The Association Between Dietary Salt Intake and the Glycaemia Response Among Type 2 Diabetes Patients in Eastern China

Yi Lin

University of Nottingham - Ningbo China <https://orcid.org/0000-0003-4417-9455>

Xi Yang

Ningbo First Hospital

Yan-Shu Chen

Ningbo First Hospital

Ye Zhou

Ningbo First Hospital

Li Li (✉ lilyningbo@163.com)

Department of Endocrinology and Metabolism <https://orcid.org/0000-0001-6301-3544>

Research

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Abstract

Background

Type 2 diabetes (T2D) is one of public health concerns in China with a rapid increase in prevalence. The study on salt intake and risk of T2D is still lack in China.

Aims

To investigate the association between dietary salt intake levels and the glycaemia response of T2D.

Methods

A total of 1145 T2D patients, who accepted standardized management by the National Standardized Metabolic Disease Management Center at Ningbo First Hospital from March 2018 to January 2020, were selected in the final analysis. Demography, lifestyle and medical information were collected through questionnaires. Anthropometry, blood pressure and biomarkers were measured by well-trained endocrinology nurses. Generalized linear models (GLM) were used to examine the association.

Results

Higher prevalence of overweight and central obesity with larger BMI and waist circumference were found in higher salt categories 6-8g/d and ≥ 8 g/d, compared to lower salt categories. Fasting plasma glucose (FPG), 2h postprandial plasma glucose, 2h postprandial insulin, total cholesterol, triglyceride and low-density lipoprotein cholesterol were significantly different across salt intake categories. GLM further shows that salt intake 6-8g/d and ≥ 8 g/d were positively associated with FPG and salt intake 6-8g/d and ≥ 8 g/d was associated with HbA1c.

Conclusion

Increasing salt intake is suggested to be associated with the glycaemia response at the fasting state in T2D patients. Hospital-based education is needed for improvement of awareness, attitude and action on restriction of salt consumption.

Introduction

Over the past three to four decades, the prevalence of diabetes increased dramatically in China due to economic development, the changes of diets and lifestyles, western influence. The prevalence of diabetes and pre-diabetes was from less than 1% in 1980 [1] to 10.3% in 2013 [2] and from 15.5% in 2008 to 35.7% in 2013 [3], respectively. Type 2 diabetes (T2D) has been the main driver for the rapid increase in prevalence of diabetes in China [4]. People with T2D are at high risk of developing cardiovascular disease (CVD), and CVD related diseases.

T2D is one of the major lifestyle-related diseases, and progression is highly correlated with behavioral and environmental factors[5]. Although salt as an essential seasoning contributing to eating pleasure and satisfaction [6], many guidelines have been promoted dietary salt restriction in patients with diabetes [7, 8]. Evidence has shown that salt intake is a key factor developing hypertension and increasing incidence of CVD in diabetes patients [9], thus, leading to increased mortality. Recent studies reported that dietary sodium intake is evidenced to be positively associated with increased blood pressure in the general population [10, 11]. Moreover, blood pressure along with hyperglycemia, is an important factor for patients with T2D.

To our best knowledge, few studies have been explored on the relationship between salt intake and T2D in China. The objective of this study is to investigate the association between dietary salt intake and the glycaemia response of T2D including blood glucose level, insulin and [hemoglobin A1_c](#) (HbA1c).

Methods

Study design and participants

The present study included 1145 patients diagnosed with T2D, aged from 18 to 75 years, from March 2018 to January 2020 at the outpatient department of the Endocrinology of Ningbo First Hospital, Zhejiang province, China and the National Standardized Metabolic Disease Management Center (MMC). T2D was diagnosed based on the definition proposed by the American Diabetes Association [12]. Patients were excluded from this study according to the exclusion criteria of T2D patients: (1) age > 75 years and age < 18 years; (2) diagnosis with any kind of cancer; (3) positive islet autoantibodies; (4) glomerular filtration rate (eGFR) < 30 mL/min; (5) severe liver dysfunction; (6) acute infectious diseases; (7) pregnancy or lactation; (8) incompleteness of standard questionnaires.

The research project was approved by the Ethics Committee of Ningbo First Hospital, China (No. 2019-R057) and followed the Declaration of Helsinki. Written informed consents were obtained from all participants.

