BODY COMPOSITION AND DIET OF CHINESE, MALAYS AND INDIANS IN SINGAPORE:

AND THEIR INFLUENCE ON CARDIOVASCULAR RISK FACTORS

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Propositions

I

Indiscriminate use of 'international' standards will lead to expensive consequences. (this thesis)

II

An equation derived from a least squares method performs better than any other in the sample from which it was derived. The accuracy of an equation is reduced when it is applied to other samples.
Guo SS. *In*:Human Body Composition. Eds Roche A et al. Human Kinetics, Il 1996. (this thesis).

III

In many publications, inappropriate use of body composition methodology has resulted in questionable conclusions.

IV

In the assessment of body composition, bioelectrical impedance owes its popularity to the ease of application and apparent sophistication of the data displayed rather than to the validity of the data.

V

It is not the food you actually ate, but what you have declared eaten that determines your health risk.

VI

Periods of retreat and reflection are as important as periods of activity for total well being and work efficiency.

VII

To learn without thinking brings about confusion. To think without learning brings about peril.
Confucius, Chinese philosopher and sage (c. 551- 479 BC)

VIII

The essence of knowledge is, having it, to apply it; not having it, to confess your ignorance.
Confucius, Chinese philosopher and sage (c. 551- 479 BC)

IX

All truth passes through three stages. First, it is ridiculed. Second, it is violently opposed. Third, it is accepted as being self-evident.
Arthur Schopenhauer, German philosopher (1788 -1860)

X

Not everything that can be counted counts, and not everything that counts can be counted.
Albert Einstein, German/American physicist (1879 -1955)

XI

There is nothing like a dream to create a future.
Victor Hugo, French author and dramatist. (1802 -1885)

Propositions belong to the thesis of Mabel Deurenberg-Yap entitled "Diet and body composition of Chinese, Malays and Indians in Singapore: and their influence on cardiovascular risk".

Wageningen University, The Netherlands, 4th October 2000.

for Paul,
Maria, Gerard & Gregory

ABSTRACT

BODY COMPOSITION AND DIET OF CHINESE, MALAYS AND INDIANS IN SINGAPORE: AND THEIR INFLUENCE ON CARDIOVASCULAR RISK FACTORS

PhD thesis by Mabel Deureneberg-Yap, Department of Human Nutrition and Epidemiology, Wageningen University, Wageningen, The Netherlands.
4th October 2000.

This thesis describes the studies on body composition and dietary intakes of the three major ethnic groups residing in Singapore, and how these are related to cardiovascular risk factors in these groups.

Body composition: Body fat percentage was measured using a four-compartment model described by Baumgartner. When the relationship between body mass index (BMI) and body fat percentage was studied, it was discovered that Singaporeans have higher percentage of body fat compared to Caucasians with the same BMI and that the BMI cut-off value for obesity in Chinese and Malays is around 27 kg/m^2 , while that for Indians is around 26 kg/m^2 . At levels of BMI and waist-to-hip ratio which are much lower than the WHO recommended cut-off limits for obesity and abdominal fatness respectively, both the absolute and relative risks of developing cardiovascular risk factors are markedly elevated for all three ethnic groups. Both the excessive fat accumulation and increased risks at low levels of BMI signal a need to re-examine cut-off values for obesity among Chinese, Malays and Indians.

Diet: Dietary intakes of energy, total fat, saturated fat, polyunsaturated fat, monounsaturated fat and cholesterol were measured using a food frequency questionnaire specially validated for this purpose. In addition, intakes of fruits, vegetables and grain-based foods were also measured using the same questionnaire. Singaporeans generally have a low intake of fruits, vegetables and whole grain products. The intake of total fat is just within the upper recommended limit while that for saturated fat is higher than the recommended level. On a group level, it is found that high intakes of fat, saturated fat and low intakes of polyunsaturated fat and vegetables affect serum cholesterol levels adversely. However, on an individual level, due to the rather homogenous intake patterns among the three groups, this cross sectional study was unable to demonstrate that dietary intakes could explain the differences in serum cholesterol levels among ethnic groups.

In summary, the thesis shows that in the light of increased body fat percentage and cardiovascular risks at low BMI, there is a need to re-examine the WHO's cut-off values for the three major ethnic groups in Singapore. Longitudinal studies are also needed for better insight into the effect of dietary intakes and other lifestyle risk factors on cardiovascular risk factors and mortality.

CONTENTS

1

General Introduction

Background

Singapore is a an island country state situated at the tip of the Malaya Peninsula, with a land area of 647.8 square kilometres, of which only 1.7% is used for agriculture. It is an equatorial country with relatively uniform temperature (25.3°C to 32.1°C), high humidity and abundant rainfall. It has a resident population of 3.16 million and is a multi-ethnic, multi-cultural society comprising mainly Chinese (77%), Malays (14%) and Indians (7.6%). The other ethnic groups make up about 1.4% of the population[1].

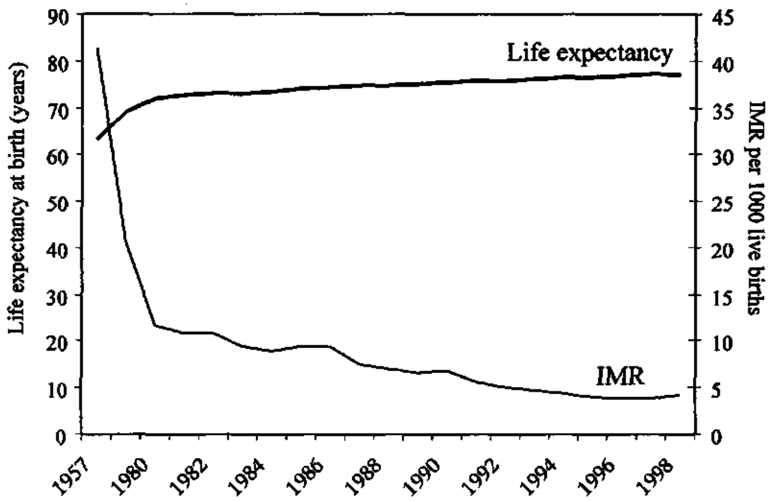
Over the last four decades, Singapore has experienced a rapid economic growth with a concomitant improvement in health status of her people. The infant mortality rate is among one of the lowest in the world at less than 4 per 1000 live births while life expectancy at birth has risen to 79.2 years for women and 75 years for men (Figure 1).

Parallel to these improvements, there has also been a change in the disease patterns among Singaporeans over the last 4 decades. The main causes of deaths moved from those arising from infectious diseases and poor environmental conditions to the so-called lifestyle diseases (Figure 2). Cancers and cardiovascular diseases (mainly coronary heart disease) are the two major causes of deaths.

The mortality from cardiovascular disease in Singapore is comparable to those of the West and higher than those in other parts of Asia, such as Japan and Hong Kong[2]. On the other hand obesity prevalence (defined as BMI of 30 kg/m^2 or more) is much lower among Singaporean adults at approximately 5% as compared to Caucasian populations[3].

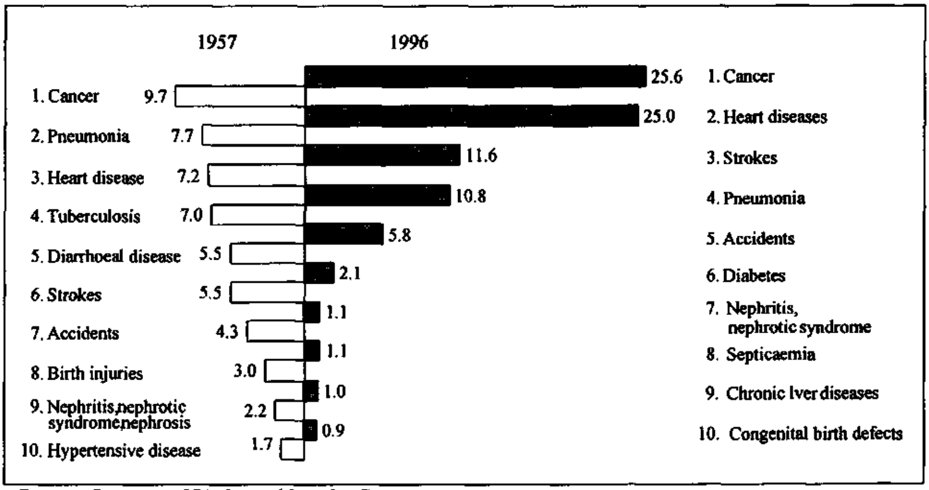
From the National Health Survey in Singapore conducted in 1992[4] and studies by Hughes et al[5,6,7], it was apparent that cardiovascular risk factors differ in the three major ethnic groups in Singapore. Such risk factors include obesity, abdominal adiposity, elevated blood pressure, abnormal blood lipids (elevated total cholesterol and LDL-cholesterol and low HDL-cholesterol levels), elevated blood glucose and insulin.

Figure 1. Life expectancy at birth* and infant mortality rate (IMR, per 1000 live births) in Singapore, 1957 - 1998**



Source: Population & Planning Unit, Ministry of Health, Singapore
Registry of Births and Deaths, Singapore

Figure 2. Top ten causes of deaths (% of all deaths) in Singapore, 1957 and 1996



Source: Registry of Births and Deaths, Singapore

There is however, no satisfactory explanation currently for the high prevalence of cardiovascular diseases in Singapore and differential rates among the different ethnic groups to enable public health measures to be carried out to arrest or even reverse the trends. Such public health measures would include provision of appropriate health education programmes for different population groups, creating a conducive environment to encourage practise of healthier lifestyles, implementing screening programmes to identify high risk cases for 'intervention' measures and having legislation that will facilitate the adoption of a healthier lifestyle (e.g. on food standards and labelling, smoking).

Dietary factors related to cardiovascular risk factors

The role of diet in cardiovascular diseases is well documented. A diet that is high in energy, total fat, saturated fat and cholesterol and relatively low in unsaturated fats, fruits and vegetables is linked to the development of cardiovascular diseases[8-14]. Thus, differences in nutrient intakes could explain the difference in levels of risk factors among the different ethnic groups in Singapore.

There is a paucity of studies examining the dietary intakes among Singaporeans and how these could be related to cardiovascular risk factors in Singaporeans[15]. The first food consumption study in Singapore was conducted in 1993 among some 470 adult Singaporeans. From that study, selected dietary practices and population mean intakes (using 24-hour dietary recalls and three-day weighed food records) of energy and nine nutrients for the different ethnic, age and sex sub-groups were determined[16]. Unfortunately, no information on risk factors among the subjects was available.

Body fat and cardiovascular risk factors

Obesity as an independent risk factor for cardiovascular diseases, particularly for coronary heart disease, has been documented in long term prospective studies[17]. It also has been recognised that obesity mediates its effects by elevating other cardiovascular risk factors, viz., dyslipidaemia (hypercholesterolaemia, hypertriglyceridaemia and low high-density lipoprotein cholesterol), hypertension and glucose intolerance[3,10,17,18]. An elevated level of body fat and the pattern of fat distribution is closely related to increased morbidity and mortality, chief among which is cardiovascular disease[19,20,21].

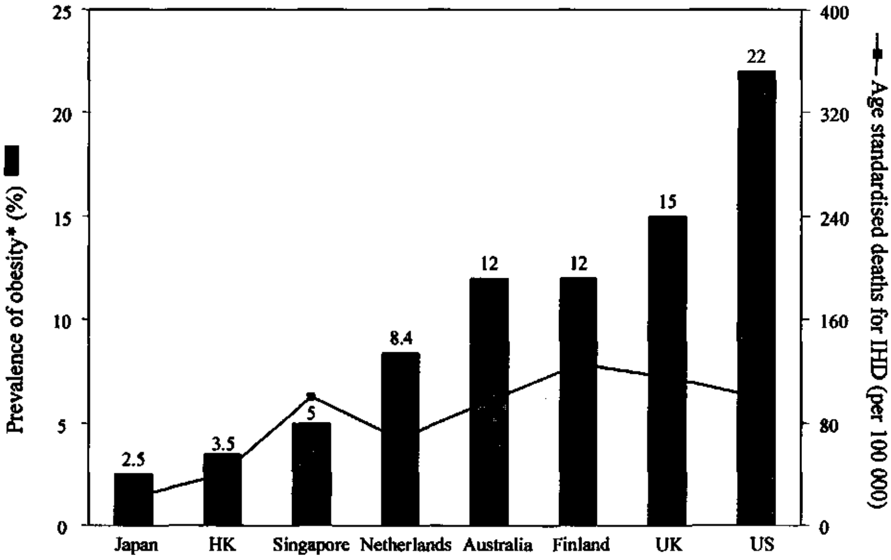
Such relationships have been clearly established in a large number of studies involving mainly Caucasian populations. For such populations, it has been found that the body mass index (BMI) cut-off points of 25 kg/m^2 for overweight and 30 kg/m^2 for obesity are appropriate as they are indicative of elevated levels of risk factors and associated with an increase in morbidity and mortality. Based on these studies, WHO has recommended present cut-off points for overweight and obesity at BMI of 25 kg/m^2 and 30 kg/m^2 [3].

A BMI of 30 kg/m^2 corresponds to about 25% and 35% body fat for Caucasian men and women[22,23]. Recently, studies have shown that BMI-body fat percentage relationships are age- and sex- specific[23-27] and most probably ethnic-specific too[28-32]. Indonesians are found to have higher body fat percentage compared to Caucasians with the same BMI[31] while the reverse may be true for Blacks[26]. For the same body fat percentage, the differences in BMI between Indonesians and Caucasians are about three units. This implies that for Indonesians, for example, BMI cut-off points for obesity should be 27 instead of 30 kg/m^2. This would then coincide with a higher prevalence of obesity. It is therefore a necessity that correct BMI cut-off points are defined for specific ethnic groups.

Recognising the limitation of using uniform BMI cut-off points across populations, WHO has recommended that research into the development of anthropometric indicators and cut-off points for total body fatness and visceral fat in relation to health outcomes appropriate for certain subgroups of age, sex and race has to be conducted[22].

The use of inappropriate BMI cut-off points could explain the discrepancy in the apparently low prevalence of obesity and high prevalence of obesity-related diseases in Singapore. In Figure 3 is a comparison of obesity rates (based on BMI of 30 kg/m^2) and age-standardised deaths rates (ASDR) from ischaemic heart disease in some selected countries. It is obvious that the low prevalence of obesity and high ASDR seen in Singapore is not consistent with international data.

Figure 3. Comparison of obesity prevalence (%) and age-standardised death rates from ischaemic heart diseases in selected countries[2,3]



HK: Hong Kong, UK: United Kingdom, US: United States of America

* BMI ≥ 30 kg/m^2

There has been no study conducted among Singaporeans to investigate the relationship between BMI and body fat and to determine if WHO's cut-off values for overweight and obesity using BMI are appropriate for the different population groups in Singapore. The relationship between BMI, abdominal fatness (as measured by waist circumference and waist-to-hip ratio) with cardiovascular risk factor has also not been explored on a population basis. If, based on findings from other Asian studies, the cut-off point for obesity among Singaporeans would be lowered, the prevalence of obesity among Singaporean men would be higher than the current figures. This could lead to unnecessarily high economic burden (both direct and indirect costs) if 'high risk' cases are missed for appropriate intervention measures [3,33].

Aims of the research project

Diet and body composition are important determinants of cardiovascular risk factors (blood pressure, blood lipids levels, blood glucose and insulin levels) in the community. Currently, there is no satisfactory explanation for the high prevalence of cardiovascular diseases in Singapore and the differences in prevalence among the different ethnic groups. There is a lack of data on dietary intakes and body composition among different ethnic groups in Singapore and how these contribute to differences observed in cardiovascular risk factors. These 'gaps' in knowledge have important public health implications on the timing and selection of high risk groups for prevention and intervention programmes in reducing prevalence of obesity and its related morbidity and mortality.

This research project, funded by the National Medical Research Council of Singapore, had two main sets of objectives:

Dietary component:

(a) To obtain 'usual' dietary intake of energy, fat, fatty acids, cholesterol, fruits and vegetables using a food frequency questionnaire; and

(b) To correlate these intakes with cardiovascular risk factors among the major ethnic groups (Chinese, Malays and Indians) in Singapore.

Body composition component:

To determine percent body fat for Singaporeans using a four-compartment model;

(a) To investigate the validity of existing indirect body composition methods for measuring body fat (hydrometry, densitometry, dual energy X ray absorptiometry) in the different ethnic subgroups in Singapore;

(b) To study the relationship between body mass index (BMI) and body fat, and to define the BMI values associated with a body fat of 25 percent in males and 35 percent in females (levels associated with lower limits of obesity);

(c) To correlate percent body fat with cardiovascular risk factors among the different ethnic groups.

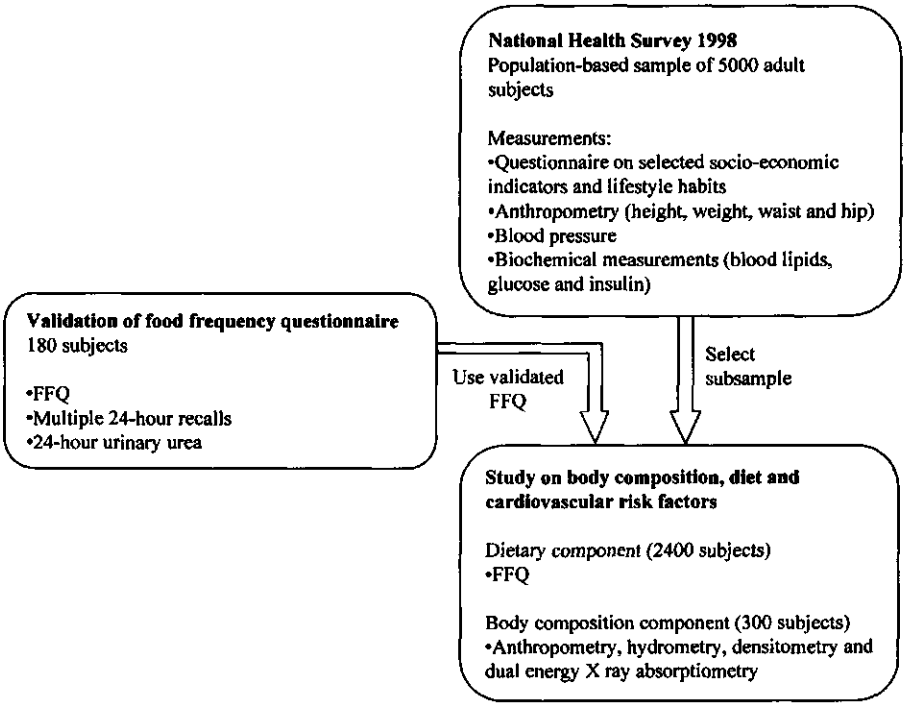
The hypotheses to be tested were:

(a) The differences in cardiovascular risk factors in the three major ethnic groups in Singapore are attributed to differences in dietary intake and body composition;

(b) The cut-off points for BMI currently used to define overweight (BMI between 25 kg/m^2 and 29.9 kg/m^2) and obesity (BMI of 30 kg/m^2 or more) are not valid for the major ethnic groups in Singapore.

The study was conducted as part of the National Health Survey in 1998 (Figure 4) and sponsored by the National Medical Research Council and the Ministry of Health in Singapore.

Figure 4. Schematic representation of the current study



Outline of the thesis

The thesis begins with an analysis of the data from the National Health Survey (NHS) conducted in 1992, studying the relationship between indices of obesity (BMI) and abdominal fatness (waist-to-hip ratio, WHR) and cardiovascular risk factors among Singaporean Chinese adults only (**Chapter 2**). This preliminary analysis of data from the previous NHS provides an indication of the absolute and relative risks of having cardiovascular risk factors at different quintiles of BMI and WHR. In **Chapter 3** is a meta-analysis of literature on the relationship between BMI and body fat percentage (BF%) among different ethnic groups.

Chapters 4 to **6** focus on body composition, beginning with a validation study of different two-compartment models in measuring body fat percentage when compared to a reference four-compartment model. To determine if the BMI cut-off value for obesity recommended by WHO is applicable to the three ethnic groups in Singapore, two criteria are used. The first is the relationship between BMI and body fat percentage, and the level of BMI which coincides with an excessive accumulation of body fat (**Chapter 5**). The second criteria is the level at which risk for co-morbidities (in particular for cardiovascular risk factors) is increased significantly (**Chapter 6**).

Chapter 7 is concerned with validation of the food frequency questionnaire to be used in the main study and **Chapter 8** reports the dietary intake of Chinese, Malays and Indians and examines if differences in dietary intakes of fat, saturated fat, unsaturated fat, cholesterol, fruits, vegetables and rice & alternatives (comprising rice, cereals, breads and noodles) could explain differences in blood cholesterol among the ethnic groups.

The final chapter summarises the main findings of the research project, discusses the public health implications of the findings and gives recommendations for future research.

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2

Manifestation of cardiovascular risk factors at low levels of body mass index and waist-hip ratio in Singaporean Chinese

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Abstract

The global prevalence of obesity, characterised by a body mass index (BMI) ≥ 30 kg/m^2, is high and is increasing. Obesity is coincided with higher risks for non-communicable diseases as cardiovascular disease (CVD) and cancer. In Singapore the prevalence of obesity differs between the three main ethnic groups (Chinese, Malays and Indians) but is relatively low compared to Western societies. Despite the low prevalence of obesity (BMI< 30 kg/m^2) the morbidity and mortality for CVD are high in Singapore. In this paper the odds ratio for increased risk factors for CVD was studied in relation to BMI quintiles and in relation to body fat distribution as measured by waist-to-hip ratio (WHR) quintiles in a representative sample of adult Singaporean Chinese. The lowest quintile was used as the reference category. The boundaries for the BMI quintiles were 18.9, 20.7 22.6 and 25.0 kg/m^2 for females and 20.0, 21,7, 23.5 and 25.6 kg/m^2 for males. The boundaries for WHR quintiles were 0.68, 0.71, 0.74 and 0.79 for females and 0.77, 0.82, 0.85 and 0.89 for males. As observed in other studies the odds ratio for high serum cholesterol, low HDL cholesterol, high total cholesterol/HDL cholesterol ratio, high serum triglyceride level, high blood pressure and high fasting blood glucose was higher in upper BMI and WHR quintiles. The effects were more pronounced in males compared to females. The odds ratio for having at least one of the mentioned risk factors was in the different BMI quintiles for females 1.3 (ns), 1.6, 2.1 and 2.7 and in males 2.7, 4.1, 6.2 and 7.3. For the WHR quintiles these figures were 0.9 (ns), 1.3 (ns), 1.9 and 2.1 for females and 2.1, 4.7, 6.7 and 12.6 for males. As the elevated risks are already apparent at low levels of BMI and low levels of WHR, it can be queried whether the cut-off points for obesity and for abdominal fat distribution as suggested by the WHO are applicable to the Singaporean Chinese population. There are indications in the literature that Asian populations have higher body fat percent at lower BMI which may explain the high odds ratios for CVD risk factors and the high morbidity and mortality at low BMI and WHR and the high morbidity and mortality from CVD in Singapore, despite relatively low population mean BMI and obesity rates.

Introduction

Obesity as an independent risk factor for cardiovascular diseases (CVD), particularly for coronary heart disease (CHD), has been well documented. It also has been recognised that obesity mediates its effects by elevating other cardiovascular risk factors, viz., dyslipidaemia (hypercholesterolaemia, hypertriglyceridaemia and low high-density lipoprotein (HDL) cholesterol), hypertension and glucose intolerance [1-5].

The mortality from CVD in Singapore is comparable to mortality figures in western industrialised countries and is higher than in other parts of Asia such as Japan and Hong Kong[6]. This is despite a much lower prevalence of obesity (defined as body mass index ≥ 30 kg/m^2) among Singaporean adults of about 5% as compared to some Caucasian populations[7,8]. The incidence of acute myocardial infarct among Singaporean Chinese males and females in 1991 was 94.3 and 27.3 per 100,000 persons aged 20-64 years while the prevalence of obesity in 1992 was only 3.2% and 3.9% respectively[8].

An elevated level of body fat percentage (BF%) and the pattern of body fat distribution, measured as waist to hip circumference ratio (WHR) is closely related to increased morbidity and mortality, among which CVD is one of the most important causes of mortality[8,10]. Such relationships have been clearly established in a number of studies involving mainly Caucasian populations. For such populations, it has been found that the body mass index (BMI) cut-off points of ≥25 kg/m^2 for overweight and ≥30 kg/m^2 for obesity are appropriate as they are indicative for elevated levels of risk factors and associated with a higher morbidity and mortality. Based on these studies, the World Health Organisation has recommended the present cut-off points for overweight and obesity at BMI ≥ 25 kg/m^2 and ≥ 30 kg/m^2 respectively[8, 11].

A BMI of 30 kg/m^2 corresponds to about 25% and 35% body fat for Caucasian men and women respectively[11,12]. Recent studies have shown that the relationship between BMI and BF% is age and sex dependent[12,13] and that the relationship may differ between ethnic groups[14,15,16]. For example Wang et al[17] reported that Asians living in New York have lower BMI but higher body fat compared to age and sex matched whites. Swinburn et al[14] reported that Polynesians have lower body fat at the same BMI compared to Caucasians. Gallagher et al [3] did not find differences between American Blacks and Whites in the relationship between BMI and BF%, whereas there are reported differences between Black populations[15]. Indonesian groups are found to have higher percentage body fat compared to Dutch Caucasians with the same BMI[16]. For the same percentage body fat, age and sex the differences in BMI between Indonesians and Dutch Caucasians is about three units. If obesity is defined as excess body fat and not excess weight, this would imply that for Indonesians, BMI cut-off points for obesity should be 27 instead of 30 kg/m^2. Lowering of the cut-off point for obesity would result in higher prevalence figures for obesity.

Similarly, studies relating fat distribution and health risks are mainly conducted among Caucasians with the subsequent cut-off points of WHR or waist circumference being developed using Caucasian data[11]. If differences in body build exist between different ethnic groups, the applicability of these cut-off points may also be questioned.

Singapore is a multi-ethnic society. The population consists of three main ethnic groups, Chinese (76%), Malays (14%) and Indians (7%), among which there are differences in cardiovascular risk factors as well as in cardiovascular mortality [6,9,18,19,20]. The purpose of this study was to study the effect of different levels of BMI and body fat distribution as measured by WHR on the risk factor profile. For this, data of the National Health Survey from 1992 were used. As the numbers of Malays and Indians in that study were relatively small, only data from Chinese are used. The paper also aims to determine if the WHO-recommended cut-off points for BMI and waist-hip ratio (WHR) are appropriate for the Chinese sub-population in Singapore.

Subjects and Methods

In 1992, the National Health Survey was conducted in Singapore to study the level and distribution of risk factors for major non-communicable diseases. Among the risk factors studied were hypertension, blood cholesterol, triglycerides, fasting blood glucose, obesity, fat distribution and smoking. The study was in conformance with the guidelines of the WHO Helsinki Conference and all participants gave informed consent.

A two-stage sampling technique was employed to obtain a sample of 5000 household units, which were socio-economically representative of the population based on house type. The first stage of the sampling used a purposive sampling technique to select polling districts within close proximity to the six survey centres (community centres). Household units of each polling district were stratified by house type and systematically selected in the second stage. Among the selected households, eligible household members were numbered and subjects were selected based on a combination of disproportionate stratified sampling by ethnic group and systematic sampling procedures. The final sample consisted of a total of 3568 subjects, comprising 65.3% Chinese, 18.3% Malays and 16.4% Indians.

For the present study only the data of the Chinese subjects (n=2319, 1211 females, 1108 males) were used. They were all aged between 18 to 69 years.

The subjects were invited to visit the community centre nearest their housing estate, having fasted for a minimum of 8 h overnight, where information was obtained by questionnaire and measurements were taken.

Weight was measured in light clothing without shoes to the nearest 0.5 kg and body height was measured to the nearest 0.5 cm without shoes using a wall-mounted stadiometer. From weight and height the body mass index (BMI, kg/m^2) was calculated. Waist circumference (to the nearest 0.5 cm) was measured at the mid-point between the iliac crest and the lower rib margin, while hip measurement (to the nearest 0.5 cm) was taken as the maximum circumference around the buttocks posteriorly and pubic symphysis anteriorly.

Blood pressure was measured to the nearest 2 mmHg using a standard mercury sphygmomanometer, with systolic pressure being the level where the first phase is heard and diastolic pressure being the level where the sounds cease (fifth phase).

A venous blood sample was taken, plasma was separated and analysed for glucose, total cholesterol, HDL-cholesterol and triglycerides by standard enzymatic methods. HDL cholesterol was measured after precipitation of LDL and VLDL with dextran sulphate and magnesium chloride. Statistical analysis were performed using SPSS for Windows[21] and using methods as recommended by Kleinbaum and Kupper[22]. Quintiles of BMI and WHR were computed for comparison of mean levels of cardiovascular risk factors among the quintiles, the lowest quintile used as the reference category. All values were age-adjusted using multivariate regression techniques. Analysis of variance (ANOVA) was used to compare means of general characteristics and risk factors between the quintiles.

Cut-off values for elevated blood pressure were defined as a systolic blood pressure (SBP) of >140 mm Hg and/or a diastolic blood pressure (DBP) of >90 mm Hg.

Cut-off points for other risk factors were for total cholesterol: (TC)>5.2 mmol/l; for HDL-cholesterol: <0.9 mmol/l); for TC/HDL-ratio: >4.4; for triglyceride (TG): >1.8 mmol/l; and fasting glucose (FG): >6.7 mmol/l[5,23-25]. Subjects with at least one risk factor were assigned to the 'Risk' group.

Odds ratio for the presence of these risk factors were computed using multiple logistic regression, with adjustment for age, current smoking, BMI (for WHR quintiles) and WHR (for BMI quintiles). Results are given as mean ± SD. For calculated Odds-ratio's the 95% confidence interval (95%CI) is given. The level of significance is 0.05

Results

Mean BMI values in the Chinese, Malays and Indian Singaporeans were 22.9 ± 4.0, 23.3 ± 3.6 and 24.4 ± 3.1 kg/m^2 for the males and 22.1 ± 4.2, 24.7 ± 4.2 and 24.4 ± 3.0 kg/m^2 for the females. More anthropometric characteristics for the Chinese population only are given in Table 1. Age and age distribution were similar between males and females. Body weight, body height, BMI, waist and WHR were significantly higher in males, whereas hip circumference did not differ between males and females. Table 2 gives mean age and mean BMI values in the quintiles for BMI and WHR for males and females.

As expected, the mean age of the subjects increases with progressively higher quintiles of BMI and WHR ($p<0.001$) for both males and females. With increasing quintiles of BMI and WHR, there is also a corresponding significant rise ($p<0.001$) in mean WHR and BMI values respectively.

Table 1. Characteristics of the Singaporean Chinese subjects.

	Females		Males	
	Mean	SD	Mean	SD
Age (years)	37.8	12.6	37.6	12.9
Height (cm)	156.3	5.8	168.1*	6.3
Weight (kg)	54.0	9.4	64.6*	10.7
Body mass index (kg/m^2)	22.1	3.8	22.8*	3.4
Waist circumference (cm)	69.6	8.8	79.1*	9.8
Hip circumference (cm)	94.8	6.7	94.6	6.2
Waist/hip ratio	0.73	0.06	0.84*	0.07

* $p<0.05$ between gender

The distribution (age-adjusted mean and SD) of risk factors over the quintiles of BMI and WHR is presented in Table 3. For all risk factors except HDL-cholesterol, the levels rise with the quintiles of BMI and WHR. Mean HDL cholesterol decreases with rising levels of the quintiles. The mean values are significantly different ($p<0.001$) between each level of the quintiles (BMI and WHR) for both males and females.

Figure 1 demonstrates the higher proportion of males and females with elevated risk factors in the higher BMI quintiles. This was also apparent for males and females in the WHR quintiles (Figure 2).

Presented in Table 4 are the odds ratios for elevated blood pressure, dyslipidaemia, elevated fasting glucose, and risk, defined when at least one of the mentioned risk factors was present, by BMI quintiles and WHR quintiles for males and females. These odds ratios are adjusted for age, number of cigarettes smoked per day, WHR (for BMI quintiles only) and BMI (for WHR quintiles only).

For males, odds ratios were significantly higher from BMI quintile 2 onwards for all risk factors except for elevated TC and FG. The odds ratio for elevated TC became significant at BMI quintile 4. The odds ratio for elevated FG was higher at higher BMI quintiles but the differences between the quintiles were not significant. For WHR quintiles, odds ratio for TC, TC/HDL ratio, TG and risk were significantly higher from WHR quintile 2 onwards, while that for elevated FG was significant at WHR quintile 5 only. Adjusted odds ratio for raised BP and low HDL were not significantly different in the WHR quintiles.

Table 2. Distribution of general characteristics of Singaporean Chinese subjects (mean, SD), by BMI quintiles, WHR quintiles and gender

BMI quintiles	No.		Range of BMI (kg/m^2)		Age (years)		BMI (kg/m^2)		WHR	
	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males
1	248	234	<18.9	<20.0	31.6 (11.3)	34.6 (13.3)	17.6 (1.1)	18.5 (1.1)	0.69 (0.04)	0.78 (0.05)
2	237	212	18.9 to < 20.7	20.0 to < 21.7	33.5 (11.3)	35.4 (12.5)	19.8 (0.5)	20.9 (0.5)	0.71 (0.05)	0.81 (0.05)
3	239	222	20.7 to < 22.6	21.7 to < 23.5	38.4 (11.8)	36.9 (12.5)	21.6 (0.6)	22.6 (0.5)	0.72 (0.05)	0.83 (0.05)
4	243	218	22.6 to < 25.0	23.5 to < 25.6	41.6 (12.1)	39.7 (12.0)	23.7 (0.6)	24.5 (0.6)	0.75 (0.05)	0.86 (0.05)
5	244	222	=>25.0	=>25.6	44.3 (11.8)	41.4 (12.7)	28.0 (2.9)	27.9 (2.2)	0.79 (0.06)	0.90 (0.05)

WHR quintiles	No.		Range of WHR (kg/m^2)		Age (years)		BMI (kg/m^2)		WHR	
	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males
1	252	206	<0.68	<0.77	27.7 (8.6)	27.7 (10.5)	19.4 (2.1)	19.9 (10.5)	0.66 (0.02)	0.74 (0.02)
2	240	259	0.68 to < 0.71	0.77 to <0.82	33.0 (9.8)	32.9 (10.7)	20.5 (2.6)	21.1 (2.2)	0.69 (0.01)	0.79 (0.01)
3	205	193	0.71 to < 0.74	0.82 to <0.85	38.8 (11.5)	38.1 (10.4)	21.6 (2.8)	22.8 (2.6)	0.73 (0.09)	0.83 (0.01)
4	291	208	0.74 to < 0.79	0.85 to <0.89	41.7 (10.9)	41.3 (11.7)	23.3 (3.8)	24.0 (2.6)	0.76 (0.01)	0.87 (0.01)
5	223	242	=>0.79	=>0.89	48.6 (11.2)	47.3 (11.2)	25.8 (3.9)	26.1 (3.4)	0.82 (0.03)	0.93 (0.03)

Table 3. Distribution of risk factors (mean, SD) corrected for age, by BMI quintiles, WHR quintiles and gender.

