

The decreased molar ratio of phytate:zinc improved zinc nutriture in South Koreans for the past 30 years (1969-1998)

Mi-Sook Do, Ria-Ann R. Lomeda, Young-Eun Cho and In-Sook Kwun[§]

Department of Food Science and Nutrition, Andong National University, Andong, Kyungpook 760-749, South Korea

Received November 22, 2007; Revised December 3, 2007; Accepted December 11, 2007

Abstract

For the assessment of representative and longitudinal Zn nutriture in South Koreans, Zn, phytate and Ca intakes were determined using four consecutive years of food consumption data taken from Korean National Nutrition Survey Report (KNNSR) every 10 years during 1969-1998. The nutrient intake data are presented for large city and rural areas. Zn intake of South Koreans in both large city and rural areas was low during 1969-1988 having values between 4.5-5.6 mg/d, after then increased to 7.4 (91% Estimated Average Requirements for Koreans, EAR = 8.1 mg/d) and 6.7 mg/d (74% EAR) in 1998 in large city and rural areas, respectively. In 1968, Zn intake was unexpectedly higher in rural areas due to higher grain consumption, but since then until 1988 Zn intake was decreased and increased back in 1998. Food sources for Zn have shifted from plants to a variety of animal products. Phytate intake of South Koreans during 1969-1978 was high mainly due to the consumption of grains and soy products which are major phytate sources, but decreased in 1998. The molar ratios of phytate:Zn and millimolar ratio of phytate:Ca:Zn were decreased due to the decreased phytate intake in South Koreans, which implies higher zinc bioavailability. The study results suggest that Zn nutriture has improved by increased dietary Zn intakes and the decreased molar ratio of phytate:Zn in South Koreans in both large city and rural areas.

Key Words: Zn and phytate intake, Korean National Nutrition Survey Report (KNNSR), molar ratio of phytate:Zn, millimolar ratio of phytate:Ca:Zn, South Korean

Introduction

The dietary habits and nutritional adequacy of populations in developing countries may change in response to improved economic prosperity and global influences. A poor infrastructure and data management system in such countries, combined with a paucity of nutrient data for local food products, usually precludes a retrospective and comprehensive temporal analysis of changing nutritional intake. South Korea has emerged from being one of the poorest countries in the world during the 1960s to one of the top 10 world economic powers at the present time. In contrast to some other developing countries, reliable and comprehensive data on food intakes in different population groups have been collected periodically since 1969.

Although some developed western countries periodically report dietary Zn intake data from nationwide nutritional surveys (UK Food Standards Agency, 2004; USDHHS & USDA, 2005), there are few reliable reports of Zn intake in Asian developing countries. There are only some previous limited Asian studies, such as in South Korea (Kwun & Kwon, 2000) and in China (Ma *et al.*, 2007). The limited information on Zn intake is probably due to difficulties in accomplishing nutrient intake studies with large sample sizes in both cross-sectional and longitudinal studies. There is a paucity of values for the Zn

content of local staple foods, or some confounding factors for Zn absorption or different dietary sources on various places and countries (Lönnerdal, 2000).

The adequate nutritional intake of Zn actually depends both on the amount of Zn in the diet and on its availability. Among many factors to affect bioavailability of dietary Zn intake, phytate (inositol phosphate) has been known well to decrease Zn bioavailability (Rimbach *et al.*, 1995). Phytate is present at high levels in unrefined cereals, legumes, nuts, and seeds and most of the phosphorus in these foods is present mostly as phytate. Phytate contains negatively charged phosphate ligands which complex with positively charged ions such as Zn^{2+} , Ca^{2+} , Mg^{2+} and Fe^{2+} . Absorption of these metals in the small intestine is therefore inhibited due to their chelation by phytate. (Graf & Eaton, 1984; Sandstead, 1991). Asian countries, such as Korea, Japan and China, have been known to consume soybean products and various grains which contain large amount of phytate. Regarding the confounding factors for Zn bioavailability such as phytate, its influence should be evaluated in population groups whose diet is enriched with them (Fuglie, 2004).

In the present study, we assessed dietary Zn status in the South Korea populations and compared Zn intakes with requirement estimates to analyze the dietary Zn status in large city and rural areas over 30 years in South Koreans. The study aim was to

[§] Corresponding Author: In-Sook Kwun, Tel. +82-54-820-5917, Fax. 82-54-820-6188, Email. iskwn@andong.ac.kr

determine the changes in the dietary Zn intake and the pattern, and molar ratios of phytate:Zn of South Koreans over the past three decades. Millimolar ratios of phytate \times Ca:Zn was also assessed to indicate possible dietary strategies for improving Zn intake.