Dietary assessment

Dietary information was collected through a standard food frequent questionnaire (FFQ), following the guidelines proposed by Ningbo first hospital. All the dietary information was collected by well-trained nurses. Quantitative dietary information was collected on how often usual foods (vegetables, fruits, soya and soya products) was consumed per day, how often meats (red meat, poultry, fish and shrimp) were consumed per week, and how many times seasoning (salt and sugar) was consumed per day. Dietary salt was categorized into 4 groups: <4g/d, 4-6g/d, 6-8g/d and ≥8g/d. The missing reports were asked to fill in and the misreports were evaluated and corrected based on daily reasonable consumption.

Demography and lifestyle

All patients, who were willing to participate in the study, were invited to complete the MMC standard questionnaires on their demography [education (low education: lower than colleagues/universities and high education: colleagues/universities or above)], lifestyle [smoking status (no current smoking, sometimes and every day); drinking alcohol status (no current drinking, sometimes and every day); physical activity], medical history and medication records.

Anthropometric measurements and blood pressure

Anthropometric measurements including body weight, height and waist circumference (WC) were measured with light clothing by well-trained endocrinology nurses. Body weight was measured using an electronic scale to the nearest 0.1kg and height was measured using a metal column height meter to the nearest 0.1cm. WC was measured at the midpoint between the inferior costal margin and the iliac crest in the midaxillary line. BMI, defining a general obesity, was calculated as weight (kg) / height (m²). Patients were classified into four BMI categories according to China Obesity Task Force as follows: underweight (<18.5 kg/m²), normal weight (18.5-23.9 kg/m²), overweight (24.0-27.9 kg/m²), and obesity ($\geq$ 28.0 kg/m²). Abdominal obesity was defined according to WC values: WC > 90 cm in men or > 85cm in women [13].

Blood pressure was measured using an electronic sphygmomanometer on the right or left arm after a 10-minute rest.

Biomarker measurements

After a 10-12h-overnight fasting, blood samples were obtained in the early morning to measure the levels of blood profiles including fasting plasma glucose (FPG), fasting insulin (FINS), glycated hemoglobin A1c (HbA1c), total cholesterol (TC), triglyceride (TG), high-density lipoprotein cholesterol (HDL-C) and low-density lipoprotein cholesterol (LDL-C). Then the 100g carbohydrate (steamed bread meal) test was performed in all subjects to assess the 2 hour postprandial plasma glucose (2hPG) and 2 hour postprandial insulin (2hINS) concentrations.

FPG and 2hPG were assessed by the glucose oxidase method and chemiluminescence immunoassay, respectively. FINS was measured by radioimmunoassay. Lipid profiles were analyzed by enzymatic procedures using an autoanalyzer (Hitachi 747; Hitachi, Tokyo, Japan). HbA1c was determined by high-pressure liquid chromatography.

Statistical analysis

The percentage of patients, mean and median values with standard deviation (SD) among the categories of salt intakes were presented as descriptive analysis. ANOVA with Bonferroni correction/ Games-Howell, and Mann-Whitney U test and Kruskal-Wallis were used to examine mean and median values of biomarkers within and between the categories of salt intakes.

Generalized linear models (GLM) were used to assess associations of salt intakes with biomarkers (FPG, 2hPG, FINS, 2hINS and HbA1c) after adjusting for confounding factors (gender, age and education levels), lifestyle factors (physical activity, smoking status and drinking status), BMI and interactions. Interactions between salt intake and confounding factors were only remained in the model.

Results were considered statistically significant at a two-tailed level of 0.05. Statistical analyses were conducted using IBM SPSS Statistics version 26.0.

Results

Study population

In total, 1045 T2D patients (63.7% men) with a mean age of 51.4 years old were included in the present study and divided into four groups according to salt intake: <4g/d (n=42), 4-6g/d (n=244), 6-8g/d (n=443) and ≥ 8 g/d (n=416 (Table 1). Around 53.1%, 68.3% and 57.1% patients had high education, no current smoking and no current drinking, respectively. In terms of weight status, 41.9%, 0.7% and 42.1% patients were defined to be overweight, obese and central obese, respectively. About 52.4% patients had the most comorbidity of hyperlipidemia followed by hypertension (39.6) and hypeluricemia (17.6%).