BMI quintiles	SBP (mmHg)		DBP (mmHg)		TC (mmol/l)		HDL (mmol/l)		TC/HDL ratio		Fasting glucose (mmol/l)		TG (mmol/l)	
	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males	Females	Males
1	105.4	114.8	60.7	65.7	4.9	4.9	1.6	1.3	3.2	3.8	5.2	5.4	0.8	1.1
	(12.3)	(13.9)	(8.6)	(9.4)	(0.9)	(1.0)	(0.3)	(0.3)	(0.7)	(1.1)	(1.2)	(1.1)	(0.3)	(1.0)
2	108.3	117.5	62.0	69.3	5.0	5.1	1.5	1.2	3.4	4.4	5.2	5.5	0.9	1.4
	(14.1)	(14.4)	(9.3)	(10.4)	(1.0)	(1.0)	(0.3)	(0.3)	(0.9)	(1.2)	(0.8)	(0.9)	(0.6)	(1.3)
3	113.8	122.0	65.5	71.7	5.3	5.3	1.5	1.2	3.8	4.8	5.4	5.8	1.1	1.6
	(17.1)	(17.5)	(9.6)	(11.3)	(1.0)	(1.0)	(0.3)	(0.2)	(1.1)	(1.4)	(1.2)	(1.6)	(0.8)	(1.3)
4	119.1	124.3	69.1	73.8	5.4	5.5	1.3	1.1	4.2	5.2	5.8	6.0	1.5	2.0
	(18.1)	(16.8)	(10.5)	(11.5)	(1.0)	(1.0)	(0.3)	(0.2)	(1.2)	(1.5)	(1.4)	(1.7)	(1.4)	(1.7)
5	126.5	130.8	74.0	78.7	5.6	5.5	1.2	1.0	4.6	5.5	6.3	6.2	1.6	2.2
	(19.4)	(18.6)	(10.8)	(12.8)	(1.0)	(1.0)	(0.3)	(0.20	(1.1)	(1.6)	(2.0)	(1.7)	(1.0)	(1.7)
Total	114.6	121.8	66.3	71.8	5.2	5.3	1.4	1.2	3.8	4.7	5.6	5.8	1.2	1.7
	(18.1)	(17.2)	(10.9)	(12.0)	(1.0)	(1.0)	(0.3)	(0.3)	(1.2)	(1.5)	(1.4)	(1.5)	(1.0)	(1.5)
WHR quintiles														
1	105.7	114.9	60.3	64.6	4.8	4.6	1.6	1.3	3.2	3.6	5.1	5.2	0.8	1.0
	(10.3)	(12.2)	(8.4)	(9.3)	(0.8)	(0.9)	(0.3)	(0.2)	(0.7)	(0.8)	(0.5)	(0.4)	(0.3)	(0.4)
2	108.1	115.6	62.6	66.6	5.0	5.1	1.5	1.2	3.4	4.3	5.2	5.3	0.9	1.2
	(11.7)	(13.5)	(8.8)	(9.2)	(0.8)	(0.9)	(0.3)	(0.3)	(0.7)	(1.3)	(0.4)	(0.5)	(0.4)	(1.1)
3	112.3	121.8	65.5	73.5	5.3	5.4	1.4	1.1	3.8	4.9	5.3	5.6	1.1	1.6
	(15.9)	(15.1)	(9.2)	(10.8)	(0.9)	(1.0)	(0.3)	(0.2)	(1.0)	(1.1)	(0.4)	(1.1)	(0.6)	(1.2)
4	118.8	125.0	69.3	75.1	5.4	5.6	1.3	1.1	4.2	5.2	5.6	6.0	1.4	2.0
	(17.8)	(16.3)	(11.2)	(11.0)	(1.0)	(1.0)	(0.3)	(0.2)	(1.1)	(1.4)	(1.3)	(1.8)	(0.9)	(1.6)
5	128.3	131.8	73.7	79.2	5.7	5.6	1.3	1.1	4.7	5.6	6.7	6.5	1.9	2.5
	(22.7)	(21.0)	(11.2)	(12.4)	(1.1)	(1.0)	(0.3)	(0.3)	(1.4)	(1.6)	(2.6)	(2.3)	(1.6)	(2.0)
Total	114.6	121.8	66.3	71.8	5.2	5.3	1.4	1.2	3.8	4.7	5.6	5.8	1.2	1.7
	(18.1)	(17.2)	(10.9)	(12.0)	(1.0)	(1.0)	(0.3)	(0.3)	(1.2)	(1.5)	(1.4)	(1.5)	(1.0)	(1.5)

SBP: systolic blood pressure; TC: serum total cholesterol; TG: serum triglycerides
DBP: diastolic blood pressure; HDL: serum high density lipoprotein
Means for all risk factors are significantly different between the quintiles (BMI and WHR).

Figure 1. Proportion of subjects with risk factors, by BMI quintiles and gender

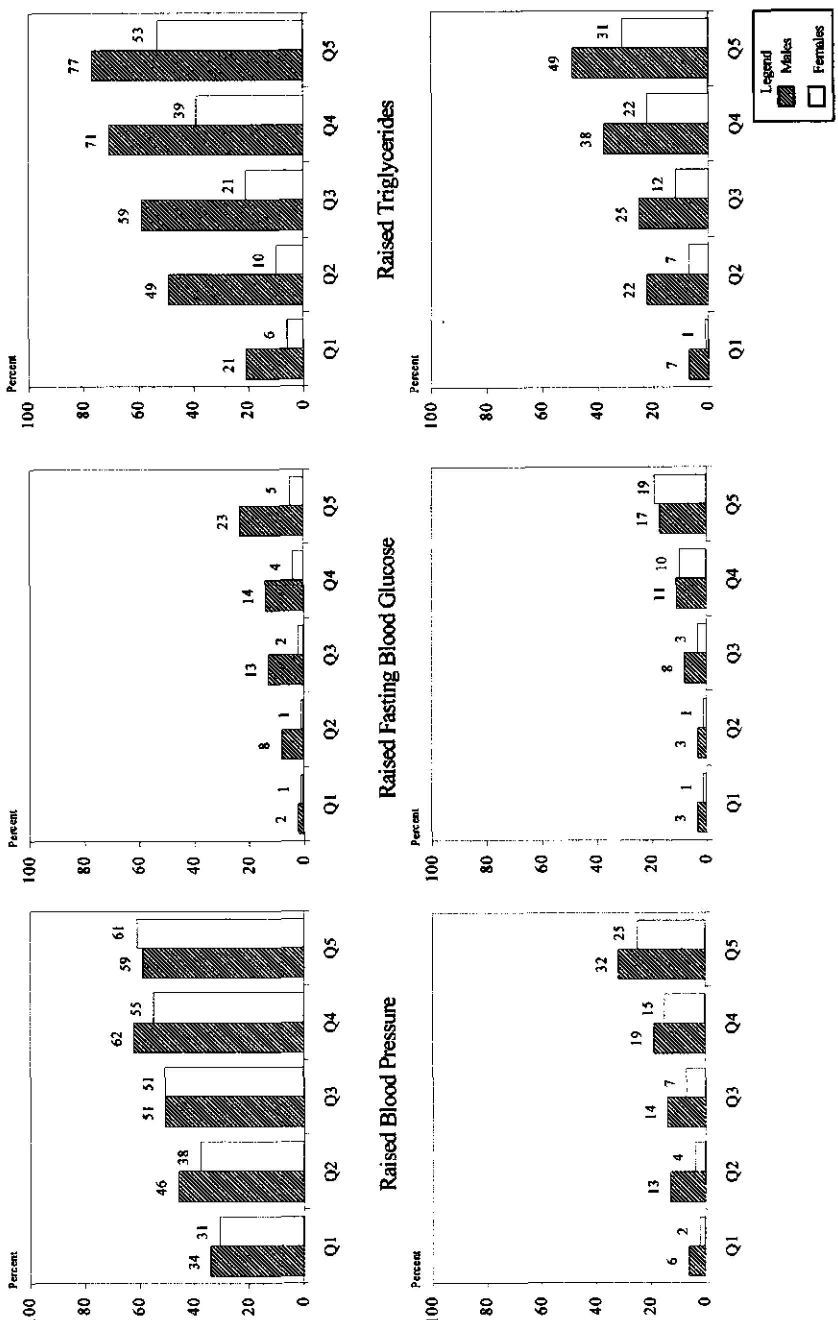


Figure 2. Proportion of subjects with risk factors, by WHR quintiles

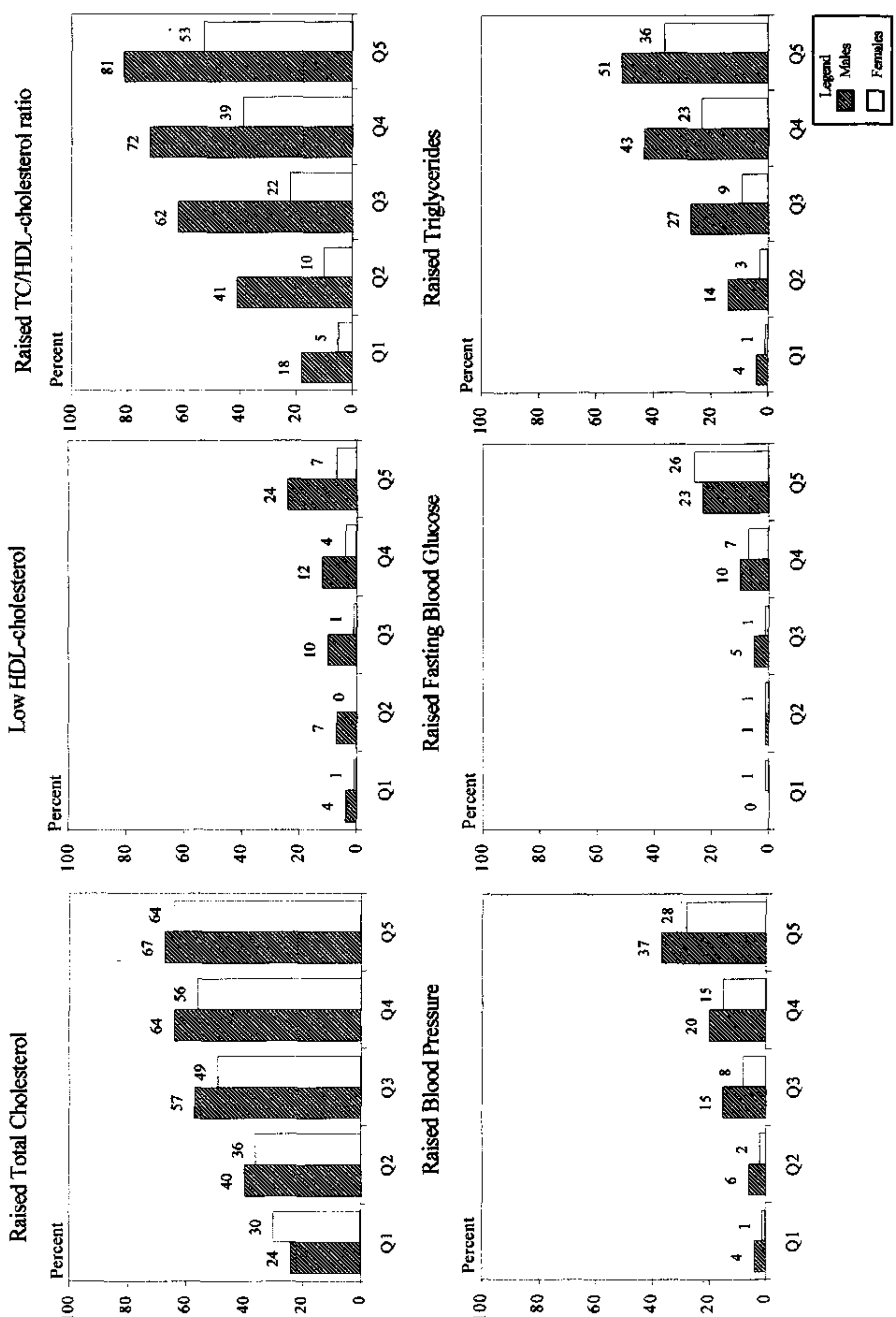


Table 4. Adjusted[#] odds ratio (OR) for each risk factor by BMI quintiles , WHR quintiles and gender.

Adjusted OR (95% CI)	BP (SBP=>140 or DBP =>90 mm Hg)	TC (=>5.2 mmol/l)	HDL (<0.9 mmol/l)	TC/HDL ratio (=>4.4)	Fasting Glucose (=>6.7 mmol/l)	TG (=>1.8 mmol/l)	At least one risk factor
Females							
BMI quintiles							
2	1.8 (0.6, 5.8)	1.3 (0.8, 1.9)	0.8 (0.2, 4.3)	1.3 (0.7, 2.6)	1.0 (0.2, 6.3)	4.6 (1.3, 16.1)	1.3 (0.9, 2.0)
3	1.9 (0.6, 5.6)	1.5 (1.0, 2.3)	1.0 (0.2, 4.6)	2.6 (1.4, 4.7)	1.5 (0.3, 7.4)	6.5 (1.9, 22.0)	1.6 (1.1, 2.4)
4	3.0 (1.0, 8.4)	1.4 (0.9, 2.2)	1.8 (0.4, 7.1)	4.6 (2.5, 8.3)	3.6 (0.8, 15.9)	9.2 (2.8, 30.7)	2.1 (1.4, 3.3)
5	3.9 (1.4, 11.4)	1.6 (0.9, 2.5)	1.3 (0.3, 5.8)	5.6 (3.0, 10.4)	4.1 (0.9, 18.4)	9.2 (2.7, 31.0)	2.7 (1.7, 4.5)
WHR quintiles							
2	1.0 (0.2, 5.5)	0.8 (0.6, 1.3)	0.6 (0.1, 6.6)	1.9 (0.9, 3.8)	0.8 (0.1, 5.9)	1.9 (0.5, 7.7)	0.9 (0.6, 1.3)
3	2.2 (0.5, 10.1)	0.9 (0.6, 1.5)	2.4 (0.4, 15.1)	4.0 (2.1, 7.8)	1.1 (0.2, 6.7)	5.1 (1.4, 17.9)	1.3 (0.8, 1.9)
4	3.2 (0.7, 14.2)	1.0 (0.6, 1.5)	7.0 (1.4, 33.7)	8.6 (4.6, 16.2)	4.9 (1.1, 22.1)	12.2 (3.6, 41.1)	1.9 (1.3, 2.9)
5	2.8 (0.6, 13.0)	0.7 (0.4, 1.3)	16.4 (3.2, 82.7)	13.2 (6.8, 25.7)	17.6 (3.9, 78.3)	16.1 (4.6, 56.5)	2.1 (1.3, 3.4)
MALES							
BMI quintile							
2	2.3 (1.1, 4.8)	1.4 (0.9, 2.2)	3.7 (1.3, 10.3)	3.8 (2.5, 5.9)	1.1 (0.4, 3.7)	3.2 (1.7, 6.1)	2.7 (1.8, 4.0)
3	2.3 (1.1, 4.7)	1.5 (0.9, 2.3)	6.6 (2.5, 1.5)	5.5 (3.6, 8.5)	3.4 (1.3, 9.2)	3.0 (1.6, 5.7)	4.1 (2.7, 6.4)
4	2.5 (1.2, 5.3)	1.8 (1.2, 2.9)	6.7 (2.5, 17.6)	8.7 (5.6, 13.5)	3.9 (1.5, 10.2)	4.0 (2.1, 7.5)	6.2 (3.9, 9.9)
5	4.5 (2.0, 9.9)	1.2 (0.7, 1.9)	11.8 (4.6, 30.4)	10.9 (6.9, 17.2)	6.0 (2.4, 15.1)	3.9 (2.0, 7.7)	7.3 (4.4, 12.0)
WHR quintile							
2	0.9 (0.37, 2.1)	1.6 (1.1, 2.5)	1.6 (0.7, 3.7)	2.9 (1.9, 4.4)	1.8 (0.2, 17.4)	3.2 (1.4, 7.1)	2.1 (1.4, 3.3)
3	1.6 (0.7, 3.7)	2.4 (1.5, 3.9)	2.3 (1.1, 5.4)	6.2 (3.9, 10.0)	5.8 (0.7, 46.5)	6.0 (2.7, 13.6)	4.7 (2.9, 7.5)
4	1.6 (0.7, 3.8)	2.6 (1.6, 4.4)	2.9 (1.3, 6.6)	9.3 (5.7, 15.1)	10.6 (1.4, 80.3)	10.6 (4.7, 24.2)	6.7 (4.0, 11.2)
5	2.2 (0.9, 5.5)	2.0 (1.1, 3.7)	6.8 (3.0, 15.1)	14.6 (8.6, 24.7)	20.9 (2.8, 154.5)	10.5 (4.3, 25.5)	12.6 (6.7, 23.5)

[#] Adjusted for age and current smoking

For females, odds ratio for raised serum TG were significantly higher from BMI quintile 2 onwards, while those for high TC/HDL ratio and risk became significant from BMI quintile 3 onwards. The adjusted odds ratio for having elevated BP and TC was significant higher from BMI quintile 4 onwards. For low HDL and elevated FG, adjusted odds ratios did not differ from 1. For the WHR quintiles, odds ratios for TC/HDL ratio and TG were higher at WHR quintile 3, while those for low HDL and elevated FG were significant at WHR quintile 5 only. For elevated BP, TC and risk, adjusted odds ratios did not differ from 1 in the quintiles of WHR.

Discussion

The WHO, in a recent publication, reports about the global epidemic of obesity[8]. In that report, normal weight is defined when having a BMI between 18.5 and 24.9 kg/m^2, overweight as a BMI between 25.0 and 29.9 kg/m^2 and obesity as a BMI $\geq$ 30.0 kg/m^2. According to these WHO cut-off points, Singapore as a total (Chinese, Malays and Indians) has a prevalence of obesity of approximately 5 percent, with remarkable differences between the three main ethnic groups and in some ethnic groups between the sexes[9,26].

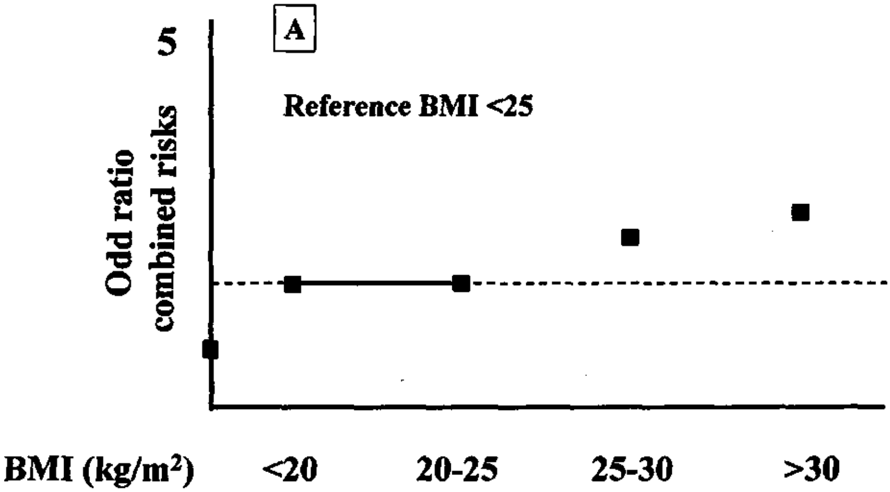
Overweight and obesity are known to be associated with elevated risk factors for CVD. In the present study the relationship between risk factors for CVD and BMI and/or body fat distribution as measured by WHR in a representative sample of the Chinese Singapore population in 1992 is reported. The results confirm findings from many other studies, most of them in Caucasian populations, that a higher BMI or a higher WHR is associated with elevated risk factors[8,27]. However, notable in the present study is the increased risk for a risk factor at relatively low levels of BMI and WHR. For example, in BMI quintile 4, which has the boundaries of 22.6 to 25.0 kg/m^2 in females and from 23.5 to 25.6 kg/m^2 in males, the risk for having at least one risk factor is 2.1 in females and as high as 6.2 in males, compared to BMI quintile 1, which is characterised by a BMI <18.9 kg/m^2 in females and <20.0 kg/m^2 in males. Thus, Singapore Chinese are already markedly at risk for elevated CVD risk factors at a BMI value that is set as 'normal' and 'acceptable' in a recent WHO report[8]. Also the waist circumference and the WHR are markedly lower compared to, for example, the values found in a recently published Dutch study[27]. Among other factors that have an impact on risk factor levels, like genetic predisposition[28] a different relationship between BMI and BF% could be responsible for the observed high odds ratios at low BMI values.

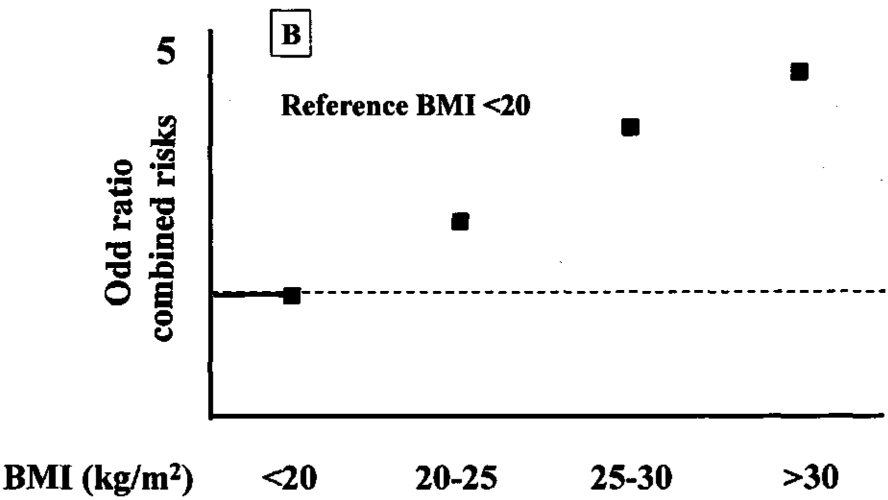
The mean BMI in the Singapore Chinese population is lower than the mean BMI in Caucasian populations[29]. For example, compared to the mean BMI of a Dutch population study conducted from 1993 to 1995[27], the mean BMI in Singapore is about 3 kg/m^2 lower. The mean BMI in Singapore, however, is comparable with the mean BMI is the three big cities in PR China[30]. If the BMI distribution of the Singapore Chinese population is compared with the BMI distribution in Caucasian societies, it is obvious that the distribution is shifted to the left. Of the Singapore Chinese population 15.7 percent of the females and 9.3 percent of the males had a BMI lower than 18.5 kg/m^2. In comparison, in the USA and France this figure is only 3.5 percent and 4.9 percent, respectively[29]. There is, however, no clinical evidence of a high prevalence of under nutrition in the Singapore Chinese population. Only 3.8 percent of the females and 3.0 percent of the males had a BMI $\geq$ 30 kg/m^2, thus were obese according to the WHO classifications, which is much lower than the prevalence figures reported in most Caucasians populations[8].

It is clear that not BMI (as an indicator of weigh corrected for height) but the actual amount of BF% is the reason for elevated risks. It has been shown in several studies that Asians have higher mean body fat and lower mean BMI compared to Caucasians[16,17,31,32], thus it is obvious that in Asians elevated risk factors can be expected at relatively low levels of BMI. In other words, it is possible that BMI cut-off points for Singaporeans are currently set at a level that does not reflect actual prevalence of obesity (excess fat in the body) and, therefore, do not coincide with the high prevalence of cardiovascular diseases.

Figure 3 compares odds ratio for having at least one risk factor if different BMI reference categories are used. If as a reference category (odds ratio = 1.0) the population group with 20< BMI <25 kg/m^2 is used, the odds ratios seem relatively low and are similar to, for example, odds ratios in a Dutch population[27]. However, approximately 20 percent of the Singapore population (those with a BMI < 20 kg/m^2) would have a negative risk (Figure 3A). If as a reference category the population group with BMI < 20 kg/m^2 is used, the odds ratios naturally increase, and, as can be seen in Figure 3B, are high at relatively low BMI values.

Figure 3. Odds ratio for at least one risk factor* in relationship to different BMI reference categories.





This is more in line with the observed high morbidity and mortality for CVD in Singapore. For the Dutch group this reference group with lower BMI values would not make sense as hardly any adult Dutch male or female would be in this group.

There are no Singapore data available that compare BF% with BMI and that thus would allow a scientifically based decision for different BMI cut-off points for obesity in Singapore. Moreover, Singapore is a multi-ethnic society with three main ethnic groups (i.e. Chinese, Malays and Indians) and the relationship between BF% and BMI could be different among these three ethnic groups. Recent studies show that in different Indonesian ethnic groups the BMI/BF% relation differs[33] and that in Indonesian Malays the BMI cut-off point could be as low as 27 kg/m^2 [16,33].

If the BMI cut-off point for obesity in the total Singapore population is lowered from 30 kg/m^2 to, for example, 27 kg/m^2, the prevalence of obesity would increase from 5 to 15 percent for males and from 8 to 16 percent for females. Such an increased prevalence should have consequences for the policy for primary health care related to overweight and obesity, as obesity is associated with increased morbidity and mortality and the cost, both in term of medical expenses and indirect economical costs would be enormous. Obviously, if obesity is not correctly classified and as a result 'high risk' cases are missed for appropriate early preventive and intervention measures, an unnecessarily high economic burden, in both direct and indirect costs, from both the condition and its related morbidity could result [7].

Before any decision about an adaptation of the BMI cut-off point for obesity in Singapore could be made, adequate research must be carried out to explore the relationship between BMI and BF% in the different ethnic groups. Ideally also, the absolute level of risk factors in relation to BMI should be studied among the Singapore ethnic groups and should be compared with other ethnic groups.

In Singaporean Chinese the risk for elevated risk factors increases with BMI and, in contrast to, for example, Caucasian populations, already apparent at low levels of BMI. One possible explanation could be a different relationship between BMI and body fat percentage, Chinese having more body fat percentage at the same BMI compared to Caucasians.

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3

Body mass index and percent body fat: a meta analysis among different ethnic groups

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Abstract

Objective: to study the relationship between body fat percent and body mass index (BMI) in different ethnic groups and to evaluate the validity of the BMI cut-off points for obesity.

Design: meta analysis of literature data.

Subjects: Populations of American Blacks, Caucasians, Chinese, Ethiopians, Indonesians, Polynesians and Thai.

Measurements: Mean values of BMI, body fat percent, sex and age were adapted from original papers.

Results: The relationship between body fat percent and BMI differs in the ethnic groups studied. For the same level body fat, age and sex, American Blacks have a 1.3 kg/m^2 and Polynesians a 4.5 kg/m^2 lower BMI compared to Caucasians. In Chinese, Ethiopians, Indonesians and Thai, BMI's are 1.9, 4.6, 3.2 and 2.9 kg/m^2 higher compared to Caucasians respectively. Slight differences in the relationship between percent body fat and BMI between American Caucasians and European Caucasians were also found. The differences found in the body fat/BMI relationship in different ethnic groups could be due to differences in energy balance as well as to differences in body build.

Conclusions: The results show that the relationship between percent body fat and BMI is different among different ethnic groups. This should have public health implications for the definitions of BMI cut-off points for obesity, which would need to be population- specific.

Key words: body fat, body mass index, body build, obesity, cut-off values, ethnic, race

Introduction

Obesity is a 'global' problem[1] as the prevalence of obesity is increasing in developed as well as in less developed countries[1,2]. Obesity is characterised by an increased amount of body fat, defined in young adults as body fat greater than 25 percent in males and greater than 35 percent in females[3,4], corresponding to a body mass index (BMI) of 30 kg/m² in young Caucasians[3]. The amount of body fat can be determined *in vivo* by a number of methods such as underwater weighing, deuterium dilution, dual energy X-ray absorptiometry or skinfold thickness measurements. For epidemiological studies the body mass index (BMI) or Quetelet-index[5], defined as body weight divided by height squared (kg/m²), is regarded as the most suitable indicator for overweight and obesity. Based on Garrow[6] the WHO recommends a BMI cut-off point for overweight at 25 kg/m², whereas for obesity a cut-off point of 30 kg/m² is recommended[1,3]. From the physiological point of view it is not the degree of excess weight (as is measured by e.g. the BMI) but the degree of body fatness that is important as a risk factor. This was already recognised by Behnke et al[7] who showed, using underwater weighing, that overweight does not necessarily coincide with an excess of body fat.

It is known that the relationship between BMI and body fat is age- and sex- dependent[8-13]. Although there are a number of publications in which no differences in the relationship between body fat and BMI between ethnic groups were found[12,13], some recent studies indicate that in some populations these differences may well exist[14-22]. Those differences may be due to differences in body build[14,15] as well as to differences in energy intake and physical activity[20]. Therefore the use of different cut-off points for different population groups may be necessary. There is, however, a lack of adequate information, world-wide but specially in less developed countries. This lack of adequate information is recognised by the WHO in its recent report in which is stated that the BMI cut-off values for overweight and obesity may not correspond with the same degree of fatness across different populations[1].

The use of adequate cut-off points is of great importance for reliable prevalence figures for obesity and consequent public health policies. Based on calculations of Rose[23] it can be concluded that lowering the cut-off point for obesity from 30 kg/m² to 27 kg/m² could increase the prevalence of obesity in a population by as much as 14 percent points. Based on data from a representative study in Singapore a lowering of the BMI cut off point from 30 kg/m² to 27 kg/m² would result in an increase in the obesity prevalence from 6.2 % to 15.3% (1993, unpublished results).

The aim of the present paper was to get more insight in differences among different ethnic groups in the relationship between body fat percent and BMI. For this, available data from studies on body fat and BMI were collected and analysed. In the analysis age and sex differences were accounted for.

Subjects and methods

Data from 32 studies[9-12,16-22,24-45] were analysed, consisting in total of 11,924 subjects, 5,563 females and 6,361 males. Criteria for inclusion of these studies from the literature using Medline were based on adequate information on (mean) body fat, (mean) BMI, gender and ethnic group. In addition, the methodology used for body fat determination should ideally be a 'reference method'. Key words that has been used were body composition, body fat, body mass index, Quetelet index , race and ethnicity. Some of the used studies could not be found with the computer search and were added from personal records.

Caucasians were used as a 'reference' group for comparison with data of other ethnic groups. American, Australian and European Caucasians were analysed as one group as no information was available on their ancestry, but they were also separately studied. Available data on Blacks were generally data on 'American' Blacks. They were separately analysed from Ethiopians. Despite the small numbers of Ethiopians they were included in the analysis as their results differed clearly from the other Black groups. Chinese were treated as one group, although there might be differences among Chinese of different origin. Also here, limited information was available about ancestry.

For 28 data points body fat was determined by densitometry (underwater weighing), in 26 studies by *dual energy X-ray absorptiometry* (DXA) in 13 studies by dilution techniques (deuterium oxide dilution), in 13 studies by a three or four-compartment model and in 14 studies using bioelectrical impedance analysis or skinfold thickness measurements. The principles of the used methodologies are described in detail elsewhere[49]. It is assumed that densitometry, DXA, deuterium dilution and a more compartment model give valid and comparable results within 2-3 percent body fat at a group level[21,33,34,44]. The studies in which skinfolds or impedance was used to determine body fat were included in the analysis because it concerned specific ethnic groups for which no other information was available.

The mean values of BMI, body fat and age from each study were used in the statistical analysis as single data points. If BMI was not reported in the original study, the index was calculated from the (mean) weight and height.

As most data were from studies in Caucasians these data were used to develop a prediction equation for body fat from BMI, taken the effects of sex and age into account. Different models were tested, but stepwise multiple linear regression techniques[46] with sex coded as dummy variable (females=0, males=1) appeared to have a higher explained variance and/or lowest prediction error compared to curvilinear models (using BMI squared). This prediction equation was applied to the different ethnic population groups and the residuals (measured minus predicted body fat percent) were calculated and tested for significance from zero. Differences in slope and/or intercept between regression lines were tested using the technique described by Kleinbaum & Kupper[47]. Males and females were generally analysed together using a dummy variable to increase the power of statistical tests. Analysis of (co)variance (AN(C)OVA) was used to compare differences in BMI between different ethnic groups, taken differences in sex distribution, age and body fat into account. For the statistical calculations SPSS for Windows[46] was used. Data are presented as mean ± standard error (SE).

Results

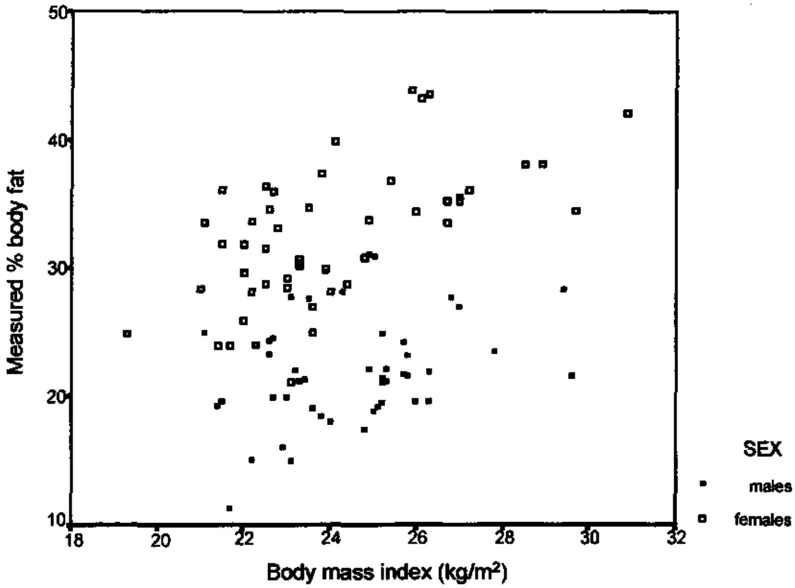
Table 1 shows the distribution of males and females participating in the different (ethnic) groups as well as their age, body fat percent and BMI and the body fat reference techniques that were used. Mean age in the separate studies ranged from 18.4 to 76.6 years, mean body fat from 11.4 to 43.9 percent and mean BMI from 19.3 to 36.0 kg/m². The unadjusted relationship between body fat percent and BMI is presented in Figure 1 for males and females. It is obvious that differences in body fat percent for the same BMI can be remarkable. Part of this difference is due to difference in gender and difference in age.

Table 1. Characteristics of the subjects in the different ethnic groups.

Number of subjects	females/males	Age (years)		Body fat (%)		BMI (kg/m^2)		Used reference method for body fat					
								UWW	D_2O	DXA	3(4)C	skinfolds	impedance
		mean	SE	mean	SE	mean	SE						
Caucasian	2516/1976	44.1	2.1	27.2	1.1	24.1	0.3	25	4	10	7		
Black	1109/849	43.0	1.9	26.6	2.0	25.7	0.5	1	2	4	4		6
Ethiopian	20/24	34.0	2.5	30.7	5.5	21.3	0.2		2				
Chinese	926/684	51.1	4.5	26.1	1.4	22.2	0.3	2	3	10			
Thai	838/2703	43.3	2.2	32.0	1.8	23.0	0.3			2		6	
Indonesian	74/77	31.3	4.3	29.3	3.7	22.4	0.7		2		2		
Polynesian	80/48	38.3	1.8	28.2	6.5	29.7	0.1						2

Abbreviations: BMI: body mass index (kg/m^2); UWW: underwater weighing; D_20: Deuterium oxide dilution; 3(4)C: 3(4)-compartment model

Figure 1. Body fat percent and BMI in males and females of all ethnic groups.



In Table 2 the regression coefficients of the stepwise multiple linear regression for the total Caucasian population are given. Gender alone explains 52 percent of the variance in body fat.

Table 2. Regression of percent body fat as dependent variable and body mass index (BMI), age and sex as independent variables for the Caucasian studies *.

Sex		Age (years)		BMI (kg/m^2)		Intercept (%)		SEE (%)	R^2
β	SE	β	SE	β	SE	Mean	SE		
-10.5	1.5	-	-	-	-	32.4	1.1	5.2	0.52
-10.5	0.9	0.28	0.03	-	-	20.0	1.6	3.2	0.81
-11.4	0.8	0.20	0.03	1.294	0.253	-8.0	5.6	2.5	0.88

* Abbreviations: β, regression coefficient; Sex: males=1, females=0; SE: standard error; SEE: standard error of estimate. All β's significant ($p<0.05$).

The complete regression equation includes sex, age and BMI as independent variables. Combined these variables explain 88 percent of the variation in body fat within the Caucasian populations. There was no interaction between BMI and sex and between BMI and age. The residuals (measured minus predicted values) were not related to age and sex, but were positively correlated with body fat ($r = 0.35$, $p < 0.05$), meaning that at higher levels of body fat percent the prediction formula underestimates body fat.

Table 3 gives for the different male and female groups the differences between measured body fat (as reported in the original paper) and predicted body fat, using the prediction formula from Table 2. For Ethiopians and Polynesians no SE is provided in the table, as there were only data from one study in each subgroup.

Table 3. Differences between measured and predicted body fat from BMI, in the different ethnic groups, using the Caucasian [1] prediction equation.