Again, since Zn deficiency is thought to be prevalent in South Korea, this study was focused to assess the change of Zn intake during years of rapid economic growth during 1969-1998.

Subjects and Methods

National Nutrition Survey Report for Koreans (KNNSR) (1969-1998)

To determine Zn nutritional assessment during the past three decades (1969-1998) in South Koreans, food consumption data were taken from the National Nutrition Survey Reports for Koreans (KNNSR) during the period 1969-1998 at 10 year intervals (1969, 1978, 1988 & 1998) (Ministry of Health & Welfare of Republic of Korea, 1971, 1980, 1990, 2000).

The survey was conducted every 2-4 years in the fall, around September, by the Korean Ministry of Health and Welfare and the Korean Nutrition Society. Each survey unit was composed of 20 households, and there were a total of 100 survey units which were composed of representative units of South Korea. This gives the representative sample of 2000 households from city and rural areas in different parts of the whole country. The representative households were selected using probability proportional and stratified multistage sampling. The civilian, non-institutionalized population of Korean for each household member was interviewed by the trained dietitians to determine food intakes on two consecutive weekdays using food records and dietary examinations. Each person's daily food intake in the sample household was adjusted as a percentage of the daily food intake of the normal male adult, whose daily food intake was given as 1.0. The normal male adult was defined as a person 172.0 cm tall, weighing 66 kg, aged 20-29 yr, and working at a medium level of labor (Korean Nutrition Society, 1995).

Assessment of Zn, Ca and phytate intake and comparison to dietary reference intakes for Koreans (KDRI)

The assessment of dietary intakes of Zn, Ca and phytate was described in our previous study (Kwon & Kwon, 2000). Daily Zn and Ca intakes were calculated from the representative foods reported in the KNNSR by using various food composition tables, databases, and literature values (Food and Drug Safety Section of Korean Ministry of Health and Welfare, 1966; Korean Dietetic Association, 1998; Korean National Rural Living Science Institute, 1996; Korean Nutrition Society, 2006; Lee *et al.*, 1998; US Department of Agriculture, 1992). In the present study, Zn assessment was updated using the recently analyzed Zn content of various Korean foods (Lee *et al.*, 1998). Zn values not

established in the Korean Food Composition Table were taken from the USA food composition tables (US Department of Agriculture, 1992) and other selected papers for Korean Food Analysis (Lee *et al.*, 1998). For food Zn and Ca values which were not cited in literature, substituted values for similar foods in the same food group were used. Zn or Ca value for each food item was multiplied by Zn or Ca contents per gram and summed all values up, which gives the average of Zn or Ca contents being consumed per day.

Phytate intakes were calculated using the phytate content of each food component and a cross-referenced index from the various literatures (Hall *et al.*, 1989; Morris & Ellis, 1980; Harland & Harland, 1980; Harland & Oberleas, 1977 & 1987; Lee *et al.*, 1998; Liebman & Landis, 1988; Lönerdal *et al.*, 1988; O'Dell *et al.*, 1972; Oberleas & Harland, 1981; Oberleas *et al.*, 1966; Sandstrom *et al.*, 1987). Particularly, phytate contents in Korean foods were calculated using the reported data (Nam, 2001) for local foods. Adjustments were made, when necessary, to take into account any known changes in phytate content arising from food processing and preparation methods.

Dietary Zn and Ca intakes were compared to the Dietary Reference Intakes for Koreans (KDRI) (Korean Nutrition Society, 2006). The newly established KDRI contains four subcategories, namely estimated average requirements (EAR), recommended intake (RI), adequate intake (AI) and tolerable upper intake level (UL). Of the four KDRI reference values, EAR which replaces the previous RDA, serves to assess adequacy of population intakes and it is the daily intake value needed for more than half (>50%) of the healthy subject group population. RI is generally used for individual nutrient assessment and it is set with the value of EAR plus twice the standard deviation. RI value is to meet the needs of 97-98% of individuals in a group, thus RI would be bigger nutrient intake value than EAR. For the group or population nutritional assessment, EAR would be more appropriate and RI can still be used for the comparison of nutrient intake. The values for Zn and Ca intake in KDRI are established for EAR, RI and UL only. In the present study, Zn and Ca intakes compared to EAR and RI as appropriate for adult males (20-29 years old), since this criteria is the same sex and age range as the KNNSR presented as per capita.

Assessment of major food items for Zn, Ca and phytate intakes

The relative importance of each food items and food groups with respect to Zn, Ca and phytate intake was established. The percentage contributions of each food item to the total daily nutrient intakes were calculated, and ranked to determine the relative importance of major food items for Zn, Ca and phytate intakes in South Koreans.

