Original Article

Trends and Nutritional Status for Magnesium in Taiwan from NAHSIT 1993 to 2008

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Data from nationwide population-based nutrition surveys in Taiwan were used to investigate trends and nutritional status for magnesium from 1993 to 2008. Dietary magnesium intake was estimated from 24-hour dietary recalls. Serum and urinary magnesium were also measured. In Nutrition and Health Survey in Taiwan (NAHSIT) 2005-2008, average magnesium intake was 305 mg and 259 mg for adult males and females, respectively, which is equivalent to 82-85% of relevant Taiwanese Dietary Reference Intakes (DRIs). After correcting intra-individual variation, 74-81% of adult subjects' dietary magnesium was estimated as sub-optimal. Mean serum magnesium concentration was 0.866 mmol/L and 0.861 mmol/L for the males and females, respectively. The prevalence of low serum magnesium (<0.8 mmol/L) was 12.3% and 23.7% for the males and females, respectively. There was positive association among dietary magnesium, blood magnesium, and urinary magnesium/creatinine ratio. From NAHSIT 1993-1996 to NAHSIT 2005-2008, dietary magnesium significantly increased (p<0.05), the blood magnesium and urinary magnesium/creatinine ratio decreased (p<0.05). The findings suggest that the relationships between dietary magnesium and biochemical markers among different nutrition and health surveys are not straightforward and need to be further clarified.

Key Words: nutrition and health survey in Taiwan (NAHSIT), nutrition status of magnesium, magnesium intake, blood magnesium, urinary magnesium/creatinine ratio

INTRODUCTION

Magnesium is an essential mineral in the human body. In healthy individuals, the red blood cell magnesium level is around 2.3-3.1 mmol/L and the serum magnesium concentration is around 0.75-0.95 mmol/L (1.8-2.3 mg/dL). Unless there is a serious lack of magnesium, the concentration of serum magnesium and red blood cell magnesium do not decline. The detailed mechanism of blood magnesium homeostasis so far remains unknown, which includes absorption through the intestinal tract, excretion from kidney, cation circulation within membrane, and hormonal regulation.[1]

The absorption rate of dietary magnesium ranges from 40% to 60%, depending on the amount of dietary magnesium. When dietary magnesium intake is lower than 24 mg/d, the absorption rate would reach up to 75%; yet, when dietary intake is above 600 mg/d, the absorption rate may be reduced to 25%.[2] Excretion of urinary magnesium, calcium and other minerals' have been found to be significantly associated with intake, indicating that the amount excreted reflects the intake.[3] In addition, amino acids and lactose will facilitate the absorption of magnesium; but too much phosphorus, oxalic acid, phytic acid and dietary fiber will reduce absorption.[4-7] The kidneys play an important role in regulating magnesium homeostasis and is a main discharge channel for absorbed magnesium. The daily excretion of magnesium is about 2-5 mol.[8] When dietary magnesium intake is low, the efficiency of kidney reabsorption will increase. In addition, high level of alcohol assumption or use of diuretics treatment increases the urinary magnesium excretion.[9]

The results from 1999-2000 Nutrition and Health Survey in Taiwan (NAHSIT) showed that among 1911 subjects aged 65 years and older, the average magnesium intake was 250 mg and 216 mg for males and females, respectively, which was equivalent to 68-70% of Taiwan Dietary Reference Intakes (DRIs) in Taiwan.[10,11] Approximately 8.0-9.1% of the Taiwanese elderly were magnesium deficient when <0.8 mmol/L was used as a cut-off. If the concentration of blood magnesium in the elderly is below 0.863 mmol/L, the risk ratio of comorbidity with diabetes would increase 3.25 fold, indicating that low blood magnesium may be associated with increase risk of diabetes. Although diet was the major

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source for blood magnesium, no association was found between dietary magnesium and blood magnesium concentration among previous surveys in Taiwan.[10] One single survey might not be able to demonstrate the profound relationship; however, if the trends of magnesium status in terms of diet, blood and urinary were compared among three surveys over the past decade in Taiwan, associations maybe found.