Ethnic group	Females		Males	
	mean	SE	mean	SE
Caucasian	0.1	0.5	0.1	0.5
American Black	-1.9*	0.8	-1.9	1.0
Ethiopian[2]	10.0	-	9.9	-
Chinese	-0.0	0.7	1.0	0.7
Thai	5.9*	0.3	7.6*	0.6
Indonesian	8.8*	1.2	6.7	1.3
Polynesian[2)]	-3.9	-	-4.1	-

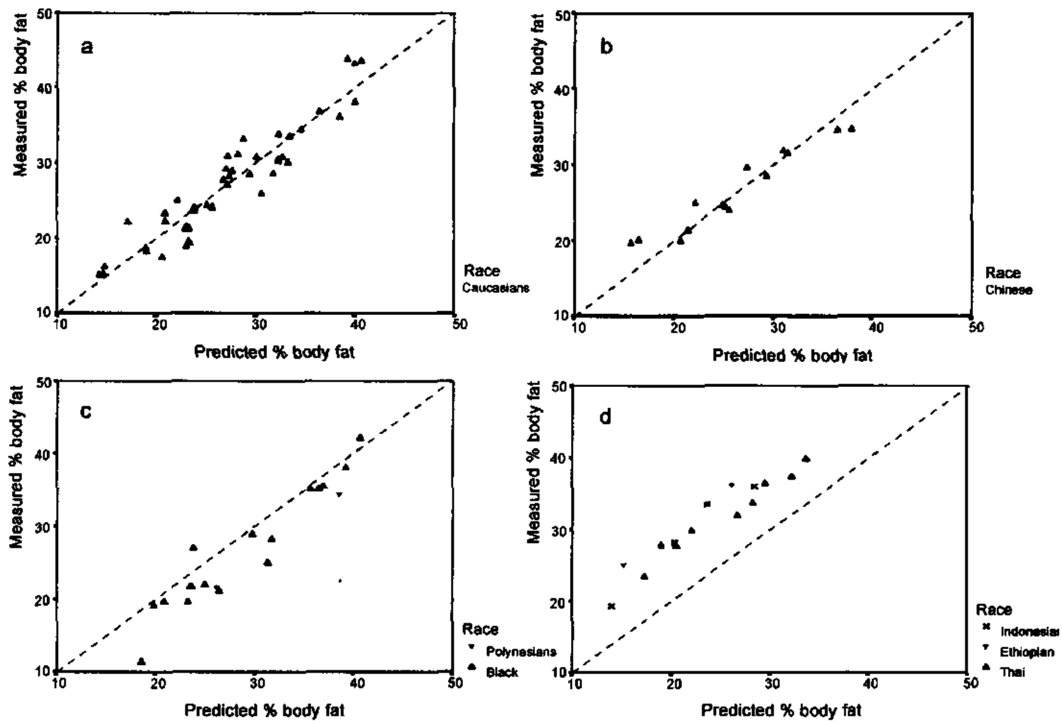
[1] prediction equation (Table 2): BF% = 1.294xBMI + 0.20xAge - 11.4xSex - 8.0
[2] No SE provided because only one data for males and females
*: $p<0.05$ from zero, otherwise not significant or too small to be tested (Indonesian, Ethiopians, Polynesians)

Figure 2a-d show plots of measured versus predicted values in relation to the line of identity (measured value equals predicted value). As expected the Caucasian data points are all located around the line of identity (Figure 2a). Also Chinese data points tend to be around the line of identity (Figure 2b) but body fat seems to be underestimated at lower BMI levels and overestimated at higher BMI levels. Polynesian and Black data points (Figure 2c) are generally below the line of identity, meaning that for the same BMI, age and sex, these ethnic groups have lower body fat. In Indonesians, Thai and Ethiopians the Caucasian prediction formula underestimates body fat, thus in these population groups body fat is relatively high in comparison with the BMI (Figure 2d). Only the Chinese data points are not parallel with the line of identity ($p<0.05$). Separate multiple regression analysis using the 15 Chinese data points showed that the regression coefficient for age is slightly lower (0.137 ±0.028) and that the regression coefficient for BMI (0.774 ± 0.490) is much lower compared to the Caucasians. The regression coefficient for sex was not different compared to the Caucasians.

Figure 3 shows that also European Caucasians and American Caucasians differ slightly in their relationship between body fat and BMI. The two indicated regression lines are not different in slope ($p=0.16$) but are different in intercept (3.8 percent body fat ($p<0.05$). When not corrected for age and sex the overall difference between measured and predicted body fat was 3.6 percent between Europeans and Americans. This difference was consistent for the different methodologies used for the body fat measurements and was 0.4 ± 0.3 percent for more compartment models ($p = 0.05$), 3.3 ±1.8 percent for deuterium dilution ($p=0.2$), 4.0 ± 0.7 percent for underwater weighing ($p<0.01$) and 5.3 ± 1.3 percent for DXA ($p<0.01$). Although the subjects in the European studies had higher ($p<0.05$) body fat (28.4 ± 8.7) compared to the Americans (23.4 ± 4.7) this difference was not responsible for the difference between measured and predicted value (ANCOVA, results not shown). Also age and sex difference between European and American Caucasians did not explain the difference.

In Figure 4 the mean difference in BMI corrected for age, sex and body fat in the different ethnic groups compared to Caucasians (as a reference) is given. The differences in BMI for a given value of body fat, age and sex are in some populations large. The BMI of Indonesians for example is 3.2 kg/m^2 lower for the same level of body fatness.

Figure 2. Relationship between measured and predicted body fat in different ethnic groups using a Caucasian prediction formula.



---------- Line of identity

Figure 3. Relationship between measured and predicted body fat in Caucasians of different origin.

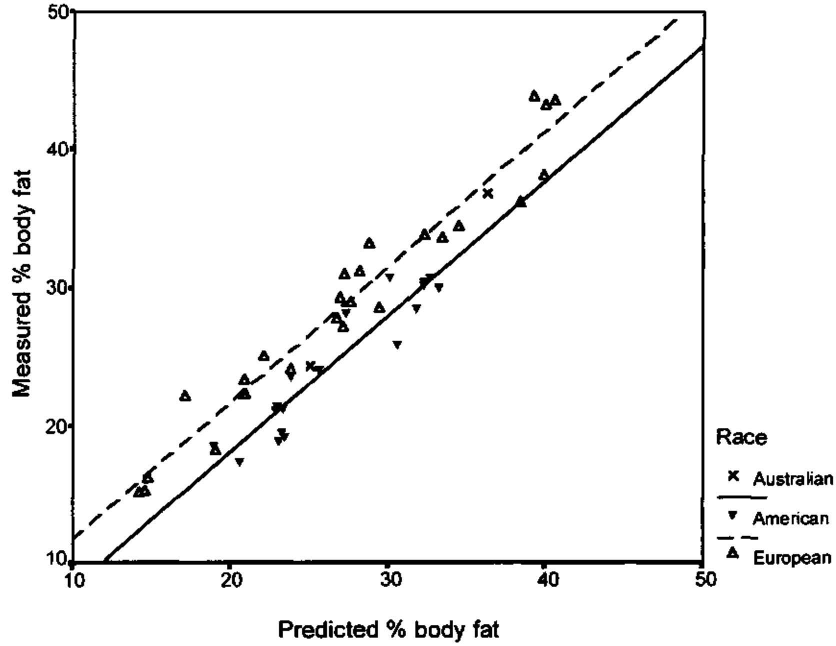
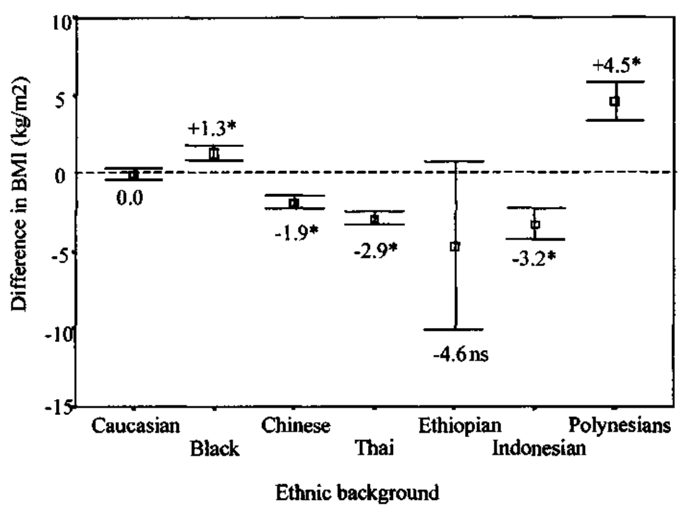


Figure 4. Adjustments to be made in BMI to reflect equal levels of body fat compared to Caucasian of the same age and sex (mean, 95% confidence interval).



Legend: Difference in BMI (kg/m^2): difference from BMI cut off point as suggested by WHO (reference 1); ns: not significant; *, $p<0.05$

Discussion

The assessment of body fat in populations is important for public health policies related to overweight and obesity. Government and responsible institutions require accurate prevalence figures of obesity to adequately address the issue of obesity-related morbidity and mortality. For population studies the BMI is generally accepted as a measure of body fatness[1,3], although there is evidence that BMI may reflect different levels of body fatness in different ethnic groups[14-22]. However, not all studies among different ethnic groups showed differences in the relationship between body fat and BMI[12,13]. It has been long established that age and sex[8,10-12] determine the relationship between body fat and BMI, thus these parameters have to be controlled for when studying the relationship between body fat and BMI among different groups. Other factors could be involved, as differences in body build[14,15], but for most populations this information is not available.

In the present paper data from the literature were used. For this it was assumed that the methods used to determine body fat in the different studies provided valid estimates of body fat, at least at a population level. Although there are studies showing that the differences between reference methods for measuring body fat among populations are not very large[21,33,34,44], it cannot be excluded that some differences in the present analysis may be partly due to differences in methodology employed. These differences could be due to technical error as well as to violations of assumptions, as e.g. hydration of fat free mass, density of fat free mass. It seems, however, unlikely that differences larger than 2-3 percent body fat are due to methodological differences. For this paper, only studies using reference methods (densitometry, deuterium oxide dilution, more compartment models and DXA) were used with the exception of a few studies which used skinfolds or impedance[17,20,28]. The reason was lack of other data in the specific ethnic groups.

The differences in body fat and BMI between the different ethnic groups as shown in Table 1 do not reflect real differences in these parameters between the populations. The subjects in the selected studies were by no means representative of their ethnic groups. For the aim of this study, a validation of the BMI as measure of body fat, this criterion is also not necessary.

Most data were available from Caucasians and therefore these data were used as reference points. Stepwise multiple regression (Table 2) resulted in a prediction equation for body fat of which the regression coefficients did not differ significantly from the regression coefficients as found in an earlier study [8] and as recently reported by Gallagher et al[12] in a study among Blacks and Whites. Curvilinear regression did not result in better predicted values (results not shown). It is remarkable that there are differences between the American Caucasians and the European (mainly UK and Netherlands) Caucasians in the relationship between body fat and BMI (Figure 3), with the Europeans having a 3.8 percent higher body fat at the same BMI level (after correction for age and sex). This is in line with results of Gallagher et al[12] that the prediction equation as developed in our laboratory[8] did overestimate body fat in the Caucasian New Yorkers. The difference is not due to differences in age and sex distribution (is controlled for in the prediction equation) between Americans and Europeans, nor by differences in level of body fat between the two groups as was tested by ANCOVA. Different levels in energy intake and energy expenditure[20] and/or differences in body build[14,15] could be a possible explanation. No data were available about the ancestry of the Caucasians and there are known differences in body build within Caucasians populations.

The prediction equation was applied to other ethnic groups, and as can be seen in Table 3 and in Figures 2a-d there are in some populations rather large differences between measured and predicted body fat. The fact that these differences are not always statistically different (Table 3) is in part due to relatively small numbers of data points in subgroups. The differences are comparable in males and females.

For Chinese there were no significant differences between measured and predicted body fat values. Notable is (see Figure 2b) that the Chinese data points are not parallel with the prediction line (line of identity). The regression between measured and predicted value was in the Chinese population significantly different for slope ($p<0.05$) and intercept ($p<0.05$) from the line of identity. Also the relationship between body fat and BMI and age was different in Chinese compared to Caucasians, showing a lower regression coefficient for BMI and a lower age effect but a much larger intercept. For this, it seems likely that body fat in Chinese is over predicted by the prediction formula, specially at lower BMI values where the impact of the (larger) intercept is greater. When BMI in the Chinese was corrected for body fat, taken age and sex into account, Chinese have lower BMI for the same body fat (see also Figure 4). This is in accordance with findings of Wang et al[18, 19] but in contrast with findings of a study in Beijing Chinese[13]. Differences and/or inconsistencies in the relationship between body fat and BMI in Chinese could be due to differences in body build, northern Chinese (Beijing) having a bigger body build than southern Chinese. It is known that Chinese have generally thinner bones compared to Caucasians[49]. Bone mineral density, however, is not significantly different from Caucasians when corrected for weight, height and age[50]. Also, Asians seem to have less muscle mass compared to Whites, also after correction for differences in BMI or differences in FFM/height^2 [51] FFM = fat free mass). The studies of Wang[18,19] only indicate 'Asians' but the subjects were mainly Chinese (Wang, personal communication). No information is, however, available about region of origin, which could have been helpful in interpreting the results.

In American Blacks as well as in Polynesians the prediction equation overestimated body fat, meaning that Blacks have lower body fat for the same BMI compared to Caucasians. When comparing American Blacks and Caucasians, the differences between measured and predicted body fat were not significant, confirming the findings of Gallagher et al[12]. However, Luke et al[20] found differences in the relationship body fat/BMI also among Blacks living in different areas. As explanation Luke et al[20] discussed differences in dietary pattern and physical activity. Remarkable is that the African (Nigerian) Blacks in the study of Luke et al have a low body fat for their BMI compared to other Blacks (outlier in Figure 2c).

In Indonesians, Thai and Ethiopians the prediction equation largely underestimated body fat. In Indonesians the underestimation was of the same magnitude in males and females independent of the used body fat methodology (3-compartment model based on densitometry and deuterium oxide dilution,[21] and deuterium dilution alone[16]. In Thai there was no difference whether skinfolds[28] or DXA[22] was used as reference method. The reason for this underestimation remains unclear, but body build of some Asians is rather slender[49] and we reported earlier a slender body build in Ethiopians[31] and recently also in Indonesians[16,21]. Subjects with a small frame but the same body height are likely to have a relatively lower FFM (due to lower muscle mass) and hence BMI is likely to underestimate their body fat when using prediction formulas developed in subjects with a bigger body build.

The reason for the different relationships between body fat and BMI in the different populations is unknown. Apart from differences between dietary patterns and differences in physical activity[20], differences in body build may be an important contributor. Norgan[14,15] has discussed the importance of relative leg length for the interpretation of the BMI, and it is known that there are differences in relative sitting height between Caucasians and Blacks and between Caucasians and Asians, with Blacks having relatively longer legs and Asians having relatively shorter legs[52]. Apart from relative leg length also a stocky or slender body build may have an impact. A stocky person is likely to have more muscle mass /connective tissue than a slender person with the same body height. Thus, at the same BMI the slender person will have more body fat. Additional anthropometric measures may be necessary to improve the quality of the BMI as an indicator of body fatness among ethnic groups.

Conclusions: the consequences of the different relationships between body fat and BMI are evident. As increased body fat and not increased weight or BMI is the risk factor for excess mortality[1,3], cut-off points for obesity (based on the BMI) could be different for different populations and as a result population specific rather than general cut-off points have to be defined. This meta-analysis shows, like some other papers in the literature, that in some populations the level of obesity in terms of body fat percent is reached at a much lower BMI compared to the cut-off values suggested by the WHO. In Indonesians, Thai and Ethiopians the cut-off values for obesity based on BMI could be as low as 27 kg/m^2, whereas in e.g. in Blacks and Polynesians the cut-off point could be slightly higher than the now used value of 30 kg/m^2. Data from this study do not allow definitive conclusions about any ethnic group as in many populations the number of data was too limited. More research in different ethnic groups is necessary, and, as the differences between the American Caucasians and the European Caucasians in this study show, also within one 'ethnic' group there could be differences that could be large enough to be important. The inclusion of body build parameters such as (relative) sitting height and skeletal widths in such studies would be advisable.

In summary: There are differences in BMI among populations at the same age, sex and level of body fatness. Consequently the prevalence of obesity in populations will be over- or underestimated using general cut-off points. The relationship between body fat and BMI in a specific population should be studied before the WHO cut-off point of 30 kg/m^2 for obesity is applied.

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Abstract

Objective: to compare body fat percent (BF%) obtained from a four-compartment (4C) model with hydrometry, dual energy X-ray absorptiometry (DXA) and densitometry among the three main ethnic groups (Chinese, Malays and Indians) in Singapore, and determine the suitability of two-compartment (2C) models as surrogate methods to assess BF% among different ethnic groups.

Design: cross-sectional study

Subjects: 291 subjects (108 Chinese, 76 Malays, 107 Indians), purposively selected to ensure adequate representation of range of age (18 to 75 years) and body mass index (BMI, 16 to 40 kg/m^2) of the general adult population, with almost equal numbers from each gender group.

Measurements: Body weight, body height, total body water by deuterium oxide dilution, densitometry with Bodpod® and bone mineral content with Hologic® QDR-4500. BF% was calculated using a four-compartment (4C) model.

Results: BF% measured by 4C model (BF4C) for the subgroups were: Chinese females (33.5±7.5%), Chinese males (24.4±6.1%), Malay females (37.8±6.3%), Malay males (26.0±7.6%), Indian females (38.2±7.0%) and Indian males (28.1±5.5%). Biases were found between BF4C and that measured by two-compartment (2C) models (viz, hydrometry, DXA and densitometry), with systematic underestimation by DXA and densitometry. On a group level, hydrometry had the lowest bias while DXA gave the highest bias. Biases from hydrometry and DXA were positively correlated with BF4C, water fraction of FFM (*f*water), mineral fraction of FFM (*f*mineral) and negatively correlated with density of the FFM (D_{FFM}), while the bias for densitometry were correlated with the above parameters in the opposite directions. The largest contributors to the biases were *f*water and D_{FFM}. Differences in *f*water and D_{FFM} also accounted for differences in biases between ethnic groups.

Conclusions: When validated against the reference 4C model, 2C models are found to be unsuitable for accurate measures of BF% due to high biases at the individual level and the violation of assumptions of constant hydration of FFM and D_{FFM} among the ethnic groups. On a group level, the best 2C model for measuring BF% among Singaporeans was found to be hydrometry.

Key words: body compostion, fat-free mass, body fat percent, four compartment model, hydrometry, densitometry, DXA, Singapore, ethnicity, Chinese, Malays, Indians

Introduction

Body composition has been studied using different methodologies, each with its own advantages and limitations[1-3]. Historically chemical two-compartment (2C) models based on information from carcass analyses are used as reference methods, against which other *in vivo* methods are generally compared. Models have been developed to assess body composition and one of the oldest models in body composition research is Siri's[4] 2C model, in which the body is divided into two clearly defined compartments, the fat mass (FM) and the fat free mass (FFM). The determination of body fat percent (BF%) using whole body densitometry is based on this model. The assumptions of densitometry are that the densities of the FM and FFM are constant at 0.9kg/l and 1.1 kg/l respectively. Total body density (D_b) is determined by dividing mass of body in air by volume of the body. The latter can be determined by underwater weighing or by air-displacement and BF% can be calculated using Siri's formula[4]. This assumption of a constant density of FFM has been challenged frequently by researchers over the past years regarding its validity among different gender, age and ethnic groups and also at different levels of body fatness[5,6,7].

Another methodology based on a 2C model is the determination of BF% using deuterium oxide dilution (hydrometry)[8]. This method assumes a constant hydration of the FFM[9]. It is known that hydration of FFM varies with age[10,11], but it is uncertain whether differences in the hydration of the FFM exist among ethnic groups. The assumption of a constant hydration of the FFM is also adopted by DXA[12].

It is obvious that the use of uniform density values or hydration factors when comparing body composition data of different (ethnic) groups may result in biased conclusions[5,13]. In recent years many studies have been performed to compare body composition between different ethnic groups[13-21]. Results of some of these studies may have been biased by violations of assumptions in the body composition techniques used.

With the advent of chemical and isotope-based methods, it has become possible to subdivide the FFM into its components: water, mineral and protein, and to determine these components with a high level of accuracy[22,23]. The use of such more-compartment models circumvents the use of non-validated assumptions in 2C models and enables reliable comparisons between groups where violation of assumptions could be present. While the use of more compartment models increases the accuracy of body composition measurements and are important reference methods, they require more time, cost and facilities which may not be widely available.

In 1998 a body composition study was conducted in Singapore as part of the National Health Survey. The study aimed to compare the BF% measured using a chemical four-compartment (4C) model and that obtained from three commonly used 2C models viz., hydrometry, DXA and densitometry among the three main ethnic groups (Chinese, Malays and Indians) in Singapore. The other objectives were to examine the validity of assumptions used in the 2C models, and to determine the suitability of 2C models as surrogate methods to measure BF% among these ethnic groups.

Subjects and methods

Three hundred participants in the 1998 National Health Survey[24] were invited to participate in a body composition study. The subjects were selected in order to cover a wide range of age and body mass index (BMI) and to ensure that the three main ethnic groups (Chinese, Malays, Indians) were well represented within each gender group. Based on power calculation, to detect a two percent point difference between measured BF4C and other 2C models, 25 subjects would be sufficient for each subgroup (ethnic and gender).

In total 108 Chinese, 76 Malays and 107 Indians (total n=291) were measured. Their ages ranged from 18 to 75 years and their BMI from 16 to 40 kg/m^2. Table 1 gives some characteristics of the subjects. All measurements were performed at the study site situated at the laboratory of the School of Physical Education, Nanyang Technological University, Singapore. Subjects were in the fasting state for at least 6 hours and voided preceding the measurements. All anthropometric measurements were performed by trained observers.

The Singapore National Medical Research Council approved the study protocol and all subjects gave their written informed consent before the measurements.

Table 1. Characteristics of study subjects (Mean, SD)

	Chinese		Malays		Indians		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Females (n)	61		33		53		147	
Age (years)	36.5	12.9	35.6	13.9	36.3	9.6	36.2	12.0
Body weight (kg)	54.9^a	11.1	58.1	11.5	61.1^b	14.1	57.8	12.6
Body height (cm)	157.8^a	5.9	154.1^b	6.1	156.5	6.1	156.5	6.1
BMI (kg/m^2)	22.1^a	4.8	24.5	4.9	24.9^b	5.3	23.6	5.2
Body density (kg/l)	1.0309^a	0.0185	1.0190^b	0.0160	1.0199^b	0.0182	1.0243	0.0186
TBW (kg)	26.0	3.4	26.3	4.0	27.0	5.1	26.4	4.2
BMC (g)	2281	315	2223	272	2309	319	2278	307
BF 4C(%)	33.5^a	7.5	37.8^b	6.3	38.2^b	7.0	36.2	7.4
Males (n)	47		43		54		144	
Age (years)	40.7	13.6	41.4	12.3	43.4	12.9	41.9	12.9
Body weight (kg)	65.0	10.8	69.0	12.4	69.8	11.9	68.0	11.8
Body height (cm)	168.9	5.2	165.9^a	6.4	169.6^b	6.9	168.3	6.4
BMI (kg/m^2)	22.8^a	3.5	25.0^b	3.8	24.3	3.7	24.0	3.7
Body density (kg/l)	1.0448	0.0148	1.0431	0.0198	1.0410	0.0155	1.0428	0.0167
TBW (kg)	36.0	4.4	37.1	4.6	36.0	5.2	36.3	4.8
BMC (g)	2709	379	2896	371	2844	419	2816	397
BF 4C (%)	24.4^a	6.1	26.0	7.6	28.1^b	5.5	26.2	6.5

^{a,b} For each row, different alphabets indicate significant difference between ethnic groups
BMI: Body Mass Index
TBW: Total body water
BMC: Bone mineral content
BF 4C : Body fat percent measured by four-compartment model

Body weight was measured to the nearest 0.1 kg in light indoor clothing without shoes, using a digital scale. A correction of 0.5 kg was made for the weight of the clothes. Body height was measured without shoes with Frankfurt plane horizontal, to the nearest 0.1 cm using a wall-mounted stadiometer. BMI was calculated as weight/height squared (kg/m^2).

Total body water (TBW) was determined using deuterium oxide dilution. The subject drank a precisely weighed amount of deuterium oxide (amount given varied between 10 and 11 grams). Three hours after dosing a 10 ml venous blood sample was taken and plasma was separated and stored at minus 20°C until analyses were performed. Plasma was sublimated and then analysed for deuterium concentration using infrared spectroscopy[25]. From the given dose and the deuterium concentration in the sublimated plasma TBW was calculated, assuming a 5 percent non-aqueous dilution of the deuterium oxide in the body[8].

Body density was determined using air plethysmography (Bodpod®, Body composition System, Life Measurements Instruments, Concord, CA) according to the instructions of the manufacturer. The method is described in detail by Dempster & Aitkens[26].

Bone mineral content (BMC) was measured using a Hologic® DXA whole body X-ray densitometer (QDR-4500, Hologic®, Waltham, MA; software version V8.23a:5). As Hologic® measurements generally result in systematic lower BMC measurements compared to Lunar® measurements[27], BMC data were corrected to Lunar® values. This was found to be necessary as the Lunar® machine was used for development of the equation of Baumgartner's four-compartment model[28]. A correction factor based on phantom measurements (Lunar aluminium 'spine' phantom) using a Lunar DPXL (software version 1.35) was determined. The found correction factor of 1.167 for the phantom was confirmed by three sets of measurements performed on two subjects over a period of one year. For each set these two subjects were measured twice within one week with both systems. Total body mineral was calculated as 1.235*BMC[28,29].

Body fat percent was calculated using the 4C model (including fat mass, TBW, total body mineral and a remaining compartment, consisting of protein and carbohydrate) as described by Baumgartner et al[28],

$$BF\% = 205*(1.34/D_b - 0.35*A + 0.56*M - 1),$$

where D_b = body density, A = water fraction of body weight and M = mineral fraction of body weight.

Fat-free mass (FFM, kg) was calculated as body weight minus fat mass. The water fraction of the FFM (*f*water) was calculated as TBW/FFM, the mineral fraction (*f*mineral) as M/FFM and the protein fraction (*f*protein) as 1- *f*water – *f*mineral. The density (kg/l) of the fat-free mass was calculated as:

$$D_{FFM} = 1/(f\text{water}/0.993 + f\text{mineral}/3.038 + f\text{protein}/1.340),$$

where 0.993 is the density of water, 3.038 the density of minerals and 1.340 the density of protein at 37°C[30].

Data were analysed using the SPSS ver 8.01 for Windows program[31]. Correlations are Pearson's correlation coefficients or partial correlation with correction for possible confounders. Differences in variables within groups were tested with the paired t-test. One sample t-test was used to test the composition and density of the FFM from assumed values. Differences between the ethnic groups were tested using analyses of (co)variance with Bonferroni post-hoc tests for multiple comparisons. Bland & Altman procedures[32] were used to test the bias of predicted BF%. Level of significance is set at $p<0.05$. Values are presented as mean ± SD, unless otherwise stated.

Results

Table 1 gives the characteristics of the study subjects. Overall the men were slightly older than the women. Expectedly, the men were taller and heavier than the women subjects. There was no age differences among the ethnic groups for both men and women. Among the women, Chinese women were the lightest and tallest with lowest BMI, highest D_b, and lowest BF%. No significant difference was noted for TBW and BMC between the ethnic groups. For the men, Indians were the tallest, and had the highest BF%. Malay men were the shortest and had the highest BMI. Chinese men had the lowest BMI and BF%. There were no significant differences in weight, TBW, BMC and D_b among men of different ethnic origins.

The composition of the FFM (calculated using the 4C model) by gender and ethnic group is presented at Table 2. No significant difference was detected for the density of FFM (D_{FFM}), and fractions of water (*f*water), mineral (*f*mineral) and protein (*f*protein) in the FFM between the women of different ethnic groups. For men, the Chinese had the lowest D_{FFM}, and highest *f*water, while Indians had the highest *f*protein. When tested against the assumed D_{FFM} of 1.100[3], women of all three ethnic groups and Indian men have significantly higher D_{FFM}. Chinese women, Indian women and Indian men also have significantly lower *f*water than the assumed 0.735[11]. All women have significantly higher *f*mineral than the assumed 0.069, while Malay women and Indian men have significantly different *f*protein compared to the assumed

0.196. There was no difference in the composition of FFM between the different age groups in this study (data not shown).

Table 2. Composition of fat free mass (FFM) by gender and ethnic group

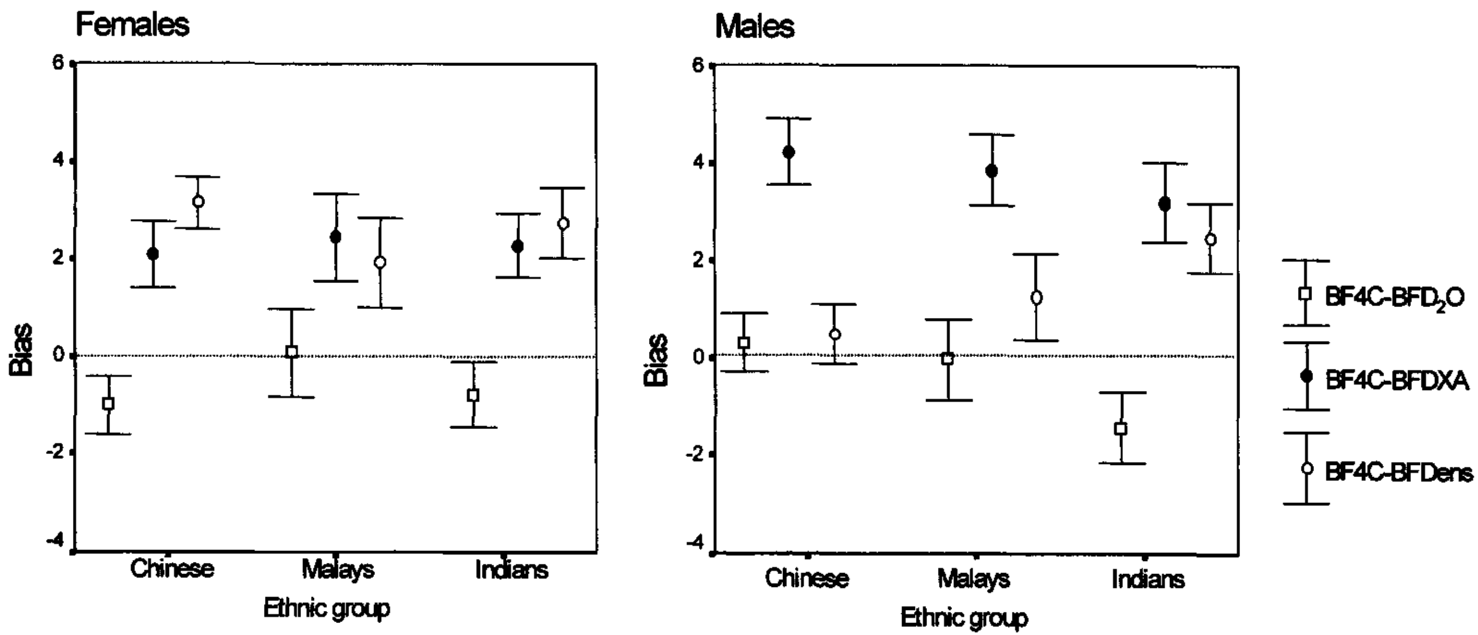
	Chinese		Malays		Indians		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Females								
Density FFM (kg/l)	1.1082*	0.0073	1.1038*	0.0098	1.1070*	0.0098	1.1068*	0.0090
Water fraction	0.725*	0.026	0.737	0.028	0.727*	0.026	0.728*	0.026
Mineral fraction	0.079*	0.010	0.078*	0.008	0.078*	0.009	0.078*	0.009
Protein fraction	0.196	0.031	0.186*	0.028	0.195	0.027	0.193	0.029
Males								
Density FFM (kg/l)	1.0987[a]	0.0066	1.1011	0.0100	1.1052[b]*	0.0086	1.1019*	0.0088
Water fraction	0.738[a]	0.019	0.735[a]	0.026	0.721[b]*	0.026	0.731	0.025
Mineral fraction	0.069	0.005	0.071	0.008	0.071	0.008	0.070*	0.007
Protein fraction	0.193[a]	0.020	0.193[a]	0.026	0.208[b]*	0.029	0.199	0.026

*significantly different from assumptions (density FFM of 1.100, *f*water of 0.735, *f*mineral of 0.069, *f*protein of 0.196)

[a,b] Different alphabets indicate signifcant difference between ethnic groups (analysis of variance, Bonferroni testing, $p<0.05$). Similar alphabets indicate no difference.

The biases (difference between BF% from 4C model and various 2C models) and error (standard deviation of the differences) are found in Table 3. DXA and densitometry both underestimated BF% in all groups, while there was a slight overestimation of BF% with hydrometry among Chinese and Indian women, and Indian men. Generally, for both men and women in all ethnic groups, the bias was smallest for BF% obtained from hydrometry , ranging from 0.1% (±2.5) in Malay women to –1.4% (±2.7) in Indian men. On the other hand, the bias was greatest between BF% obtained from DXA, from 2.1% (±2.6) in Chinese women to 4.2% (±2.4) in Chinese men. For women, there was no significant difference in the biases between BF% from 4C model and all the other 2C models among ethnic groups. Among men, the bias for hydrometry was significantly more for Indian men compared to the other two groups, with hydrometry overestimating BF% in Indians. Densitometry underestimated BF% in Indian men and the bias is significantly more than for Chinese men. These differences in bias between ethnic groups (for men) were not statistically significant after being corrected for age, *f*water and *f*mineral differences among groups, using analysis of covariance with Bonferroni testing for multiple comparisons. Figure 1 presents the 95%

Figure 1. Comparison of bias (difference between body fat percent obtained from four-compartment and two-compartment models), by gender and ethnic groups. Bars represent 95% confidence intervals.



BF4C: Body fat percent obtained from four-compartment model
BFD2O: Body fat percent obtained from hydrometry
BFDXA: Body fat percent obtained from DXA
BFDens: Body fat percent obtained from densitometry

confidence interval (CI) for the biases between BF% from 4C model and 2C models. For most groups, the biases were significantly different from zero, except among Malay men and women (hydrometry) and Chinese men (hydrometry and densitometry).

Table 3. Comparison of biases (mean and standard deviation) between %BF from four compartment model (4C) and %BF from two compartment models

	Chinese		Malays		Indians	
Bias	mean	SD	mean	SD	mean	SD
Females						
4C minus						
Hydrometry	-1.0	2.3	0.1	2.5	-0.8	2.4
DXA	2.1	2.6	2.5	2.5	2.3	2.4
Densitometry	3.2	2.1	1.9	2.6	2.7	2.6
Males						
4C minus						
Hydrometry	0.3	2.0	0.0	2.6	-1.4	2.7
DXA	4.2	2.4	3.9	2.4	3.2	3.0
Densitometry	0.5	2.0	1.2	3.0	2.5	2.6

No statistical significant difference in biases between ethnic groups using analysis of covariance (with Bonferroni test for multiple comparisons), with correction for differences in age, *f*water and *f*mineral between groups.

Table 4. Correlations between biases and body fat percent from four compartment model (BF4C), water fraction of FFM (*f*water) and density of FFM (D_{FFM})

Bias	BF4C	*f*water	*f*mineral	D_{FFM}
	r	r	r	r
Females				
4C minus				
Hydrometry	0.35*	0.99*	0.19*	-0.85*
DXA	0.62*	0.57*	0.15	-0.47*
Densitometry	-0.39*	-0.86*	0.31*	0.99*
Males				
4C minus				
Hydrometry	0.33*	0.99*	0.02	-0.90*
DXA	0.56*	0.51*	0.18*	-0.38*
Densitometry	-0.33*	-0.89*	0.41*	0.99*

r= Pearson partial correlation coefficients with correction for age and ethnicity

* $p<0.05$

Table 4 shows the partial correlations between the biases with BF4C, *f*water, *f*mineral and D_{FFM}, with correction for age and ethnicity. The biases arising from hydrometry and densitometry are strongly correlated with the *f*water. The bias from hydrometry was positively correlated ($r = 0.99$ for both men and women) while that for densitometry was negatively correlated (females $r = -0.86$, males $r = -0.89$, $p<0.05$). Bias from DXA was also significantly correlated with *f*water (females $r = 0.57$ and males 0.51, $p<0.05$). The biases from hydrometry, densitometry and DXA were also strongly correlated with D_{FFM}, but in the opposite directions from those of *f*water. The *f*mineral was correlated positively with the biases from hydrometry and densitometry in women, and from DXA and densitometry in men, but to a much lesser degree than for *f*water.

Discussion

This study shows that the use of 2C models to determine BF% in adult Singaporeans instead of 4C models leads to large individual biases in the BF% measurement. On a group level, the best 2C model for BF% measurement was found to be hydrometry.

The study samples was selected purposively from the population sample of the National Health Survey (NHS) conducted in 1998, to ensure that there was adequate representation from each of the three ethnic groups (Chinese, Malays and Indians) for each gender group. As the purpose of this study was to compare BF% measurement using different methodologies, it was vital that there were enough subjects in the entire age and BMI range of the main sample of the NHS rather than to have a truly random sample of the population. Nonetheless, the conclusions of this study are relevant for adult Chinese, Malays and Indians in Singapore.

