies, such as iron deficiency (ID) [4]. Both obesity and ID are independently major disease burdens [5,8]. Obesity is currently considered a global pandemic, while ID continues to be the most prevalent single micronutrient deficiency in the world [6–8]. A connection between obesity and

ID was first reported in obese adolescents, who apparently had lower serum Fe concentrations compared to non-obese adolescents [9,10]. Other studies have described an association between ID and obesity in children and adults [11–13]. The proposed mechanisms that explain this relationship include diminished Fe absorption and decreased Fe mobilization from stores due to inflammation, as well as increased Fe requirements due to high blood volume [14]. Evidence shows elevated inflammatory biomarkers, such as C-reactive protein (CRP), in obese subjects when compared to non-obese subjects and the detrimental effect that pro-inflammatory molecules have on Fe status [15]. To our knowledge, only one study to date has reported an inverse relationship between body mass index (BMI) and Fe absorption, independent of Fe status in childbearing age women [16].

Chile is a country in the advanced stages of nutritional transition. Under-nutrition has virtually disappeared, however, obesity rates and risk factors for chronic diseases are rising. Although anemia

* Corresponding author at: Av. El Líbano 5524, Macul, Santiago, Postal Code: 783 04 90, Chile. Tel.: +56 29781482; fax: +56 22214030.

E-mail address: molivare@inta.uchile.cl (M. Olivares).

is not a public health problem in childbearing age women [17], ID is still highly prevalent. Thus, the objective of the present study is to determine the association between BMI and both Fe absorption and Fe status in Chilean childbearing age women.

Subjects and methods

Design

A cross-sectional study was designed using data from 318 women who participated in previously published [18–27] and non-published Fe absorption studies, between 1997 and 2007 at the Institute of Nutrition and Food Technology (INTA), University of Chile. None of the women were pregnant, confirmed by a negative urine test for human chorionic gonadotropin. All of the women were using a birth control method (e.g., intrauterine device, oral contraceptive, or tube ligation) at the time of the study, were in apparent good health, and none had consumed vitamin or mineral supplements in the 6 months prior to the studies.

BMI classification

Weights and heights were obtained using standardized procedures [18–27]. Body mass index was calculated from bodyweight/height², as defined by the World Health Organization (WHO) [28]. Women were classified as normal (BMI ≥ 18.5 to < 25 kg/m²), overweight (BMI ≥ 25 kg/m² to < 30 kg/m²) or obese (BMI ≥ 30 kg/m²), according to WHO criteria [28].

Iron absorption

The participants received, after an overnight fast, either a single dose of 0.5 mg of Fe (group 1; $n = 137$) or 3 mg of Fe plus ascorbic acid (1:2 molar ratio) (group 2; $n = 181$) as ferrous sulfate (FeSO₄) labeled with either ⁵⁹Fe (37 kBq) or ⁵⁵Fe (111 kBq), radioisotopes of high specific activity (NEN, Life Science Products, Boston, MA, USA). In addition, venous blood samples were drawn to assess hematological parameters and to measure circulating radioactivity. Blood radioactivity was estimated according to the method described by Eakins and Brown [29]. The percentages of Fe absorption were calculated on the basis of blood volume estimated by height and weight [30], assuming 80% incorporation of the radioisotope into erythrocytes [31].

Iron status and hematological parameters

Hemoglobin (Hb), mean cell volume (MCV) (CELL-DYN 1700, ABBOTT Diagnostics, Abbott Park, IL CELL Dyn), serum Fe, total iron binding capacity (TIBC), transferrin saturation (Sat) [32], erythrocyte Zn protoporphyrin (Zpp) measured by hematofluorometry (hematofluorometer Model 206D, AVIV Biomedical Inc, Lakewood,

NJ), and serum ferritin (SF) were assessed by an enzyme immune assay of double sandwich (INACG) [33].

Anemia was defined as Hb < 12 g/dL and iron deficiency anemia (IDA) was defined as Hb concentrations < 12 g/dL with at least two of the following abnormal indicators of Fe status: Sat $< 15\%$, MCV < 80 fL, SF < 12 μ g/L and Zpp > 70 μ g/dL red blood cells (RBC) [34]. ID without anemia was defined as Hb concentrations > 12 g/dL with at least two abnormal indicators of Fe status. Depleted Fe stores were defined as SF < 12 μ g/L. Fe status was considered to be normal when all of these laboratory indexes were within the reference ranges.