Assessment of molar ratio of phytate:Zn and millimolar ratio of phytate \times Ca:Zn

Table 1. Average Zn and Ca intakes in South Koreans over thirty years (1969-1998) using representative National Nutrition Survey Reports for South Koreans (KNNSR) and the comparison to the estimated average requirements (EAR) and the recommended intake (RI) ¹⁻³

Year	Zn intake (%EAR, %RI)		Ca intake (%EAR, %RI)		Phytate	
	Large city	Rural area	Large city	Rural area	Large city	Rural area
1969	4.5 (56, 45)	5.4 (67, 54)	195.6 (34, 28)	213.3 (37, 30)	965.2	1148.4
1978	4.8 (59, 48)	4.7 (58, 47)	247.9 (43, 35)	216.3 (37, 31)	990.1	1044.0
1988	5.6 (69, 56)	4.9 (60, 49)	364.3 (63, 52)	289.6 (50, 41)	843.1	902.3
1998	7.4 (91, 74)	6.7 (83, 67)	473.4 (82, 68)	420.6 (73, 60)	581.3	654.9

¹ Zn, Ca and phytate intakes are presented as mg/day/capita.

² Food consumption data for the calculation of daily Zn and Ca intakes were taken from the National Nutrition Survey Reports for South Koreans (KNNSR) as described in Methods for more details (Ministry of Health and Welfare of Republic of Korea, 1971, 1980, 1990, 2000)

³ EAR and RI values for nutrient intake comparison were used of 20-29 years old male, since KNNSR was reported as 'capita' who was set for 20-29 years old man. The values are 8.1 mg/d for EAR and 10 mg/d for RI for Zn and 580 mg/d for EAR and 700 mg/d for RI for Ca. EAR is set for the daily intake value needed for more than half percent (>50%) of the healthy subject group population and RI is set to meet the needs of almost all (97-98%) individuals in a group.

The daily molar ratio of phytate:Zn and millimolar ratio of phytate×Ca:Zn were calculated as follows; the molar intake of phytate (molecular weight, 660.1) was divided by the molar intake of Zn (molecular weight, 65.4). The millimolar ratio of phytate×Ca:Zn was estimated in a similar fashion using the millimolar intake of Zn, Ca (molecular weight, 40.1) and phytate.

Results

Zn, Ca and phytate intakes of South Koreans (1969-1998) and comparison to KDRI

A comparison of the daily intakes of Zn and Ca to KDRI (EAR and RI) is shown in Table 1. During the first two decades (1969-1988), Zn intake in large cities increased while Zn intake in rural areas decreased. Unexpectedly, Zn intake in 1969 was higher value in rural areas than the large cities (5.4 vs 4.5 mg/d/capita), but since then, from 1978 to 1998, the pattern was reversed as being higher value in large cities than in rural areas. However, Zn intake of South Koreans in 1998 in both areas was still lower than the expected Zn EAR for Koreans.

The daily Ca intake of South Koreans over the three decades (1969-1998) gradually increased in both the large city and rural areas by about two-fold. Ca intake in 1969 was a higher value in rural areas and reversed since then, which gives lower Ca intakes in rural areas than in large city areas, as was the case for Zn intake.

Molar ratio of phytate: Zn and phytate×Ca:Zn

The molar ratios for phytate:Zn and millimolar ratio of phytate×Ca:Zn for the South Korean diet are shown in Table

Table 2. Molar ratios of Zn, Ca and phytate in South Koreans¹.

Year	Phytate : Zn (molar)		Phytate x Ca : Zn (millimolar)	
	Large city	Rural area	Large city	Rural area
1969	21.3	21.1	103.7	112.1
1978	20.4	22.0	126.3	118.7
1988	14.9	18.2	135.5	131.8
1998	7.6	9.7	90.3	101.6

¹ The molar ratio of phytate:Zn was calculated as the mole of phytate intake (molecular weight, 660.1) was divided by the mole of Zn intake (molecular weight, 65.4). The millimolar ratio of phytate×Ca:Zn was estimated in a similar manner using the millimole of Zn, Ca (molecular weight, 40.1) and phytate intake.

2. Molar ratios of phytate:Zn over 30 years from 1969 to 1978 in large cities and rural areas were far greater than 15, a threshold value for relative risk of Zn deficiency (Gibson, 2006) and even equal or above 20, a value for critical Zn deficiency (Gibson, 1991). During 1969 to 1988, the ratio of phytate:Zn was about the same in both areas in each year. Notably, in 1998, the ratio of phytate:Zn in the large city (7.6 molar ratio) decreased, compared to those people living in rural area (9.7 molar ratio).