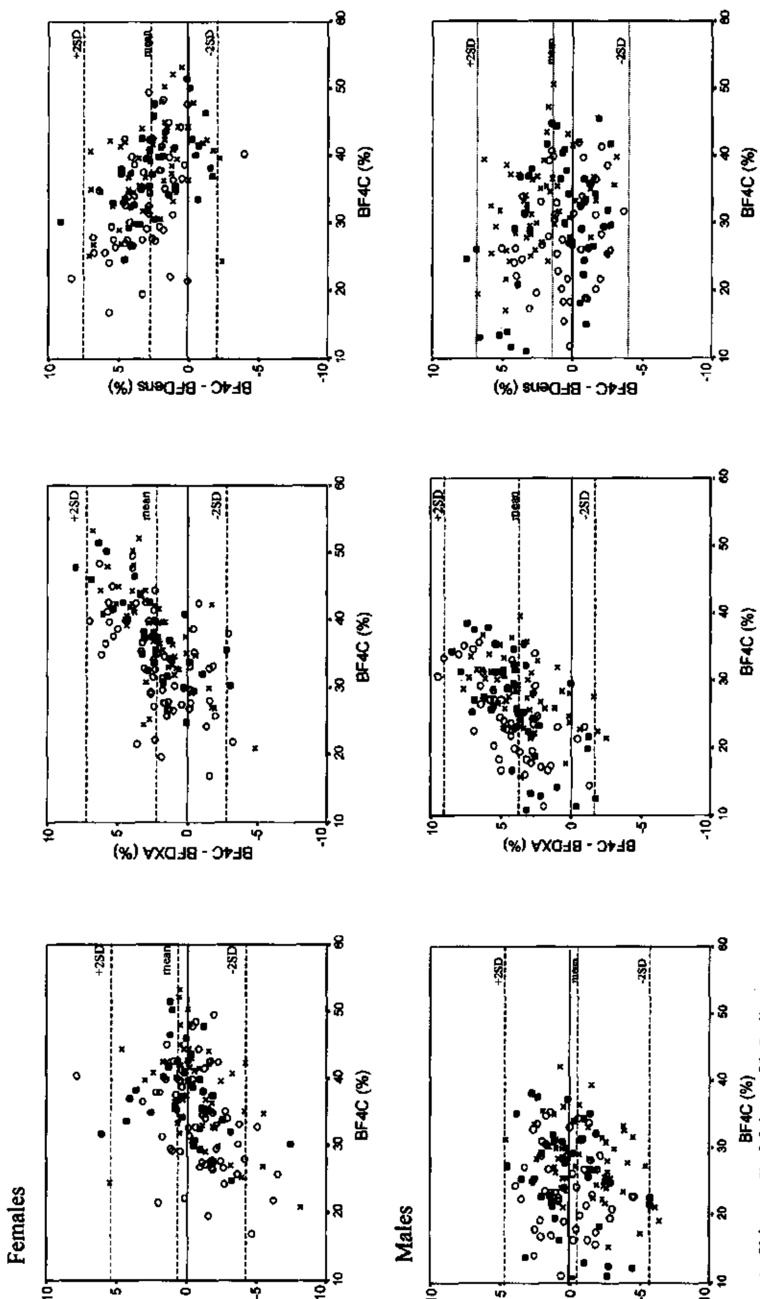
All measurements were performed with same instrumentation and by the same team of investigators using standardised protocols to avoid any systematic technical bias. A correction factor of 1.167 was applied to BMC measurements in this study using the Hologic ® DXA machine to correct towards measurements obtained by Lunar® machine. This was necessary as the Baumgartner formula used in this study was developed using a Lunar ® machine. The correction factor was obtained by 20 repeated phantom measurements on each machine and also by repeated sets of measurements of two subjects scanned by both machines over one year. This factor is close to the factor of 1.154 found by Tothill et al[27]. Body volume as measured by air displacement using the Bodpod® and hydro-densitometry gave comparable results as reported in literature among young adults[26,33,34]. There are however also reported small differences between air displacement and hydro-densitometry, with values from air displacement being both higher[35] and lower[36,37].

On a group level, the mean bias in BF% estimation using hydrometry and densitometry were small, at 2.5% or less, while that from DXA is higher, between 2.1% and 4.2%. Generally, the BF% obtained from hydrometry agreed most closely with that from the 4C model, with the smallest bias (Table 3 and Figure 1). However, individual errors were much higher due partly to biological variation in the composition of the FFM (mainly in *f*water and to a lesser extent *f*mineral) and partly to measurement errors inherent for each method. The maximum individual bias is around 10% for all three methods.

The correlations of the biases arising from hydrometry and densitometry with BF4C model (Figure 2) are partly contributed by the differences in *f*water and D_{FFM} between lean and obese subjects observed in this study. Leaner subjects tend to have lower *f*water and higher D_{FFM} than the assumed values of 0.735 and 1.100 kg/l (data not shown) respectively leading to overestimation of BF% by hydrometry and underestimation of BF% by densitometry. This increase in *f*water and decrease in D_{FFM} with increasing BF% confirmed the theory discussed in the literature[38,39]. No age influence on *f*water and D_{FFM} was observed in the subjects of this study, even though this was found in other studies[7,40], most likely due to the lack of sufficient subjects in the extreme age groups (<20 years and >65 years) in the present study sample. Some researchers have conjectured that the water and bone mineral content of the female body are more variable compared to males, and that 2C models would be less valid with higher individual error in females[41-43]. However this study does not support this hypothesis, as it can be seen from Tables 2 and 3 that in both males and females, similar variability exists in composition of FFM and biases in BF% measurement for different 2C models.

The biases in the estimation of BF% by the three 2C models are mainly related to *f*water, D_{FFM} and to a lesser extent the *f*mineral, as can be seen in Table 4. A *f*water smaller than

Figure 2. Plots of biases (differences between BF4C model and two-compartment models) against BF4C, by gender and ethnic groups



O:Chinese ■ :Malays X :Indians

BF4C - Body fat percent obtained from four-compartment model

BFD$_2$O - Body fat percent obtained from hydrometry

BFDXA - Body fat percent obtained from DXA

BFDens - Body fat percent obtained from densitometry the assumed 0.735 causes an overestimation of BF% by hydrometry[44], while a higher D_{FFM} than the assume 1.100 kg/l would lead to underestimation of BF% by densitometry[45]. In this study, the *f*water for the subgroups are very close to the assumed value leading to small mean bias and error when estimating BF% using hydrometry. On the other hand, the higher D_{FFM} in most groups has resulted in systematic underestimation of BF% by densitometry at group level. DXA also systematically underestimated BF% in all groups in this study. The positive correlation of the bias from BF% estimation by DXA with *f*water and *f*mineral and negative correlation with D_{FFM} shows that DXA has its limitations[46,47] and is not entirely free of assumption of constant hydration[12].

Conclusion

From this study, it was found that in almost all groups, there were significant biases between BF% measured by 4C model and that measured using hydrometry, DXA and densitometry. On a group level, there was systematic underestimation of BF% by DXA and densitometry due mainly to violation of assumptions of constant hydration of FFM and D_{FFM} used in these 2C models. The bias for hydrometry was close to zero for all groups. The differences in the biases between ethnic groups were mostly attributed to the differences in composition of FFM, mainly *f*water and partly to *f*mineral. Similarly, the relationship between the biases and the degree of body fatness could be partly explained by the increasing *f*water and decreasing D_{FFM} as BF% increases. There was no observed age influence on the biases obtained from BF% estimations from different 2C models.

There are considerable intra-subject variations in the biases for all the 2C models due to individual differences in the *f*water and D_{FFM} from the assumptions made in these models. Thus, on an individual level, to obtain an accurate measure of BF%, a 4C model would be advisable. However for population studies, the small mean bias and error from BF% estimation using hydrometry makes this the method of choice when compared to densitometry and DXA. Additional advantages of hydrometry that make it suitable for use in field conditions are low respondent burden and no requirement for cumbersome instrumentation.

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5

The paradox of low body mass index and high body fat percentage among Chinese, Malays and Indians in Singapore

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Abstract

Objective: to study the relationship between percentage body fat and body mass index (BMI) in three different ethnic groups in Singapore (Chinese, Malays and Indians) in order to evaluate the validity of the BMI cut-off points for obesity.

Design: cross-sectional study

Subjects: 291 subjects (108 Chinese, 76 Malays, 107 Indians), purposively selected to ensure adequate representation of range of age (18 to 75 years) and body mass index (BMI, 16 to 40 kg/m^2) of the general adult population, with almost equal numbers from each gender group.

Measurements: Body weight, body height, sitting height, wrist and femoral widths, skinfold thicknesses, total body water by deuterium oxide dilution, densitometry with Bodpod® and bone mineral content with Hologic® QDR-4500. Body fat percent was calculated using a four-compartment model.

Results: Compared to percentage body fat (BF%) obtained using the reference method, BF% for the Singaporean Chinese, Malays and Indians were under-predicted by BMI, sex and age when an equation developed in a Caucasian population was used. The mean prediction error ranged from 2.7% to 5.6% body fat. The BMI/BF% relationship was also different among the three Singaporean groups, with Indians having the highest BF% and Chinese the lowest for the same BMI. These differences could be ascribed to differences in body build. It was also found that for the same amount of body fat as Caucasians who have a body mass index (BMI) of 30 kg/m^2 (cut-off for obesity as defined by WHO), the BMI cut-off points for obesity would have to be about 27 kg/m^2 for Chinese and Malays and 26 kg/m^2 for Indians.

Conclusions: The results show that the relationship between BF% and BMI is different between Singaporeans and Caucasians and also among the three ethnic groups in Singapore. If obesity is regarded as an excess of body fat and not as an excess of weight (increased BMI), the cut-off points for obesity in Singapore based on the BMI would need to be lowered. This would have immense public health implications in terms of policy related to obesity prevention and management.

Key words: percentage body fat, body mass index, body build, obesity, cut-off values, Singaporeans, Chinese, Malays, Indians, Caucasians, race, ethnicity, public health, four-compartment model.

Introduction

WHO has defined obesity as a condition with excessive fat accumulation in the body to the extent that health and well being are adversely affected[1]. Implicit in this definition is the need to be able to accurately measure the amount of body fat and the level at which disease risk is increased.

Indirect and doubly indirect methods have been developed to measure percentage body fat (BF%) for most studies as direct methods (cadavaric studies and in vivo neutron activation analysis) are either impossible or too prohibitive in terms of cost and risk. Indirect methods that are commonly used include densitometry, dilution techniques and dual energy X-ray absorptiometry (DXA). Each of these methods has its own advantages and limitations[2-4]. These techniques depend on the use of equations to calculate BF% from the measured body parameter, and such equations were developed mainly in the 'normal' Caucasian population and based on certain assumptions. Densitometry, using underwater weighing or more recently air-displacement[5], is a classical method, long regarded as a method of reference. Dilution techniques, for example deuterium oxide dilution, depend on the assumption that hydration of fat free mass (FFM) is fixed and constant[6]. DEXA scanning has been found to be highly valid for bone mineral density, but unfortunately not as good for determination of BF%. Varying body sizes could affect the accuracy of DEXA in the measurement of BF%[7]. There are also differences between machines[8] and even between different models[9], rendering the standardisation of methodology difficult.

For best and least biased information, more-compartment models in which the variations in water content and mineral content in the fat free mass are accounted for[10], should be used. However, the combination of techniques required makes this method expensive and not suitable for use in large epidemiological studies.

Doubly indirect methods (predictive methods) are normally employed for large population studies as they are generally affordable, easy to perform and require minimal equipment and specialised manpower. The body mass index (BMI), defined as weight/height squared (kg/m^2), is one such method that is commonly used as a surrogate measure for BF%. BMI is generally well correlated with BF% and is a good indicator of level of 'risk'[11]. Cut-off points for obesity as defined by the WHO[1] are based on BMI-values. But these cut-off points are based on studies on the relationship between BMI and morbidity and mortality in western populations[12,13] and it may be questionable whether they are valid in other populations.

In recent years several studies have shown a different relationship between BMI and BF% among ethnic groups. For example Wang et al.[14] in a study in New York, found that Asians had a lower mean BMI but a higher BF% than Caucasians of the same age and sex. Guricci et al.[15] reported that Indonesians had for the same BF% a BMI that is about 3 units lower than Dutch Caucasians. On the other hand, Gallagher et al.[16] did not find differences in the relationship between US Whites and Blacks. In a meta-analysis of available data from the literature it was clearly shown that differences in the BMI/BF% relationship exists among ethnic groups[17].

In Singapore, the mean BMI is low compared to most Western countries, but the mortality from cardiovascular diseases is similar to these countries[18]. In an earlier study in Singaporean Chinese it was found that the odds ratio of having cardiovascular risk factors was high at low BMI levels[19]. The before mentioned studies raised the suspicion that the BMI cut-off for obesity as defined by WHO may not adequately reflect the actual obesity status and thus the disease risk of Singaporeans[19,20]. However, no adequate information on the relationship between BMI and BF% was available for Singaporeans.

For this reason a body composition study was performed to study the relationship between BMI and BF% in the three ethnic groups (Chinese, Malays and Indians) in Singapore. To avoid systematic biases in the determination of BF% due to violation of assumptions in one or more ethnic groups, BF% was determined using a four-compartment model based on densitometry, deuterium dilution and dual energy X-ray absorptiometry (DXA) measurements [21].

Subjects and methods

During the 1998 National Health Survey 300 volunteers were invited to participate in a body composition study. The inclusion criteria for selection were that the subjects need to be distributed over the whole range of age and BMI of the main study, with almost equal numbers in each ethnic (Chinese, Malays, Indian) and sex group. Of the final participants that underwent all measurements 108 were Chinese, 76 were Malays and 107 were Indians. Their age ranged from 18 to 75 years and their body mass index from 16 to 40 kg/m^2. Table 1 gives some characteristics of the subjects. All measurements were performed at the study site situated at the laboratory of the School of Physical Education, Nanyang Technological University, Singapore. Subjects fasted from food and drinks at least 6 hours and voided preceding the measurements. All anthropometric measurements were performed by trained observers. The Singapore National Medical Research Council approved the study protocol and all subjects gave their informed consent before the measurements.

Body weight was measured to the nearest 0.1 kg in light indoor clothing without shoes, using a digital scale. A correction of 0.5 kg was made for the weight of the cloths. Body height was measured without shoes with Frankfurt plane horizontal, to the nearest 0.1 cm using a wall-mounted stadiometer. Sitting height was measured with a wall-mounted stadiometer with the subject sitting on a small stool with a flat and hard sitting board with the lower legs hanging. The height of the stool was subtracted from the reading. Relative sitting height was calculated as sitting height/standing height. A low relative sitting height indicates relatively long legs.
From weight and height the body mass index (BMI) was calculated as weight/height squared (kg/m^2). Percentage body fat was predicted from BMI, age and sex with a formula developed and validated in Caucasians[22]:

$$BF\% = 1.2 * BMI + 0.23 * age - 10.8 * sex - 5.4$$

Wrist width was measured with an anthropometric calliper at the left and the right sides over the distal ends of the radius and the ulna to the nearest 0.1 cm. Knee width was measured to the nearest 0.1 cm, at the left and right sides in the sitting position, lower legs relaxed with the knee flexed at a 90-degree angle over the femur condyles. The mean values of left and right widths were used in the statistical calculations. A parameter for slenderness[20] was calculated as height/(sum of wrist and knee widths, cm/cm). Obviously, a higher index indicates a more slender body build or frame.

Biceps, triceps, subscapular and supra-iliac skinfolds were measured in triplicate to the nearest 0.2 mm, on the left side of the body, according to Durnin & Womersley[23]. The mean value of each measurement was used in the prediction of BF%[23]. For the determination of total body water (TBW) the subject drank a precisely weighed amount of deuterium oxide (amount given varied between 10 and 11 grams). After three hours, 10 ml venous blood was taken and plasma was obtained and stored in well-sealed tubes at minus 20 degrees until analyses. Deuterium was analysed after sublimation of the plasma using infrared spectroscopy [24]. From the given dose and the deuterium concentration in plasma TBW was calculated, assuming a 5 percent non-aqueous dilution of the deuterium in the body[2].

Body density was determined using air plethysmography (BODPOD®, Body composition System, Life Measurements Instruments, Concord, CA) according to the instructions of the manufacturer. The method is described in detail by Dempster & Aitkens[5]. Body volume was calculated as weight/density.

Bone mineral content (BMC) was measured using a Hologic DXA whole body X-ray densitometer (QDR-4500, Hologic, Waltham, MA; software version V8.23a:5). As Hologic measurements generally result in systematic lower BMC measurements compared to Lunar measurements[8], the BMC data were corrected to Lunar values. This was found to be necessary as for development of the equation of Baumgartner's four-compartment model[21] a Lunar machine was used. A correction factor based on phantom measurements (Lunar aluminium 'spine' phantom) using a Lunar DPXL (software version 1.35) was determined. The found correction factor of 1.167 for the phantoms was confirmed by 3 sets of measurements performed on two subjects over a period of one year. For each set these two subjects were measured twice within one week with both systems. Total body mineral was calculated as 1.235*BMC[21,25]. Percentage body fat was calculated using the four-compartment model as described by Baumgartner et al[21],

$$BF\% = 100*(2.75 * BV - 0.714 * TBW + 1.148 * M - 2.05 * BW)/weight$$

where BV= body volume, M = total body mineral and BW = body weight.

Fat-free mass (FFM, kg) was calculated as body weight minus fat mass. Data were analysed using the SPSS for Windows program[26]. Correlations are Pearson's correlation coefficients or partial correlation with correction for possible confounders. The relationship between BMI and BF% was analysed using stepwise multiple regression, with age, sex (females = 0 and males = 1) and ethnicity as independent variables. The dummy variables for ethnicity were E_1 and E_2. For Chinese $E_1 = 0$ and $E_2 = 1$, for Malays $E_1 = 1$ and $E_2 = 0$, and for Indians $E_1 = 1$ and $E_2 = 1$. Parallelism of the regression equations for the sexes and the ethnic groups was tested using interaction factors between the independent variables[27]. Differences between the sexes and differences between the ethnic groups were tested using analyses of (co)variance. Bland & Altman statistics[28] were used to test the bias of predicted BF%. Differences in variables within groups were tested with the paired t-test. Level of significance is set at $p<0.05$. Values are presented as mean ± SD, unless otherwise stated.

Results

Table 1 gives characteristics for the males and females of each ethnic group. Normal differences between males and females were observed, males being taller and heavier, and having a lower percentage body fat. Age did not differ significantly between the groups. Indian females had significantly higher body weight than Chinese females. Body height of Malay males and females was shorter than that of their Chinese and Indian counterparts. The BMI of Chinese females was lower than that of Malay and Indian females, but in males only the BMI from Chinese was significantly lower than that of Malays. BF% was lower in Chinese females compared to Malay and Indian females, but in males the difference in BF% was only between Chinese and Indians. Body fat predicted from BMI using a Caucasian prediction equation was significantly ($p<0.001$) underestimated in all subgroups. This shows that Singaporeans have higher body fat at the same BMI compared to Caucasians. Body fat predicted from skinfolds was only significantly ($p<0.001$) underestimated in Malay and Indian females. Relative sitting height was significantly lower in the Indian males and females compared to their Chinese and Malays counterparts. In males the difference between Malays and Chinese was also statistically significant. Malay males and females had a significant higher slenderness index than Chinese and Indians. The correlation between BMI and BF% was 0.75, 0.72 and 0.76 in Chinese, Malay and Indian females respectively and 0.76, 0.78 and 0.68 in Chinese, Malay and Indian males respectively (all values $p<0.001$).

Table 2 gives the regression coefficients (SE) of the stepwise multiple regression in the order the independent variables entered the equation. The final prediction equation,

$$BF\% = 1.04*BMI - 10.9*sex + 0.1*age + 2.0E_1 + 1.5*E_2 + 5.7$$

explains 74 percent of the variation in BF% when the independent factors are controlled for, and has a standard error of estimate of 4.4% body fat. With BMI, age, sex and E_1 and E_2 in the model there was a non-significant interaction between BMI and sex ($p=0.065$) showing that the regression lines are slightly but not significantly different for the sexes. No interaction between E_1 and E_2 with BMI or age was observed. However there was a significant interaction between E2 and sex, showing that in the Malays the regression coefficient for sex was slightly higher compared to the Chinese and Indian females. Taking this interaction into account resulted only in a very minor improvement of the regression equation (change in SEE 0.03%). Therefore it was decided to continue analyses without this interaction. Regression analysis using BMI-squared (assuming curvilinear relationship between BF% and BMI) resulted in a lower (72% instead of 74%) explained variance.

The residuals of predicted BF% in the different population groups and the correlation with the level of BF% are given in Table 3. The bias was in neither group significant different from zero, but in all groups the correlation with the level of BF% was high. For the total population a Bland & Altman plot is given in Figure 1.

Table 1. Characteristics of the subjects (mean ± SD)

	Chinese				Malays				Indians			
	Females		Males		Females		Males		Females		Males	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Age (years)	36.3	12.8	40.7	13.6	35.6	13.9	41.4	12.3	36.6	10.1	43.4	12.8
Weight (kg)	54.7	11.1	65.0	10.8	58.1	11.5	69.0	12.4	61.2	13.9	69.8	11.9
Height (cm)	157	5.9	169	5.2	154	6.1	166	6.4	157	6.0	170	6.9
BMI (kg/m^2)	22.1	4.8	22.8	3.5	24.5	4.8	25.0	3.7	24.9	5.2	24.2	3.6
$BF\%_{4c}$	33.4	7.5	24.4	6.1	37.8	6.3	26.0	7.5	38.3	6.9	28.0	5.4
$BF\%_{BMI}$	29.5	7.4	20.5	5.7	32.2	7.9	23.3	6.0	32.9	7.6	22.9	5.5
$BF\%_{skfd}$	33.3	6.3	24.4	6.3	35.8	6.4	26.2	7.6	35.8	5.6	27.3	6.0
Rel SH	0.54	0.15	0.54	0.15	0.53	0.14	0.54	0.13	0.53	0.12	0.52	0.15
Slenderness	11.5	0.8	10.9	0.8	11.3	0.9	11.2	0.5	10.9	0.4	11.2	0.5

Legend:
BMI: body mass index; $BF\%_{4C}$: body fat percent from four-compartment model; $BF\%_{BMI}$: body fat percent predicted from BMI ; $BF\%_{skfl}$: body fat percent predicted from skinfolds; Rel SH: relative sitting height (sitting height/standing height); Slenderness: height/sum (wrist + knee diameter)

Table 2. Regression coefficients (SE) of the stepwise multiple regression of body fat percent as dependent variable.

BMI (kg/m^2)		Sex		Age (years)		E_1		E_2		Intercept		R^2	SEE (%)
β	SE	β	SE	β	SE	β	SE	β	SE	β	SE		
1.11	0.09	-	-	-	-	-	-	-	-	4.7	2.2	0.34	6.99
1.16	0.06	-10.3	0.5	-	-	-	-	-	-	8.8	1.5	0.71	4.63
1.07	0.06	-10.8	0.5	0.09	0.02	-	-	-	-	7.2	1.5	0.73	4.48
1.03	0.06	-11.0	0.5	0.10	0.02	1.4	0.6	-	-	7.2	1.5	0.73	4.44
1.04	0.06	-10.9	0.5	0.10	0.02	2.0	0.6	1.5	0.7	5.7	1.6	0.74	4.42

BMI: body mass index; sex: (females=0, males =1); age: in years; E1 and E2 ethnicity: Chinese $E_1 = 0$ and $E_2 = 1$; Malays $E_1 = 1$ and $E_2 = 0$; Indian $E_1 = 1$ and $E_2 = 1$; R^2: explained variance; SEE: standard error of estimate

Table 3. Bias (mean, SD) of predicted BF % from BMI, age, sex and ethnicity in the different subgroups and the correlation of the bias with the level of BF%.

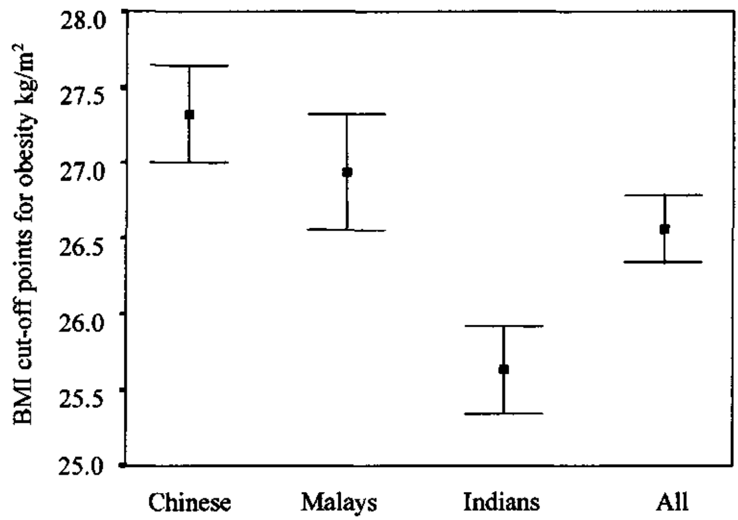
	Females						Males					
	Chinese		Malays		Indians		Chinese		Malays		Indians	
Bias (%)*	-0.3	4.7	1.1	4.2	-0.3	4.9	0.4	3.7	-0.9	4.8	0.3	3.7
Correlation of bias with BF%**	0.66		0.43		0.54		0.75		0.83		0.66	

BF%: body fat percent: BMI, body mass index (kg/m^2); Bias: measured BF% minus predicted BF%.
* Bias in all subgroups not different from zero.
** All correlations significant ($p<0.001$).

The residuals of a regression model without E1 and E2 showed a significant partial correlation (after correction for the level of BF%) with slenderness (part $r = 0.318$, $p<0.001$) and with relative sitting height (part $r = -0.191$, $p<0.001$).

From age and sex of the individual Singaporean subjects it was calculated, using the Caucasian prediction equation, how high their BF% would be if their BMI would have been 30 kg/m^2, i.e. the cut-off point for obesity as defined by WHO. This BF% level was used to recalculate their BMI using the Singaporean prediction equation to obtain a BMI level that is equivalent with the WHO cut-off point for obesity in Caucasians. Figure 2 shows that Singaporeans with a BMI of about 27 kg/m^2 have the same level of body fatness as Caucasians with a BMI of 30 kg/m^2 . There are slight differences between Chinese and Malays but the difference with Indians is more pronounced. The BMI value in Singaporeans that corresponds to the same BF% in Caucasians with a BMI of 25 kg/m^2 is about 21 kg/m^2.

Figure 2. Calculated BMI cut-off points for obesity for Singapore Chinese, Malays and Indians based on the WHO obesity cut off point for Caucasians.



Discussion

The subjects participating in this study were a selected group of Singaporean Chinese, Malays and Indians, age 18 to 75 years. They were purposively selected from a larger representative population sample of the National Health Survey 1998 (NHS), to ensure adequate representation from the entire range of age and BMI, with almost equal numbers from all the ethnic and gender groups, rather than having similar age, BMI, ethnic and gender distribution to the general population. This sample selection process was important for the purpose of this study, which was to study the relationship between BMI and BF%.

There are apparent differences in height, weight, BMI and percentage body fat between the three ethnic groups, the Malays being the shortest, the Chinese being the lightest. The BMI of the Chinese is 2-3 units lower and their BF% is about 3% lower compared to those of their Malays and Indian counterparts.

Compared to other population-based body composition studies the BMI is relatively low in comparison with BF%. For example Lean et al[29] reported in Scottish males and females of the same age a BMI of about 25 kg/m^2, whereas BF% was only 22 % in males and 34% in females. In a study of Gallagher et al[16] BF% in 50 years old Caucasians females was 30% whereas their BMI was as low as 23.3 kg/m^2. Males in that study had a higher BMI (25 kg/m^2) but a relatively low BF% of 21 %. Also the under prediction of BF% from BMI using a Caucasian (Dutch) prediction formula shows that Singaporeans have a high BF% at a relatively low BMI[22]. Applying the Caucasian regression equation from the meta-analysis[17] resulted even in slightly higher differences between measured and predicted BF% (results not shown). This confirms earlier findings in study of Wang et al.[14], showing that Asians have lower BMI but higher BF% than Caucasians. A different relationship between BMI and BF% in Asians compared to Caucasians has been recently reported in several studies among Indonesian population groups[15,30], in Thai populations[31,32], in Japanese (Gallagher et al, personal communication) as well as in young Singaporean Chinese[20]. It has to be noted that such a different relationship was not reported in Beijing Chinese compared to Dutch Caucasians[20,33]. Differences have also been observed between different Black populations[34] and between Caucasians and Polynesians[35]. The present study confirms that the relationship between BMI and BF% in Singaporeans is not only different compared to Caucasians, but is also different among the three main ethnic groups in Singapore: Chinese, Malays and Indians. For the same BMI, age and sex, Chinese have the lowest BF% while Indians have the highest.

One possible drawback of earlier studies reported in the literature, when comparing different (ethnic) groups, is the possible limitation of the used reference methods to determine BF%. For example in the studies of Guricci et al[15,30] deuterium oxide was used as the reference method to determine BF%. It was assumed that all the ethnic groups had the same constant hydration factor of the fat free mass (hydration = 0.73),[2,6]. It can not be excluded that there might be differences in the hydration of the fat free mass (FFM) among different ethnic groups, which could be attributed to, for example, climatic conditions, which could cause a directional bias in the results and thus lead to the wrong conclusions. Also the differences as shown in a meta- analysis[17] of reported literature data could be due to such methodological differences. For this reason, in the present study, a multi-compartment model (body weight = fat mass + water + mineral + protein) was used for the determination of BF%, to avoid any bias due to violation of assumptions that form the base for single methods such as densitometry or deuterium oxide dilution. Such a model was also used by Gallagher et al[16] in their study comparing US Blacks and Whites. Because of the use of this four-compartment model it can be assumed that the differences found among the four ethnic groups (namely Caucasians and the three ethnic groups in Singapore) discussed in this paper are not due to violation of assumptions in the body composition methodology.

The differences in the relationship between BMI and BF% that were found between the three Singaporean ethnic groups can be ascribed to differences in body build. The residuals of a regression equation without E1 and E2 show a significant partial correlation (after correction for the level of BF%) with slenderness and relative sitting height. Also, in a stepwise multiple regression model with BMI, age, sex, relative sitting height and slenderness as independent variables, ethnicity did not contribute significantly anymore. This confirms the findings in earlier studies[20,30] that body build is at least partly responsible for the different relationship between BMI and BF%. A stocky person (low slenderness index) is likely to have more bone, connective tissue and muscle mass, thus less body fat for a given body height and weight than a more slender person. In other words, BF% will be relatively low compared to the BMI. Subjects with relatively long legs (low relative sitting height) have less mass per unit length, so their BMI will be relatively low, compared to their BF%. The effect of relative sitting height has been discussed earlier by Norgan[36,37]. Other authors[34] discussed as possible explanation for differences in the BMI/BF% relationship differences in physical activity level. No valid information was available about the physical activity level of the subjects in this study. Data from the 1998 National Health Survey[38] indicated that most Singaporeans have a sedentary life style, engaging in less than 1.5 hours of physical activity per week. This could be due to a combination of climate (warm and humid), living and working conditions and well organised and highly effective public transport, all factors which are disincentives for any sort of physical activity or exercise during leisure time other than in air-conditioned rooms.

If obesity is defined as an excess body fat, it seems logical that a different relationship between BMI and BF% among populations would result in population-specific BMI cut-off points for obesity, rather than a uniform cut-off point as is currently recommended by WHO[1]. For Singaporeans this would mean that the BMI cut-off points for obesity should be about 26 kg/m^2 for Indians and about 27 kg/m^2 for Chinese and Malays. This cut-off point of 27 kg/m^2 for Malays equals the currently used cut-off point in Indonesia (with a predominantly Malay population), the validity of which was confirmed by studies of Guricci et al[15]. A lowering of the cut-off point for obesity would also be justified if elevated cardiovascular risk were to be present at low BMI levels, as was recently found in Chinese Singaporeans[19]. The presence of cardiovascular risk factors at different BMI levels will be further studied among the three ethnic groups in Singapore to test this hypothesis (paper in preparation).

Generally, if the cut-off point for obesity in Singapore would be lowered to 27 kg/m^2, this would have immense impact on the prevalence of obesity among the adult Singapore population. Compared to a BMI cut-off point of 30 kg/m^2 the prevalence would increase in females from 6.5 % to 15.4 % and in males from 5.2% to 17.3%. These higher prevalences are more in line with the relatively high level of chronic degenerative diseases in Singaporeans and with their increased relative risk for cardiovascular risk factors at lower BMI levels[19]. Unnecessary to say that such an increase in prevalence figures would have serious implications in terms of public health policy.

In summary, Singaporeans have higher percentage body fat at a lower BMI compared to Caucasians, but differences in the BMI/BF% relationship also exist among Singaporean Chinese, Malays and Indians. The differences can be explained by differences in body build. If obesity is defined as excess body fat rather than excess weight, the obesity cut-off point for Singaporeans should be 27 kg/m^2 in stead of 30 kg/m^2. The lowering of the cut-off point for obesity would more than double the prevalence figures in Singapore.

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6

Relationships between indices of obesity and its co-morbidities among Chinese, Malays and Indians in Singapore

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Submitted

Abstract

Objective: To investigate the effect of body mass index (BMI) and body fat distribution as measured by waist-to-hip ratio (WHR) and waist circumference (waist) on the cardiovascular risk factor profile of the three major ethnic groups in Singapore (Chinese, Malays, Indians) and to determine if WHO recommended cut-off values for BMI, WHR and waist are appropriate for the different sub-populations in Singapore.

Design: cross-sectional population study.

Subjects: 4723 adult subjects (64% Chinese, 21% Malays and 15% Indians) were selected through a multi-staged sampling technique to take part in the National Health Survey in 1998.

Measurements: Data on socio-economic status (education level, occupation, housing type) and lifestyle habits (smoking and physical activity); body weight, body height, waist and hip circumferences and blood pressure measured using standardised protocols. Fasting venous blood samples obtained for determination of serum total cholesterol, high density lipoprotein cholesterol (HDL), low density lipoprotein cholesterol (LDL), triglycerides (TG); venous blood sample for two hour oral glucose tolerance test (OGTT).

Results: Absolute and relative risks for at least one cardiovascular risk factor (elevated TC, elevated TC/HDL ratio, elevated TG, hypertension and diabetes mellitus) were determined for various categories of BMI, WHR and waist. At low categories of BMI (BMI between 22 and 24 kg/m^2), WHR (WHR between 0.80 and 0.85 for women, and between 0.90 and 0.95 for men) and waist (waist between 75 and 80 cm for women and between 80 and 85 cm for men), the absolute risks are high, ranging from 41% to 81%. At these same categories the relative risks are significantly higher compared to the reference category, ranging from odds ratio of 1.97 to 4.38. These categories of BMI, WHR and waist are all below the cut-off values of BMI, WHR and waist recommended by World Health Organisation (WHO).

Conclusions: The results show that at relatively low BMI, WHR and waist, Singaporean adults experience elevated levels of risks (absolute and relative) for cardiovascular risk factors. These findings, in addition to earlier reported high percent body fat among Singaporeans at low levels of BMI, confirm the need to revise the WHO cut-off values for the various indices of obesity and fat distribution, viz., BMI, WHR and waist in Singapore.

Key-words: obesity, abdominal fatness, BMI, WHR, waist circumference, cut-off values, cardiovascular risk factors, Singaporeans, Chinese, Malays, Indians, ethnicity, public health, costs of obesity.

Introduction

Obesity has recently been viewed as a global epidemic by the WHO, with likelihood of the situation worsening, not only in the developed countries, but also in developing countries with changes in dietary habits and activity levels. The issue of rising obesity rates and its co-morbidities is recognised by many other Asian countries, such as China (including Hong Kong), Japan, Korea, Malaysia and India, as was presented during the Asian BMI/Obesity Workshop meeting (9th European Congress on Obesity, Milan 1999).

According to the World Health Organisation, obesity is defined as a condition with excessive fat accumulation in the body to the extent that health and well being are adversely affected[1]. Although there are many methods available for the measurement of body fat percentage (BF%) *in vivo*, most of these methods are not suitable for large-scale population studies[2]. It was shown in several studies that the body mass index (BMI), defined as weight/height squared (kg/m^2) is highly correlated with BF% and is thus a suitable surrogate parameter for defining obesity in large scale studies[3-5].

High values of BMI, in fact BF%, are closely linked to increased morbidity and mortality, among which cardiovascular diseases (CVD) is one of the most important causes of mortality[1,6,7]. Such relationships have been clearly established in a number of studies involving mainly Europids. For such populations, it has been found that the BMI cut-off points of ≥ 25 kg/m^2 for overweight and ≥ 30 kg/m^2 for obesity are appropriate as they are indicative of increased risk for co-morbidities and mortality. Based on these studies, WHO has recommended the present cut-off points for overweight and obesity at BMI ≥ 25 kg/m^2 and ≥ 30 kg/m^2 respectively[1,8]. Similarly, abdominal body fat distribution as assessed by waist circumference (waist) or by waist-to-hip circumference ratio (WHR) coincides with increased morbidity and mortality[9] . Cut off points for elevated risk have been set by WHO at a waist exceeding 80 cm and 94 cm, and WHR exceeding 0.85 and 1.00 for women and men respectively[1].

In recent years many studies have shown that the relationship between BMI and BF% is different among ethnic groups,[10-14], which may have consequences for the definition of obesity based on BMI. In a recent study it was shown that for the same BF%, Singaporeans have a BMI that is three to four kg/m^2 lower than Europids[15-16], with slight differences between the three main ethnic groups in Singapore (Chinese, Malays and Indians). Based on the different relationships between BMI and BF% it may be questioned whether the WHO cut-off value for obesity of 30 kg/m^2 is appropriate for all populations, particularly for Singaporeans[15].