Ethical approval

All studies were performed in accordance with the Helsinki Declaration, and were approved by the Ethics Committee at INTA, University of Chile, before their execution. The doses of radioisotopes used were approved by the Chilean Commission on Nuclear Energy.

Statistical analysis

Normally distributed variables were described by means and standard deviations (SD). Distributions of SF and Zpp concentrations were skewed, therefore the values were log-transformed and the results were then retransformed into antilogarithms to recover the original units. SF results are expressed as geometric means and range ± 1 SD.

The differences between dose groups, classifications of normal, overweight or obese, were assessed by two-way ANOVA with a post hoc Scheffé test. The relationship between Fe absorption, SF and BMI was calculated with a Pearson correlation coefficient. SF was expressed as a natural logarithm.

The statistical significance level was set at $p < 0.05$. All statistical analyses were performed with STATA, version 10.0 (StataCorp, College Station, TX, USA).

Results

The general characteristics of the women are shown in Table 1. The mean age of all the women ($n = 318$) was 40 ± 5 y. There was a statistically significant difference in the age of the women between the groups with different doses of Fe. Of all the women, twenty-nine percent were classified as having normal weight, 47% as overweight and 24% as obese. The mean BMIs were 23 ± 1 kg/m², 27 ± 1 kg/m² and 33 ± 3 kg/m², respectively.

Out of all the women, the prevalence of IDA, ID without anemia, Fe depleted stores, and normal Fe status was 7%, 9%, 18% and 66%, respectively. There were no significant differences in Fe status within each category of BMI classification.

The percentage of Fe absorption was significantly lower in obese women compared to normal-weight ($p < 0.02$) and overweight women ($p < 0.005$) (Table 2).

Table 1
Characteristics of women (mean \pm SD).

	Iron dose (0.5 mg)			Iron dose (3 mg) ^a				
	<i>n</i>	Normal (<i>n</i> = 45)	Overweight (<i>n</i> = 75)	Obese (<i>n</i> = 17)	<i>n</i>	Normal (<i>n</i> = 47)	Overweight (<i>n</i> = 74)	Obese (<i>n</i> = 60)
Age ^b (y)	135	37.6 \pm 4.4	39.7 \pm 4.3	38.9 \pm 4.3	181	40.7 \pm 5.1	40.2 \pm 4.9	40.6 \pm 5
Weight (kg)	137	57.1 \pm 5.4	66.3 \pm 7.0	76.7 \pm 5.8	181	55.5 \pm 5.8	67.0 \pm 6.4	81.1 \pm 10.6
Height (m)	137	1.57 \pm 0.05	1.56 \pm 0.06	1.55 \pm 0.05	181	1.56 \pm 0.07	1.57 \pm 0.06	1.55 \pm 0.06
BMI ^c (kg/m ²)	137	23.1 \pm 1.2	27.2 \pm 1.4	31.8 \pm 1.3	181	22.8 \pm 1.8	27.3 \pm 1.4	33.8 \pm 4.0

2-way ANOVA for repeated measures.

^a 2:1 molar ratio ascorbic acid to iron.

^b There were significant differences between Fe doses groups ($p < 0.05$).

^c There were significant differences between Fe doses ($p < 0.05$) and nutritional status; Sheffé post hoc test: normal vs. overweight, normal vs. obese and overweight vs. obese ($p < 0.0001$).

Table 2
Iron absorption according to nutritional status and iron dose.

	Iron dose (0.5 mg)			Iron dose (3 mg) ^a			P ^b			
	n	Normal (n = 45)	Overweight (n = 75)	Obese (n = 17)	Normal (n = 47)	Overweight (n = 74)	Obese (n = 60)	Nutritional status	Iron dose	Interaction
Iron absorption (%) ^c	137	32.9 (15.9–68.2)	33.0 (15.9–68.6)	19.7 (8.4–46.3)	36.0 (15.5–83.3)	35.9 (18.0–71.8)	30.1 (14.5–62.5)	0.010	0.037	0.336

Scheffé post hoc test: normal vs. obese ($p < 0.02$), overweight vs. obese ($p < 0.005$) and normal vs. overweight ($p < 0.02$).

^a 2:1 molar ratio ascorbic acid to iron.

^b 2-way ANOVA.