MATERIALS AND METHODS

Subjects and data source

The 2005-2008 Nutrition and Health Survey in Taiwan (NAHSIT 2005-2008) was a government-sponsored survey in which 24-h dietary recall and health status assessment were carried out.[12,13] This survey used a multi-staged stratified sampling method. The 358 counties and cities in Taiwan were divided into five strata based on geographical location and the population density. In each stratum, three stages of sampling were carried out. Then, in each stratum study subjects were sampled according to gender (males and females) and age.[13] Dietary magnesium intake were estimated by the recall data gathered from 2,911 subjects aged 19 years and older who had completed the dietary assessment. Serum and urinary magnesium concentrations were calculated from data obtained from subjects who had biochemical measurements.

Serum magnesium analysis

The serum magnesium concentration was measured with the colorimetric method by Roche Cobas Integra 800. The principle of using colorimetric assay involves xylidyblue reaction with blood magnesium which forms an alkaline complex with absorption at 520 nm. The amount of serum magnesium is positively correlated with the formation of this alkaline complex. The Glycoletherdiamine-N, N, N', N'-tetraacetic acid (GEDTA) was used to avoid calcium interference.[14] The diagnostic criterion for magnesium deficiency was blood magnesium levels below 0.8 mmol/L. Urinary magnesium concentration was measured by the same method as serum magnesium. The quantitative determination of urinary creatinine was measured by the Kinetic colour test (Integra 800, Roche Diagnostics). Creatinine forms a yellow-orange coloured compound with picric acid in an alkaline medium. The rate of change in absorbance at 505 nm is proportional to the creatinine concentration in the sample.[15] Urinary magnesium/creatinine ratio (mmol/L: mmol/L) was then calculate to represent urinary magnesium status.

Statistical analysis

Gender differences were assessed using the t-test, age and strata group differences analyzed with ANOVA. Estimates were expressed as either mean ± standard error or as percentages. Pearson correlation was used to assess the correlation between dietary magnesium intake, serum magnesium and the ratio of urinary magnesium to creatinine. Linear regression was used to evaluate trends across age groups and three NAHSITs. SAS (version 9.2) and SUDAAN (version 10.0) software were used for statistical analysis.[16,17] All variables were weighted to represent the general Taiwanese population. The percentage of dietary magnesium below DRIs was adjusted by inter-individual to inter-individual variance ratio.[18] The level for statistical significance was set at $p<0.05$ for all tests.

RESULTS

Dietary intake of magnesium in NAHSIT 2005-2008

Dietary intake of magnesium by gender and age was presented in Table 1. Total subjects were 2,911, with 1447 males and 1464 females aged 19 years and older. The average daily dietary intake of magnesium were 305 mg for males and 259 mg for females ($p=0.001$), which is equivalent to 85% and 82% of the DRIs, respectively. Seventy-four percent of males and eighty-one percent of females had daily dietary magnesium intake below the DRIs level. Males had a significant higher dietary magnesium intake than females at every age group. Both genders had the highest magnesium intake in the age group of 45 to 64 years, and the lowest value in age interval of 65 years and older. Mean daily dietary intake of magnesium by stratum and gender was listed in Table 2. Among the five geographic strata of Taiwan (North 1st, North 2nd, Central, Southern and Eastern), the range of daily dietary magnesium intake was between 279 to 329 mg for males, and between 223 to 293 mg for females. Compared with North 1st area, people in the Central area, and females in North 2nd and East Coast area had a significant lower value of daily dietary magnesium intake. When comparing three specific areas (Hakka, Mountainous and Penghu) with five geographic areas of Taiwan, the people in the Mountainous area were found to have a significant lower value of daily dietary magnesium intake (male/female: 248 mg/205 mg) than the average intake of the total population.

Blood magnesium and urinary magnesium status in NAHSIT 2005-2008

Table 3 represented the serum magnesium concentration by age and gender. The mean concentration for serum magnesium was 0.861 and 0.866 mmol/L for females and males, respectively. No significant difference was found between gender or among age groups. Using serum

Table 1. Mean daily dietary intake of magnesium by gender and age in NAHSIT 2005-2008

Age (Years)	Male				Female			
	N	Means (mg)	% DRIs	<DRIs (%)	N	Means (mg)	% DRIs	<DRIs (%)
All	1447	305	85	74	1464	259†	82	81
19-44	485	299	83	76	489	253†	80	85
45-64	481	329	91	65	490	282†‡	90‡	71
65+	481	279†§	78§	87	485	227†‡§	72‡§	93

Mean and SE for each age group were estimated, using SUDAAN. The t-test was assessed between gender in same age group and ANOVA was assessed among age goup. †significant difference (p value <0.05) when compared to male in same age group. ‡significant difference ($p<0.05$) when compared to 19-44 age group. §significant difference ($p<0.05$) when compared the group to 45-64 age group.