Obesity as an independent risk factor for CVD, particularly for coronary heart disease (CHD), has been documented in long term prospective studies[6]. It also has been recognised that obesity mediates its effects by elevating other cardiovascular risk factors, viz., dyslipidaemia (hypercholesterolaemia, hypertriglyceridaemia and low high-density lipoprotein (HDL) cholesterol), hypertension and glucose intolerance[1,6-8,17,18]. The prevalence of obesity (BMI ≥ 30 kg/m^2) in Singapore in 1992 was 5%[19], which is much lower than the prevalence in developed countries such as Finland, Australia, United Kingdom and the United States, whose obesity prevalence ranged from 12% to 22%[1]. On the other hand, the age-standardised deaths from ischaemic heart disease, at 100 per 100 000 population, is comparable to the same developed countries whose rates are from 97 per 100 000 (Australia) to 125 per 100 000 (United States)[20], and higher than in other parts of Asia such as Japan (22 per 100 000) and Hong Kong (40 per 100 000)[20]. Singapore is a multi-ethnic society with a population consisting of three main ethnic groups, Chinese (76%), Malays (14%) and Indians (7%), among which exist differences in cardiovascular risk factors as well as in cardiovascular mortality[19,21,22-24].

The purpose of this study was to investigate the effect of BMI and body fat distribution as measured by WHR and waist on the cardiovascular risk factor profile of Singaporeans. For this purpose, data of the National Health Survey from 1998 were used[25]. The study also examined if WHO recommended cut-off values for BMI, WHR and waist are appropriate for three different sub-populations (Chinese, Malay and Indian) in Singapore.

Subjects and methods

The second National Health Survey (NHS) was conducted between September and November 1998. Based on data obtained during the first NHS in 1992[19], a sample size of 5000 subjects was calculated to detect changes in prevalence in risk factors compared to 1992. The population selection was done in two phases. In the first phase of the survey 11,200 households were selected from the National Database on Dwellings maintained by the Department of Statistics. For logistic reasons and convenience only six community centres were selected as sites for the survey. These households were representative of the house type distribution of the whole housing population in Singapore. The selected households were notified by post, followed up by house-visits to enumerate all members within the age range of 18 to 69 years. In phase 2, a random sample of 7,500 persons was selected, based on a disproportionate stratified sampling design, where all subjects from phase 1 were first stratified by age and ethnic group and then systematically selected. Malays and Indians were over sampled to ensure sufficient sample size in these two ethnic groups. The ethnic composition of the final sample (n=4723) was 64% Chinese, 21% Malays and 15% Indians. There were no differences in the characteristics of the non-respondents and the subjects in the final sample. In the analysis, weight values were applied, where appropriate, to reflect the actual ethnic, age and gender distribution in the population.

Selected subjects were invited to visit the community centres on designated days and times and shortly before the actual visit the subjects were reminded by phone at which occasion also further detailed instructions were given. A detailed description of the methodology is given elsewhere[25].

All survey field workers were briefed extensively on the survey methodology and underwent rigorous training in the survey procedures assigned to them. A one-day trial of the survey was conducted to hone the field worker's skills and familiarise them with the survey procedure.

The Ministry of Health and the National Medical Research Council in Singapore approved the study protocol and all subjects gave their written consent on the actual survey day.

An interview-administered questionnaire was used to get information about occupation, educational level, smoking habits (number of cigarettes smoked per day) and physical activity (number of sessions of aerobic activity engaged in per week).

Weight was measured in light indoor clothes without shoes using calibrated digital scales with an accuracy of 0.1 kg. Body height was measured with the Frankfurt plane horizontal, to the nearest 0.1 mm without shoes using wall-mounted stadiometers. From weight and height the body mass index (BMI, weight/height^2, kg/m^2) was calculated. Waist was measured to the nearest 0.1 cm, midway between the lower rib margin and the iliac-crest at the end of a gentle expiration[26]. Measurements were taken directly on the skin. Hip circumference was measured to the nearest 0.1 cm over the great trochanters[8,26] directly over the underwear. The waist to hip ratio (WHR) was calculated.

Overnight fasting blood samples were taken and plasma was separated and analysed on the same day. Total cholesterol (TC) was determined using an enzymatic method with a commercially available test kit (Boehringer Mannheim GmbH, test kit #1489704, Mannheim, Germany). HDL-cholesterol (HDL) was determined by the homogeneous enzymatic test (Boehringer Mannheim GmbH, test kit # 1731203, Mannheim, Germany). LDL cholesterol (LDL) was measured with the homogeneous turbidimetric method (Boehringer Mannheim GmbH, test kit # 1730843), Mannheim, Germany). Fasting glucose (FG) and glucose after the two-hour oral glucose tolerance test (OGTT) was measured enzymatically with the GOD-POD method (Boehringer Mannheim GmbH, test kit # 1448684, Mannheim, Germany). Triglyceride (TG) was determined enzymatically with the GPO-PAP method (Boehringer Mannheim GmbH, test kit # 1555626, Mannheim, Germany). All chemical analyses were done with a Boehringer Mannheim/Hitachi 747 analyser.

Blood pressure was measured using a standard mercury sphygmomanometer and a cuff of suitable size at the right arm after an adequately rest period of at least 15 minutes. Korotkoff phase I and phase V were used for systolic (SBP) and diastolic blood pressure (DBP) respectively[27]. Cut-off values for hypertension were defined as SBP $\geq$ 140mmHg and/or DBP $\geq$ 90mmHg[28] , elevated TC as TC $\geq$ 6.2 mmol/l, elevated TC/HDL ratio as ratio $\geq$ 4.4[29], elevated TG as TG $\geq$ 1.4 mmol/l[30]and diabetes mellitus as OGTT $\geq$ 11.1 mmol/l[31]. 'Risk' was defined as having at least one of the above risk factors.

Subjects were assigned to categories of BMI, WHR and waist using pre-set border values for given parameters as recommended by the International Obesity Task Force during the Asian

BMI/Obesity Workshop meeting in Milan in 1999. The number of persons at risk in each of these subgroups was calculated, stratified by gender.

To ensure that there were enough subjects in each sub-category for males and females, the data for all ethnic groups were pooled for the analysis of absolute risks and relative risks of having at least one risk factor by the BMI, WHR and waist categories. This was also to enable that recommendations for BMI, WHR and waist cut-off points would apply to the entire population rather than to subgroups on a national basis for public health purposes. Where applicable, ethnicity was controlled for in statistical analysis. Categories 1 (see Table 3 for definition of categories) of BMI, WHR and waist were used as reference categories for the computation of relative risks.

Statistical analyses were performed using SPSS 8.0.1[32]. Values are given as mean ± SD. Relative risk (odds ratio) with 95% confidence intervals was calculated using logistic regression during which confounding variables (age, ethnicity, occupational status, educational level, number of cigarettes smoked, BMI or WHR, physical activity levels) were adjusted for. A significance level of 0.05 was used.

Results

The study population comprised subjects from three ethnic groups, Chinese, Malays and Indians, aged 18 to 69 years. The characteristics for the subjects are shown in Table 1. Among the females, Chinese are the tallest and lightest, with the smallest waist and hip circumferences. Chinese women also have the lowest BMI and WHR compared to Malay and Indian women. For the males, Chinese men are also the lightest and have the smallest waist and hip circumferences, while Malay men are the shortest. Malay men have the highest BMI while Indian men have the largest WHR. The mean values for TC, HDL, LDL, SBP, DBP, TG and OGTT are also given in Table 1.

Table 1 Characteristics of subjects by different ethnic group-sex categories

	Ethnic group							
	Chinese		Malays		Indians		Total	
	mean	SD	mean	SD	mean	SD	mean	SD
Females (n)	1758		445		339		2542	
Age (years)	37.6[a]	12.1	38.2	12.8	40.0[b]	11.9	38.0	12.2
Weight (kg)	54.5[a]	9.0	62.5[b]	13.5	62.4[b]	12.8	57.0	11.1
Height (cm)	157.3[a]	5.5	154.3[b]	5.8	155.8[c]	5.9	156.6	5.7
BMI (kg/m^2)	22.1[a]	3.6	26.3[b]	5.5	25.8[c]	5.3	23.3	4.6
Waist (cm)	73.1[a]	8.5	79.6[b]	12.3	81.9[c]	11.7	75.4	10.3
Hip (cm)	93.4[a]	6.8	100.0[b]	10.9	100.4[b]	9.6	95.5	8.7
WHR	0.78[a]	0.06	0.80[b]	0.11	0.81[b]	0.07	0.79	0.07
TC (mmol/l)	5.3[a]	1.1	5.7[b]	1.2	5.3[a]	1.0	5.5	1.1
HDL (mmol/l)	1.7[a]	0.4	1.6[b]	0.3	1.4[c]	0.3	1.7	0.4
LDL (mmol/l)	3.3[a]	0.9	3.7[b]	1.1	3.5[c]	1.0	3.4	1.0
SBP (mmHg)	117.0[a]	16.7	123.7[b]	20.3	118.6[a]	17.4	119	17.7
DBP (mmHg)	70.5[a]	10.8	74.7[b]	12.0	70.0[c]	11.2	71	11.2
TG (mmol/l)	1.2[a]	0.7	1.4[b]	0.9	1.3[b]	0.7	1.2	0.8
OGTT (mmol/l)	6.7[a]	2.8	7.7[b]	3.7	7.7[b]	4.0	7.0	3.2
Males (n)	1470		404		307		2181	
Age (years)	38.2[a]	12.3	39.3[b]	12.6	41.1[b]	12.0	38.8	12.4
Weight (kg)	67.5[a]	11.6	69.2[b]	12.6	70.8[b]	12.3	68.3	11.9
Height (cm)	169.5[a]	6.1	166.8[b]	6.2	169.8[c]	6.4	169.0	6.3
BMI (kg/m^2)	23.5[a]	3.7	24.8[b]	4.2	24.6[b]	4.2	23.9	3.9
Waist (cm)	84.0[a]	9.9	86.0[b]	10.8	88.9[c]	10.8	85.0	10.3
Hip (cm)	95.9[a]	6.8	98.1[b]	7.6	98.5[b]	8.1	96.7	7.3
WHR	0.87[a]	0.06	0.87[a]	0.06	0.90[b]	0.06	0.88	0.06
TC (mmol/l)	5.5[a]	1.0	5.9[b]	1.1	5.7[a]	1.2	5.6	1.1
HDL (mmol/l)	1.4[a]	0.3	1.3[b]	0.3	1.2[c]	0.3	1.3	0.3
LDL (mmol/l)	3.5[a]	0.9	4.0[b]	1.0	3.9[b]	1.1	3.7	1.0
SBP (mmHg)	125.2[a]	15.1	125.8	17.7	124.4[b]	16.5	125.2	15.8
DBP (mmHg)	77.4	10.6	77.8	11.9	77.5	11.5	77.5	11.0
TG (mmol/l)	1.7[a]	1.5	2.0[b]	1.5	2.0[b]	1.7	1.8	1.5
OGTT (mmol/l)	6.5[a]	2.7	7.1[b]	3.5	7.5[b]	4.0	6.8	3.1

[a,b,c] For each row, different alphabets indicate significant differences in means between ethnic groups (age-adjusted for all variables)

Legend of abbreviations:

BMI:	Body Mass Index
Waist:	Waist circumference
Hip:	Hip circumference
WHR:	Waist-to-Hip ratio
TC:	Total serum cholesterol
HDL:	High density lipoprotein cholesterol
LDL:	Low density lipoprotein cholesterol
SBP:	Systolic blood pressure
DBP:	Diastolic blood pressure
TG:	Triglycerides
OGTT:	2-hour oral glucose tolerance test

Cut-off values recommended by WHO for definition of obesity and abdominal fatness are used[1]. Cut-off values for the cardiovascular risk factors are also as recommended by WHO[28,30,31], except for TC and TC/HDL ratio, which are by the National Institutes of Health[29]. Overall, the crude prevalence of obesity is highest among Malays (16.5%), followed by the Indians (13.3%) and Chinese (3.7%). On the other hand, Indians have the highest prevalence for large waist (44.0%) and high WHR (16.7%). The prevalence of elevated TC and hypertension was highest among Malays (35.0% and 10.1% respectively), while Indians have the highest prevalence for elevated TC/HDL ratio (48.0%), elevated TG (30.8%) and diabetes mellitus (10.7%). The prevalence of obesity, abdominal fatness and individual risk factors for the different gender and ethnic groups are presented at Table 2. The proportion of subjects with obesity, high waist, high WHR, elevated TC, elevated TC/HDL ratio, elevated TG, hypertension and diabetes mellitus are significantly different between ethnic groups (for both men and women) except for hypertension among men.

The prevalence of risk factors by gender and the categories of BMI, WHR and waist are given in Tables 3a-3c. As expected, proportion of subjects with the various risk factors increases with increasing categories of BMI, WHR and waist. However, it is also evident that the various risk factors are manifested at fairly low levels of BMI, WHR and waist. For example, a high proportion of men with BMI between 22 to 24 kg/m^2 (BMI category 3) experienced some form of dyslipidaemia: 29.4% with elevated TC, 45.0% with elevated TC/HDL ratio and 33.0% with elevated TG. Similarly, the proportions of men in WHR category 3 (WHR between 0.85 and 0.90) with elevated TC, elevated TC/HDL ratio and elevated TG are 26.9%, 46.1% and 35.8% respectively. Prevalence of dyslipidaemias are also high among those men defined as having 'normal' waist (85 to 90 cm). The trends are similar in women, albeit less pronounced.

Figures 1 – 3 show the proportion of subjects with at least one risk factor by gender and categories of BMI, WHR and waist. Here it is shown that at low categories of these indices, high proportions of subjects have manifested at least one of the five risk factors. At BMI category 2 (BMI 22 to 24 kg/m^2), 41% of women and 61% of men have at least one risk factor, whilst at WHR category 3 (WHR 0.75 to 0.80 for women, 0.85 to 0.90 for men) 28% of women and 59% of men experience at least one risk factor. More than a quarter of women

Table 2 Prevalences (%) of obesity, large waist circumference, high WHR and cardiovascular risk factors in Singaporean adults, by different ethnic group-sex categories

	Ethnic group			
	Chinese	Malays	Indians	Total
Females (n)	1758	445	339	2542
BMI ≥ 30 kg/m² *	3.0	23.1	18.3	8.5
Waist circumference ≥80 cm*	20.1	45.2	58.7	29.6
WHR ≥0.85*	12.3	20.2	27.7	15.7
TC ≥ 6.2mmol/l*	18.9	30.8	18.0	20.9
TC/HDL ratio ≥ 4.4*	12.8	25.4	33.6	17.8
TG ≥ 1.8 mmol/l*	12.6	20.2	19.2	14.8
SBP≥ 140mmHg and/or DBP ≥90mmHg*	4.7	9.9	4.4	5.6
OGTT ≥ 11.1 mmol/l*	5.1	9.0	10.3	6.5
Males (n)	1470	404	307	2181
BMI ≥ 30 kg/m² *	4.6	9.2	7.8	5.9
Waist circumference ≥ 94 cm*	15.7	22.5	27.7	18.7
WHR ≥1.00*	2.2	2.0	4.6	2.5
TC ≥ 6.2mmol/l*	22.8	39.6	29.6	26.9
TC/HDL ratio ≥ 4.4*	38.6	57.7	63.8	45.7
TG ≥ 1.8 mmol/l*	30.6	41.6	43.6	34.5
SBP≥ 140mmHg and/or DBP ≥90mmHg	9.7	10.4	9.4	9.8
OGTT ≥ 11.1 mmol/l*	4.4	6.4	11.1	5.7

* significant differences between groups (χ^2 test), $p<0.05$

Legend of abbreviations:

BMI:	Body Mass Index	LDL:	Low density lipoprotein cholesterol
Waist:	Waist circumference	SBP:	Systolic blood pressure
WHR:	Waist-to-Hip ratio	DBP:	Diastolic blood pressure
TC:	Total serum cholesterol	TG:	Triglycerides
HDL:	High density lipoprotein cholesterol	OGTT:	2-hour oral glucose tolerance test

at waist category 3 (waist 70 to 75 cm) and one third of men in the same category (waist 75 to 80 cm) have at least one risk factor. When the data is weighted to reflect the actual age, gender and ethnic distribution of Singaporeans, it is found that 54% of Singaporeans with at least one risk factor (56% women, 54% men) have a 'normal' BMI below 25 kg/m^2, while 90% (87% women, 92% men) have BMI below the obesity level (30 kg/m^2). For WHR, 85 % of Singaporeans with at least one risk factor (68% women, 96% men) have a WHR below the cut off values of 0.85 and 1.00 for women and men respectively. Similarly, 65% of Singaporeans with at least one risk factor (51% women, 74% men) have waist of below 80 cm and 94 cm for women and men respectively.

Table 3a. Prevalence (%) of risk factors in Singaporean adults, by gender and BMI categories

BMI Categories (kg/m^2)	n	Elevated TC ≥6.2 mmol/l	Elevated TC/HDL ratio ≥4.4	Elevated TG ≥1.8 mmol/l	HBP ≥ 140/90 mmHg	Diabetes mellitus OGTT ≥11.1 mmol/l
Females						
1 (<20)	637	9.7	3.5	3.0	0.9	1.1
2 (20 to <22)	523	15.5	7.3	7.5	1.9	2.9
3 (22 to < 24)	463	24.2	18.8	16.4	5.0	7.1
4 (24 to < 26)	314	24.8	22.3	18.5	7.0	8.0
5 (26 to <28)	248	27.0	33.5	27.0	11.7	8.9
6 (28 to <30)	140	32.9	40.0	31.4	8.6	17.1
7 (=>30)	217	39.2	44.2	33.6	18.4	18.0
Total	2542	20.9	17.8	14.8	5.6	6.5
Males						
1 (<20)	333	12.6	11.4	9.3	2.1	1.2
2 (20 to <22)	355	21.1	27.0	17.5	4.5	2.5
3 (22 to < 24)	500	29.4	45.0	33.0	7.6	4.6
4 (24 to < 26)	428	28.3	54.4	41.8	10.3	5.1
5 (26 to <28)	276	33.3	67.8	52.5	17.4	9.4
6 (28 to <30)	161	42.2	78.9	58.4	18.6	9.3
7 (=>30)	128	32.0	71.1	59.4	24.2	20.3
Total	2181	26.9	45.7	34.5	9.8	5.7

Legend of abbreviations:

BMI: Body Mass Index
HBP: High blood pressure (SBP≥140 mmHg and/or DBP≥ 90 mmHg)
TC: Total serum cholesterol
HDL: High density lipoprotein cholesterol
SBP: Systolic blood pressure
DBP: Diastolic blood pressure
TG: Triglycerides
OGTT: 2-hour oral glucose tolerance test

Table 3b. Prevalence of risk factors in Singaporean adults, by sex and WHR categories

WHR categories	n	Elevated TC	Elevated TC/HDL ratio	Elevated TG	HBP	Diabetes mellitus
		≥6.2 mmol/l	≥4.4	≥1.8 mmol/l	≥ 140/90 mmHg	OGTT ≥11.1 mmol/l
Females						
1 (<0.70)	143	7.0	1.4	3.5	2.1	0.0
2 (0.70 to <0.75)	546	11.7	4.0	2.9	1.1	0.7
3 (0.75 to <0.80)	896	17.2	11.7	8.7	3.7	2.2
4 (0.80 to <0.85)	557	23.9	25.5	21.2	7.9	10.2
5 (0.85 to <0.90)	278	39.6	40.6	36.0	13.7	18.0
6 (>=0.90)	122	49.2	55.7	48.4	14.8	27.9
Total	2542	20.9	17.8	14.8	5.6	6.5
Males						
1 (<0.80)	238	10.1	9.7	6.3	0.8	1.3
2 (0.80 to <0.85)	492	17.1	24.0	14.8	3.5	1.4
3 (0.85 to <0.90)	657	26.9	46.1	35.8	6.8	2.6
4 (0.90 to <0.95)	525	38.9	66.3	49.9	15.8	8.4
5 (0.95 to <1.00)	215	36.7	77.2	62.3	26.5	18.1
6 (>=1.00)	54	33.3	72.2	61.1	18.5	27.8
Total	2181	26.9	45.7	34.5	9.8	5.7

Legend of abbreviations:

WHR: Waist-to-Hip ratio
HBP: High blood pressure (SBP≥140 mmHg and/or DBP≥ 90 mmHg)
TC: Total serum cholesterol
HDL: High density lipoprotein cholesterol
SBP: Systolic blood pressure
DBP: Diastolic blood pressure
TG: Triglycerides
OGTT: 2-hour oral glucose tolerance test

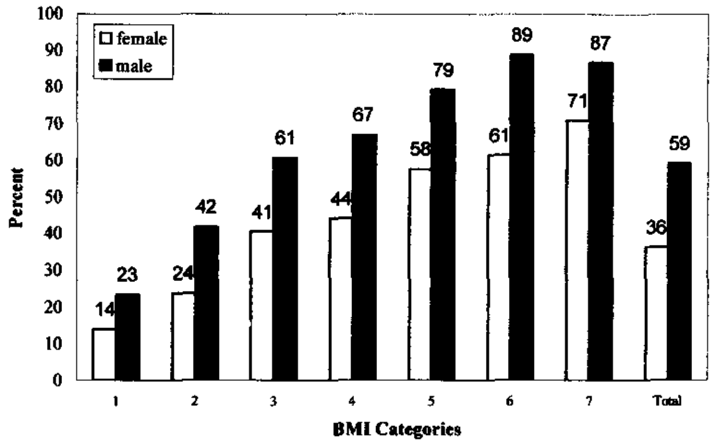
Table 3c. Prevalence of risk factors in Singaporean adults, by sex and waist categories

Waist categories (cm)	n	Elevated TC ≥6.2 mmol/l	Elevated TC/HDL ratio ≥4.4	Elevated TG ≥1.8 mmol/l	HBP ≥ 140/90 mmHg	Diabetes mellitus OGTT ≥11.1 mmol/l
Females						
1 (<65)	322	9.6	1.2	2.5	0.6	0.3
2 (65 to <70)	528	10.6	4.2	2.3	0.8	0.9
3 (70 to <75)	518	15.6	9.8	8.5	2.9	2.9
4 (75 to <80)	421	24.7	19.7	19.2	5.9	5.7
5 (80 to <85)	304	28.9	30.3	24.7	8.6	12.2
6 (85 to <90)	209	35.4	40.7	29.2	12.4	14.4
7 (90 to <95)	117	40.2	47.0	39.3	15.4	18.8
8 (>=95)	123	40.7	48.8	39.8	21.1	25.2
Total	2542	20.9	17.8	14.8	5.6	6.5
Males						
1 (<70)	141	7.8	5.7	2.1	2.8	1.4
2 (70 to <75)	226	16.4	13.7	9.3	1.3	0.9
3 (75 to <80)	294	15.3	20.4	13.3	2.7	1.7
4 (80 to <85)	408	28.7	42.2	30.1	6.6	2.7
5 (85 to <90)	442	30.1	55.0	43.0	10.6	5.4
6 (90 to <95)	315	37.1	69.8	53.3	14.6	8.3
7 (95 to <100)	205	35.6	72.7	54.6	19.0	8.8
8 (>=100)	150	35.3	76.0	64.0	26.7	24.7
Total	2181	26.9	45.7	34.5	9.8	5.7

Legend of abbreviations:

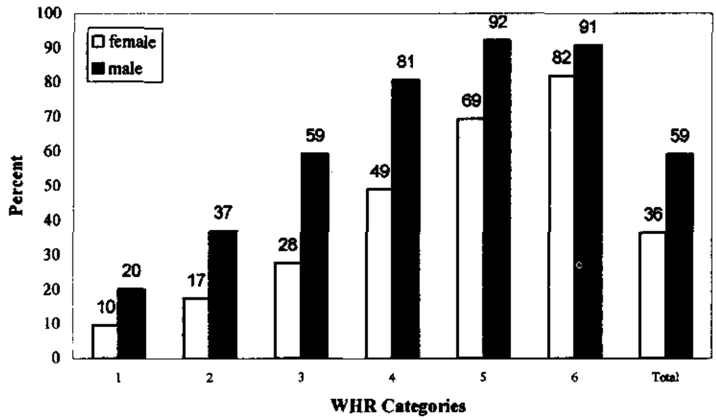
Waist	Waist circumference	SBP:	Systolic blood pressure
HBP:	High blood pressure (SBP≥140 mmHg and/or DBP≥ 90 mmHg)	DBP:	Diastolic blood pressure
TC:	Total serum cholesterol	TG:	Triglycerides
HDL:	High density lipoprotein cholesterol	OGTT:	2-hour oral glucose tolerance test

Figure 1. Proportion of Singaporean adults with at least one risk factor, by gender and body mass index (BMI) categories*



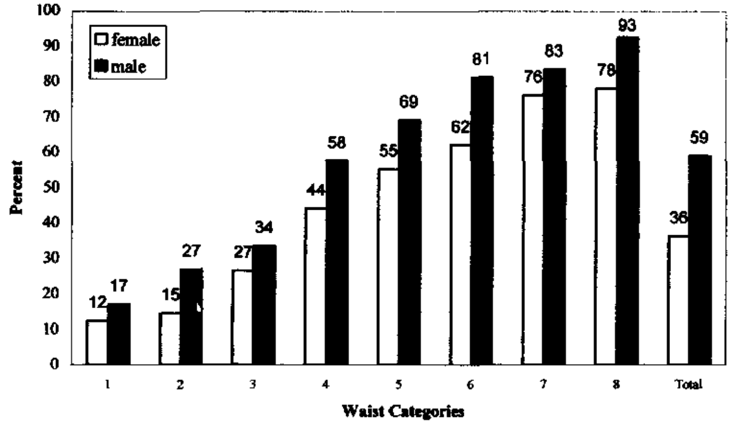
*BMI categories	kg/m^2
1	<20
2	20 to <22
3	22 to < 24
4	24 to < 26
5	26 to <28
6	28 to <30
7	=>30

Figure 2. Proportion of Singaporean adults with at least one risk factor, by gender and waist-to-hip (WHR) categories



*WHR categories	women	men
1	<0.70	<0.80
2	0.70 to <0.75	0.80 to <0.85
3	0.75 to <0.80	0.85 to <0.90
4	0.80 to <0.85	0.90 to <0.95
5	0.85 to <0.90	0.95 to <1.00
6	>=0.90	>=1.00

Figure 3. Proportion of Singaporean adults with at least one risk factor, by gender and waist circumference (waist) categories*



*Waist categories	cm	
	women	men
1	<65	<70
2	65 to <70	70 to <75
3	70 to <75	75 to <80
4	75 to <80	80 to <85
5	80 to <85	85 to <90
6	85 to <90	90 to <95
7	90 to <95	95 to <100
8	>=95	>=100

The relative risks (RR) of developing at least one risk factor are presented as odds ratios (OR) for the different gender and BMI/WHR/waist categories at Tables 4a-c. Category 1 is used as the reference category for all the categories of indices. The risks is considered to be moderately increased when RR is between 2 to 3, and greatly increased when RR is > 3. For BMI categories, the risk for having at least one risk factor is greatly increased from category 3 (≥ 22 kg/m^2) onwards for men, and from category 5 (≥26 kg/m^2) onwards for women. Risk is significantly increased from category 4 of WHR (≥ 0.80 for women and ≥0.90 for men) and category 4 of waist (≥ 75 cm for women and ≥ 80 cm for men) for both men and women. All the categories with significantly increased risks are considered to be within the normal limits set by WHO currently.

Table 4a. Odds ratio (OR) with 95% confidence intervals (CI) for at least one risk factor by gender and BMI categories (corrected for age, ethnic group, educational level, occupation, physical activity, smoking, WHR)

Females				Males			
BMI category (kg/m^2)	n	OR	95% CI	BMI category (kg/m^2)	n	OR	95% CI
1 (<20)	637	1.00	-	1 (<20)	333	1.00	-
2 (20 to <22)	523	1.22	(0.88,1.69)	2 (20 to <22)	355	1.90	(1.30, 2.78)
3 (22 to < 24)	463	2.22	(1.61, 3.06)	3 (22 to < 24)	500	3.14	(2.17, 4.56)
4 (24 to < 26)	314	1.97	(1.38, 2.83)	4 (24 to < 26)	428	3.69	(2.47, 5.51)
5 (26 to <28)	248	3.07	(2.08, 4.54)	5 (26 to <28)	276	5.53	(3.45, 8.87)
6 (28 to <30)	140	2.99	(1.86, 4.83)	6 (28 to <30)	161	9.09	(4.83, 17.09)
7 (=>30)	217	5.50	(3.54, 8.53)	7 (=>30)	128	8.90	(4.53, 17.48)
Total	2542				2181		

Legend of abbreviations:
BMI: Body Mass Index
WHR: Waist-to-Hip ratio

Table 4b. Odds ratio (OR) with 95% confidence intervals (CI) for at least one risk factor by gender and WHR categories (corrected for age, ethnic group, educational level, occupation, physical activity, smoking, BMI)

Females				Males			
WHR category	n	OR	95% CI	WHR category	n	OR	95% CI
1 (<0.70)	143	1.00	-	1 (<0.80)	238	1.00	-
2 (0.70 to <0.75)	546	1.69	(0.90, 3.17)	2 (0.80 to <0.85)	492	1.25	(0.83, 1.88)
3 (0.75 to <0.80)	896	1.76	(0.96, 3.26)	3 (0.85 to <0.90)	657	1.49	(0.98, 2.28)
4 (0.80 to <0.85)	557	2.81	(1.50, 5.26)	4 (0.90 to <0.95)	525	2.59	(1.60, 4.19)
5 (0.85 to <0.90)	278	4.38	(2.24, 8.56)	5 (0.95 to <1.00)	215	3.91	(1.95, 7.87)
6 (>=0.90)	122	5.40	(2.44, 11.94)	6 (>=1.00)	54	2.28	(0.77, 6.81)
Total	2542			Total	2181		

Legend of abbreviations:
BMI: Body Mass Index
WHR: Waist-to-Hip ratio

Table 4c. Odds ratio (OR) with 95% confidence intervals (CI) for at least one risk factor by gender and waist categories (corrected for age, ethnic group, educational level, occupation, physical activity, smoking, BMI)

Females				Males			
Waist category (cm)	n	OR	95% CI	Waist category (cm)	n	OR	95% CI
1 (<65)	322	1.00	-	1 (<70)	141	1.00	-
2 (65 to <70)	528	0.85	(0.55, 1.31)	2 (70 to <75)	226	1.43	(0.79, 2.61)
3 (70 to <75)	518	1.33	(0.86, 2.07)	3 (75 to <80)	294	1.28	(0.70, 2.34)
4 (75 to <80)	421	2.18	(1.34, 3.54)	4 (80 to <85)	408	2.40	(1.28, 4.50)
5 (80 to <85)	304	2.60	(1.49, 4.52)	5 (85 to <90)	442	2.54	(1.28, 5.06)
6 (85 to <90)	209	3.18	(1.68, 6.03)	6 (90 to <95)	315	3.29	(1.49, 7.24)
7 (90 to <95)	117	5.04	(2.34, 10.86)	7 (95 to <100)	205	2.87	(1.16, 7.11)
8 (>=95)	123	4.72	(1.89, 11.79)	8 (>=100)	150	4.66	(1.47, 14.78)
Total	2542			Total	2181		

Legend of abbreviations:
BMI: Body Mass Index
Waist: Waist circumference

Discussion

In the process of determining the cut-off values of obesity and abdominal fatness appropriate for Singaporeans, two criteria were examined. One was that the cut-off values should coincide with increased body fat accumulation and the other was that there should be increased risks for the co-morbidities associated with the indices of obesity. In a previous paper[15] , it was shown that Singaporeans have a higher BF% for the same levels of BMI as Europids and that, based on BF%, the BMI cut-off values for overweight and obesity should be two to three kg/m^2 lower than the recommended WHO value, at 23 kg/m^2 and 27 kg/m^2 respectively. The current paper shows the relatively high prevalence beginning at low categories of BMI, WHR and waist (BMI category 3, WHR category 4 and waist category 4) commonly regarded as 'normal' by WHO standards. This trend is similar for both gender and the three ethnic groups. The proportion of Singaporeans with at least one risk factor that are missed when WHO's cut-off values are used for BMI, WHR and waist are 90%, 85% and 65% respectively, indicating that these cut-off values are inappropriately high for Singaporeans. The findings of this study could be extrapolated to the general Singapore adult population as the sample was selected to ensure that there was adequate representation from all the three major ethnic groups over the adult age range living in Singapore. During data analysis, appropriate weight values were applied to reflect the ethnic, age and gender distribution in the population.

When these high prevalence of population at risk are considered together with greatly increased relative risks of having at least one risk factor experienced at these levels, it is obviously necessary to re-examine the validity of WHO's cut off values for the various indices of obesity for Singaporeans. During the computation of relative risks for each index of obesity, subjects of all ethnic groups have been pooled to increase the power of the analysis, with correction for age, smoking habits, physical activity levels, educational levels, occupation status and other indices of obesity. When entered as a covariate in the multiple regression analysis, ethnicity was not found to have a significant impact on the ORs of the different categories of obesity indices (data not shown). Category 1 of the various obesity indices has been used as the reference category when computing relative risks (ORs) for cardiovascular risk for two main reasons. Firstly, a large proportion (21%) of the population fall within this category, without any appreciable clinical evidence of under-nutrition. Secondly, while the mean values for all risk factors are lowest (highest for HDL) in category

1 of all the three indices, the absolute risks are already high in this category, with 17%, 16% and 14% of those in BMI category 1, WHR category 1 and waist category 1 respectively having at least one risk factor. Thus the use of category 1 as the reference category would not artificially inflate the ORs of the other categories.

The markedly increase in absolute and relative risks with increasing categories of obesity indices is consistent with the high mortality from ischaemic heart disease experienced by Singaporeans (age standardised deaths at 100 per 100,000 population[20]). The discrepancy between the high cardiovascular mortality and apparently low national obesity prevalence of 6%[25] (defined as BMI $\geq$ 30kg/m^2) could be partially explained by the presence of excessive BF% among Singaporeans at low levels of BMI when compared to Europids[15]. Based on percent body fat and presence of risk factors, the currently recommended BMI cut off values for overweight ($\geq$25 kg/m^2) and obesity ($\geq$30 kg/m^2) are likely to be not relevant for Singaporeans. A BMI of $\geq$23 kg/m^2 and $\geq$27 kg/m^2 as the cut off values for overweight and obesity would be more consistent with the current findings. At these levels, 59% of those who are overweight and 78% of those who are obese would have at least one risk factor. The relative risk of having at least one risk factor would be moderately increased for overweight men and women and greatly increased for obese men and women. With these lowered cut-off values, the prevalence of overweight among Singaporeans would increase from 24% to 32% and obesity rates would be more than doubled, from 6 to 16%. These levels of obesity would then be consistent with countries with comparable levels of deaths from ischaemic heart disease[20].

With WHR and waist, the cut-offs are more difficult to determine, as there is currently no study that correlates the amount of abdominal fat with WHR and waist among Singaporeans. From the present study based solely on the presence of at least one cardiovascular risk factor, the absolute risk increased fairly sharply from category 4 onwards (Figures 2 and 3). These are also the levels whereby relative risks become significant and are doubled (Tables 4b and 4c). These levels are below the cut-off values recommended by WHO. For purposes of identifying high risk cases, it would be necessary to lower cut-off values of WHR to 0.80 for women and 0.90 for men, and waist of 75 cm and 80 cm for women and men respectively.

The implications of lowering cut-off values for the indices of obesity are multi-faceted, in terms of public health policy, clinical management guidelines and economics. The actual costs of obesity and its co-morbidities (direct costs to the health systems and indirect costs to the individual and the community) have not been assessed in detail in Singapore. Judging by the estimated accrued direct costs that could be attributed to obesity and its co-morbidities, which ranged from NZ$135 million in New Zealand (population 3.6 millions) to US$51.6 billion in the United States (population 274 millions)[1], it could be assumed that a high economic burden (both direct and indirect costs) from obesity and its related co-morbidities could result if 'high risk' cases are missed for appropriate intervention measures.

Conclusion

It is recognised that the case for lowering of cut-off values would be strengthened if there would be supporting longitudinal data on morbidity and mortality. However this study has shown that at relatively low levels of indices of obesity (BMI) and fat distribution (WHR and waist), absolute and relative risks of having at least one cardiovascular risk factor are increased remarkably among the three major ethnic groups in Singapore. These, in combination with the elevated BF% at low levels of BMI, suggest that the cut-off values presently recommended by WHO for these indices (BMI $\geq$30 kg/m^2; WHR $\geq$ 0.85 for women and $\geq$ 1.00 for men; waist $\geq$ 80 cm for women and $\geq$ 94 cm for men) are likely to be too high for the different population groups in Singapore. Appropriate cut-off values are necessary for the identification of high risk individuals for further screening and intervention.