The suggested critical values for the millimolar ratio of phytate×Ca:Zn have been reported as >200 (Gibson, 2006). The millimolar ratios of phytate×Ca:Zn in large cities during the period 1969-1988 increased having 103-135.5 millimolar, however, the ratios decreased almost two-fold in 1998. The millimolar ratios of phytate×Ca:Zn is shown with a similar pattern to the molar ratio of phytate:Zn being observed, namely a lower ratio in the large city area than in the rural area.

Major food items for Zn, Ca and phytate intakes

The amounts and percentage contributions of each major food items to daily intake of Zn, Ca and phytate are shown in Table 3. For thirty years, Zn intake from plant food groups decreased, while Zn intake from animal groups increased. In 1969-1978, barley, rice and soybean were major sources of Zn. In 1988-1998, beef became the second major source of Zn intake, which was a minor source in 1969. The major contribution for Zn intake was rice for thirty years with decreasing contribution of 36% in 1969 to 20% in 1998. The major Ca source for over 30 years was anchovy and one-third of the daily Ca intake was provided by vegetables. In 1989-1998, the principal Ca source was milk, instead of grain products which was the main source in 1969-1878. Among the foods consumed by South Koreans for three decades, cereals and grain products supplied most of the dietary phytate (69-85%), followed by legumes, fruits, and seasonings. The high phytate-containing foods in the Korean diet were rice and soybean products, such as soybean paste, soybeans, soy sauce and tofu.

Discussion

This study presents the data for Zn intake of South Koreans over a 30 year period (1969-1998) since the National Nutrition

Table 3. Contributions of the major food items to Zn, Ca and phytate intakes in South Koreans in 1969-1998 [mg/d/capita (% daily total intake)]