Table 2. Daily dietary intake of magnesium by stratum in NAHSIT 2005-2008

IV Southern Stratum	Male				Female			
	N	Means (mg)	%DRIs	<DRIs (%)	N	Means (mg)	%DRIs	<DRIs (%)
Total	1447	305‡	85	74	1464	259	82	81
I Northern 1st	290	323	90	66	298	293	93	65
II Northern 2nd	292	329‡	92‡	64	296	253†	80†	85
III Central	289	279†‡	78†	86	292	223†	71†	93
IV Southern	288	300	83	86	288	256	81	84
V Eastern	288	293‡	81	82	290	243†	77†	85
VI Hakka	298	296‡	82	80	296	261	83	82
VII Mountainous	284	248§	69§	88	288	205§	65§	96
VIII PengHu Is	294	319‡	89‡	72	295	236	75	90

Values for each age group were expressed as mean ± SE, percent and weighted with SUDAAN and the ANOVA was assessed among age group.
†significant difference (p<0.05) when compared the group II-V to I.
‡significant difference (p<0.05) between gender in same area group.
§significant difference (p<0.05) when compared the group VI-VIII to total population.

Table 3. Serum magnesium concentration by age and gender in NAHSIT 2005-2008

Age (Years)	Male		Female		p Value
	N	Mean±SE (mmol/L)	N	Mean±SE (mmol/L)	
All	385	0.866±0.011	414	0.861±0.013	0.330
19-44	99	0.865±0.011	121	0.853±0.014	0.127
45-64	137	0.866±0.014	153	0.876±0.014	0.207
65+	149	0.870±0.013	140	0.856±0.017	0.210
p trend		0.704		0.826	

Mean and SE for each age group were estimated, using SUDAAN. The t-test was assessed between gender. p value <0.05 indicated significant difference between genders, and p trend was analyzed for age effort.

Table 4. The prevalence of magnesium deficiency by age and gender in NAHSIT 2005-2008

Gender	Age (years)	N	<0.8 mmol/L	0.8-1.0 mmol/L	>1.0 mmol/L
				%	
Male	all	385	12.3	84.6	3.1
	19-44	99	6.9	90.4	2.7
	45-64	137	17.1‡	79.1‡	3.8
	65+	149	19.0‡§	78.1‡	2.9
	p rend		0.0046	0.0062	0.9146
Female	all	414	23.7†	72.9†	3.4
	19-44	121	26.4†	72.8†	0.9
	45-64	153	18.4	74.4	7.2‡
	65+	140	25.7	70.0	4.3
	p trend		0.901	0.644	0.149

Mean and SE for each age group were estimated, using SUDAAN. The t-test were assessed between gender in same age group and ANOVA was used to assessed difference among age group.†significant difference(p value <0.05) when compared to male in same age group. ‡significant difference (p<0.05) when compared to 19-44 age group. §significant difference (p<0.05) when compared the group to 45-64 age group.

magnesium concentration below 0.8 mmol/L as an indicator for deficiency, prevalence of magnesium deficiency was 12.3% for males and 23.7% for females (p<0.05) (Table 4). The prevalence of magnesium deficiency for males augmented as age increased (p trend =0.005). In the age group of 19 to 44 years old, females (26.4%) had a significant higher prevalence of magnesium deficiency than males (6.9%). The ratio of urinary magnesium to creatinine by age and gender was presented in Table 5. The mean of urinary magnesium/creatinine ratio was 0.310 for males and 0.435 for females. Females had significant higher ratios than males (p<0.001) in all age groups. For both genders, the ratio was augmented as age increased (p trend <0.001). Table 6 showed correlation coefficients between dietary magnesium intake, serum magnesium and urinary magnesium/creatinine ratio. There was a positive correlation between dietary magnesium intake and serum magnesium concentrations (γ=0.081, p=0.023), dietary magnesium intake and urinary magnesium/ creatinine ratio (γ=0.083, p=0.019) for all samples; and similar association were seen in each genders. Nevertheless, the correlation coefficient (γ) were quite low and not significant between serum magnesium concentrations and urinary magnesium/creatinine ratios.