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7

Validation of a semi-quantitative food frequency questionnaire for estimation of intakes of energy, fats and cholesterol among Singaporeans

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Abstract

The aim of this study was to assess the relative validity of a 159-item semi-quantitative food frequency questionnaire (FFQ) for use among adult Singaporeans, and its ability to classify intakes of energy, total fat, saturated fat, polyunsaturated fat, monounsaturated fat and cholesterol into quintiles of intakes for purposes of epidemiological studies. A total of 126 subjects (84 women and 42 men) took part in the study which included an interview using the newly developed FFQ (assess past month's intake) and three 24-hour (24H) recalls (reference method, collected over a period of one month). Subjects also collected two 24-hour urinary samples for urea from which total nitrogen excretion was assessed to validate protein intake. When compared to the reference method, the FFQ slightly overestimated the intakes of energy, total fat, and types of fat as reflected by the difference in means and the ratio of FFQ to 24H intakes. The overestimation ranged from 1% to 11% of the reference method. Dietary cholesterol was underestimated by 17% by the FFQ. These differences were however not statistically significant. Pearson's correlation coefficients (95% confidence intervals (CI)) between intakes assessed by FFQ and reference method varied from 0.58 (0.45, 0.69) for total fat to 0.39 (0.23, 0.53) for polyunsaturated fat. Cross-classification into quintiles resulted in correct classification into the same or adjacent quintiles in 70% of subjects, with only 1 or 2 subjects being grossly misclassified. Nitrogen (N) intake from the 24H recalls did not differ significantly from that estimated from the urinary nitrogen excretion. The mean (±SD) difference was 0.0±0.4g and the Pearson correlation coefficient (95% CI) was 0.55 (0.31, 0.72). It is concluded that the newly developed FFQ is an adequate tool for classifying individual's intakes into quintiles for epidemiological studies among Singaporean adults.

Keywords: semi-quantitative food frequency questionnaire, validation study, multiple 24-hour recalls, urinary biomarkers, Singaporeans.

Introduction

The mortality from cardiovascular disease in Singapore is comparable to those of the West and higher than those in other parts of Asia (such as Japan and Hong Kong)[1].

From the National Health Survey in Singapore conducted in 1992[2] and studies by Hughes et al[3-9], it is apparent that cardiovascular risk factors differ in the three major ethnic groups (Chinese, Malays, Indians) in Singapore. Such risk factors include obesity, abdominal fat distribution, elevated blood pressure, abnormal blood lipids, elevated blood glucose and insulin. Indians have the highest incidence of acute myocardial infarcts followed by Malays and Chinese[2].

There is however, no satisfactory explanation currently for the high prevalence of cardiovascular diseases in Singapore and differential rates among the ethnic groups to enable public health measures to be carried out to arrest and even reverse the trends.

The role of diet in cardiovascular diseases is well-documented[10-14]. A diet high in energy, total fat, saturated fat and cholesterol and relatively low in unsaturated fats, fruits and vegetables has been linked to the development of cardiovascular risk factors. Differences in nutrient intakes could explain part of the variation in levels of risk factors among the different ethnic groups in Singapore.

Unfortunately, there has been a paucity of studies examining the dietary intakes among Singaporeans and how these are related to cardiovascular risk factors among the different ethnic groups in Singapore[9]. One main reason is the lack of a suitable local dietary tool to be able to assess individuals' usual intake over a period of time. Some methodologies used in published studies included dietary history, multiple 24-hour recalls, multiple dietary records and food frequency questionnaire[14]. The most appropriate method is dependent on the purpose of the study. For ranking of individuals by relative levels of nutrient intake (for evaluation of etiologic hypotheses and interactions), the common tool used is the food frequency method[15, 16]. However, methodologies developed in other populations are not suitable for use in Singapore due to the large variety of local foods consumed by the different ethnic groups that differ from those consumed elsewhere. The present study, conducted in early 1998, aimed to develop a dietary tool suitable for ranking individuals into quintiles of intakes of energy, total fat, saturated fat, polyunsaturated fat, monounsaturated fat and cholesterol and correlate these with cardiovascular risk factors. The dietary tool, a semi-quantitative food frequency questionnaire (FFQ), was to be first designed using a data-based approach. This newly developed FFQ was then validated against multiple 24-hour recalls (reference dietary method). In addition urinary urea (nitrogen) was used to validate the assessed protein (nitrogen) intake from the reference method. An important consideration in the development of the FFQ was that it should be relatively simple and brief to administer (less than 30 minutes) to reduce the burden on both the interviewers and the respondents. The FFQ should also be capable of assessing nutrients as well as foods or food types. This was to permit determination of food sources of nutrients being studied and enable appropriate public education to be carried out.

Methods

Development of food list

The semi-quantitative food frequency questionnaire (FFQ) would comprise a food list of items commonly consumed in Singapore, to be used for assessing frequency of intakes of these food items over the past one month. This food list aimed to include not only foods that were rich in energy or the selected nutrient, but also foods that were important to the population's intake of the nutrient of interest. The list of foods was developed by means of a data-based approach similar to those used by Block et al[15], using dietary data from a food consumption study among Singaporeans conducted in 1993[17]. This 1993's dataset consisted of intakes of 1147 foods and nutrients based on three-day weighed food records of 457 subjects. There was an over sampling of Malays and Indians, with each group making up 20% of the sample population, to ensure adequate representation. The remaining 60% comprised Chinese (the most common ethnic group in Singapore). This 1993 study was part of the National Health Survey[2] with a population sample of some 5000 adults obtained from stratified multi-staged sampling.

The dataset of 1147 foods were first grouped into 161 conceptually similar major food types (e.g. plain steamed rice and rice porridge were grouped as 'white rice', and different types of noodles fried in similar manner were grouped as 'fried noodles'). The other criteria for grouping were that the foods should be similar in nutrient content per usual serving (not per 100g), and should enable classification of individuals with respect to nutrient intake. In addition, respondents should be able to make the necessary distinctions between the food types[15]. For each food group, careful consideration was given to ensure that foods from the three ethnic groups were represented. The questionnaire was pre-tested among the three groups for completeness of food list.

The food composition database residing in the Ministry of Health in Singapore was used to estimate the nutrient content of the food types. The amount of energy and each of the nutrients contributed by each food item was computed based on its nutrient composition, weight of the food item consumed and the frequency of consumption. This computation ensured that foods with lower nutrient composition but eaten frequently would not be overlooked.

Food items were included in the food list if they made an important contribution to the overall intakes of energy, fats and cholesterol. The percent contribution of each of the food types to total energy and the five selected nutrients, viz., total fat, saturated fat, polyunsaturated fat, monounsaturated fat and cholesterol was determined and foods were ranked in descending order of their contribution for each of the nutrients. The cumulative percent contribution was computed and foods contributing cumulatively to 90% of the total intakes of energy or one of the five nutrients were included in the list.

To identify foods important for explaining the variance of intake between persons, a stepwise multiple regression analysis as described by Byers et al[18] was performed. The regression analysis was performed separately for energy and each of the five nutrients. The contribution of each nutrient by individual food items (independent variables) was regressed on the total intake of the same nutrient (dependent variable). The fraction of the variance in the total energy/nutrient that could be progressively explained by an expanding list of food items was expressed as the cumulative R^2 as each food item was entered in a stepwise fashion into the regression model. Food items that contributed to 90% of the cumulative R^2 for energy and each of the other five nutrients were then included in the food list if they were not already in. The basic list of food items was 145 after taking into consideration their contribution to the absolute intakes and variance of intakes of energy and the five nutrients. This list was able to account for more than 99% of the intakes of energy and the five nutrients. In fact, for energy, 75 items alone were able to account for 90% of intake. Adequate capture of energy intake would enhance the capture of a wide range of nutrients[15].

This basic food list was further enhanced to ensure that cooking methods for the different main food types were captured for better assessment of fat intake. In each of the food groups, care has been taken to take cooking methods into account. For example there are two items of chicken curry - one cooked with coconut milk and one without. This is the same for all dishes requiring coconut as an ingredient. Even for the desserts commonly consumed, such as red bean soup, there are different codes when that is consumed with coconut cream or without. Every cooked food item was coded in 3 different ways depending on the cooking oil/fat used during preparation (e.g predominantly polyunsaturated, monounsaturated or saturated cooking oil/fat).

Additions to each of the food item (e.g. addition of sugar, creamer, different types of milk to beverages) were also included to refine the list. Fruits and vegetables were classified into different subtypes (e.g., by physical characteristics and cooking methods) for future correlation with cardiovascular risk factors, when values for various antioxidants and phytochemicals would be available in the local food composition database[19]. The final food list of 159 individual items was grouped into 23 main food types and 25 sub-food types. As far as possible, these were structured according to meal types. (see Annex 1)

Validation of the FFQ

The final FFQ comprising the rather comprehensive list of food items was then put to the final validation testing among 180 adults. The sample size was calculated using the inter- and intra-person variation in intakes of energy and five nutrients obtained from the 1993 study. About 150 subjects would be sufficient for the detection of differences of 10% in intakes between subjects.[20]

For the validation study, a team of nutritionists and dieticians underwent a two-day training on interviewing techniques, reviewing of questionnaire and coding of data. The training included both theory and practical sessions.

The Ministry of Health and the National Medical Research Council in Singapore approved the study protocol and all subjects gave their written consent on the actual survey day.

Subjects were recruited from a typical housing estate in Singapore through home visits. Only those between the ages of 19 and 69 years were recruited. Those who agreed to participate were then invited to the community club for the interviews. Each of the subjects had to undergo four interviews, beginning with the FFQ, to be followed at least three weeks later by the three 24-hour dietary recalls. This sequence was scheduled to reduce possible influences of learned responses when reporting intakes for the FFQ. Weight and height measurements were taken during the first interview. Body weight was measured to the nearest 0.1 kg in light indoor clothing without shoes, using a digital scale. Body height was measured without shoes with Frankfurt plane horizontal, to the nearest 0.1 cm using a wall-mounted stadiometer. From the weight and height, body mass index (BMI, kg/m^2) was calculated.

The FFQ was administered in the language (either in English, Mandarin, Malay or Tamil) that the subject was most comfortable with, with use of interpreters where necessary. The length of interview ranged from 30 minutes to 45 minutes (if interpreter was needed). The subject was asked to recall usual intakes of the foods on the food list over the past one month. The usual serving sizes of each food item in common household measures (e.g rice bowl, soup spoon, cups) were included in the list. Columns were provided to enable subjects to report intake as frequency per day, per week or per month. To aid the recall, life size food models, food pictures and household utensils were used. Subjects could choose to report the intake in the preferred serving sizes (this was later coded as fractions of the standard serving portions). Foods consumed less than once a month were not recorded. The first of the 24-hour recalls took place at least three weeks after the administration of the FFQ. These 24-hour recalls included two weekdays and one weekend (Sunday) and were conducted at least one week apart from each other. Only Sunday was considered as a weekend, as the normal workweek in Singapore comprised six working days. As for the FFQ, the necessary memory aids were used to facilitate recalls. During the first two interviews for 24-hour recalls, subjects were also given verbal and written instructions to collect 24-hour urinary samples according to the protocol described by Bingham et al[21]. Collection commenced on the morning after the interviews. After the collection was completed, the urinary samples were collected from the subjects and sent to the laboratory immediately for analysis of urea and creatinine. Urinary urea was determined by enzymatic method using a commercially available test kit (Boehringer Mannheim/Hitachi 1 820 206 R2), and urinary creatinine by a modified Jaffé method[22]. Only the data of those subjects (n=46) who completed the FFQ, at least two dietary recalls and collected two valid 24-urinary samples were used for the validation of protein (nitrogen) intake. Samples are considered adequate and valid when the creatinine excretion was within the expected range (males between 124 and 230 mmol/kg/d and females between 97 and 177 mmol/kg/d)[23].

The relative validity of the food frequency questionnaire (FFQ) was conducted by comparing the intakes of energy and five nutrients obtained against the weighted means from multiple (three) 24-hour dietary recalls. The weighted average intake for the multiple 24H recalls was calculated as:

$$\frac{(6 * \text{mean weekday intakes}) + (1 * \text{weekend intake})}{7}$$

The validity in this study is not expected to be absolute as no dietary survey method has been shown to be free of systematic errors in free living subjects[20,24,25].

Intakes of energy and each of the nutrients obtained from the FFQ and multiple 24-hour dietary recalls were divided into quintiles of intake. The ability of the FFQ to accurately classify individuals into the same or adjacent quintile of intake as that obtained from the reference method was tested using χ^2 test. Differences between values obtained from the FFQ and reference method were tested using paired T-test, and Pearson's correlation coefficients were calculated between intakes obtained from the two methods.

The ability of the multiple 24-hour dietary recalls to estimate dietary intakes of the subjects was verified by the use of an additional urinary biomarker as recommended by Bingham et al[21]. The reported intake of nitrogen (N) from the 24-hour dietary recalls was compared to intake estimated from 24-hour urinary urea excretion. In a diet high in protein, 90% of urinary N consists of urea[26]. A constant fraction of 81% was used to estimate N intake from total urinary N excretion[24]. These factors were used to estimate N intake from urea excretion

[Estimated N intake = (N from urea/0.9)/0.81]. Paired t-test of difference and Pearson's correlation analysis were performed on the dietary N intake and estimated N intake data.

All data were analysed using SPSS ver 8.0[27]. Values are given as mean ± SD. Correlation coefficients are presented as Pearson's correlation coefficients with 95% confidence intervals. Relationship of the difference between dietary N intakes and estimated N intake (from urinary N excretion) and the mean N intakes obtained from both methods is presented as a Bland and Altman plot.[28] Significance level was set at $p < 0.05$.

Results

The study population consisted of 180 subjects, with 117 women and 63 men. After eliminating incomplete records (less than two 24-hour dietary recalls), 126 subjects were left (84 women and 42 men). These subjects had a mean (±SD) age of 44.7±11.1 years, height of 160.8±8.7 cm, weight of 62.3±12.7 kg and BMI of 24.0±3.9 kg/m^2. Of the 126, only 46 subjects had valid urine samples (two samples with creatinine excretion within normal limits). These subjects were slightly older (mean age of 47.6 ± 11.6 years), but had a similar ethnic, height, weight and BMI distribution compared to those without complete urine samples.

Reported intakes of energy, total fat, saturated fat, polyunsaturated fat, monounsaturated fat, cholesterol and protein using FFQ and multiple 24-hour (24H) recalls are given in Table 1. Overall, there was over reporting of intakes with the FFQ for energy, total fat and types of fat, and underreporting for cholesterol and protein as reflected by the differences in means and the % reference (FFQ*100/24H). These differences were, however, small and not significant except for polyunsaturated fat, cholesterol and protein.

In Table 2, the quintiles of intakes for energy, total fat, types of fat and cholesterol are presented. As expected, the range of intakes for males is higher than females for all nutrients. After dividing into quintiles, the expected misclassifications were calculated based on the correlation coefficients. For energy and all nutrients, the FFQ was found to be adequate for classifying subjects into the same or adjacent quintiles of intakes when compared to the multiple 24-hour recalls. The observed proportions of misclassifications were not significantly different from that expected for energy and the nutrients tested (Table 3). The

Table 1: Comparison of intakes between multiple 24-hour dietary recalls (24H) and food frequency questionnaire (FFQ)# in Singaporean adults.

Food component	24H*		FFQ*		Difference **		%reference ***	Correlation coefficient[§]	
Energy (kcal)	1893	(520)	1961	(605)	-68	(-162, 26)	104	0.56	(0.43, 0.67)
Fat (g)									
Total	63.1	(22.4)	64.8	(27.9)	-1.7	(-5.9, 2.5)	103	0.58	(0.45, 0.69)
Saturated	23.0	(8.8)	23.5	(11.1)	-0.5	(-2.3, 1.3)	102	0.51	(0.37, 0.63)
Polyunsaturated	13.8	(6.2)	15.3	(7.9)	-1.4	(-2.8, -0.1)	111	0.39	(0.23, 0.53)
Monounsaturated	21.4	(8.6)	21.6	(10.9)	-0.2	(-2.0, 1.5)	101	0.50	(0.36, 0.62)
Cholesterol (mg)	271	(170)	226	(120)	45	(18, 71)	83	0.51	(0.37, 0.63)
Protein (g)	75.4	(26.5)	69.7	(24.0)	5.7	(1.1, 10.4)	92	0.46	(0.31, 0.59)

n= 126

* mean ± SD

** calculated as 24H – FFQ, mean paired difference, (95%CI)

***(FFQ/24H)*100

[§] Pearson's product-moment correlation coefficient, r (95% CI)

Table 2. Quintiles of intakes of energy, total fat, types of fat and cholesterol by gender

	N	Food component	Upper limits for first four quintiles 1[st]	2[nd]	3[rd]	4[th]
Females	84	Energy (kcal)	1328	1598	1914	2277
		Fat (g)				
		Total	39.5	48.2	64.0	81.7
		Saturated	12.9	16.8	23.3	29.6
		Polyunsaturated	8.2	10.8	15.4	20.7
		Monounsaturated	12.0	16.4	21.1	27.5
		Cholesterol (mg)	115	160	213	284
Males	42	Energy (kcal)	1730	1987	2398	2785
		Fat (g)				
		Total	45.1	60.3	79.2	97.2
		Saturated	17.1	20.2	28.6	38.1
		Polyunsaturated	10.2	12.9	17.3	27.6
		Monounsaturated	13.9	19.8	22.6	33.0
		Cholesterol (mg)	144	195	271	372
All	126	Energy (kcal)	1373	1724	2040	2455
		Fat (g)				
		Total	41.9	53.1	67.7	84.9
		Saturated	13.4	18.2	24.1	31.3
		Polyunsaturated	9.0	11.2	15.6	21.6
		Monounsaturated	12.4	16.7	21.6	29.8
		Cholesterol (mg)	120	170	237	326

Table 3. Cross classification of dietary intakes in Singaporean adults into quintiles by FFQ (total number of subjects=126) and 24H recalls.

Food component	Same or adjacent category (n)	Gross misclassification (n)**	p*
Energy (kcal)	88	0	0.65
Fat (g)			
Total	85	2	0.29
Saturated	91	2	0.54
Polyunsaturated	76	1	0.29
Monounsaturated	89	1	0.77
Cholesterol (mg)	89	1	0.77
Protein (g)	71	2	0.57

* χ^2 to test observed misclassifications from expected

** being classified from one extreme category to the other extreme category

Table 4. Comparison of 24-hour dietary N intake and estimated N intake from urinary urea excretion (n=46) in Singaporean adults

N intake (g/d)		Estimated N intake (g/d)*		Difference (intake – estimated)		Correlation coefficient**	
Mean	SD	Mean	SD	Mean	95% CI	r	95% CI
10.2	2.6	10.2	2.6	-0.0	(-0.7, 0.7)	0.55	(0.31, 0.72)

*calculated as *[(N excretion from urea/0.9)/0.81]*

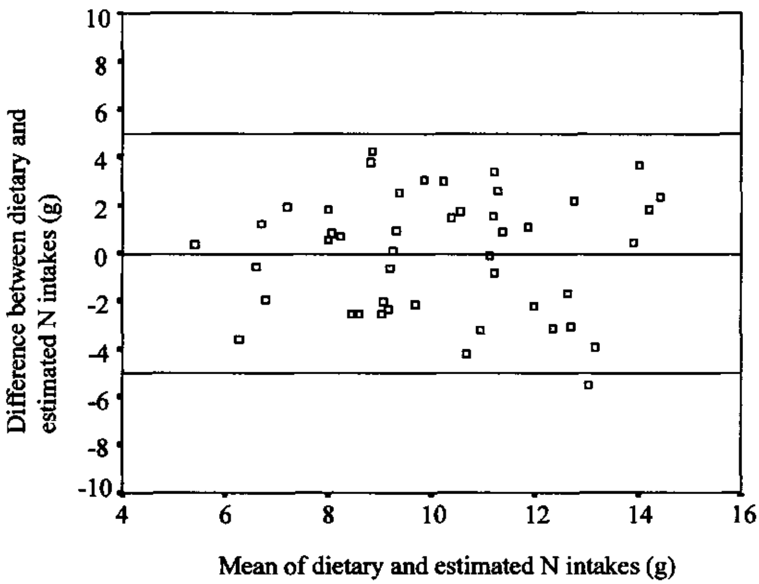
** Pearson's product-moment correlation coefficient ($p<0.05$

percentage of gross misclassifications were small (classified from one extreme category to the other extreme category), with only two (1.8%) subjects being grossly misclassified for total fat, saturated fat and protein intakes, only 1 subject (0.9%) for polyunsaturated fat, monounsaturated fat and cholesterol, and none for energy.

The comparison between reported dietary intakes of N (from reference dietary method) and estimated N intakes (from urinary N excretion) is at Table 4. The mean N intake of 10.2±2.6g was the same as that estimated from urinary N. The mean difference between actual and estimated dietary N intake was 0.0± 0.4g. The Pearson's product correlation coefficient between dietary N and estimated N intake was 0.55 (0.31, 0.72).

The Bland and Altman plot of difference in dietary and estimated N intakes against the mean of dietary and estimated N intakes (Figure 1) showed that the differences were not significantly correlated to the level of N intakes (r=0).

Figure 1. Plot of difference in dietary N intakes (from multiple 24-hour recalls) and estimated N intakes (from urinary N excretion) against mean of dietary and estimated N intakes



Discussion

The sample population of 180 was selected from a typical housing estate with different flat-types in Singapore. This study did not require a representative sample due to the nature of the methodology employed. The proportion of residents of different ethnic groups in this housing estate was, however, similar to the ethnic distribution in Singapore, majority being Chinese, with 14% Malays and 7% Indian. The other ethnic groups which made up about 3% of the population were not included in the sample. The low number of respondents (n=46) who collected both urinary samples satisfactorily was due to the difficulties presented by the hot humid weather which made it rather unpleasant to collect and store the urine for 24 hours. This was especially so for workers who need to bring the containers to work as not all workplaces are air-conditioned. However, the characteristics of these 46 subjects are comparable to the total number of subjects.

The FFQ was chosen as the possible tool for detection of 'usual' intakes of energy, total fat, saturated fat, polyunsaturated fat, monounsaturated fat and cholesterol as it has a low respondent burden and high response rate compared to other methods such as the dietary history and repeated weighed food records. As the purpose for its development is to classify subjects into quintiles of intake and not to measure the individual's absolute intake, it is considered an adequate tool despite its limitations[29]. While many researchers have developed FFQs for studies on diet- disease relationship, these FFQs could not be easily adapted for use in the local context for various reasons. The most important limitation in using FFQs developed in other populations is the food list. The food list to be in Singapore has to include foods commonly consumed by the population, which are important contributors to the dietary intakes of the foods/nutrients being studied. Such foods should also be able to account for variation in intakes of the nutrients concerned. Many foods and their cooking methods are unique to the local context, and nutrient data are often not available from other commonly used databases. As such, much work has been put in by the Ministry of Health in Singapore to systematically analyse the nutrient composition of foods commonly eaten in Singapore, both by direct laboratory analysis and indirect analysis using a computer programme developed specially for this purpose. The availability of this food composition tables, together with the 1993's dataset on foods consumed by the population (obtained from three-day weighed food records) made it possible to develop a FFQ for the local population.

In the development of the FFQ, certain issues were considered to ensure its applicability in Singapore. By using a data-based approach, it was ensured that the food list would include foods that are commonly consumed by the adult population in Singapore. The portion sizes used in the food list are in common household measures for ease of estimation of portion eaten. Foods were grouped in a manner to allow for estimation of fat and types of fat. Thus food items which were conceptually similar were further grouped by cooking methods and also by the form commonly eaten by the subjects (e.g. poultry with skin, poultry without skin were in different main food types). The food items in each group had similar energy, fat and cholesterol content per serving. There is a fairly extensive intermingling of all races in Singaporeans resulting in diets comprising foods originating from different ethnic backgrounds. For example, in the hawker centres or food courts (a collection of food stalls selling ready-to-eat foods) patronised by almost all, one can find Chinese, Indian and Malay foods sold side by side and it is not uncommon for patrons to buy from more than one stall. More recently halal Chinese foods are also available locally. Thus it is necessary that the types of foods included in the list covered those consumed by all three ethnic groups, making this questionnaire valid for all three ethnic groups.

During the validation study, the choice of reference method was made to enable ranking of individuals into quintiles rather than to estimate actual individual intake. Multiple 24-hour recalls would enable this without imposing too high a respondent burden (compared to food records or dietary history). This was the method thought to be most appropriate for population groups where there is a possibility of variation in the quality of food-record data [30]. The estimated N intake from the urinary biomarker correlated well with the dietary N intake data for this reference method. This, together with the mean difference between the estimated and dietary N intakes of 0.0 ±0.4g, supports the suitability of the multiple 24-hour recalls as a reference method in this study. The use of the additional biochemical marker has the advantage in that the potential sources of random error occurring with the urinary marker are different from those of the questionnaire measurement (in this case, the FFQ). In addition, these errors are also unlikely to be correlated with those of daily intake measurements (the reference method). Kaaks[31], therefore advocated the use of the additional biochemical marker in validation studies to make it more likely that criteria of independent errors are met.

The deviation of the intake data obtained from the newly developed FFQ as compared to the reference method is within the limits reported in other studies. For fat intake (a major concern in this study), studies conducted by various research groups reported an overestimation with FFQ in the range of between 1 to 55% of the reference method[32-36]. The overestimation found in this study is 3% of the reference. The Pearson correlation coefficient of 0.58 between fat intake from FFQ and reference method in this study is also consistent with those reported in other studies. For example, most studies in America reported correlation coefficients of between 0.4 to 0.7, both in minority and non-minority groups[30], while a study in the Netherlands reported a fairly high correlation coefficient of 0.78[37]. This correlation appeared to be inversely proportionate to the time interval between the administrations of the different methodologies. All the intakes obtained from this newly developed FFQ are significantly correlated to those obtained from the reference method, ranging from 0.56 for energy to 0.39 for polyunsaturated fat.

The main purpose of this validation study was to determine the ability of the newly developed FFQ to classify individuals into the respective quintiles of intake when compared to multiple 24-hour recalls over a reference period of one month. Cross-classification resulted in correct classification into the same or adjacent quintile for 70% of cases for energy and the five nutrients, with a minimum of gross misclassifications. Statistical testing showed that the proportion of misclassification was not significantly more than that expected, on the basis of the correlation coefficients.

In conclusion, the newly developed FFQ has been found to be an adequate tool for the assessment of dietary intakes of energy, total fat, saturated fat, polyunsaturated fat, monounsaturated fat and cholesterol among adult Singaporeans. The FFQ can be used as a dietary tool to classify individuals into quintiles of intake for purposes of evaluating etiologic hypotheses and interactions between dietary intakes and disease risk factors.

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Annex 1

	Food group	No. of items	Subgroups	No. of items
1.	Bread	7		
2.	Bread spreads	5		
3.	Cereals	2		
4.	Rice	2		
5.	Flavoured rice	7		
6.	Flavoured porridge	1		
7.	Noodles	12	Noodles in soup	2
			Dry noodles	2
			Fried noodles	4
			Noodles in lemak (creamy) gravy	3
			Others	1
8.	Vegetables	28	Pale green leafy	5
			Dark green leafy	5
			Tomatoes, carrots, red/yellow peppers	4
			Fresh legumes and pulses	5
			Mixed vegetables	5
			Potatoes	1
			Others (roots/stems)	3
9.	Tofu/beancurd	2		
10.	Salad dressings	3		
11.	Fruits	5		
12.	Poultry	12	Poultry without skin	6
			Poultry with skin	6
13.	Meat	19	Meat – lean	7
			Meat – lean and fat	7
			Meat – preserved/cured	5
14.	Fish/Seafood	14	Fish	7
			Other seafood	7
15.	Eggs	2		
16.	Desserts/Local snacks	8	Desserts in soup	2
			Kueh kueh – steamed	2
			Others	4
17.	Biscuits, pastries and cakes	6		
18.	Fast foods and soft drinks	5		
19.	Nuts	2		

Food group	No. of items	Subgroups	No. of items
20. Tidbits and snacks	3		
21. Hot beverages*	3		
22. Milk and dairy products	7	Milk	3
		Yoghurt	2
		Cheese	2
23. Alcoholic beverages	4		

* a choice of 7 additions could be made

* for cooked items with added fat or oils, a choice of 8 types could be made.

8

Can dietary factors explain differences in serum cholesterol profiles among different ethnic groups (Chinese, Malays and Indians) in Singapore?

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Submitted

Abstract

Objectives: In Singapore, there exists differences in risk factors for coronary heart disease among the three main ethnic groups, Chinese, Malays and Indians. This study aimed to investigate if differences in dietary intakes of fat, types of fat, cholesterol, fruits, vegetables and grain foods could explain the differences in serum cholesterol levels between the ethnic groups.

Subjects: 2408 adult subjects (61.0% Chinese, 21.4% Malays and 17.6% Indians) were selected systematically from the subjects who took part in the National Health Survey in 1998.

Design: cross sectional study

Measurements: A food frequency questionnaire was used to assess intakes of energy, total fat, saturated fat, polyunsaturated fat, monounsaturated fat, cholesterol, fruits, vegetables and cereal based foods. The Hegsted score was calculated. Serum total cholesterol, low density lipoprotein cholesterol, high density lipoprotein cholesterol were analysed and the ratio of total cholesterol to high density lipoprotein cholesterol was computed.

Results: On a group level (six gender-ethnic groups), Hegsted score, dietary intakes of fat, saturated fat, cholesterol, vegetables and grain foods were found to be correlated to serum cholesterol levels. However selected dietary factors did not explain the differences in serum cholesterol levels between ethnic groups when multivariate regression analysis was performed, with adjustment for age, body mass index, waist-hip ratio, cigarette smoking, occupation, education level and physical activity level.

Conclusion: This cross sectional study shows that while selected dietary factors are correlated to serum cholesterol at a group level, they do not explain the differences in serum cholesterol levels between ethnic groups independently of age, obesity, occupation, educational level and other lifestyle risk factors

Keywords: dietary factors, serum cholesterol, ethnic, Chinese, Malays, Indians, Singapore

Introduction

The mortality from cardiovascular disease in Singapore is high, with age-standardised deaths from ischaemic heart disease at 100 per 100,000 population[1]. This is comparable to developed countries such as Australia (97 per 100,000) and United States (125 per 100,000), but higher than in other parts of Asia with similar economic development, such as Japan (22 per 100 000) and Hong Kong (40 per 100,000)[1].

Singapore is a multi-ethnic society with a population consisting of three main ethnic groups, Chinese (77%), Malays (14%) and Indians (7.6%). From the National Health Survey in Singapore conducted in 1992 and 1998[2,3] and studies by Hughes et al[4-7], it is apparent that cardiovascular risk factors and mortality differ in the three major ethnic groups in Singapore. Such risk factors include obesity, abdominal fat distribution, elevated blood pressure, abnormal blood lipids, elevated blood glucose and insulin. The prevalence of obesity is highest among the Malays, followed by the Indians and Chinese, while Indians have the highest prevalence of abdominal fatness. Malays have the highest prevalence of hypertension and hypercholesterolemia. On the other hand, Indians have the highest prevalence of diabetes mellitus and are more likely to have hyperinsulinaemia. Overall, Indians have the highest incidence of acute myocardial infarcts followed by Malays and Chinese[4]. Among the three ethnic groups, there are also differences in lifestyle risk factors, such as smoking, alcohol consumption and physical activity levels. Most of the smokers (at least one cigarette per day) in Singapore are males, with the proportion of Malay smokers being 1.5 times more than the Chinese and Indians. Only 2.6% of adult Singaporeans profess to be regular drinkers of alcoholic beverages (≥4 days a week), with Chinese being the group that is more likely to be regular drinkers. The proportion of adults who professes to have regular physical activity (exercised ≥20minutes for ≥3 days a week) is highest for the Indians[3].

The causes of coronary heart disease are multi-factorial, including lifestyle related risk factors, genetic factors, environmental factors and inadequate or ineffective medical care[8]. Among the lifestyle related risk factors are diet, smoking and physical activity. The decline in deaths from coronary heart disease in the United States and other developed countries has been partly attributed to lifestyle changes[9,10,11]. One of the main predictors of coronary heart disease mortality is serum cholesterol which is known to be strongly related to coronary heart disease mortality both at population and individual levels[12]. Elevated total serum cholesterol (TC), particularly low-density lipoprotein cholesterol (LDL), and low levels of high-density lipoprotein cholesterol (HDL) are known risk factors for coronary heart disease[13]. The relationship between serum cholesterol and risk for coronary heart disease is strong and continuous, with risk increasing progressively with increases in total serum cholesterol from 3.9 mmol/l onwards[14, 15].

Cross country comparisons of data suggest that certain dietary profiles are associated with elevated serum cholesterol levels and mortality from coronary heart disease. Elevated serum cholesterol is generally observed with national diets rich in animal products and refined cereals rather than more 'plant-based' diets of developing countries[14,16]. Keys reported in a comparative study of seven countries that there are strong associations between fat intake (particularly saturated fat) and elevated serum cholesterol levels and heart disease. An intake of saturated fat of more than 10% of total energy is observed to be correlated with a marked and progressive increase in mortality. The hypercholesterolaemic effect of saturated fat is found to be enhanced by a diet high in cholesterol[17]. On the other hand, international comparative studies suggest that consumption of fruit and vegetables is inversely correlated to mortality from heart disease[18]. This can have been effected via antioxidants abundant in fruit and vegetables. Another food group found to be beneficial for heart health is grains, most probably through dietary fibre and a combination of other non-nutrients such as phytoestrogens (e.g. lignans) and antioxidants (e.g. vitamin E)[18,19].

Thus a diet that is high in total fat, saturated fat and cholesterol, but low in unsaturated fats, fruit and vegetables has an adverse effect on serum cholesterol[14,16,20] and differences in dietary intakes might explain part of the variation in levels of risk factors among the different ethnic groups in Singapore.

The aim of this study was to determine the intakes of energy, total fat, types of fat, cholesterol, fruit, vegetable and cereal based foods among three ethnic groups in Singapore and examine if the differences in serum cholesterol levels between ethnic groups could be explained by intake patterns after correction for known confounders (age, body mass index, waist-to-hip ratio, cigarette smoking, physical activity pattern, occupation and educational level).

Subjects and methods

The study was conducted as part of the National Health Survey in 1998 (NHS98)[3]. During the NHS98, the population selection was done through a multi-staged sampling process. This process has been previously described[3]. Malays and Indians were over sampled to ensure sufficient sample size in these two ethnic groups. The survey yielded a response rate of 64.5% and the ethnic composition of the final sample (n=4723) was 64% Chinese, 21% Malays and 15% Indians. There were no differences in the characteristics of the non-respondents and the subjects in the final sample. A subsample of 2408 subjects were selected systematically (1 in 2) on site to participate in the dietary survey. This sample was similar in characteristics with the subjects who took part in the NHS98, except for a slight under representation of Chinese (61.0%) and over representation of Indians (17.6%). In the analysis, weight values were applied, where appropriate, to reflect the actual ethnic, age and gender distribution of the general Singaporean adult population.

All survey field workers were briefed extensively on the survey methodology and underwent rigorous training in the survey procedures assigned to them. A one-day trial of the survey was conducted to hone the field worker's skills and familiarise them with the survey procedure.

The Ministry of Health and the National Medical Research Council in Singapore approved the study protocol and all subjects gave their written consent on the actual survey day.

An interview-administered questionnaire was used to get information about occupation, educational level, smoking habits (number of cigarettes smoked per day) and physical activity (number of sessions of aerobic activity engaged in per week).

Weight was measured in light indoor clothes without shoes using calibrated digital scales with an accuracy of 0.1 kg. Body height was measured with the Frankfurt plane horizontal, to the nearest 0.1 cm without shoes using wall-mounted stadiometers. From weight and height the body mass index (BMI, weight/height^2, kg/m^2) was calculated. Waist was measured to the nearest 0.1 cm, midway between the lower rib margin and the iliac-crest at the end of a gentle expiration . Measurements were taken directly on the skin. Hip circumference was measured to the nearest 0.1 cm over the great trochanters directly over the underwear[21]. The waist to hip ratio (WHR) was calculated.

Overnight fasting blood samples were taken and plasma was separated and analysed on the same day. Total cholesterol (TC) was determined using an enzymatic method with a commercially available test kit (Boehringer Mannheim GmbH, test kit #1489704, Mannheim, Germany). HDL-cholesterol (HDL) was determined by the homogeneous enzymatic test (Boehringer Mannheim GmbH, test kit # 1731203, Mannheim, Germany). LDL cholesterol (LDL) was measured with the homogeneous turbidimetric method (Boehringer Mannheim GmbH, test kit # 1730843), Mannheim, Germany). TC to HDL ratio (TCHDL) was calculated.