^c Geometric mean (range \pm 1 SD)

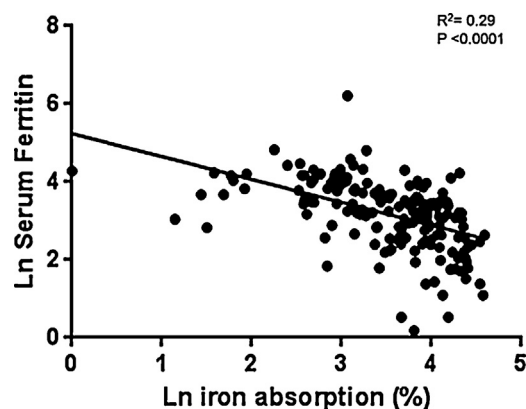


Fig. 1. Relationship between the natural logarithm of iron absorption and the natural logarithm of serum ferritin.

BMI was inversely correlated with the natural logarithm of Fe absorption ($r = -0.148$, $p < 0.01$). Also, the natural logarithm of SF was inversely correlated with the natural logarithm of Fe absorption ($r = -0.54$, $p < 0.0001$) (Fig. 1).

As expected, the women who received 3 mg Fe plus ascorbic acid (1:2 molar ratio) had higher Fe absorption compared to the women who received 0.5 mg of Fe without ascorbic acid ($p < 0.05$).

Hematological parameters and Fe status biomarkers are shown in Table 3. Hb ($p < 0.02$) and SF ($p < 0.001$) concentrations were significantly higher in obese subjects compared with those classified as having normal BMI.

Discussion

Obesity and Fe deficiency are major global health concerns worldwide [28,33]. Obesity is usually associated with over-nutrition and Fe deficiency with under-nutrition. Although the conditions represent opposite ends in the spectrum of malnutrition, they appear to be linked [35]. An inverse association between Fe status and adiposity has been described in several populations since 1962 [10]. Consistently, we found that women with obesity absorb less Fe than overweight women or women with normal BMIs, showing an inverse correlation between BMI and Fe absorption. Similar results were reported by Zimmerman et al., showing that higher BMIs are associated with lower fractional Fe absorption in childbearing age women, independent of Fe status [16].

Although obese women displayed a lower percentage of Fe absorption, apparently this did not affect their Fe status. A possible explanation for this is the intake of bread, made with Fe fortified flour (30 mg Fe/kg), in Chilean women. It has been reported that the average daily intake of Fe fortified bread is 239 g [36]. This intervention may contribute to adequate Fe supply for erythropoiesis.

In the present study, the concentrations of SF and Hb were significantly higher in obese women than in women with normal BMIs. Also, SF showed an inverse correlation with Fe absorption.

With respect to SF, this relationship is likely mediated by inflammation. Several studies conducted in obese children and adults have shown increased levels of pro-inflammatory molecules, such as CRP, IL-6 and hepcidin, compared to normal weight subjects [12,13,15,37–39]. Increased hepcidin levels may decrease Fe absorption through the reduction of the expression of DMT-1 and the release of Fe through sequestration of ferroportin [40,41]. Thus, the pro-inflammatory state present in most of the obese can impair Fe status by decreasing Fe bioavailability and affecting Fe status biomarkers. Although it has been postulated that obesity and overweight may be associated with poor dietary Fe intake, studies that have estimated dietary Fe intake in Chilean childbearing

Table 3
Iron status biomarkers.

	Iron dose (0.5 mg)			Iron dose (3 mg) [†]			P ^b		
	Normal (n=45)	Overweight (n=75)	Obese (n=17)	Normal (n=47)	Overweight (n=74)	Obese (n=60)	Nutritional status	Iron dose	Interaction
	N	n	n	n	n	n			
Hb (g/dL)	137	13.3 ± 1.2	14.0 ± 1.3	181	13.4 ± 1.6	13.9 ± 1.0	0.035 ^d	0.901	0.852
MCV (fL)	137	89 ± 7	86 ± 9	137	87 ± 8.3	86 ± 4	0.281	0.455	0.600
Fe (µg/dL)	136	80 ± 37	77 ± 27	156	87 ± 32	88 ± 30	0.978	0.084	0.925
TIBC (µg/dL)	136	325 ± 57	335 ± 111	156	339 ± 65	342 ± 61	0.861	0.607	0.416
Sat (%)	136	25.3 ± 13.1	24.4 ± 8.6	181	27.4 ± 11.8	27.2 ± 10.3	0.963	0.093	0.980
Zpp (µg/dL RBC) ^c	137	58 (38–88)	54 (40–74)	137	72 (46–116)	73 (53–100)	0.528	0.006	0.578
SF (µg/L) ^c	136	23 (11–49)	35 (17–72)	180	17 (7–44)	28 (11–74)	0.009 ^e	0.217	0.254

Abbreviations: hemoglobin (Hb), mean cell volume (MCV), serum iron (Fe), total iron binding capacity (TIBC), zinc protoporphyrin (Zpp), serum ferritin (SF).