Trends in nutritional status of magnesium from NAHSIT 1993-1996 to 2005-2008

Three populations representative NAHSITs between 1993 and 2008 (NAHSIT 1993-1996, NAHSIT 1999-2000 and NAHSIT 2005-2008) were used to analyze the magnesium status over the past decade in Taiwan. Trend in daily dietary intake of magnesium by age and gender was presented in Figure 1. From NAHSIT 1993-1996 to NAHSIT 2005-2008, the dietary magnesium intake increased for both genders and in all age groups. The percentages of individuals meeting the dietary magnesium DRIs showed a similar trend by age and gender from 1993 to 2008. For males in the 45-64 years age group, and females in 19-44 years and 45-64 years age groups, the value of dietary magnesium intake and percentage of individuals meeting dietary magnesium DRIs in NAHSIT 2005-2008 were significantly higher than those in NAHSIT 1993-1996 (p<0.05).

Table 5. Ratio of urinary magnesium to creatinine by age and gender in NAHSIT 2005-2008

Age (years)	Male		Female		p Value
	N	Mean±SE	N	Mean±SE	
All	385	0.310±0.009	414	0.435±0.009	<0.001
19-44	99	0.241±0.012	121	0.372±0.014	<0.001
45-64	137	0.366±0.020‡	153	0.499±0.016‡	<0.001
65+	149	0.398±0.018‡§	140	0.540±0.013‡§	<0.001
p trend	<0.001		<0.001		

Mean and SE (mmol/L:mmol/L) for each age group were estimated, using SUDAAN. The t-test were assessed group and ANOVA was used to assessed difference among age group. The p value was compared between gender in same age group and p-trend analyzed with age effort. ‡significant difference (p<0.05) when compared to 19-44 age group. §significant difference (p<0.05) when compared the group to 45-64 age group.

Table 6. Correlation between dietary magnesium intake, serum magnesium and ratio of urine magnesium to creatinine in NAHSIT 2005-2008

Variables	Daily Mg intake (mg)	Serum Mg (mmol/L)	Urine Mg/ Creatinine ratio
	γ / p value		
All			
Daily Mg intake (mg)	1	0.081 / 0.023	0.083 / 0.019
Serum Mg (mmol/L)		1	0.030 / 0.403
Urinary Mg-Creatinine ratio (mmol/L:mmol/L)			1
Males			
Daily Mg intake (mg)	1	0.075 / 0.145	0.165 / 0.001
Serum Mg (mmol/L)		1	-0.011 / 0.827
Urinary Mg-Creatinine ratio (mmol/L:mmol/L)			1
Females			
Daily Mg intak (mg)	1	0.085 / 0.085	0.090 / 0.067
Serum Mg (mmol/L)		1	0.071 / 0.147
Urinary Mg-Creatinine ratio (mmol/L:mmol/L)			1

Pearson correlation analyzed with SAS.