To assess the 'usual' dietary intakes of the subjects over the past one month, a food frequency questionnaire (FFQ) was used. This FFQ was developed for the purpose of assessing intakes of energy, total fat, saturated fat, polyunsaturated fat, monounsaturated fat and cholesterol among adult Singaporeans[22]. Included in this questionnaire was a section for obtaining details on intakes of food groups, particularly fruit and vegetables. It comprised a food list of 159 individual food items grouped into 23 main food types and 25 sub-food type and was found to be an adequate tool to classify individuals into quintiles of intake[22]. Nutritionists and nutrition technologists underwent two days of training to standardise interviewing techniques. A further two days were spent in training of data handling.

The FFQ was administered in the language (either in English, Mandarin, Malay or Tamil) that the subject was most comfortable with, with use of interpreters where necessary. The subject was asked to recall usual intakes of the foods on the food list over the past one month. The usual serving sizes of each food item in common household measures (e.g rice bowl, soup spoon, cups) were included in the list. Columns were provided to enable subjects to report intake as frequency per day, per week or per month. To aid the recall, life size food models, food pictures and household utensils were used. Subjects could choose to report the intake in the preferred serving sizes (this was later coded as fractions of the standard serving portions).

Foods consumed less than once a month were not recorded. The food composition database residing in the Department of Nutrition in Singapore was used for computation of intakes of energy (kcal), protein (g), fat (g), saturated fat (g), polyunsaturated fat (g), monounsaturated fat (g) and cholesterol (mg). Percent of energy as total fat (%fat), saturated fat (%sfa), polyunsaturated fat (%pufa), monounsaturated fat (%mufa) were calculated. Cholesterol intake was also expressed as cholesterol(mg) per 1000 kcal. Quintiles of intakes were computed for these nutrients and food groups (servings of fruit, vegetables, rice and alternatives). Rice and alternatives (rice group) comprise cereal-based foods such as all varieties of rice, noodles, breads and grain products. The Hegsted score was also calculated according to the formula[23],

$$\text{Hegsted score} = 2.16*\%\text{sfa} - 1.65*\%\text{pufa} + 0.0677*\text{cholesterol} - 0.53$$

The higher the Hegsted score, the greater is the cholesterol-raising effect of the diet. This score has been chosen as it takes into account lipid-related components of the diet known to affect total serum cholesterol. The composite score was used in the multivariate analysis in place of its components, %sfa, %pufa and cholesterol intakes. The Hegsted score could be used subsequently to predict changes in serum cholesterol levels when longitudinal data on changes in %sfa, %pufa and cholesterol intakes are available.

As the intakes of fruit, vegetables, rice group, and Hegsted score were skewed to the right, they were log-transformed and used in statistical analysis. Log transformation was also performed for TC, LDL, HDL and TCHDL as these were also positively skewed.

Statistical analyses were performed using SPSS 8.01[24]. Values are given as mean ± SD. Analysis of (co)variance was used to test differences in levels of serum cholesterol and dietary intakes between ethnic groups with age as covariate. Correlations are Pearson's partial correlation coefficients with correction for age. Multivariate analysis of variance was conducted to analyse the difference in levels of serum cholesterol (TC, LDL, HDL, TCHDL) between ethnic groups as contributed by the different covariates (such as age, BMI, WHR, educational level, occupation, lifestyle factors and dietary factors). Relative risk (odds ratio) of elevated serum cholesterol levels between quintiles of dietary intakes was calculated using logistic regression with adjustment for age, ethnicity, occupational status, educational level, number of cigarettes smoked, BMI, WHR, physical activity levels. A significance level of 0.05 was used.

Results

Table 1 shows some of the characteristics of the study population. There were no age differences between the ethnic groups, for both females and males. Among the women, Chinese have the lowest body weight, and were taller, with the lowest BMI. They also have the smallest waist circumference (waist) and WHR. Indian women have the largest waist and WHR. For men, Malays were the shortest and have the highest BMI, while Indians have the largest waist and WHR. Chinese men have the lowest BMI .

In Table 2 the dietary intakes of total energy, total fat, protein, %fat, %sfa, %pufa, %mufa and cholesterol are presented along with intakes of fruits, vegetable and rice group. The computed Hegsted score is also found in Table 2. Among the women, Indians have the highest intakes of energy, %fat, %pufa, vegetables and rice group, with the lowest %mufa in their diet. Chinese women have the lowest rice group, %fat and %sfa intakes. Malay women have the lowest vegetable intakes. There is no difference in intakes of protein and fruits. For men, there is no difference in dietary intakes of energy, total fat, protein, vegetables and rice group among the ethnic groups. Chinese men have the lowest %fat and %sfa, while Malay men have the highest %fat and lowest %pufa. Indian men consumed the highest %pufa and most servings of fruit. For both men and women, Indians have the lowest cholesterol intakes, both in absolute amounts and when expressed as per 1000 kcal and also the lowest Hegsted score.

When the mean intakes of each of the six gender-ethnic group was correlated with the mean levels of serum cholesterol, Pearson correlation coefficients for the six groups are positive between TC and Hegsted score ($r = 0.77$), %sfa ($r = 0.61$), rice group ($r = 0.60$) and negative between TC and vegetables ($r = - 0.82$). TCHDL is positively correlated with %sfa ($r = 0.86$), Hegsted score ($r = 0.67$), rice group($r = 0.70$) and %fat ($r = 0.60$). Strong negative correlations are found between HDL and %sfa ($r = -0.85$), %fat ($r = -0.72$) and rice group ($r = -0.63$).

Table 1. Distribution of some characteristics of sample population

	Chinese		Malays		Indians		Total	
	mean	SD	mean	SD	Mean	SD	mean	SD
Females (n)	806		268		224		1298	
Age (years)	38.5	12.2	37.8	12.2	38.7	11.2	38.4	12.0
Weight (kg)	54.4[a]	8.8	62.5[b]	12.8	61.9[b]	11.7	57.4	10.9
Height (cm)	157.1[a]	5.5	154.3[b]	5.9	156.1[c]	6.0	156.4	5.8
BMI (kg/m2)	22.1[a]	3.5	26.3[b]	5.1	25.5[b]	4.9	23.5	4.5
Waist (cm)	73.2[a]	8.3	78.9[b]	10.6	81.2[c]	10.8	75.8	9.8
WHR	0.78[a]	0.05	0.80[b]	0.10	0.81[b]	0.07	0.80	0.07
Males (n)	663		247		200		1110	
Age (years)	39.2	12.6	38.7	12.4	40.7	11.1	39.3	12.3
Weight (kg)	67.7	11.9	69.5	12.0	69.7	11.9	68.5	12.0
Height (cm)	169.3[a]	6.5	166.6[b]	6.3	169.8[a]	6.5	168.8	6.6
BMI (kg/m2)	23.6[a]	3.8	25.0[b]	4.0	24.2	3.8	24.0	3.9
Waist (cm)	84.4[a]	9.9	85.9	10.6	88.2[b]	10.2	85.4	10.2
WHR	0.88[a]	0.06	0.87[a]	0.06	0.90[b]	0.06	0.88	0.06

[a,b,c] For each row, different alphabets indicate significant difference between ethnic groups.

Figures 1 and 2 compare the percentiles of intakes of selected food components (%fat, % sfa, servings of fruit + vegetables and rice). Among the women, Chinese have lowest values for all percentiles of %fat and %sfa. For %fat, Malay and Indian women have similar values up to 50[th] percentile. At the higher percentiles, Indians have higher values, indicating that there are more Indian women in the higher range of intake compared to Malays. Both Indian and Malay women have similar values of %sfa for all percentiles. For men, Chinese have lowest values while Malays have highest for all percentiles of %fat and %sat. More Indian women tend to have higher intakes of fruit & vegetables and rice & alternatives when compared to Malay and Chinese women. Chinese men have lower intakes of fruit & vegetables and higher intakes of rice & alternatives throughout the range of intakes.

Table 2. Distribution of selected dietary intakes by gender and ethnic groups

	Chinese		Malays		Indians		All	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Females								
Energy (kcal)	1812[a]	606	1902[a]	641	2081[b]	710	1879	640
Total fat (g)	55.2[a]	24.5	60.5[b]	26.4	66.3[c]	28.9	58.2	26.0
% fat	26.8[a]	5.4	27.9[b]	5.4	28.2[c]	5.4	27.3	5.4
% sfa	10.1[a]	2.5	11.6[b]	2.9	11.5[b]	2.9	10.7	2.8
% mufa	9.3[a]	2.3	9.1[a]	2.3	8.0[b]	2.3	9.0	2.4
% pufa	5.6[a]	2.2	5.1[b]	2.2	6.2[c]	2.6	5.6	2.3
Protein (g)	63.5	23.2	61.4	22.4	63.0	21.1	63.0	22.7
Chol (mg)	222[a]	114	236[a]	122	197[b]	115	220	116
Chol(mg)/1000kcal	120[a]	42	121[a]	41	92[b]	38	116	43
Hegsted score	14.7[a]	7.7	15.6[a]	8.3	12.9[b]	7.8	14.6	7.9
Fruits (servings)	1.24	0.97	1.28	1.10	1.37	0.94	1.27	0.99
Vegetables (servings)	1.27[a]	0.79	1.22[a]	0.92	1.42[b]	0.65	1.29	0.79
Rice group (servings)	5.42[a]	1.88	5.48	2.27	5.84[b]	1.96	5.51	1.97
Males								
Energy (kcal)	2337	777	2340	799	2358	704	2341	769
Total fat (g)	70.2	31.2	73.5	34.7	72.2	28.3	71.3	31.5
% fat	26.5[a]	5.4	27.6[b]	6.4	27.2	5.4	26.8	5.6
% sfa	10.4[a]	2.5	11.8[b]	3.2	11.3[b]	3.0	10.9	2.8
% mufa	9.2[a]	2.3	9.0[a]	2.6	8.1[b]	2.2	9.0	2.4
% pufa	4.9[a]	1.7	4.4[b]	1.7	5.5[c]	2.2	4.9	2.3
Protein (g)	70.4	31.5	80.4	33.8	74.5	48.8	76.2	29.5
Chol (mg)	294[a]	148	295[a]	164	244[b]	141	285	151
Chol (mg)/1000kcal	124[a]	39	123[a]	43	103[b]	45	120	42
Hegsted score	19.5[a]	10.1	19.6[a]	11.1	16.2[b]	9.5	18.9	10.3
Fruits (servings)	1.32[a]	1.01	1.26	1.30	1.56[b]	1.09	1.35	1.09
Vegetables (servings)	1.36	0.86	1.30	0.81	1.41	1.05	1.36	0.90
Rice group (servings)	7.23	2.39	7.08	2.55	6.97	2.89	7.15	2.54

[a,b,c] For each row, different alphabets indicate significant difference between ethnic groups. ($p<0.01$, ANCOVA with age as covariate)

% fat	% energy as fat
% sfa	% energy as saturated fatty acids
% mufa	% energy as monounsaturated fatty acids
% pufa	% energy as polyunsaturated fatty acids
Chol	cholesterol

Table 3. Distribution of TC, LDL, HDL, TC/HDL, by gender and ethnic group

	Chinese		Malays		Indians		All	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Females								
TC (mmol/l)	5.4[a]	1.1	5.7[b]	1.1	5.3[a]	1.0	5.4	1.1
LDL (mmol/l)	3.3[a]	1.0	3.7[b]	1.1	3.5[b]	0.9	3.4	1.0
HDL (mmol/l)	1.7[a]	0.4	1.6[b]	0.3	1.4[b]	0.3	1.6	0.4
TC/HDL	3.3[a]	1.0	3.8[b]	1.1	4.0[b]	1.1	3.5	1.1
Males								
TC (mmol/l)	5.5[a]	1.0	5.9[b]	1.2	5.7	1.0	5.6	1.1
LDL (mmol/l)	3.5[a]	0.9	3.9[b]	1.1	3.8[b]	1.0	3.7	1.0
HDL (mmol/l)	1.4[a]	0.3	1.3[b]	0.3	1.2[b]	0.3	1.3	0.3
TC/HDL	4.2[a]	1.4	4.9[b]	1.6	4.9[b]	1.4	4.5	1.5

[a,b,c] For each row, different alphabets indicate significant difference between ethnic groups using analysis of covariance with age as covariate.

TC	Total serum cholesterol
LDL	Low density lipoprotein cholesterol
HDL	High density lipoprotein cholesterol
TC/HDL	Ratio of TC to LDL

Table 3 presents the levels of total serum cholesterol (TC), low density lipoprotein cholesterol (LDL), high density lipoprotein cholesterol (HDL) and ratio of TC to HDL (TCHDL) levels for the different groups. Chinese (men and women) have the lowest TC, LDL, and TCHDL levels while Malay men and women have the highest TC levels.

Relative risks (odds ratio) of having elevated TC (≥6.2mmol/l), LDL (≥ 4.1 mmol/l), TCHDL (≥4.4) or low HDL (<0.9 mmol/l)[13] was computed for quintiles of intake of energy, %fat, %sfa, %pufa, %mufa, cholesterol, rice, fruit and vegetables, with correction for age, BMI and WHR. There is no significant difference in relative risks for increasing quintiles of intake for all risk factors. When comparing the dietary intake, there is no significant difference in the intake of the above named dietary factors between subjects with elevated risks and those with normal levels of TC, LDL, HDL and TCHDL (tested using analysis of variance and correcting for age). There is also no difference in Hegsted score between those who elevated TC and those with normal TC.

In Table 4, the amount of variance (R^2) in serum cholesterol levels between ethnic groups that could be explained by the different variables are presented. It can be seen that the factors in Model 1, (age, BMI and WHR), account for most of the differences between ethnic groups, ranging from 22.5% (for TC) to 29.8% (for LDL) in women, and from 17.9% (TC) to 33.7%(TCHDL) in men. In Model 2, educational level, occupational status, activity level and smoking are entered into the regression analysis resulting in slight increases in R^2. The further addition of dietary factors to the other variables (Model 3) accounts for only small increases in R^2 of about 1% or less.

Table 4. Variance in blood lipid levels between ethnic groups (Chinese, Malays, Indians) accounted for by different parameters, by gender

	Model 1 variables[a] R squared*	Model 2 variables[b] R squared*	Model 3 variables[c] R sqaured*
Females			
TC (mmol/l)	0.225	0.226	0.228
LDL (mmol/l)	0.257	0.258	0.262
HDL (mmol/l)	0.244	0.244	0.240
TC/HDL	0.298	0.299	0.299
Males			
TC (mmol/l)	0.179	0.186	0.194
LDL (mmol/l)	0.227	0.233	0.238
HDL (mmol/l)	0.222	0.238	0.241
TC/HDL	0.337	0.356	0.360

TC Total serum cholesterol (log)
LDL Low density lipoprotein cholesterol (log)
HDL High density lipoprotein cholesterol (log)
TC/HDL Ratio of TC to LDL (log)
[a] Age; body mass index; waist-hip ratio
[b] Age; body mass index; waist-hip ratio; educational level; activity level; smoking status
[c] Age; body mass index; waist-hip ratio; educational level; activity level; smoking status; dietary intake of energy; percent energy as fat, percent energy as monounsaturated fatty acids, Hegsted score (log); servings of fruit (log), vegetables (log) and rice group (log).
R squared Amount of variance as explained by the respective groups of variables as they are entered as covariates in the analysis of covariance, when comparing levels of serum cholesterol between ethnic groups

Figure 1. Distribution of subjects by percentiles of fat and saturated fat intakes (percent of energy) by gender and ethnic group

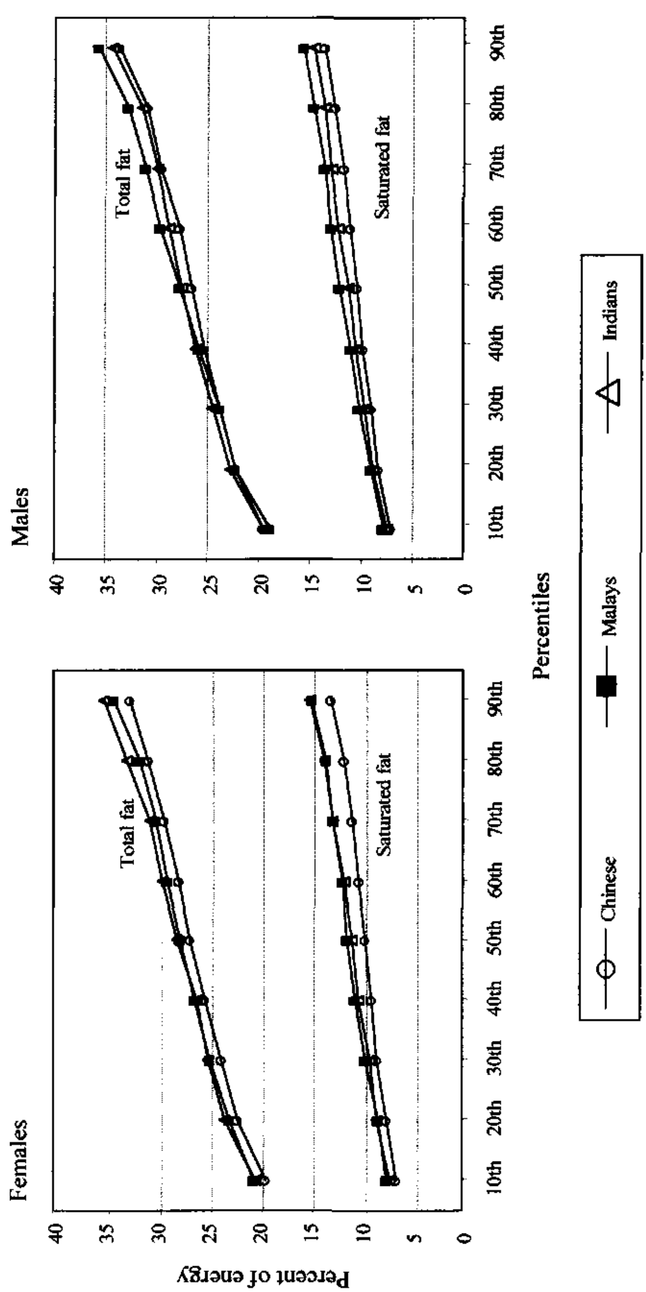
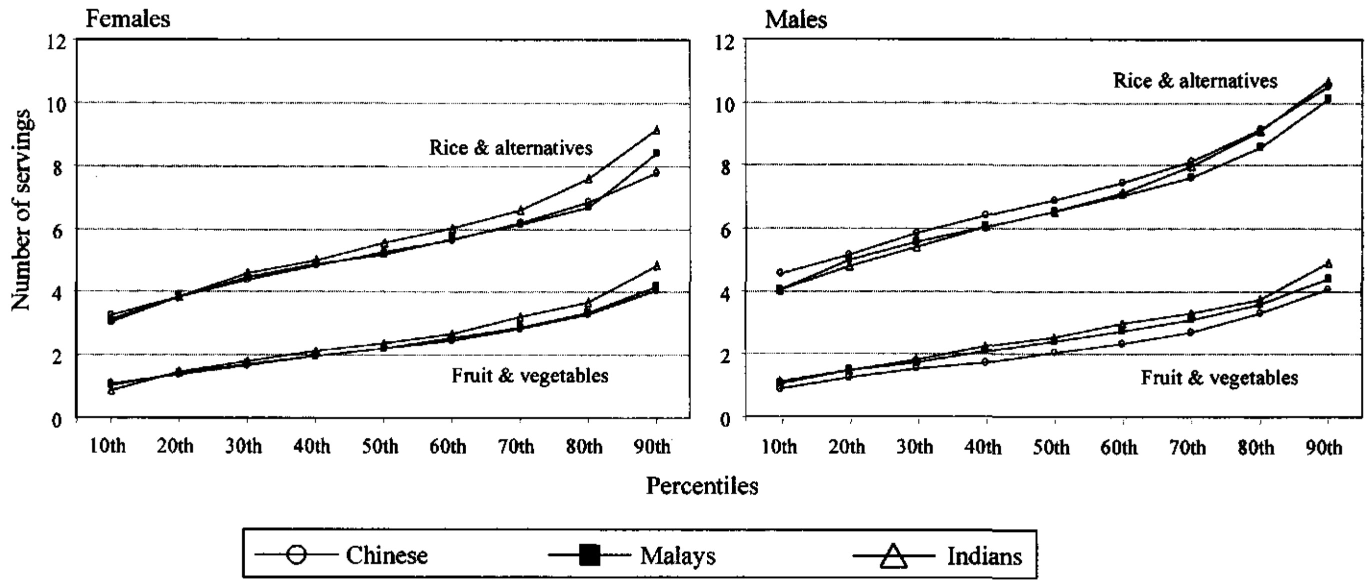


Figure 2. Distribution of subjects by percentiles of intakes of rice group and fruits & vegetables (servings per day) by gender and ethnic group



Discussion

In this study it was found that, generally the diet of Singaporeans is low in fruits and vegetables. The amount of servings of rice and alternatives fell within the 5 to 7 servings recommended[25], but in a previous report it was shown that only 0.11 servings of these were made of wholegrains[26]. The absolute intakes of total fat, saturated fat and cholesterol are lower than that for US, Finland, the Netherlands and Italy, but higher than Japan[33] . When expressed as percent of energy intake, the mean %fat intake was within the recommended limit of <30% of energy intake[14,15], but the %sfa was higher than the recommended limit of 10% of energy intake[14,15] for all gender-ethnic groups. Such a dietary profile (low in fruits, vegetables wholegrain and, high %sfa) has been found to correspond to a high risk for coronary heart disease on a population level[14, 18, 27].

Indeed, when correlating the mean intakes of these six gender-ethnic groups with their respective serum cholesterol levels, the correlations are consistent with reports from the literature regarding the effects of fat and types of fat on serum cholesterol levels. The unexpected adverse correlation between rice group and serum cholesterol levels could be because the type of grain based foods consumed in Singapore are mainly of the refined type (with wholegrains making up less than 0.11 serving per day of the average adult diet) and that rice and noodles, the staple food of Singaporeans, are often consumed prepared with high fat and high saturated fat ingredients[26]. Rice flavoured with high fat ingredients and fried noodles contribute to almost 14% of the total fat intake and 15% of total saturated fat intake of Singaporeans[26], making them the major contributors compared to other food groups.

However, on the individual level, as shown in the present study, the selected dietary factors could not account for the differences in serum cholesterol levels between the different ethnic groups when possible confounders were taken into account. The same dietary methodology was employed for all three ethnic groups and measured 'usual' consumption over the same reference period of one month. The food composition tables used comprise local foods analysed in the same laboratory in the three years prior to the conduct of the present study. Thus it is unlikely that inconsistent methodology or differences in food composition tables could have affected the results as was the case in some studies comparing population groups[27]. The food frequency questionnaire used to assess dietary intakes was found during the validation study to slightly overestimate intakes of total fat (by 3%) saturated fat (by 2%), monounsaturated fat (by 1%) when compared to the referent method. Intake of polyunsaturated fat was overestimated by 11% and that for cholesterol was underestimated by 17%[22]. Such variations are within the limits (between 1% and 55%) reported by other studies[28-32]. However, on a group level, the questionnaire was found to be adequate for classifying individuals into quintiles of intake for correlation purposes[22].

The results from this study show that on a group level, %fat, %sfa, Hegsted score and intakes of vegetables and rice group are correlated with serum cholesterol levels. However, at the individual level, these dietary factors do not explain the differences in serum cholesterol levels between the ethnic groups. This does not imply that these factors are not important determinants of coronary heart disease risks. One of the reasons that dietary factors could not explain the difference in serum cholesterol among ethnic groups may be the fairly homogenous intakes of the selected nutrients and food types between individuals. While the mean differences for the intakes are found to be statistically different between some groups, the actual differences are small and the large sample sizes could have contributed to the statistical significance. The distribution of intakes as seen in Figures 1 and 2 show that there are only slight differences throughout the range of intakes. Another reason is that determinants of disease at the individual level are not necessarily the same as those in the population level[33]. Correlations between factors and disease (risks) found at cross country studies could be confounded by a multitude of other factors, including genetic, cultural, environmental and lifestyle factors. Another consideration that has to be taken into account is the composition of saturated fat in the diet and the presence of other modulating or potentiating factors. For example, not all saturated fats are equally cholesterolaemic and the saturated fat effect is related to the dietary cholesterol load and lipoprotein metabolism (or lipoprotein setpoint) of the individual[27,33,35]. More recent literature also suggests that high intakes of fruits and vegetables can modulate the effects of dietary fat [36].

Certainly, a major drawback of the present study is the cross sectional nature. As it is the first of such studies done on a national scale in Singapore, it forms the baseline from which a prospective study can be carried out as part of the national health survey which is conducted once every five years. Such a prospective study can then study the influences of changes in dietary and other lifestyle factors on disease risks and provide better evidence on how these could be addressed to lower the individual and population risks.

In summary, the current study shows that on a population basis, dietary factors (total fat, saturated fat, Hegsted score, fruits, vegetables, rice group) are correlated to serum cholesterol levels. However during individual-based analysis, the relative risks for having elevated TC, LDL, TCHDL and low HDL are not found to be increased with the quintiles of intakes of these dietary factors, and the intakes were not different between those with normal serum cholesterol levels and those with abnormal levels. Dietary factors are not responsible for the differences in serum cholesterol levels among three ethnic groups in Singapore. In view of the shortcomings of a cross sectional study, a prospective study is recommended to further investigate the relationship between changes in diet (and other lifestyle risk factors) and coronary risks among the different ethnic groups.

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9

General Discussion

This thesis presents the principal findings of a study on body composition, diet and cardiovascular risk factors among three ethnic groups in Singapore. The study was conducted as part of the National Health Survey in 1998 (NHS 98), a national cross-sectional survey conducted to determine the prevalence of selected diseases and their associated risk factors. From the main sample of the NHS 98, sub-samples were selected to participate in the dietary and body composition components of the present study. The objectives of the study are presented in Chapter 1.

Background information

In Singapore, a Review Committee on National Health Policies recommended in 1991 the adoption of a health promotion and disease prevention approach to combat the rising prevalence of lifestyle related diseases in Singapore[1]. The recommendation subsequently led to the launch of the National Healthy Lifestyle Programme in 1992, to promote healthy lifestyles among Singaporeans, and to provide a conducive and supportive environment for the practice of such lifestyles. The first National Health Survey in Singapore was conducted in the same year to study the prevalence of certain lifestyle-related diseases and disease risk factors among Singaporeans[2]. It was to form the baseline from which subsequent national studies would be conducted to monitor changes in risk factors. Findings from these studies would help formulate health policies and strategies for health promotion and disease prevention to reduce morbidity and mortality in Singapore.

In 1998, the second National Health Survey was conducted and it was within this framework that the present study was carried out.

Main findings

Body composition

One of the main aims in this study was to determine if the body mass index (BMI) cut-off values for overweight and obesity as recommended by WHO are valid for the different ethnic groups in Singapore. The approach taken was to evaluate the two criteria in the WHO's definition of obesity which states that obesity is a condition with excessive fat accumulation in the body to the extent that health and well being are adversely affected [3]. The study first established the relationship between BMI and body fat percentage and then determined the risk for selected co-morbidities at various BMI categories.

BMI and body fat percentage

Body fat percentage (BF%) was measured by a four-compartment model described by Baumgartner et al [4], and the relationship between BF% and BMI examined in 291 subjects. It was found that, when a BF% prediction equation based on BMI developed in Caucasian populations was applied to the three ethnic groups in Singapore, there was a gross underestimation of actual BF% measured by the reference method. The bias in prediction ranged from 2.7% to 5.6% body fat. This indicates that the BMI-BF% relationships in Chinese, Malays and Indians are different from that of Caucasian populations. This relationship is described as:

$$BF\% = 1.04*BMI - 10.9*sex + 0.1*age + 2.0E_1 + 1.5E_2 + 5.7$$

where the E_1 and E_2 are dummy variables. For Chinese, $E_1=0$, $E_2=1$, for Malays $E_1=1$, $E_2=0$, and for Indians $E_1=1$, $E_2=1$. Sex is coded as 0 for females and 1 for males. Thus for the same BMI values, Chinese have the lowest BF% while Indians have the highest. This equation explains 74 percent of the variation in BF% when the independent factors are controlled for, and has a standard error of estimate of 4.4 percent body fat, which is comparable to BMI-based prediction formulas in current literature[5,6]. One possible explanation for these differences in the BMI-BF% relationship is the differences in body build (slenderness and relative leg length) between ethnic groups, as was also found in earlier studies[7,8,9]. For the same BF% as obese Caucasians with a BMI of 30 kg/m^2, the BMI of Chinese and Malays should be around 27 kg/m^2 while that for Indians should be around 26 kg/m^2. The value for Malays is similar to those found in studies done among Indonesians in Indonesia[5]. A nomogram for the calculation of BMI and body fat percentage from weight, height, age, sex and ethnicity is presented at Annex 1.

BMI and cardiovascular risk factors

The data from the 1992 National Health Survey were explored for possible relationships between selected cardiovascular risk factors and quintiles of body mass index (BMI) and waist-to-hip ratio (WHR). Due to the small numbers of other ethnic groups in that survey, only data for Chinese subjects (n=2319) were used. What was found was that at low levels of BMI and WHR in Chinese, there was an apparent elevated relative risk for at least one of the cardiovascular risk factors, viz., hypertension, hypercholesterolaemia, hypertriglyceridaemia and diabetes mellitus, after correction for age-effects and smoking status (Table 4 of **Chapter 2**).

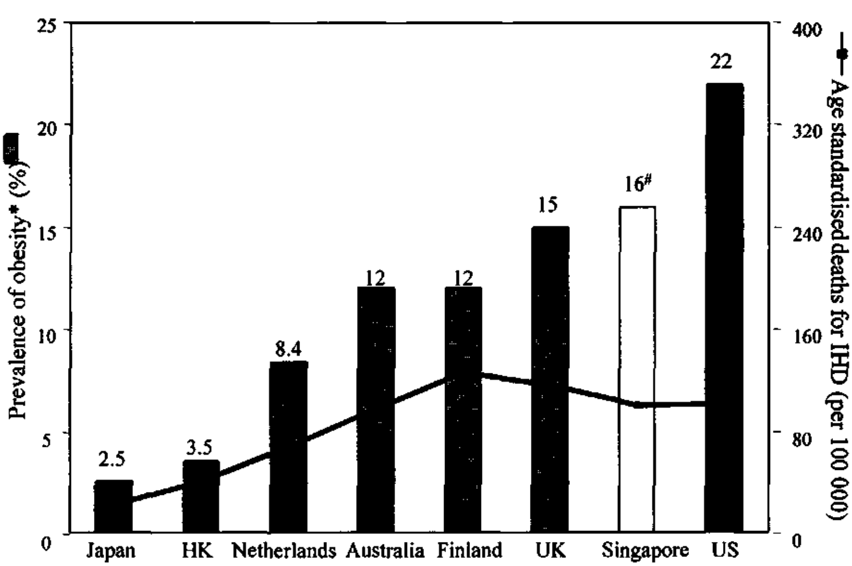
In order to investigate if the findings also apply to all major ethnic groups in Singapore, a total of 4723 subjects from the 1998 National Health Survey were studied for the relationship between selected cardiovascular risk factors and BMI. Other indices studied were those of abdominal fatness, viz., waist circumference and waist-to-hip ratio (WHR). The absolute and relative risks for at least one cardiovascular risk factors, viz., elevated total blood cholesterol, elevated total cholesterol to HDL cholesterol ratio, elevated triglycerides, hypertension and diabetes mellitus were determined for various categories of BMI, WHR and waist circumference, with correction for age, cigarette smoking, physical activity level, educational level and occupation.

For all the ethnic groups, it was found that at low categories of BMI (between 22 and 24 kg/m^2), WHR (between 0.80 and 0.85 for women, and between 0.90 and 0.95 for men) and waist (between 75 and 80 cm for women and between 80 and 85 cm for men), the absolute risks are high, ranging from 41% to 81% (Figures 1 to 3 in **Chapter 6**). At these same categories the relative risks are significantly higher compared to the reference category, ranging from odds ratio of 1.97 to 4.38 (Tables 4a-c in **Chapter 6**). These categories of BMI, WHR and waist are all far below the cut-off values of BMI, WHR and waist as recommended by WHO[3].

The markedly increase in absolute and relative risks with increasing categories of obesity indices is consistent with the high mortality from ischaemic heart disease experienced by Singaporeans. The discrepancy between the high cardiovascular mortality and apparently low national obesity prevalence (defined as BMI $\geq$ 30kg/m^2) could be partially explained by the presence of excessive BF% among Singaporeans at low levels of BMI when compared to Caucasians. Based on percentage body fat and presence of risk factors, the currently recommended BMI cut off values for overweight (≥25 kg/m^2) and obesity (≥30 kg/m^2) are likely to be not relevant for Singaporeans. A BMI of ≥23 kg/m^2 and ≥27 kg/m^2 as the cut off values for overweight and obesity would be more consistent with the current findings. At these levels, 59% of those who are overweight and 78% of those who are obese would have already at least one risk factor. The relative risk (RR) of having at least one risk factor would be moderately increased for overweight men and women (RR between 2 and 3) and greatly increased for obese men and women (RR > 3). The consequence of lowering BMI cut-off values for overweight and obesity would be that the prevalence of overweight among Singaporeans would increase from 24% to 32% and obesity rates would be more than doubled, from 6 to 16%.

Such an 'increase' in prevalence figures would have serious implications in terms of public health policy. If Figure 3 in **Chapter 1** were to be redrawn as the following Figure 1, using the cut-off points for obesity as 27 kg/m^2, it could be seen that the prevalence of obesity would then be consistent with countries with comparable levels of deaths from ischaemic heart disease.

Figure 1. Comparison of obesity prevalence (%) and age-standardised death rates from ischaemic heart diseases in selected countries



HK: Hong Kong, UK: United Kingdom, US: United States of America
*BMI ≥ 30 kg/m^2
BMI ≥ 27 kg/m^2

Dietary Intakes

Validation of a food frequency questionnaire

For this study, one of the objectives was to develop a suitable tool for classifying individuals into quintiles of intakes of energy, total fat, types of fat and cholesterol for purposes of epidemiological studies. The tool deemed to be suitable for such a purpose is the food frequency questionnaire [10,11,12]. It was decided to develop a food frequency questionnaire rather than adopt one developed in other populations for various reasons. One main reason was the wide variety of foods that are unique to Singapore and thus questionnaires developed in other populations are not suitable for local use. Another reason was that a computerised food composition database has been recently established in Singapore comprising analysed nutrient data for a large number of local foods and ingredients, making such a validation study possible.

The food list for the proposed questionnaire was developed using a data-based approach such that foods that are commonly consumed by all ethnic groups and are important contributors of the nutrients/foods being studied would be included[10]. In addition, these food items had also to account for variation in intakes of the nutrients concerned[13]. Special emphasis was placed on methods of preparation in order to capture adequate information on fat content.

The questionnaire was then validated against multiple 24-hour recalls. Additional urinary marker was used to verify the multiple 24-hour recalls, as recommended by Bingham[14] and Kaaks[15] to make it more likely that criteria of independent errors are met. The urinary marker that was chosen was multiple 24-hour urinary urea excretion (for estimation of nitrogen intake) and completeness of collection was counter checked using 24-hour urinary creatinine excretion. In addition, special emphasis was placed to ensure that intakes of food groups, viz., fruits, vegetables and rice & alternatives (comprising rice, cereals, breads and noodles) were captured during the dietary interview.

It was found that the food frequency questionnaire was able to classify 70% of subjects into same or adjacent quintiles of intakes (energy, protein, fat, saturated fat, polyunsaturated fat, monounsaturated fat, cholesterol) when cross classified with the quintiles obtained from multiple 24-hour recalls. There was over-reporting of intakes of energy (by 4%), total fat (by

3%), saturated fat (by 2%), polyunsaturated fat (by 11%) and monounsaturated fat (by 1%) and under-reporting of intakes of cholesterol (17%) by the food frequency questionnaire when compared to the reference method.. The deviation of intake data obtained by the food frequency questionnaire as compared to the reference method, and the correlation coefficients between intakes obtained from both methods (Table 1 of **Chapter 7**) were within the limits reported in studies conducted among various ethnic groups [12,16,17,18,19,20].

Diet and cardiovascular risk factors

The validated food frequency questionnaire was used to assess usual intakes of energy, total fat, types of fats, cholesterol, fruits, vegetables and rice & alternatives (over a period of one month) among the different ethnic groups in Singapore (n=2408). The intakes of fat, saturated fat, polyunsaturated fat and monounsaturated fat were also expressed as percent of total energy intake (%fat, %sfa, %pufa, %mufa respectively) and cholesterol intake as cholesterol (mg) per 1000 kcal of energy. Hegsted score (2.16*%sfa – 1.65*%pufa +0.0677*cholesterol – 0.53) was computed to assess the cholesterolaemic effect of the diet. What was striking about the findings was the rather homogenous intakes of the food types and nutrients among the three ethnic groups.