^a 2:1 molar ratio ascorbic acid to iron.

^b 2-way ANOVA.

^c Geometric mean (range ± 1 SD).

^d Scheffé post hoc test: normal vs. overweight, $p < 0.02$.

^e Scheffé post hoc test: normal vs. obese, $p < 0.001$.

age women have not shown lower intake of this mineral in obese women compared to those with normal BMIs [42]. A sub sample of 44 women included in this study showed a mean Fe intake of 15.2 ± 4.3 mg/day, 16.1 ± 5.1 mg/day and 15.1 ± 5.6 mg/day for normal, overweight and obese women, respectively. No significant differences in Fe intake were found by comparing BMIs [24]. Similar results were reported by Cepeda et al. in Mexican women, who did not show differences in Fe intake by BMI classification [43].

Regarding Hb, in 1981 Scheer et al. evaluated whether Hb criteria should be adjusted for obesity. They concluded that further adjustment for obesity appears unwarranted and would complicate efforts to optimize the screening for anemia [14]. It has been reported that higher Hb levels in obese adults could be explained by comorbidities commonly present in the obese, such as chronic tissue hypoxia, obstructive sleep apnea and other obesity-related respiratory conditions, which may lead to polycythaemia [12].

The strengths of this study include a large sample size and the use of a well-known technique to measure Fe absorption. There are also some limitations to this study. Inflammation status was not assessed in these women. As mentioned before, it has been reported that inflammation also influences Fe status biomarkers [37,44–46]. Moreover, SF is a recognized acute phase protein (APP) and for that reason, the Center for Disease Control and Prevention (CDC) [34] recommends determining Fe status considering at least one APP; such as CRP or high sensitivity CRP, to adjust for the effect of inflammation on Fe status biomarkers. We cannot rule out the effect of inflammation on the determination of Fe status. Finally, we did not estimate dietary intake, which limits our analysis of the contribution of diet to overweight, obesity, Fe absorption and Fe status.

More robust designs are needed to assess the cause-effect between Fe absorption and obesity, and vice versa. Ideally, these studies should be done in groups vulnerable to ID, specifically children and childbearing age women. The inclusion of other Fe biomarkers, such as a soluble transferrin receptor, would allow for the amount of Fe in the body to be estimated from the ratio of SF receptors to SF, using the equation developed by Cook et al. [47]. Similar studies should incorporate superior methods for determining adiposity; such as fat tissue percentage through bio-impedance, DEXA, deuterium isotopes, etc.

Conclusion

Although we did not observe a relationship between BMI and Fe status, obese women displayed lower Fe absorption compared to overweight and normal weight women, possibly due to subclinical inflammation associated with obesity.

Conflict of interest

The authors declare no conflicts of interest.

Acknowledgments

The study was partially supported by grants from Fondo Nacional de Desarrollo Científico y Tecnológico (FONDECYT) Chile #. 1950242, 1040879, 1070665.

We would like to thank Sotiris Chaniotakis for editing this manuscript.

References

- [1] Doak CM, Adair LS, Bentley M, Monteiro C, Popkin BM. The dual burden household and the nutrition transition paradox. *Int J Obes (Lond)* 2005;29:129–36.
- [2] Popkin BM. The nutrition transition: an overview of world patterns of change. *Nutr Rev* 2004;62(7 Pt 2):140–3.