1969						
Rank	Zn		Ca		Phytate	
1	Barley	2.10 (35.8)	Anchovy	58.05 (24.8)	Rice	529.3 (51.3)
2	Rice	1.70 (29.0)	Leafy radish kimchi	28.43 (12.2)	Barley	216.9 (21.0)
3	Red pepper paste	0.30 (4.8)	Soybean	26.95 (11.5)	Soy sauce	55.9 (5.4)
4	Soybean paste	0.20 (3.6)	Pumpkin	14.90 (6.4)	Wheat flour	52.8 (5.1)
5	Wheat flour	0.18 (3.1)	Barley	14.16 (6.1)	Potato	41.0 (4.0)
6	Green pepper	0.17 (2.9)	Rice	12.65 (5.4)	Soybean	32.9 (3.2)
7	Potato	0.15 (2.6)	Soybean paste	12.26 (5.2)	Soybean paste	24.9 (2.4)
8	Pumpkin	0.15 (2.6)	Korean cabbage	8.93 (3.8)	Sesame toasted	21.0 (2.0)
9	Soybean	0.11 (1.9)	Korean cabbage kimchi	7.85 (3.4)	Garlic	20.2 (2.0)
10	Beef	0.10 (1.7)	Wheat	5.89 (2.5)	Small red bean	11.0 (1.1)
	<i>Total</i>	<i>5.16 (88.0)</i>	<i>Total</i>	<i>190.1 (81.3)</i>	<i>Total</i>	<i>1005.9 (97.5)</i>
1978						
Rank	Zn		Ca		Phytate	
1	Rice	1.90 (39.7)	Barley	51.57 (23.0)	Rice	600.8 (55.8)
2	Barley	0.60 (11.9)	Anchovy	29.67 (13.2)	Soybean	150.7 (14.0)
3	Soybean	0.50 (10.4)	Pumpkin	23.05 (10.3)	Barley	103.8 (9.6)
4	Beef	0.40 (9.1)	Black pepper	15.90 (7.1)	Wheat flour	44.2 (4.1)
5	Soybean paste	0.30 (6.1)	Leafy radish kimchi	13.40 (6.0)	Soybean paste	34.9 (3.2)
6	Granulated ark shell	0.20 (4.5)	Rice	11.14 (5.0)	Soy sauce	26.2 (2.4)
7	Wheat flour	0.15 (3.1)	Soybean paste	8.74 (3.9)	Garlic	12.8 (1.2)
8	Egg	0.13 (2.7)	Loaches	8.10 (3.6)	Leafy radish kimchi	12.2 (1.1)
9	Pumpkin	0.10 (2.0)	Wheat	7.04 (3.1)	Potato	10.9 (1.0)
10	Leaf radish kimchi	0.07 (1.4)	Soysauce	6.99 (3.1)	Pumpkin	4.5 (0.4)
	<i>Total</i>	<i>4.35 (90.9)</i>	<i>Total</i>	<i>175.6 (78.3)</i>	<i>Total</i>	<i>1001.0 (93.0)</i>
1988						
Rank	Zn		Ca		Phytate	
1	Rice	2.00 (37.5)	Anchovy	67.1 (19.7)	Rice	632.7 (73.8)
2	Beef	0.80 (15.8)	Milk	50.4 (14.8)	Soybean curd	74.4 (8.7)
3	Pork	0.30 (5.7)	Korean cabbage kimchi	44.9 (13.2)	Soybean	36.0 (4.2)
4	Egg	0.24 (4.5)	Tofu	26.7 (7.9)	Wheat flour	18.7 (2.2)
5	Milk	0.19 (3.6)	Radish	14.5 (4.3)	Soy sauce	16.5 (1.9)
6	Mackerel	0.13 (2.5)	Rice	13.3 (3.9)	Garlic	16.0 (1.9)
7	Soybean curd	0.13 (2.4)	Laver	10.1 (3.0)	Soybean paste	15.0 (1.8)
8	Soybean paste	0.13 (2.4)	Welsh onion	9.4 (2.8)	Barley	9.5 (1.1)
9	Soybean	0.12 (2.2)	Egg	7.2 (2.1)	Korean cabbage kimchi	8.8 (1.0)
10	Korean cabbage kimchi	0.08 (1.7)	Cabbage kimchi	6.7 (2.0)	Potato	5.6 (0.7)
	<i>Total</i>	<i>4.12 (78.3)</i>	<i>Total</i>	<i>250.3 (73.7)</i>	<i>Total</i>	<i>833.2 (97.2)</i>
1998						
Rank	Zn		Ca		Phytate	
1	Rice	1.45 (20.0)	Milk	75.0 (16.1)	Rice	616.6 (20.7)
2	Beef	1.06 (14.7)	Anchovy	38.7 (8.3)	Garlic	382.8 (12.8)
3	Pork	0.47 (6.5)	Kimchi	37.8 (8.1)	Soybean paste	218.4 (7.3)
4	Milk	0.29 (4.0)	Soybean curd	25.2 (5.4)	Potato	210.8 (7.1)
5	Eggs	0.28 (3.9)	Fish paste	14.6 (3.1)	Barley	187.0 (6.3)
6	Kimchi	0.15 (2.0)	Radish	13.2 (2.8)	Soybean curd	127.7 (4.3)
7	Green tea beverage	0.15 (2.0)	Rice	9.7 (2.1)	Wheat flour	93.8 (3.1)
8	Soybean	0.14 (1.9)	Welsh onion	9.6 (2.1)	Glutinous rice	85.4 (2.9)
9	Bread	0.13 (1.8)	Salt fermented	9.6 (2.1)	Korean cabbage kimchi	75.0 (2.5)
10	Salt fermented	0.12 (1.7)	Cracker	9.4 (2.0)	Foxtail millet	69.7 (2.3)
	<i>Total</i>	<i>4.24 (58.5)</i>	<i>Total</i>	<i>242.8 (52.1)</i>	<i>Total</i>	<i>2067.2 (69.3)</i>

Note : Values were calculated from the daily food intakes in 1969 to 1998 Korean National Nutrition Survey Reports (KNNSR) in nationwide in South Korea.

Survey for Koreans (KNNS) has been established since 1969 in South Korea. To our knowledge, representative Zn intake of South Koreans both in large city and rural area over longitudinal periods has not previously been reported. We previously reported the representative Zn intake of South Koreans in large cities and rural areas for cross-sectional time point at 1995 using KNNS Report (Kwun & Kwon, 2000). The implications of our previous and present results are of considerable nutritional significance for South Koreans and perhaps for populations of other developing countries. Importantly, this study presents representative Zn intake information for South Koreans using the data from the nationwide Korean National Nutrition Survey (KNNS) Reports, rather than from the Zn intake of selected Korean people. Furthermore, we compared Zn intake in relation to the Dietary Reference Intake values for Koreans (KDRI) which were newly established in 2005. The results broaden and update the information from our previous study, which also assessed the dietary molar ratios of phytate:Zn and millimolar ratio of phytate:Ca:Zn of South Koreans (Kwun & Kwon, 2000).