Among all patients, only 2.2% patients had salt intake less than 4g/d. Compared to lower salt intake, the higher prevalence of overweight patients and central obesity was observed in the group of higher salt intakes (4-6g/d, ≥ 8 g/d). Similarly, the higher prevalence of hypertension, hyperlipidemia, hypeluricemia and coronary disease was in the group of higher salt intakes.

Table 1. Clinical characteristics of patients with type 2 diabetes, stratified according to salt intakes					
	Total	<4g/d (n=42)	4-6g/d (n=244)	6-8g/d (n=443)	≥8g/d (n=416)
Male (%)	746 (65.2)	25 (59.5)	153 (62.7)	284 (64.1)	284 (68.3)
Age (years)	51.4 (11.7)	51.0 (13.2)	50.9 (12.2)	51.8 (11.4)	51.3 (11.6)
Duration of diabetes (years)	7.5 [6.4]	7.4 (6.8)	7.4 (6.7)	7.8 (6.3)	7.2 (6.4)
Education					
High education	608 (53.1)	19 (45.2)	133 (54.5)	243 (54.9)	213 (51.2)
Currently smoking status					
No	782 (68.3)	30 (71.4)	184 (75.4)	301 (67.9)	267 (64.2)
Sometimes	73 (6.4)	4 (9.5)	21 (8.6)	25 (5.6)	23 (5.5)
Everyday	290 (25.3)	8 (19.0)	39 (16.0)	117 (26.4)	126 (30.3)
Currently drinking status					
No	654 (57.1)	29 (68.0)	160 (65.5)	247 (55.8)	218 (52.4)
Sometimes	256 (22.4)	8 (19.0)	55 (22.5)	111 (25.1)	82 (19.7)
Everyday	235 (20.5)	5 (11.9)	29 (11.9)	85 (19.2)	116 (27.9)
Weight status					
Underweight	243 (21.2)	12 (28.6)	51 (20.9)	76 (17.2)	104 (25.0)
Normal weight	414 (36.2)	17 (40.5)	92 (37.7)	177 (40.0)	128 (30.8)
Overweight	480 (41.9)	13 (31.0)	100 (41.0)	185 (41.8)	182 (43.8)
Obesity	8 [0.7]	0 (0.0)	1 (0.4)	5 (1.1)	2 (0.5)
Waist circumference status					

Central obesity	482 (42.1)	21 (50.0)	117 (49.0)	214 (48.3)	260 (62.5)
Hypertension (%)	453 (39.6)	16 (38.1)	89 (36.5)	170 (38.4)	178 (42.8)
Hyperlipidemia (%)	600 (52.4)	22 (52.4)	126 (51.6)	231 (52.1)	221 (53.1)
Hypeluricemia (%)	202 (17.6)	5 (11.9)	40 (16.4)	75 (16.9)	82 (19.7)
Coronary disease (%)	48 (4.2)	0 (0.0)	12 (4.9)	22 (5.0)	14 (3.4)
Stroke (%)	37 (3.2)	0 (0.0)	13 (5.3)	13 (2.9)	11 (2.6)
Heart failure (%)	2 (0.2)	0 (0.0)	0 (0.0)	1 (0.2)	1 (0.2)

Risk factors among salt intake categories

In T2D patients, risk factors including BMI, WC, FPG, 2hPG, 2hINS, TC, TG and LDL-C were significant across salt intake categories, whereas, SBP and DBP were not found significant difference (Table 2). Within salt intake categories, mean values of FPG, 2hPG, HbA1c, TC and LDL-C in the group of salt intake $\geq 8\text{g/d}$ were found to be significantly higher than the values in the group of lower salt intake categories ($<4\text{g/d}$ and $4\text{-}6\text{g/d}$).