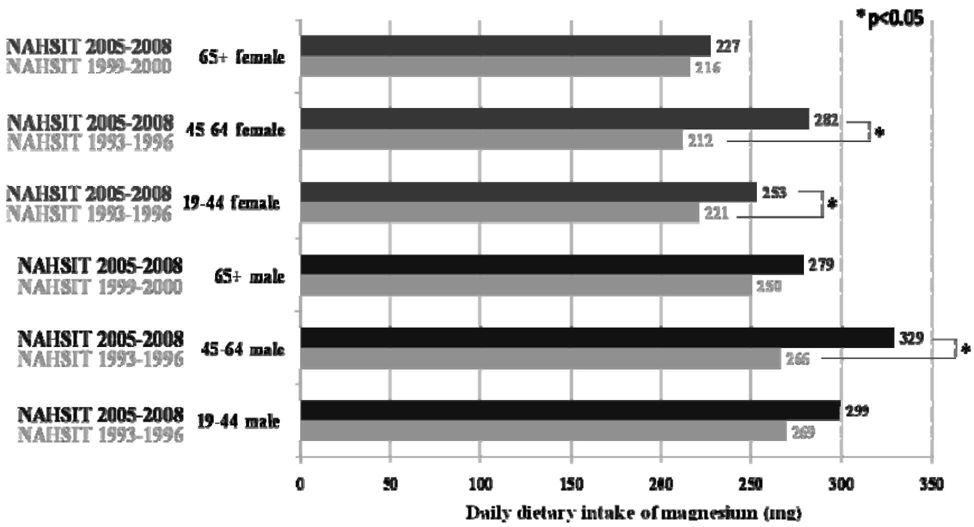

Figure 1. Trend in daily dietary intake of magnesium by age and gender.

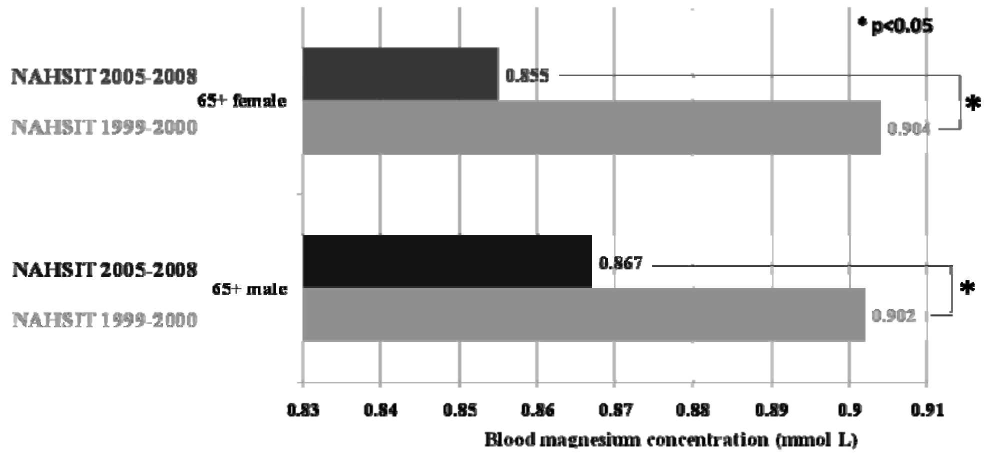

Figure 2. Trend in blood magnesium concentration in elderly by gender.

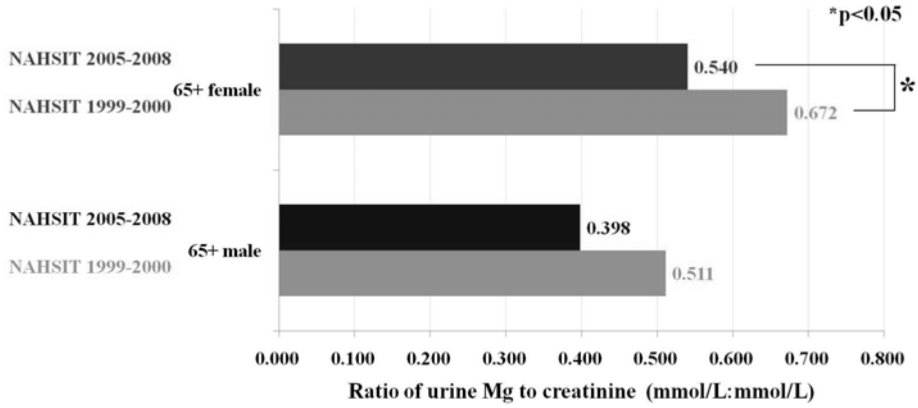

Figure 3. Trend in urinary magnesium to creatinine ratio in elderly by gender.

NAHSIT 1993-1996 did not examine serum and urinary magnesium; thus, trend analyses for serum and urinary magnesium in this study only compared NAHSIT 1999-2000 and NAHSIT 2005-2008. Figures 2 and 3 provided the information for trend in blood magnesium concentration and urinary magnesium/creatinine ratio by gender in the elderly (65 years and older). The concentration of blood magnesium significantly decreased from NAHSIT 1999-2000 to NAHSIT 2005-2008 for both males (from 0.902 to 0.867 nmol/L) and females (from 0.904 to 0.855 nmol/L). The trend in ratio of urinary magnesium/creatinine decreased from NAHSIT 1999-2000 to NAHSIT 2005-2008. For males, it decreased from 0.672 to 0.540, and for females, from 0.511 to 0.398. The decline for female was significantly different (p<0.05).