The trend of Zn intake in South Koreans

Since the early 1970s, South Korea has experienced one of the fastest economic growth rates recorded for any country in the world in recent history. The change in economic fortunes has brought profound changes in lifestyle and nutritional habits. The traditional Korean diet was based on plant foods, with high intakes of grain products and legumes and relatively low intakes of milk and meats. The changes in diet are characterized by increasing contributions of animal foods like meat, fish and their products. The variety of traditional foods, such as rice and grains, kimchi (fermented oriental cabbage), soybean and its products, red pepper powder and paste, has however been retained and intakes have quantitatively increased. This trend in dietary habits is indicated in the present study, since Zn, Ca and phytate intakes have increased over the last thirty years.

The data analyzed by this study highlight several implications on Zn intake for past 30 years in South Koreans. Firstly, the increase in Zn intake (from dietary calculations using food consumption data) was 2.9 mg/d over the past three decades (4.5 mg/d to 7.4 mg/d), and this increase was greatest during the last decade since the 1990s. Secondly, the apparent dietary Zn intake of South Koreans in the late 1990s was approaching that of Western countries, and Zn food sources were shifting from plant foods to a variety of animal foods. Thirdly, Zn and phytate intakes were higher in rural areas than in large city areas due to higher intake in whole grain in rural areas in 1969, but it was reversed in thirty years later in 1998 due to higher intake in animal food in the large city. *Fourthly*, even though quantitative Zn intake, phytate intake was still moderately high which may cause adverse effects on Zn nutriture due to the high molar ratio of phytate:Zn and millimolar ratio of phytate:Ca:Zn.

The recommended dietary Zn intake level for South Koreans

has decreased over time, from an RDA of 15mg/d for men and 12mg/d for women, which was first established in 1995 (Korean Nutrition Society, 1995), and 10 mg/d for men and 8 mg/d for women, which is the present KDRI (Korean Nutrition Society, 2006). These values can be compared to the US DRI of 9.4 mg/d for adult men (National Academy Science, US Dietary Reference Intakes, 2002; UK Food Standards Agency, 2004) and the recommended nutrient intake (RNI) for the United Kingdom of 9.5 mg/d. In the present study, Zn intake of South Koreans was compared to the EAR and the RI of the Dietary Reference Intake for Koreans (Korean Nutrition Society, 2005). In 1998, Zn intake of South Koreans in large cities (7.4 mg/d) was 91% of estimated average requirement (EAR, 8.1 mg/d) and 74% of recommended intake (RI, 10 mg/d). Since the KDRI for Zn has decreased, more South Koreans are meeting or exceeding this level. However, during the period of 1969-1988, Zn intake of South Koreans was around 4.5-5.6 mg/d which is equivalent to the low levels (3.7-5.4 mg/d) reported for the developing countries (Gibson, 2006). However, during the decade of late 1998, Zn intake in South Koreans markedly increased to 7.4 mg/d, which was same level to that of UK women (7.4 mg/d), but lower than that of UK adult men (10.2 mg/d) in 2000/2001 (UK Food Standards Agency, 2004), and also lower than that of normal healthy Americans (11.9-12.3 mg/d). Zn intake of South Koreans is lower than the Zn intake level reported in China (10.6 mg/d) for the 2002 China Nationwide Nutrition and Health Survey, which uses almost the same nutritional survey scheme of the KNNS (Ma *et al.*, 2006). However, Zn intake of Koreans in 1998 was higher than in most developing countries, such as Thailand (4.4 mg/d), Egypt (5.2 mg/d) or Mexico (5.4 mg/d) (Gibson, 2006). Therefore, the study results show that the Zn intake in South Korea has been improving over the past three decades from poor Zn intake levels towards meeting the optimal Zn reference intake level. In the present study, the Zn intake (7.4 mg/d) in 1998 was slightly lower than in the previous report for 1995 (10.1 mg/d) (Kwun & Kwon, 2000).

Zn and phytate intakes of South Koreans in 1969 were higher in rural areas than in large city areas, however, this pattern had reversed by 1998, when the highest levels were recorded in large city areas (Table 1). The pattern implies that in the 1960s, most of the Zn food sources were plant-foods which also contain higher phytate. Cereals and grains are the major sources of Zn and phytate which accounts for 69 and 77% of the recommended daily intake for Koreans in 1969, respectively. The pattern of reasonably high Zn and phytate intake in plant-food oriented diets has been shown in previous studies of countries where plant food is the major dietary supply, (9.0 and 2254 mg/d) (Gibson, 2006; Fitzgerald *et al.*, 1993), Malawi (6.0 and 1617 mg/d) or Mexico (5.4 and 1666 mg/d) (Gibson, 2006). In South Koreans, during the 1960s, Zn and phytate intakes were higher in rural areas where more plant foods were consumed. As the economic status of the country increased the pattern for Zn was reversed probably in part due to an increase in animal food intake in urban areas.