Table 2. Mean and median values of risk factors of type 2 diabetes stratified according to salt intake					
Factors*	<4g/d (n=42)	4-6g/d (n=244)	6-8g/d (n=443)	≥8g/d (n=416) ^a	P
BMI	25.3 (4.1)	25.1 (3.8)	24.9 (3.6)	25.9 (3.8) ^f	0.001
WC	87.2 (10.9)	87.7 (10.5)	87.9 (9.7)	90.4 (9.5) ^{cf}	<0.001
SBP (mmHg)	132.6 (18.5)	133.2 (17.6)	131.2 (17.7)	133.8 (18.3)	0.179
DBP (mmHg)	79.6 (12.0)	79.2 (11.4)	78.8 (11.0)	79.8 (10.6)	0.607
FPG (mmol/L)	7.6 (2.5)	8.2 (3.0)	8.7 (2.9)	8.9 (3.0) ^{ac}	0.007
2hPG (mmol/L)	12.6 (5.1)	12.6 (4.6)	14.0 (5.6) ^c	14.2 (5.0) ^c	0.001
FINS (mIU/L)	10.8 (48.2)	11.2 (38.8)	12.2 (44.1) ^c	12.2 (44.1)	0.103
2hINS (mIU/L)	37.6 (168.5)	37.6 (168.5)	43.0 (225.3)	44.9 (159.6)	<0.001
HbA1c (%)	7.7 (1.8)	7.6 (1.9)	8.2 (2.1) ^c	8.4 (2.0) ^d	0.314
TC (mmol/L)	4.4 (1.0)	4.4 (1.1)	4.6 (1.2)	4.7 (1.3) ^c	0.007
TG (mmol/L)	1.4 (0.876)	1.3 (1.2)	1.4 (1.6) ^c	1.6 (2.1)	0.016
LDL-C (mmol/L)	2.9 (0.784)	2.8 (0.851)	2.9 (0.865)	3.0 (0.910) ^c	0.015
HDL-C (mmol/L)	1.2 (0.284)	1.2 (0.303)	1.2 (0.288)	1.1 (0.272)	0.107
BMI, body mass index; WC, waist circumference; SBP, systolic blood pressure; DBP, diastolic blood pressure; FPG, fasting plasma glucose; 2hPG, 2 hour postprandial plasma glucose; FINS, fasting plasma insulin; 2hINS, 2 hour postprandial plasma insulin; HbA1c, glycated hemoglobin A1c; TC, total cholesterol; TG: triglycerides; HDL, high-density lipoprotein cholesterol; LDL, low-density lipoprotein cholesterol.					
*FINS, 2hINS and TG were presented as median values and the rest factors were presented as mean values.					
^a Significant difference from salt intake <4g/d , P < 0.05					
^b Significant difference from salt intake <4g/d, P ≤ 0.001					
^c Significant difference from salt intake 4-6g/d, P < 0.05					
^d Significant difference from salt intake 4-6g/d, P ≤ 0.001					
^e Significant difference from salt intake 6-8g/d, P < 0.05					

^f Significant difference from salt intake 6-8g/d, $P \leq 0.001$

Associations between salt intake and blood glucose, insulin and HbA1c

Associations of salt intake with plasma glucose, insulin and HbA1c among T2D patients were further investigated by GLM (Table 3, Table 4 and Table 5). Salt intake 6-8g/d and ≥ 8 g/d were positively associated with FPG ($\beta=1.0$, $P=0.030$; $\beta=1.2$, $P=0.010$, respectively), and ≥ 8 g/d was associated with HbA1c ($\beta=0.694$, $P=0.032$). Therefore, the results show that salt intake 6-8g/d increased 1.0 mmol/L FPG and 0.694 mmol/L HbA1c, and salt intake ≥ 8 g/d increased 1.2 mmol/L FPG, compared to salt intake <4 g/d.

Table 3. Association of salt intakes with plasma glucose				
Salt intake*	β	SE	95% CI	P
<u>Fasting plasma glucose</u>				
4-6g/d	0.616	0.494	-0.352, 1.6	0.212
6-8g/d	1.040	0.478	0.104, 2.0	0.030
>8 g/d	1.2	0.480	0.298, 2.2	0.010
2 hour postprandial plasma glucose				
4-6g/d	1.5	0.829	-1.6, 1.7	0.944
6-8g/d	1.4	0.826	-0.251, 3.0	0.098
>8 g/d	1.5	0.829	-0.164, 3.1	0.078
SE, standard error; CI, confidence intervals				
*Less than 4g/d salt intake is reference in the models				