- [3] Food and Agriculture Organization of the United Nations. The double burden of malnutrition. Case studies from six developing countries. *FAO Food Nutr Pap* 2006;84:1–334.
- [4] Datz C, Felder TK, Niederseer D, Aigner E. Iron homeostasis in the metabolic syndrome. *Eur J Clin Invest* 2013;43:215–21.
- [5] Razak F, Corsi DJ, Subramanian SV. Change in the body mass index distribution for women: analysis of surveys from 37 low- and middle-income countries. *PLoS Med* 2013;10:1–13.
- [6] Swinburn BA, Sacks G, Hall KD, Mc Pherson K, Finegood DT, Moodie ML, et al. The global obesity pandemic: shaped by global drivers and local environments. *Lancet* 2011;378:804–14.
- [7] Popkin BM, Adair LS, Nq SW. Global nutrition transition and the pandemic of obesity in developing countries. *Nutr Rev* 2012;70:3–21.
- [8] World Health Organization. Worldwide prevalence of anemia, 1993–2005: WHO global database on anaemia. Geneva, Switzerland: WHO; 2008.
- [9] Seltzer C, Mayer J. Serum iron and iron-binding capacity in adolescents. II. Comparison of obese and nonobese subjects. *Am J Clin Nutr* 1963;13:354–61.
- [10] Wenzel BJ, Stults HB, Mayer J. Hypoferraemia in obese adolescents. *Lancet* 1962;2:327–8.
- [11] Zekanowska E, Boinska J, Gliemza-Kucharska P, Kwapisz J. Obesity and iron metabolism. *J Biotechnol Comput Biol Bionotechnol* 2011;92:147–52.
- [12] Cheng HL, Bryant C, Cook R, O'Connor H, Rooney K, Steinbeck K. The relationship between obesity and hypoferraemia in adults: a systematic review. *Obes Rev* 2012;13:150–61.
- [13] del Giudice EM, Santoro N, Amato A, Brienza C, Calabro P, Wiegerinck, et al. Hepcidin in obese children as a potential mediator of the association between obesity and iron deficiency. *J Clin Endocrinol Metab* 2009;94:5102–7.
- [14] Scheer JC, Guthrie HA. Hemoglobin criteria with respect to obesity. *Am J Clin Nutr* 1981;34:2748–51.
- [15] Yanoff LB, Menzie CM, Denkinge B, Sebring NG, Mc Hugh T, Remaley AT, et al. Inflammation and iron deficiency in the hypoferraemia of obesity. *Int J Obes (Lond)* 2007;31:1412–9.
- [16] Zimmermann MB, Zeder C, Muthayya S, Winichagoon P, Chaouki N, Aeberli I, et al. Adiposity in women and children from transition countries predicts decreased iron absorption, iron deficiency and a reduced response to iron fortification. *Int J Obes (Lond)* 2008;32:1098–104.
- [17] Encuesta nacional de salud. Chile. Ministerio de Salud. Chile; 2003. Available at <http://www.minsal.cl> (accessed on 06.01.14).
- [18] Pizarro F, Zavaleta N, Hertrampf E, Berlanga R, Camborda L, Olivares M. Efecto de la altura sobre la absorción de hierro. *Arch Latinoam Nutr* 1998;48:25–8.
- [19] Olivares M, Pizarro F, Walter T, Arredondo M, Hertrampf E. Bioavailability of iron supplements consumed daily is not different from that of iron supplements consumed weekly. *Nutr Res* 1999;19:179–90.
- [20] Olivares M, Pizarro F, Ruz M. Zinc inhibits nonheme iron bioavailability in humans. *Biol Trace Elem Res* 2007;117:7–14.
- [21] Walter T, Pizarro F, Olivares M. Iron bioavailability in corn-masa tortillas is improved by the addition of disodium EDTA. *J Nutr* 2003;133:3158–61.
- [22] Olivares M, Pizarro F, Gaitan D, Ruz M. Acute inhibition of iron absorption by zinc. *Nutr Res* 2007;27:279–82.
- [23] Olivares M, Pizarro F, Ruz M. New insights about iron bioavailability inhibition by zinc. *Nutrition* 2007;23:292–5.
- [24] Lopez de Romaña D, Ruz M, Pizarro F, Landaeta L, Olivares M. Supplementation with zinc between meals has no effect on subsequent iron absorption or on iron status of Chilean women. *Nutrition* 2008;24:957–63.
- [25] Olivares M, Pizarro F, López de Romaña D, Ruz M. Acute copper supplementation does not inhibit non-heme iron bioavailability in humans. *Biol Trace Elem Res* 2010;136:180–6.