Zn Deficiency based on phytate:Zn molar ratio phytate×Ca:Zn millimolar ratio

The moderately high phytate intake values of South Koreans in this study are possibly due to the following reasons. Over the past decades, the major grains in the Korean diet have gradually changed from milled white rice to less-milled whole or partial-milled various grains, which have higher phytate content. This trend is largely a consequence of increased health concern in urban populations even in rural area as their economic status improves. Another reason for high phytate intake which is specific for South Koreans is the consumption of soybean and its products, which is high even when compared to the Chinese (Ma *et al.*, 2005; Ma *et al.*, 2007). Koreans eat considerably more Zn-absorption inhibiting soy products (such as soy flour, soy protein isolate or tofu processed with calcium sulfate) which reduce Zn bioavailability, as compared to processed-soy products (such as soy sauce, natto, or miso etc.) which inhibit Zn absorption less and are more commonly eaten by Chinese or Japanese. In addition, the database for the phytate content of Korean foods is not yet completely established so some phytate values used for this study are substitute values which may bias the results towards an increase in the apparent intake of phytate. Even accounting for this, it is likely that high phytate consumption among South Koreans is a major adverse factor for optimal Zn nutriture in South Koreans.

Decreased phytate intake may result in a decrease in the molar ratio of phytate:Zn and millimolar ratio of phytate×Ca:Zn. Since Korean diet shifted from plant food groups to animal food groups during 1988 to 1998 due to and the improving economic status, this would be the reason for the decreased ratio of phytate×Ca:Zn. The decreased molar ratios of phytate, Ca and Zn would have contributed to a positive effect on Zn absorption, surpassing critical thresholds of Zn deficiency. The results of the present study have shown that the common diet of South Koreans has lowered phytate:Zn molar and phytate×Ca:Zn millimolar ratios, which indicates the Koreans might not be at risk from Zn deficiency since the dietary intake of Zn is improving and phytate intake decreased.

In conclusion, this study showed that dietary Zn intake in South Koreans over the past thirty years (1969-1998) has improved both as regards the dietary recommendation level, and also the variety of food sources. During 1998, however, there is still a relatively high risk of Zn deficiency among South Koreans due to the composition of phytate-rich foods, such as whole grains and soybean products, which is quite specific for Korean diets and contributes to the high molar ratios of phytate:Zn and phytate×Ca:Zn. The study reports the dietary Zn, Ca and phytate status that serves as a meaningful reference in nutritional Zn pattern among South Koreans for a longitudinal period. Also, the study suggests strategies for improving consumption of phytate-rich foods in relation to the reported pattern of molar ratios of phytate:Zn and millimolar ratio of phytate×Ca:Zn for the past 30 years.

Acknowledgement

This study was supported by ANU 2004 Research Grant. None of the authors have any conflict of interest regarding the contents of this paper.

Literature cited

- Fitzgerald SL, Gibson RS, Quan de Serrano J, Portocarrero L, Vasquez A, de Zepeda E, Lopez-Palacios CY, Thompson LU, Stephen AM, Solomons NW (1993) Trace element intakes and dietary phytate/Zn and Ca x phytate/Zn millimolar ratios of periurban Guatemalan women during the third trimester of pregnancy. *Am J Clin Nutr* 57:195-201.
- Fuglie KO (2004) Challenging Benet's Law: the new economics of starchy staples in Asia. *Food Policy* 29:187-202.
- Gibson RS, Smit Vederkooy PD & Thompson L (1991) Dietary phytate x Ca/Zn millimolar ratios and Zn nutriture in some Ontario preschool children. *Biol. Trace Element Res Biol Trace Ele Res* 30, 87-94.
- Gibson RS (2006) Zn: the missing link in combating micronutrient malnutrition in developing countries. *Proc Nutr Soc* 65, 51-60.
- Graf E & Eaton JW (1984) Effects of Phytate on Mineral Bioavailability in Mice. *J Nutr* 114:1192-1198
- Hall MJ, Downs L, Ene MD & Farah D (1989) Effect of reduced phytate wheat bran on Zn absorption. *Eur J Clin Nutr* 43, 431-440.
- Harland BF & Harland J (1980) Fermentative reduction of phytate in rye, white, and whole wheat breads. *Cereal Chem.* 57, 226-229.
- Harland BF & Oberleas D (1977) A modified method for phytate analysis using an ion-exchange procedure: application to textured vegetable proteins. *Cereal Chem* 54, 827-830.
- Harland BF & Oberleas D (1987) Phytate in foods. *World Rev Nutr Diet* 52, 235-59.
- Korean Dietetic Association (1998) Nutrition Anywhere Database 1st edition. Seoul, Republic of Korea.
- Korean Ministry of Health and Welfare (1996) *Korean Food Composition Table*. Food and Drug Safety Section.
- Korean National Rural Living Science Institute (1996) *Korean Food Composition Table* Fifth revision.
- Korean Nutrition Society (1995) *Recommended Dietary Allowances for Koreans*, 6th rev. ed., Seoul: The Korean Nutrition Society.
- Korean Nutrition Society (2000) *Recommended Dietary Allowances for Koreans*, 7th rev. ed., Seoul: The Korean Nutrition Society.
- Korean Nutrition Society (2006) Computer Aided Nutritional (CAN-Pro) Analysis Program Software, version 3.0 for 2005 Dietary Reference Intakes for Koreans (2005 KDRI).
- Kwon IS & Kwon CS (2000). Dietary molar ratios of phytate : Zn and millimolar ratios of phytate x Ca : Zn in South Koreans. *Biol Trace Ele Res* 75, 29-41.
- Lee JY, Paik HY & Joong H (1998) Supplementation of Zn nutrient database and evaluation of Zn intake of Korean adults living in rural area. *Korean Journal of Nutrition* 31, 1324-1337.
- Liebman M & Landis W (1988) Comparison to Ca provided by cheese, and to assess the overall Zn bioavailability of tofu-compared to cheese-containing diets. *Nutr Res* 47, 6-14.
- Lönnerdal B, Hendrickx D, Burns RA & Keen CL (1988) Effect of phytate removal on Zn absorption from soy formula. *Am J Clin Nutr.* 48, 1301-1306.