Table 4. Association of salt intakes with insulin				
Salt intake*	β	SE	95% CI	P
<u>Fasting insulin</u>				
4-6g/d	-6.0	14.0	-33.5, 21.5	0.669
6-8g/d	15.5	13.6	-11.1, 42.0	0.255
>8g/d	0.157	13.6	-26.6, 26.9	0.991
<u>2 hour postprandial insulin</u>				
4-6g/d	-7.1	30.9	-67.6, 53.4	0.818
6-8g/d	41.2	29.9	-17.4, 99.8	0.168
>8g/d	11.3	30.0	-47.5, 70.1	0.706
SE, standard error; CI, confidence intervals				
*Less than 4g/d salt intake is reference in the models				

Table 5. Association of salt intakes with HbA1c				
Salt intake	β	SE	95% CI	P
4-6g/d	-0.128	0.333	-0.781, 0.525	0.701
6-8g/d	0.461	0.322	-0.171, 1.1	0.153
>8g/d	0.694	0.324	0.060, 1.3	0.032
SE, standard error; CI, confidence intervals; HbA1c, glycated hemoglobin A1c				
*Less than 4g/d salt intake is reference in the models				

Discussion

To date, the association of salt intake with T2D in China was not well investigated and understood. The present study, using clinical data of the outpatient department of the Endocrinology and MMC, is to analyze the association of dietary salt intake and the parameters of the glycaemia response (plasma glucose, insulin and HbA1c) in patients with T2D in Eastern China. The findings indicated that salt intake was positively associated with FPG and HbA1c.

One previous study conducted on Ningbo citizens in Eastern China showed that higher fasting blood glucose level was found in the group of higher salt intake ($\geq 6\text{g/d}$) compared to it in the group of salt intake ($<6\text{g/d}$) [11]. The results of the Chinese study is in line with our findings on fasting blood glucose

among Chinese in the Eastern China, although target populations are different. The mechanism of the association between dietary salt intake and risk of T2D is unclear yet. Increasing dietary salt intake may increase activities of the renin-angiotensin-aldosterone system [14] and stimulate sympathetic activity [15] and cause insulin resistance [16, 17]. Therefore, it may contribute to the development and progression of diabetes complications.

The relationship between dietary salt intake and risk factors of T2D has been explored through observational studies, intervention studies and meta-analysis [11, 18-20]. A previous 13-week intervention study conducted on 17 elderly volunteers provided a low-salt diet (LSD) and a high-salt diet (HSD) showed that fasting glucose was lower in LSD (5.4 mmol/L) than HSD (5.6 mmol/L), although no significant difference in insulin levels was found between LSD and HSD [19]. Our findings show that dietary salt intake was positively associated with HbA1c, which is consistent with the results from one intervention study [18]. This observer-blind randomized controlled trial recruiting 70 patients with acute non-cardioembolic mild ischemic stroke reported that HbA1c decreased more in the lifestyle intervention group providing reduction in salt intake compared to controlled group, although no significant difference was found between 2 groups [18]. Strazzullo and his colleagues conducted a meta-analysis including 13 studies with 177025 participants indicated an effect between the HbA1c level and dietary sodium intake for the development of CVD [20].

Higher salt intake was found to be related to high prevalence of overweight and obesity compared to lower salt intake in the present study. Additionally, high blood lipid levels were found significant with increasing dietary salt intake in our study. The potential hypothesis is that high salt intake might increase the risk of T2D through weight gain due to appetite and over-consumption of energy, fat and cholesterol [21]. It is known that T2D can be caused by obesity due to insulin resistance [22]. Increased fat free acid level in blood can inhibit insulin suppression of hepatic glucose production [23]. Salt intake is a key factor to increase the feeling of thirsty, resulting in more amount of fluid drinks [24]. Increasing 1 g/d salt intake was positively associated with an increase in 100 g/d total fluid and 27 g/d sugar-sweetened soft drink consumption [25]. Hereby, it may contribute to high blood pressure/hypertension.

Several dietary guidelines recommend and advocate that patients with T2D should decrease their dietary salt intake due to benefits for lowering a modest blood pressure [7, 8]. In the present study, no significant difference in SBP and DBP was found across salt intake categories. This can be explained that the majority of our patients were not diagnosed with hypertension. The World Health Organization (WHO) Cardiovascular Diseases and Alimentary Comparison (WHO-CARDIAC) Study conducted on pre- and post-menopausal women from 17 countries reported that 24 h sodium excretion was positively associated with blood pressure [26], thus, indicating that hypertension might be related to increase the risk of developing T2D.