DISCUSSION

The mean daily dietary intake of magnesium for people over 19 years old was 305 mg for males and 259 mg for females in NAHSIT 2005-2008. Compared with previous two NAHSITs, among various age groups in NAHSIT 2005-2008, dietary magnesium intake increased 5-33%, the percentage of people with dietary magnesium achieving DRIs increased 3-22%. On the other hand, in females and in males over 65 years old specifically, the percentage of individuals with dietary magnesium below DRIs also increased 2% to 10%. In general, an upward trend was observed for dietary magnesium intake over the past decade. However, when compared with other Western countries, the average intake of dietary magnesium in Taiwan was lower than majority of these countries (Table 7).[19,20] It indicates the need to improve dietary magnesium intake.

In general, the serum magnesium concentration in a healthy individual is about 0.75-0.95 mmol/L (1.8-2.3 mg/dL). Unless there is a serious lack of dietary magnesium, the concentration of serum magnesium does not decline, although the detailed mechanism of blood magnesium homeostasis so far remains unclear. According to Lakshmanan,[21] when daily intake of magnesium in young healthy males and females reached 330 mg and 237 mg respectively, around 4.3 mg per kilogram per day, the absorption and excretion of magnesium maintained positive equilibrium. Another study from Japan pointed out that 300 mg of daily magnesium intake (5 mg/kg/d) would maintain the positive equilibrium.[22] In our study, when dietary magnesium intake was converted to body weight basis, the average magnesium intake would be 4.5 mg/kg/d which is well within the range of 4.3 and 5.0 mg/kg/d for NAHSIT 2005-2008.

Despite of a general increase in dietary magnesium, we observed a puzzling decrease in serum and urinary magnesium. Epidemiologic studies have shown that magnesium status is related with inflammation and chronic diseases. King found that human magnesium intake was inversely associated with C-reactive protein concentration,

Table 7. Dietary magnesium contents in different countries

Taiwan (2005-2008)			Austria			Denmark			Germany			Hungary			USA (1999-2000)			Italy			Spain			UK		
Age (ys)	N	Means (mg/d)	Age (ys)	N	Means (mg/d)	Age (ys)	N	Means (mg/d)	Age (ys)	N	Means (mg/d)	Age (ys)	N	Means (mg/d)	Age (ys)	N	Means (mg/d)	Age (ys)	N	Means (mg/d)	Age (ys)	N	Means (mg/d)	Age (ys)	N	Means (mg/d)
Male																										
19-44	485	299													20-39	635	337									
45-64	481	329	55-64	21	311										40-59	577	349									
65+	481	279	65-74	22	341	65-74	122	380	≥65	1509	474	≥60	55	381	60+	767	316	≥65	ND	199	65-75	382	295	65-74	313	258
			75-84	22	281	75-80	64	334																75-84	360	233
			85+	22	233																			85+	178	214
Female																										
19-44	489	253													20-39	849	242									
45-64	490	282	55-64	180	286										40-59	641	258									
65+	485	227	65-74	121	288	65-74	103	307	≥65	1690	377	≥55	105	328	60+	770	236	≥65	ND	199	65-75	429	250	65-74	278	208
			75-84	160	271	75-80	44	276																75-84	303	188
			85+	93	235																			85+	301	178

ND: no data.

and in turn, to the risk of cardiovascular disease.[23] In addition, animal experiments indicate that signs of marginal-to-moderate magnesium deficiency could be compensated or exacerbated by factors influencing inflammatory and oxidative stress.[23] Moreover, Guerrera *et al.* found that the effective and proper magnesium intake would lower the risk of the metabolic syndrome, type 2 diabetes and others diseases.[24,25] Besides chronic diseases, Nielsen *et al.*[26] found that obesity was associated with both a chronic low-grade inflammation and a increased incidence of low magnesium status. In other words, magnesium status may be compounded by the inflammatory states associated with various cardiometabolic diseases.