- Lönnerdal B (2000) Dietary factors influencing Zn absorption. *J Nutr* 130 (suppl) 1378S-83S.
- Ma G, Jin Y, Piao J, Kok F, Guusje B & Jacobsen E (2005) Phytate, calcium, iron and Zn contents and their molar ratios in foods commonly consumed in China. *J Agric Food Chem* 53:19285-19290.
- Ma G, Li Y, Jin Y, Zhai F, Kok FJ & Yang X (2007) Phytate intake and molar ratios of phytate to Zn, iron and calcium in the diets of people in China. *Eur J Clin Nutr* advance online publication, 23 August 2006.
- Ministry of Health and Welfare of Republic of Korea & Korean Nutrition Society (1971, 1980, 1990, 2000) National Nutrition Survey Reports. Ministry of Health and Welfare of Republic of Korea & Korean Nutrition Society. Seoul, Republic of Korea.
- Morris ER & Ellis R (1980) Effect of dietary phytate/Zn molar ratio on growth and bone Zn response of rats fed semipurified diets. *J Nutr* 110, 1037-1039.
- Nam GY (2001) Analysis of phytate content in Koreans food items and effect of cooking on phytate content and zinc bioavailability in Korean diet. MS Thesis, Seoul National University.
- National Academy Science (2002) Dietary Reference Intakes (DRIs) Report (USA). <http://www.nap.edu>.
- O'Dell BL, Burpo CE & Savage JE (1972) Evaluation of Zn availability in foodstuffs of plant and animal origin. *J Nutr* 102, 653-660.
- Oberleas D, Muhrer ME & O'Dell BL (1966) *The availability of Zn from foodstuffs, in Zn metabolism*, pp. 225-238 [AS Prasad, editor] Springfield: Academic Press.
- Oberleas D & Harland BF (1981) Phytate content of foods: Effect on dietary Zn bioavailability. *J Am Diet Assoc* 79, 433-436.
- Rimbach G, Brandt K, Most E & Pallanf J (1995) Supplemental phytic acid and microbial phytase change zinc bioavailability and cadmium accumulation in growing rats. *J Trace Elem Med Biol* 9:117-122.
- Sandstead HH (1991) Assessment of zinc nutriture. *J Lab Clin Med* 118:299-300.
- Sandstrom B, Almgren A, Kivisto B & Cederblad A (1987) Zn absorption in humans from meals based on rye, barley, oatmeal, triticale and whole wheat. *J Nutr* 117, 1898-1902.
- US Department of Agriculture (1976-92) *Composition of foods* (Agriculture Handbook, No. 8.1-8.21).
- U.S. Department of Health and Human Services and U.S. Department of Agriculture (2005) Dietary Guidelines for Americans, 6th Edition, Washington, DC: U.S. Government Printing Office, January 2005.
- UK Food Standards Agency and the Departments of Health by the Office for National Statistics and Medical Research Council Human Nutrition Research (2004) The National Diet & Nutrition Survey: adults aged 19 to 64 years, Volume 5. London: TSO.