Interestingly, dietary salt intake was not found to be significantly associated with postprandial plasma glucose and postprandial insulin. Few studies have been investigated on the relationship between dietary salt intake, and postprandial plasma glucose and insulin responses. An intervention study including six

healthy adults, assigned randomly meals with or without added salt, suggested that moderate salt intake increased postprandial plasma glucose and insulin levels [27]. Sodium can facilitate the absorption of glucose in the small intestine [28]. The potential reason can be that most of our participants had been diagnosed with T2D for a certain period so that postprandial plasma glucose and insulin responses to dietary salt cannot be the same like healthy participants due to insensitive digestion system.

Moreover, it has been well educated on the relationship between dietary salt intake and hypertension in Chinese population. In addition, the knowledge on glycaemia control through the duration and the quantity of carbohydrate consumption from foods is understood as well [29]. Patients with diabetes are recommended to restrict total consumption of energy and carbohydrates in order to control body weight and blood glucose levels. However, the knowledge of the effect of salt intake on the risk of T2D needs more attention. Therefore, hospital-based education and community-based education are necessarily required regarding health effects of excess salt intake, food labelling and food sources.

Several study limitations need to be considered. First, causality between salt intake and factors of T2D cannot be achieved according to the nature of cross-sectional study design. Second, because of the structure of FFQ, quantitative salt intake could not be obtained, although the categories of salt intake could be collected from the patients. Therefore, it may not accurately reflect daily dietary salt intake among T2D patients. Then, total energy intake was not adjusted in the model due to the FFQ. In addition, medication of lowering blood glucose was not adjusted in the model, which might influence the associations. However, the average of FPG and 2hPG were still higher the cut-off values of diagnosis for diabetes, thus, mediation might be a minor influencing factor on the associations. Additionally, the reported dietary salt level could be biased towards misreporting because of patients' psychology. Furthermore, due to regional patients from Eastern China, so the findings cannot be representative for the entire Chinese population with T2D.

Conclusion

Dietary salt intake is suggested to be positively associated with fasting plasma glucose and HbA1c among T2D patients. Hospital-based education is needed for improvement of awareness, attitude and action on restriction of salt consumption among patients with T2D. Intervention study should be carried out to investigate the impact of the dose of salt intake on the glycaemia response of T2D patients for future research.

Abbreviations

CVD: cardiovascular disease; eGFR: glomerular filtration rate; FFQ: food frequent questionnaire; FINS: fasting insulin; FPG: Fasting plasma glucose; GLM: Generalized linear models; HbA1c: [hemoglobin A1c](#); HDL-C: high-density lipoprotein cholesterol; HSD: a high-salt diet; LDL-C: low-density lipoprotein cholesterol; LSD: low-salt diet; MMC: Metabolic Disease Management Center; TC: total cholesterol; T2D:

Type 2 diabetes; TG: triglyceride; WC: waist circumference; WHO: World Health Organization; 2hPG: 2 hour postprandial plasma glucose

Declarations

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Author contributions

Lin Y performed and interpreted statistical analysis and drafted manuscript writing. Yang X, Chen YS, and Zhou Y were responsible for data collection and quality control. Li L contributed to the study design for the whole research.

All authors have given final approval of the version to be published and agree to be accountable for all aspects of the work. All authors read and approved the final manuscript.

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Availability of data and materials

The dataset used and analyzed for the current study is available from the corresponding author on reasonable request.

Ethics approval and consent to participate

The research project was approved by the Ethics Committee of Ningbo First Hospital, China (No. 2019-R057) and followed the Declaration of Helsinki. Written informed consents were obtained from all participants.

Consent for publication

Not applicable.

Competing interests

The authors declared no conflict of interest.

Author details

Center for Health Economics, School of Economics, Faculty of Humanities and Social Sciences, University of Nottingham, Ningbo, Zhejiang province, China, 199, Taikang East Road, University Park, 315100 Ningbo, Zhejiang, China;

Yi Lin

Department of Nutrition, Ningbo First Hospital, 59, Liuting Street, 315010 Ningbo, Zhejiang province, China;

Xi Yang

Department of Endocrinology and Metabolism, Ningbo First Hospital, 59, Liuting Street, 315010 Ningbo, Zhejiang province, China

Yan-Shu Chen, Ye Zhou, Li Li

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