- [26] Olivares M, Pizarro F, Pineda O, Name JJ, Hertrampf E, Walter T. Milk inhibits and ascorbic acid favors ferrous bis-glycine chelate bioavailability in humans. *J Nutr* 1997;127:1407–11.
- [27] Olivares M, Pizarro F, Hertrampf E, Fuenmayor G, Estevez E. Iron absorption from wheat flour: effects of lemonade and chamomile infusion. *Nutrition* 2007;23:296–300.
- [28] World Health Organization. Report of a WHO consultation on obesity. Obesity: preventing and managing the global epidemic. Geneva, Switzerland: WHO; 2000. p. 894. Technical Report Series.
- [29] Eakins JD, Brown DA. An improved method for the simultaneous determination of iron-55 and iron-59 in blood by liquid scintillation counting. *Int J Appl Radiat Isot* 1966;17:391–7.
- [30] Nadler S, Hidalgo JU, Bloch T. The Tulane table of blood volume in normal man. *Surgery* 1962;51:224–32.
- [31] Bothwell TH, Finch CA. Iron metabolism. Boston: Little, Brown and Co; 1962.
- [32] Fischer DS, Price DC. A simple serum iron method using the new sensitive chromogen tripyridyl-s-triazine. *Clin Chem* 1964;10:21–31.
- [33] International Anemia Consultative Group. Measurement of iron status. A report of the International Anemia Consultative Group (INACG). Washington, DC: Nutrition Foundation; 1985.
- [34] CDC. Recommendations to prevent and control iron deficiency in the United States. *MMWR* 1998;47 (RR-3).
- [35] Cepeda-Lopez AC, Aeberli I, Zimmermann MB. Does obesity increase risk for iron deficiency? A review of the literature and the potential mechanisms. *Int J Vitam Nutr Res* 2010;80:263–70.
- [36] Hertrampf E, Cortés F, Erickson JD, Cayazzo M, Freire W, Bailey L. Consumption of folic acid-fortified bread improves folate status in women of reproductive age in Chile. *J Nutr* 2003;133:3166–9.
- [37] McClung JP, Karl JP. Iron deficiency and obesity: the contribution of inflammation and diminished iron absorption. *Nutr Rev* 2009;67:100–4.
- [38] Tussing-Humphreys LM, Nemeth E, Fantuzzi G, Freels S, Guzman G, Holterman AX, et al. Elevated systemic hepcidin and iron depletion in obese premenopausal females. *Obesity* 2010;18:1449–56.
- [39] Aaeribigbe O, Piza P, Vorster H, Kruger S. The relationship between iron status and adiposity in women from developing countries: a review. *Crit Rev Food Sci Nutr* 2014;54:553–60.
- [40] Ganz T. Hepcidin, a key regulator of iron metabolism and mediator of anemia of inflammation. *Blood* 2003;102:783–8.
- [41] Hintze K, Mc Clung JP. Hepcidin: a critical regulator of iron metabolism during hypoxia. *Adv Hematol* 2011;2011:1–7.
- [42] Rebolledo A, Vásquez M, del Canto B, Ruz M. Assessment of quality and adequacy of the diet of women from the Metropolitan Region of Chile [Evaluación de la calidad y suficiencia de la alimentación de un grupo de mujeres de la Región Metropolitana de Chile]. *Rev Chil Nutr* 2005;32:118–25.
- [43] Cepeda-Lopez AC, Osendarp SJ, Melse-Boonstra A, Aeberli I, Gonzalez-Salazar F, Feskens E, et al. Sharply high rates of iron deficiency in obese Mexican women and children are predicted by obesity-related inflammation rather than by differences in dietary iron intake. *Am J Clin Nutr* 2011;93:975–83.
- [44] Beard JL, Murray-Kolb LE, Rosales FJ, Solomons NW, Angelilli ML. Interpretation of serum ferritin concentrations as indicator of total-body iron stores in survey populations: the role of biomarkers for the acute phase response. *Am J Clin Nutr* 2006;84:1498–505.
- [45] Menzie CM, Yanoff LB, Denkinge BI, Mc Hugh T, Sebring NG, Calis KA, et al. Obesity-related hypoferraemia is not explained by differences in reported intake of heme and nonheme iron or intake of dietary factors that can affect iron absorption. *J Am Diet Assoc* 2008;108:145–8.
- [46] Tomkins A. Assessing micronutrient status in the presence of inflammation. *J Nutr* 2003;133(5 Suppl. 2):1649–55.
- [47] Cook JD, Flowers CH, Skikne BS. The quantitative assessment of body iron. *Blood* 2003;101:3359–64.