Since prevalence of obesity, the metabolic syndrome, and diabetes increase drastically since the 1993-1996 period,[27] these chronic conditions and the associated factors influencing oxidative stress and low-grade inflammation may have influenced magnesium metabolism and explain the decreased magnesium concentration in serum and urine.

Furthermore, dietary make-up has evolved in Taiwan. Wu *et al.*[12] studied Taiwanese dietary content in the past decade; and found that the intake of legume and its products tended to increase with time, especially in 45-64 years age group. Every 0.3-0.4 servings of legume rich food intake will increase 54-58% dietary magnesium intake. This indicated that the changes in dietary patterns in recent years might be beneficial for the increase of dietary magnesium content. In addition, for the people living in the Mountainous area, the levels of dietary magnesium intake and the percentage of people reaching magnesium DRIs were significantly lower than those in the other areas or in Taiwan as a whole.[10] Further research is needed to explore whether the absorption and excretion of magnesium will be affected by the make-up of foods such as other nutrients and photochemical as well as inflammatory diseases.

Studies found that inadequate magnesium intake may reduce glucose tolerance and increase insulin resistance; besides, low concentration of serum magnesium was found to increase the risk ratio of diabetes morbidity and to raise the systolic blood pressure, blood glucose and insulin concentration.[28-32] The long-term low dietary magnesium intake causes blood magnesium deficiency and then may increase the risk of suffering from a variety of chronic diseases. Even though the mean of dietary magnesium in Taiwan is within the range of many Western countries, in order to ensure adequate magnesium status of, it is important to encourage the general public to consume more magnesium-rich foods, such as whole grains, legumes, nuts, and vegetables.

CONCLUSION

It can be concluded that in recent years, dietary magnesium intake in Taiwan tended to increase, but still intake for a large proportion of people still fall within the suboptimal range for dietary magnesium. Hence, in addition to continue monitoring the nutritional status for dietary magnesium intake by using nutrition and health survey system, it is important to bring to the attention of the public to consume more magnesium rich foods, such as whole grains, legumes, and starchy vegetables. On the other hand, the serum magnesium concentration showed a controversial downward trend in the Taiwanese population, despite an overall improvement of dietary magnesium. Future research is needed to untangle the complex relations between dietary magnesium, other dietary factors affecting inflammation and oxidative stress, and chronic diseases.

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AUTHOR DISCLOSURES

Jui-Line Wang, Yao-Lin Weng, Wen-Harn Pan and Mei-Ding Kao, no conflicts of interest.

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Original Article

Trends and Nutritional Status for Magnesium in Taiwan from NAHSIT 1993 to 2008

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臺灣地區國人鎂營養狀況及其變遷: 由 NAHSIT 1993-2008

本研究之目的是探討臺灣民眾鎂之營養狀況與變化趨勢。以「臺灣營養健康狀況變遷調查 2005-2008」中 19 歲以上 2911 獨立樣本進行分析，飲食鎂攝取量由 24 小時回憶法評估，並同時分析血清鎂與尿鎂濃度。結果顯示，男、女性飲食鎂攝取量分別約為 305 mg 及 259 mg，約達臺灣「國人膳食營養素參考攝取量」(DRIs)的 82-85%，鎂攝取量低於 DRIs 比率為 74-81%。男、女性血清鎂平均濃度分別為 0.866 mmol/L 及 0.861 mmol/L。以血清鎂濃度<0.8 mmol/L 為缺乏指標，男、女性血清鎂缺乏比例分別為 12.3%及 23.7%。國人飲食鎂攝取量與血清鎂濃度、尿鎂/肌酸酐濃度比呈正相關性。另外，從 NAHSIT1993-1996 與 NAHSIT2005-2008 營養調查資料分析近十年來臺灣地區國人鎂營養狀況，結果發現國人飲食鎂攝取量呈現顯著增加趨勢($p<0.05$)，但是血清鎂濃度與尿鎂/肌酸酐濃度比則呈現顯著下降趨勢($p<0.05$)。因此由趨勢分析結果顯示，於不同調查間之飲食鎂攝取量及鎂攝取量與鎂營養狀況之相關性仍需進一步探討與釐清。

關鍵字：臺灣營養健康狀況變遷調查、鎂營養狀況、飲食鎂、血清鎂、尿鎂/肌酸酐濃度比