Generally, it was found that the diet of Singaporeans is low in fruits and vegetables and whole grain products. The fat intake (at about 27% of total energy intake for both males and females) is within the recommended upper limit (30% of total energy), but the intake of saturated fat is higher than the recommended 10% of total energy with corresponding lower intakes of polyunsaturated fat and monounsaturated fat. Such a 'high-risk' dietary profile has been found to correspond to risk for coronary heart disease on a population level [21,22].

On a group level, the mean intakes of each gender-ethnic group were highly correlated with mean serum cholesterol. Total serum cholesterol was found to be positively correlated with Hegsted score (r=0.77) and intake of rice & alternatives (r=0.60) and negatively correlated with vegetables (r=-0.82). The total cholesterol to HDL cholesterol ratio was found to be positively correlated with Hegsted score (r=0.67), rice & alternatives (r=0.70) and fat intake (r=0.60). HDL cholesterol level was negatively correlated with fat intake (r=-0.70) and rice & alternatives (r=-0.63). Such findings are consistent with the effects of fat intake, in particular saturated fat intake with serum cholesterol levels. The adverse effect of rice & alternatives on serum cholesterol levels could be partly due to the low proportion of whole grain products consumed and also to the method of preparation. Both rice and noodles, the staple foods of Singaporeans, are often prepared with high fat and /or saturated fat ingredients which are the main sources of fat and saturated fat, contributing to 14% of total fat intake and 15% of total saturated fat intake to the diet of adult Singaporeans[23].

However, on the individual level, these dietary factors did not explain the differences in serum cholesterol levels between the ethnic groups. Dietary factors could account only for less than 1% of the differences in total serum cholesterol, HDL-cholesterol, LDL-cholesterol and total cholesterol to HDL cholesterol ratio after the effects of age, BMI, WHR, activity levels, cigarette smoking and occupation were taken into account.

Discussion

Cardiovascular risk factors

A number of cardiovascular risk factors are monitored by the National Health Survey, done once every five years. These include blood pressure and other blood parameters such as blood lipids (total cholesterol, HDL-cholesterol, LDL-cholesterol, triglycerides), fasting and post-prandial insulin and glucose besides anthropometric assessment. Other lifestyle risk factors including socio-economic status, cigarette smoking, alcohol consumption, physical activity levels were obtained through interviews.

All biochemical parameters were performed in the reference laboratory in Singapore, which is internationally accredited, and using standardised protocols. Physical measurements were done according to published protocols from WHO[24,25].

All survey field workers were briefed extensively on the survey methodology and underwent rigorous training in the survey procedures assigned to them. A one-day trial of the survey was conducted to hone the field worker's skills and familiarise them with the survey procedure.

The above procedures were strictly adhered to as it was important that the quality of the data collected is ensured, both for the monitoring of national trends and also for international comparisons.

Body composition

To accurately measure the body fat percentage in the study population, it was necessary to select a methodology that is free of assumptions and is regarded as a 'gold' standard[26]. For this, the model described by Baumgartner et al is used. In this model the body is divided into fat mass, minerals, water and a fourth compartment comprising protein and glycogen. Each of the latter three components was determined individually using dual energy X ray absorptiometry, deuterium oxide dilution and densitometry respectively. The difference between total body weight and these three components yielded the actual fat mass of the individual.

Commonly used methodologies to measure body fat percentage are indirect methods using a two-compartment model that either assume a constant density of fat-free mass (such as densitometry) and/or constant hydration fraction of the fat-free mass (such as hydrometry and dual energy X ray absorptiometry). Body fat percentage would then be calculated based on the difference between body weight and fat-free mass derived from these methods. Such assumptions have been found to be not valid among different age-, ethnic-, gender groups and also at different levels of body fatness over the past few years [27,30,31]. The application of such methodologies without foreknowledge of the validity of the assumptions can easily lead to biased conclusions.

For this study, the validity of the various two-compartment models were studied in the three ethnic groups, and it was found that due to the high individual bias (resulting from individual variation in the composition of fat-free mass), hydrometry, densitometry and dual energy X ray absorptiometry were all found to be inadequate to measure body fat of individuals. On a group level, the violation of assumptions has also led to systematic underestimation of body fat percentage by densitometry and dual energy X ray absorptiometry. Hydrometry has the lowest mean bias and error of the three methodologies and was found to be suitable for use on a group level.

The different relationship between BMI and BF% in the different ethnic groups as compared to Caucasians was also found in some recent studies and summarised in **Chapter 3**. For the same level of BF%, age and sex as Caucasians, it was found that the BMI of American Blacks and Polynesians were 1.3 kg/m^2 and 4.5 kg/m^2 higher, while that for Chinese, Ethiopians, Indonesians and Thais were 1.9 kg/m^2, 4.6 kg/m^2, 3.2 kg/m^2 and 2.9 kg/m^2 lower respectively. Even within the same 'ethnic' group as in Caucasians, slight differences were detected between American and European Caucasians, with Europeans having a higher BF% than Americans at the same BMI, after correction for age and sex. In practical terms, it would mean that for Polynesians, BMI cut-off point for obesity should be 34.5 kg/m^2 while that for Indonesians should be 26.8 kg/m^2. Unfortunately, data from these studies could not be conclusive as the different reference methods used to measure BF% in the different ethnic groups could have partly contributed to the differences in BMI-BF% relationship between groups. Another limitation was the small sample sizes in some of these studies, particularly those for Asian populations. Inadequate parameters also did not allow for possible explanations of the differences observed in BMI-BF% relationship.

The present study has overcome the problems of the fore-mentioned studies by using an accepted reference method for all ethnic groups studied. Power calculation has also ensured adequate numbers in each subgroup for the purposes of comparison between groups. The additional anthropometric measurements have shown that body build (slenderness and leg lengths) could partially explain differences in relationship between groups. Thus the evidence that BMI cut-off points should be lowered is strong and non-ambiguous. This is further supported by the study showing markedly elevated absolute and relative risks for cardiovascular risk factors at BMI levels that are much lower than those currently recommended by WHO for obesity.

Dietary Intakes

The food frequency questionnaire was chosen as the dietary tool to be used in this study as the intention was to be able to classify subjects into quintiles of intakes for energy, fat, types of fat and cholesterol for epidemiological studies. In addition, it was to be able to quantify intakes of fruits, vegetables and grain foods. After the validation study, it was found to be able to serve the above purposes adequately for the three ethnic groups.

As for other cross-cultural studies involving diet and cardiovascular risks (and mortality), such as the Seven Countries Study[28] and the MONICA (Monitoring of cardiovascular risk factors) project [29], the high group mean intakes of fat, saturated fat, polyunsaturated fat, cholesterol and low intake of vegetables were found to be adversely correlated to serum cholesterol. On the other hand, at the individual level, dietary intakes as measured by the food frequency questionnaire could not explain the differences in serum cholesterol levels between the ethnic groups after adjustment for other possible confounders. However, this does not imply that these factors are not important determinants of coronary heart disease risks. One of the reasons that dietary factors could not explain the difference in serum cholesterol among ethnic groups may be the fairly homogenous intakes of the selected nutrients and food types between individuals [32]. There are only slight differences throughout the range of intakes (Figures 1 and 2 of **Chapter 8**). Another reason is that determinants of disease at the individual level are not necessarily the same as those in the population level [33]. Correlations between factors and disease (risks) found at cross-country studies could be confounded by a multitude of other factors, including genetic, cultural, environmental and lifestyle factors [34]. Another consideration that has to be taken into account is the composition of saturated fat in the diet and the presence of other modulating or potentiating factors. It is now known that not all saturated fats are equally cholesterolaemic and the saturated fat effect is related to the dietary cholesterol load and lipoprotein metabolism (or lipoprotein setpoint) of the individual [22, 35, 36]. More recent literature also suggests that high intakes of fruits and vegetables can modulate the effects of dietary fat[37] and international comparative studies suggest that consumption of fruit, vegetables and whole grains is inversely correlated to mortality from heart disease, possibly by mediating their effects dietary fibre and a combination of other non-nutrients such as phyto-estrogens (e.g. lignans) and antioxidants (e.g. vitamin E) [38,39]. Thus the actual quantification of the role of a single nutrient or food component in serum cholesterol requires the in-depth study of interactions between nutrients and food components.

Admittedly, the food frequency questionnaire is not meant for the detection of individual intakes, and as such could be one of the reasons why dietary factors was only shown to contribute to only 1% of the differences in serum cholesterol levels among the three ethnic groups. A more robust method to measure actual individual intakes would be the dietary history method or the multiple food intake recall or record methods, preferably covering different seasons in a year [40]. The main purpose of the food frequency questionnaire, besides being able to classify subjects into levels of intakes for correlation with risk factors, was to be a dietary tool for the monitoring of trends of intakes of various food types, fat, types of fats and cholesterol on a group level and how this change contribute to changes in risk factors. For example, the cholesterolaemic effect of dietary intakes could be estimated using a suitable score such as Hegsted score. By monitoring the main food sources of fat, types of fat and cholesterol, it would enable the formulation of more specific nutrition education messages for the different population groups.

One major drawback of the present dietary study is the cross sectional nature. As it is the first of such studies done on a national scale in Singapore, it forms the baseline from which a prospective study can be carried out as part of the national health survey, which is conducted once every five years. Such a prospective study can then investigate the influences of changes in dietary and other lifestyle factors on disease risks and provide better evidence on how these could be addressed to lower the individual and population risks.

Implications of findings and recommendations

This study has discovered several significant new findings, particularly in the areas of the relationship between BMI (as an index of obesity) and body fat percentage and also cardiovascular risk factors. It has also uncovered questions that need to be further investigated for the comprehension of the role of prevention and/or lowering of risk factors in reducing mortality from coronary heart disease on a population basis.

Lowering of BMI cut-off values for obesity

The study on body composition was undertaken for the first time on a large scale in Singapore and also the region using a referent four-compartment model. The evidence is clear that WHO's cut-off value for obesity is not valid for Singaporeans. Singaporeans have higher level of body fat percent compared to Caucasians at the same level of BMI, (after correction for age and sex) and based on body fat percent, the cut-off value for obesity should be about 27 kg/m^2 instead of 30 kg/m^2. This was supported by the markedly elevated absolute and relative risks of having cardiovascular risk factors at low levels of BMI. The risks are also apparent at levels of WHR and waist circumferences that are below the WHO's recommended cut off values. Unfortunately, it was not within the confines of this study to also study the relationship between waist circumference and abdominal fatness and thus the recommendations for WHR and waist circumference could only be supported by manifestations of risk factors and not levels of abdominal fat.

Recently, scientists from China, India, Japan, Korea, Malaysia and Indonesia concurred, based on findings that risk factors are apparent at low levels of BMI, WHO's cut-off values for obesity are not valid for their respective populations. These preliminary findings were presented at the Asian Workshop on BMI/Obesity held in Milan in 1999. The data from the current study, which includes evidence that not only risk factors, but also body fat percent are elevated at low BMI values, presents a strong case for the lowering of BMI cut-off value for obesity among Asian populations. The actual level that this should be lowered to would depend on the scientific findings of each country, based on the two criteria for the definition of obesity. If BMI cut-off value for obesity is to be lowered, it would have tremendous implications in terms of public health policy for the prevention and management of obesity and its co-morbidities. In Singapore, the overall prevalence of obesity would more than doubled, from the current 6% (based on BMI of 30 kg/m^2) to 16.4% (based on BMI of 27 kg/m^2). Using these cut-off values for screening would enable the detection of high-risk groups for further investigations and intervention where necessary.

Establishment of population-specific standards

The inappropriate BMI cut-off value for obesity is but one evidence that Asians are different from Caucasians. Even within the broad classification of Asians, differences exist between different ethnic groups and this could be seen among the three main ethnic groups living in the same geographical region. This study has also raised the possibility of inappropriate cut-off values for WHR and waist circumference based on the presence of risk factors. The Seven Countries Study has shown also differences in absolute mortality risks for the same level of serum cholesterol. At serum cholesterol of 5.2 mmol/l, the 25-year coronary heart disease mortality rate was five times higher in Northern Europe compared with Mediterranean Southern Europe and Japan [41,42]. The relative increase in mortality due to a given cholesterol increase was similar in all cultures except Japan[41,42]. Such a situation could certainly apply also to other parameters whereby cut-off values for normality are adopted from studies conducted mainly in ethnically different population groups.

Thus it is important, that whenever possible, population-specific standards based on well-standardised validation studies be established. Examples of such studies could include for example the determination of level of abdominal fat at different waist measurements, the relationship between serum cholesterol levels and mortality from ischaemic heart disease.

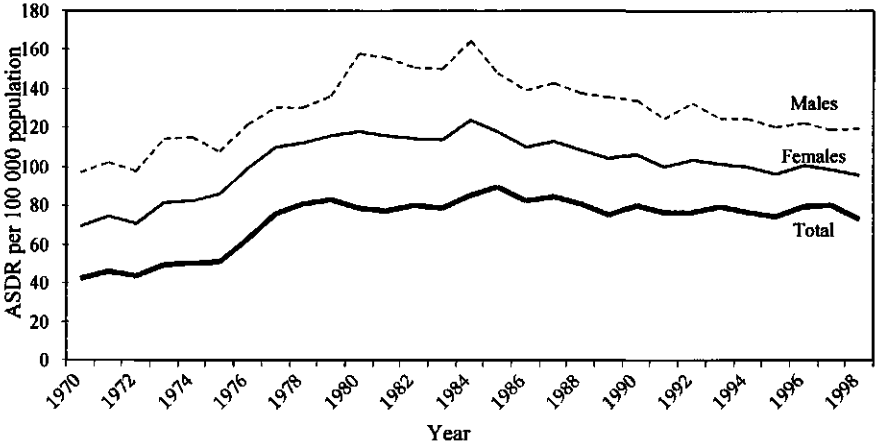
Need for longitudinal studies

The mortality from coronary heart disease has declined in many developed countries such as in the United States, Canada, Australia, Netherlands and Finland [41,43,44,45,46,47,48], but on the rise in some developing countries [43]. A large part of the decline in the mortality is a result of reduction in risk factors, such as serum cholesterol, hypertension and smoking and about half is due to improvements in medical treatment [29,48]. In many longitudinal and cross-country studies, certain dietary factors have been shown to be related to lower serum cholesterol and mortality from coronary heart disease [22,29,41,42,49,50]. Dietary factors that contributed to this included lower intakes of saturated fat and cholesterol intake, higher intakes of polyunsaturated fat, fruits and vegetables. The beneficial effect of replacing saturated fats with other fats and lowering cholesterol intakes was also found in various metabolic ward studies [51,52].

In Singapore, the trends of mortality from ischaemic heart disease are shown at Figure 2. A decline was seen in the mid-1980s, largely due to improvement in medical treatment of coronary heart disease.

The current study could not find the association between dietary factors and serum cholesterol levels, mainly due to insufficient inter-person variation and its cross sectional nature. The latter limitation also applies to other risk factors like obesity, abdominal fatness, smoking, hypertension and physical activity patterns.

Figure 2. Age-standardised death rates from ischaemic heart disease, 1970-1988 (per 100 000 population)



Source: Registry of Births and Deaths, Singapore

The mortality rates from ischaemic heart disease reached a plateau after 1990 and are beginning to show some decline in 1997 and 1998. This further decline could be due to concerted national efforts directed at public education regarding healthy lifestyles (smoking, diet and exercise). To be able to quantify the benefits of dietary and other lifestyle changes on lowering serum cholesterol and thereby the mortality from coronary heart disease, longitudinal studies will be necessary. The present study and the two well-standardised National Health Surveys have established the baseline for most of the parameters and risk factors for future follow up. This, in combination with the high quality mortality statistics would enable Singapore to estimate the role of changes in risk factors and mortality from coronary heart disease and enable the effective implementation and evaluation of the ongoing Healthy Lifestyle Programme to lower risk factors among Singaporeans.

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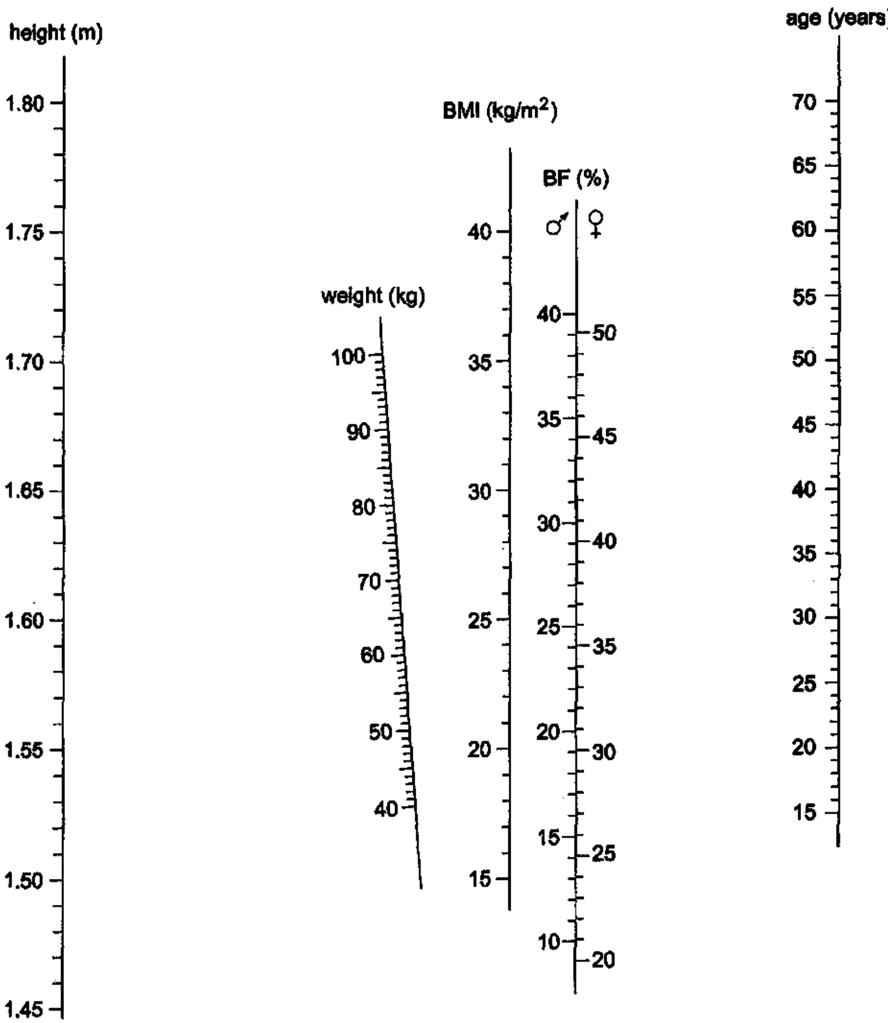
Annex 1

NOMOGRAM FOR ADULT CHINESE, MALAYS AND INDIANS IN SINGAPORE



Note: Add 1.7% body fat to readings for Indians
Nomogram is not suitable for very active and muscular persons

Summary

In Singapore, the rapid economic development and advancement in health care over the last four decades has resulted in improved health status of its citizens. Concomitantly, mortality patterns have changed, moving from those of infectious origins and poor environmental conditions to the chronic degenerative diseases such as cancers and cardiovascular diseases. This change could be partly attributed to change in lifestyle habits such as dietary intakes, physical activity patterns and smoking habits.

Mortality from cardiovascular diseases (mainly ischaemic heart disease) among Singaporeans is high, accounting for about 25% of total deaths annually. On the other hand, the prevalence of obesity, which is a major determinant of cardiovascular risk factor, is rather low at about 5% (using BMI cut-off value of 30 kg/m^2 or more) compared to other developed countries. It is also known, that among the three major ethnic groups in Singapore (Chinese, Malays and Indians), the prevalence of cardiovascular risk factors and mortality differ. These differences could be due to differences in genetic factors and/or lifestyle factors among the three ethnic groups.

This thesis presents the findings of studies on body composition and dietary intakes among the three ethnic groups in Singapore and the possible influences these could have on cardiovascular risk among these groups.

Body composition

Obesity is an independent risk factor for cardiovascular diseases. It also mediates its effects by elevating other cardiovascular risk factors. The body mass index (BMI, kg/m^2) has been used as a surrogate measure of obesity, and the World Health Organisation (WHO) has defined the BMI cut-off point for obesity as 30kg/m^2 or more, based on morbidity and mortality studies performed on Caucasian populations. However, recent studies among some groups such as Polynesians, Indonesians, Ethiopians, Blacks and Chinese have shown a universal BMI cut-off point for obesity may not be appropriate. To investigate if the WHO cut-off point was valid for the different ethnic groups in Singapore, a four-compartment model (comprising body fat, total body mineral, total body water and a fourth compartment,

protein and glycogen), as described by Baumgartner was used in this study to measure body fat in 291 subjects. This model circumvents the need to assume constant density of fat-free mass and constant fraction of water in fat-free mass, in contrast to most two-compartment models (densitometry, hydrometry and dual energy X-ray absorptiometry), and is commonly regarded as a reference method for measurement of body fat. When the relationship between BMI and body fat percentage (BF%) was examined, it was found that Chinese, Malays and Indians have higher BF% at the same BMI levels as Caucasians. At levels of BF% corresponding to obesity (BMI ≥ 30 kg/m^2) in Caucasians, the BMI cut-off point for obesity for Chinese and Malays was found to be about 27 kg/m^2 while that for Indians was about 26 kg/m^2.

The relationship between various indices of obesity and abdominal fatness (BMI, waist, waist-to-hip ratio) and cardiovascular risk factors (hypertension, hypercholesterolaemia, hypertriglyceridaemia and diabetes mellitus) was then examined among the 4723 subjects of the 1998 National Health Study. It was found that at low levels of BMI (between 22 and 24 kg/m^2), waist circumference (between 75 and 80 cm for women and between 80 and 85 cm for men) and waist-to-hip ratio (between 0.80 and 0.85 for women and between 0.90 and 0.95 for men) the absolute and relative risks of having at least one cardiovascular risk factors was markedly elevated. These findings strengthened the case for the lowering of WHO recommended cut-off points for obesity and abdominal fatness as these are likely to be inappropriate for Singaporeans. Studies done in other Asian countries such as China, India, Japan, Korea, Indonesia and Malaysia (presented at an Asian BMI/obesity Workshop in Milan in June 1999) concurred with the findings of this study.

Diet

A food frequency questionnaire (FFQ) was validated against multiple 24-hour dietary recalls and an additional urinary marker. Particular attention was also given to ensure that the food list included foods consumed by all ethnic groups and that main and sub-types of fruits, vegetables and grain foods (including rice, noodles, bread, cereals) were covered. Details of cooking methods and cooking oil/fats used were obtained to better quantify the intake of fat and types of fat by the different ethnic groups. This food frequency questionnaire was found to be adequate for the detection of group intakes and for the classification of subjects into quintiles of intakes for fat, types of fat and cholesterol for purposes of epidemiological studies.

Dietary intakes and serum cholesterol levels were studied in 2408 subjects (systematically selected from the 1998 National Health Survey). The nutrients studied were energy, total fat, types of fat and cholesterol and the food types were fruits, vegetables and grain foods. The intakes of fat, saturated fat, polyunsaturated fat and monounsaturated fat were expressed as percentage of total energy intake (%fat, %sfa, %pufa, %mufa respectively) while cholesterol was expressed as intake per 1000 kcal. Hegsted score (2.16*%sfa – 1.65*%pufa +0.0677*cholesterol – 0.53) was computed to assess the cholesterolaemic effect of the diet.

On a group level (six ethnic-gender groups), it was found that, Hegsted score, %fat and grain foods were positively correlated while vegetables is negatively correlated with serum cholesterol levels. However, on an individual level, the differences in dietary intakes could not explain differences in levels of serum cholesterol among groups after age, BMI, waist-hip-ratio and other lifestyle factors (smoking, physical activity, occupation, educational level) were taken into account. This is most probably due to the fairly homogenous intake of the studied nutrients by all groups and the cross sectional nature of the study. Correlations between factors and disease (risks) found at cross country studies could be confounded by a multitude of other factors, including genetic, cultural, environmental and lifestyle factors. Recent studies have also shown that different saturated fats have different cholesterolaemic effects and these could be further confounded by presence of modulating or potentiating factors. Some examples of these potentiating factors are dietary cholesterol load and lipoprotein metabolism (or lipoprotein setpoint) of the individual while high intakes of fruits and vegetables can modulate the effects of dietary fat.

Implications and recommendations

This study has found several significant new findings, particularly in the areas of the relationship between BMI (as an index of obesity) and body fat percent and also cardiovascular risk factors. It has also uncovered questions that need to be further investigated for the comprehension of the role of prevention and/or lowering of risk factors in reducing mortality from coronary heart disease on a population basis.

The evidence is strong for the lowering of BMI cut-off values for overweight and obesity, based on the presence of excessive body fat and markedly elevated absolute and relative risks for cardiovascular risk factors. However, the implications for this change would be rather tremendous in terms of public health policy for the prevention and management of obesity and its co-morbidities. In Singapore, the overall prevalence of obesity would more than doubled, from the current 6% (based on BMI of 30 kg/m^2) to 16.4% (based on BMI of 27 kg/m^2). Using these cut-off values for screening would enable the detection of high-risk groups for further investigations and intervention where necessary. This study also raises the question of validity of WHO's cut-off points for indices of abdominal fatness, viz., waist circumference and waist-to-hip ratio, and the need for further studies to investigate the relationship between such indices and abdominal fat among Singaporeans.

The current study could not find the association between dietary factors and serum cholesterol levels, mainly due to insufficient inter-person variation and its cross sectional nature. To be able to quantify the benefits of dietary and other lifestyle changes on lowering serum cholesterol and thereby the mortality from coronary heart disease, longitudinal studies will be necessary. The present study and the two well-standardised National Health Surveys have established the baseline for most of the parameters and risk factors for future follow up. This, in combination with the high quality mortality statistics would enable Singapore to estimate the role of changes in risk factors and mortality from coronary heart disease and enable the effective implementation and evaluation of the ongoing Healthy Lifestyle Programme to lower risk factors among Singaporeans.

Samenvatting

De snelle economische groei en vooruitgang in de gezondheidszorg in Singapore gedurende de laatste vier decennia hebben geresulteerd in een verbeterde gezondheidstoestand van haar bevolking. Als gevolg daarvan is het sterftepatroon verschoven van aandoeningen als gevolg van slechte omgevingsfactoren en als gevolg van infectieziektes naar een patroon van chronische ziektes zoals kanker en cardiovasculaire aandoeningen.

Deze veranderingen kunnen gedeeltelijke worden toegeschreven aan veranderingen in leefgewoontes zoals voedingsgewoontes, lichamelijk activiteiten patroon en rookgedrag.

De sterfte als gevolg van cardiovasculaire aandoeningen (voornamelijk ischaemische hartziektes) is hoog in Singapore en verantwoordelijk voor ongeveer 25 percent van de jaarlijkse sterfte. Van de andere kant is de prevalentie van obesitas (grenswaarde een body mass index (BMI) van 30 kg/m^2), een belangrijke determinant voor cardiovasculair risico, met 5 percent vrij laag in vergelijking met andere landen. Het is bekend dat tussen de drie belangrijkste etnische groeperingen in Singapore (Chinezen, Maleisiërs en Indiërs) de prevalentie van risicofactoren en het mortaliteitspatroon verschilt. Deze verschillen zouden zowel het gevolg kunnen zijn van genetische factoren als ook van verschillen in leefgewoontes tussen de drie etnische groepen.

In dit proefschrift worden de resultaten besproken van studies in de drie etnische groeperingen in Singapore naar lichaamssamenstelling en voedselconsumptie en de mogelijke invloed hiervan op cardiovasculair risico.

Lichaamssamenstelling

Obesitas verhoogt een aantal risicofactoren voor cardiovasculaire aandoeningen maar is daarnaast ook een onafhankelijke risicofactor. De body mass index wordt vaak gebruikt als index voor obesitas en de Wereld Gezondheids Organisatie (WHO) heeft obesitas gedefinieerd als een BMI van 30 kg/m^2 en hoger. Deze grenswaarde is gebaseerd op ziekte- en sterftegegevens in Kaukasiërs. Echter, recente studies laten zien dat een dergelijke uniforme grenswaarde voor obesitas voor sommige etnische groeperingen, zoals Polynesiërs, Indonesiërs, Ethiopiërs, Afro-Amerikanen en Chinezen niet valide zou kunnen zijn.

In een onderzoek bij 291 personen is nagegaan of de grenswaarde voor obesitas zoals door de WHO aangegeven, valide is voor de drie etnische groeperingen in Singapore. Hiertoe is bij de deelnemers de hoeveelheid lichaamsvet bepaald met behulp van een vier-compartimenten model, bestaande uit vet, mineraal, water en eiwit (plus glycogeen). Dit model is, in tegenstelling tot de meeste twee-compartimenten modellen (densitometrie, isotoop verdunning en DXA), vrij van de aanname dat de densiteit van de vetvrije massa constant is of dat de hydratie van de vetvrije massa constant is, en is tegenwoordig algemeen geaccepteerd als referentiemethodiek voor de bepaling van lichaamsvet. De resultaten van deze studie laten zien dat zowel Chinezen, Maleisiërs als ook Indiërs een hoger percentage lichaamsvet hebben bij een zelfde BMI dan Kaukasiërs. Bij een vergelijkbaar lichaamsvetpercentage bij een Kaukasiër met een BMI van 30 kg/m^2, zou de BMI bij Chinezen en Maleisiërs ongeveer 27 kg/m^2 zijn, en bij Indiërs ongeveer 26 kg/m^2.

In een tweede studie is de relatie tussen verschillende indices van obesitas en abdominale vetverdeling (BMI, middelomtrek, middel-heup omtrekverhouding) en cardiovasculaire risicofactoren (hoge bloeddruk, verhoogd serumcholesterol, verhoogd serumtriglyceride en diabetes mellitus) bestudeerd bij de 4723 deelnemers aan de National Health Survey 1998. De resultaten laten zien dat reeds bij lage BMI-waardes (tussen 22 en 24 kg/m^2), lage waardes van middelomtrek (tussen 75 en 80 cm voor vrouwen en tussen 80 en 85 cm voor mannen) en bij lage waardes van middel-heup omtrekverhouding (tussen 0,80 en 0,85 voor vrouwen en tussen 0,90 en 0,95 voor mannen) het absolute en relatieve risico voor de aanwezigheid van minimaal één risicofactor belangrijk verhoogd is. Ook deze resultaten suggereren dat de door de WHO aanbevolen grenswaardes voor obesitas waarschijnlijk niet valide zijn voor Singapore. Onderzoek in andere Aziatische landen zoals China, India, Japan, Korea, Indonesië en Maleisië (gepresenteerd op de Aziatische BMI/obesitas Workshop gedurende het Europese Obesitas Congres in juni 1999) bevestigen de resultaten.

Voeding

Een voedselfrequentie vragenlijst, speciaal ontwikkeld voor gebruik in Singapore, is gevalideerd tegen herhaalde 24-uurs voedselnavraag en tegen ureumuitscheiding in 24-uurs urine. In de vragenlijst was speciale aandacht voor voedingsmiddelen zoals gebruikt door alle etnische groeperingen en voor alle soorten groente, fruit en graanproducten (inclusief rijst, noodles, brood en granen). Ook werd navraag gedaan naar details van bereidingswijze en gebruikt bak- en braadvet/ braadolie. Hierdoor was het mogelijk de opneming van totaal vet en soort vet bij de verschillende etnische groeperingen te kwantificeren. De voedselfrequentie vragenlijst bleek in staat personen te groeperen in quintielen van opneming voor totaal vet, soort vet en cholesterol voor gebruik in epidemiologische studies.

De relatie tussen voedselconsumptie en serumcholesterol niveau is bestudeerd bij 2408 personen, systematisch geselecteerd uit de populatie van de National Health Survey 1998, waarbij speciale aandacht was voor energieopneming, totaal vet, soort vet en cholesterol alsmede voor fruit, groente en graanproducten. De opneming van vet en soort vet is uitgedrukt als percentage van de opgenomen energie (%vet, %vv, %eov %mov) en cholesterol inneming is uitgedrukt als cholesterol per 1000 kcal. De Hegsted score (2,16 * %vv – 1,65 * %mov + 0,0677 * cholesterol – 0,53) is berekend teneinde het cholesterolemische effect van de voeding te schatten.

Op populatieniveau (zes groepen: drie etnische groepen verdeeld over de twee geslachten) waren de Hegsted score, %vet en graanproducten positief gecorreleerd met serum cholesterol. Echter, op individueel niveau konden de verschillen in voedselconsumptie de verschillen in serumcholesterol niet verklaren, ook niet na correctie voor leeftijd, BMI, middel-heup omtrekverhouding en leefgewoontes als roken, lichamelijke activiteit, beroep en opleidingsniveau). Waarschijnlijk is dit het gevolg van de vrij homogene voedselopneming in de bestudeerde populatie en ook het feit dat de studie een dwarsdoorsnede studie is, zal hebben bijgedragen. Correlaties tussen factoren en (risico voor) ziekte bij dwarsdoorsnede studies kunnen door een veelvoud van variabelen worden beïnvloed, zoals genetische, culturele en omgevingsfactoren alsmede leefgewoonte. Recente studies hebben laten zien dat verschillende soorten verzadigd vet een wisselend effect hebben op serumcholesterol en dit op zijn beurt kan verder verstoord worden door modulerende en versterkende factoren. Voorbeelden van dergelijke versterkende factoren zijn cholesterolgehalte in de voeding en het lipoproteine metabolisme van het individu, terwijl een hoge opneming van groente en fruit het effect kan afzwakken.

Implicaties en aanbevelingen
In de uitgevoerde studies zijn verschillende bevindingen duidelijk geworden, met name op het gebied van de relatie tussen BMI (als index of obesitas) en lichaamvetpercentage en ook cardiovasculaire risicofactoren. Het onderzoek heeft echter ook een aantal vragen opgeroepen op het gebied van preventie en/of verlaging van risicofactoren voor de reductie van coronaire hartziekte, vragen die om verdere studie vragen.

De aanwijzingen dat een verlaging van de BMI grenswaarde voor obesitas noodzakelijk is, zijn sterk, zowel gebaseerd op de aanwezigheid van overmatig lichaamsvet alsmede op sterk verhoogde absolute en relatieve risicofactoren voor cardiovasculaire risicofactoren. De gevolgen van een dergelijke verlaging voor de preventie en behandeling van obesitas in termen van volksgezondheid zijn echter enorm. Voor Singapore zou de prevalentie van obesitas meer dan verdubbelen van 6 percent (gebaseerd op de tegenwoordige grenswaardes voor obesitas van BMI 30 kg/m^2) tot 16,4 percent (gebaseerd op een BMI grenswaarde van 27 kg/m^2). Het gebruik van deze grenswaarde voor screening zou echter tijdig de hoog risico groepen detecteren en nader onderzoek en interventie mogelijk maken.
De studie roept ook vraagtekens op bij de huidige grenswaardes voor abdominale vetverdeling, in casu middelomtrek en middel-heup omtrekverhouding. Een nadere onderzoek naar de relatie tussen abdominale vetverdeling en antropometrische indices hiervoor lijkt op zijn plaats.

De huidige studie kon geen verband vinden tussen voedingsfactoren en serum cholesterol niveau, hoofdzakelijk vanwege een te lage tussen-persoon variatie in voedselconsumptie en vanwege het feit dat de studie een dwarsdoorsnede studie was.

Om de positieve effecten van een verandering in voedingsgewoontes en leefstijlfactoren op serumcholesterol te kwantificeren, zijn longitudinale vervolgstudies noodzakelijk. De huidige studie en de twee National Health Surveys in 1993 en in 1998 hebben de basis gelegd voor dergelijke vervolgstudies.
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About the author

Mabel Deurenberg-Yap was born on 4 September 1960 in Singapore. Most of her education was completed in Singapore. In 1984 she obtained her medical degree from the National University of Singapore and practised in various hospitals and polyclinics for five years. In 1990, she received her Masters degree in Public Health from the National University of Singapore under a government scholarship. In the same year, she joined the newly established Department of Nutrition of the Ministry of Health and worked in the areas of nutrition promotion, research, and training of health professionals. She spent four months on attachment to Monash Medical Centre and Canberra Department of Health in Australia in 1992, studying nutritional epidemiology and national food consumption studies. In 1997, she obtained a Postgraduate Diploma in Human Nutrition from Deakin University in Australia by distance learning.

She started her PhD studies in Wageningen Agricultural University in September 1997 after being awarded a government scholarship. During the phase I period, the study proposal on body composition, diet and cardiovascular risk factors of the three ethnic groups in Singapore was prepared and funding obtained from the National Medical Research Council of Singapore and the Ministry of Health, Singapore. This study formed part of the National Nutrition Survey and National Health Survey in 1998. Fieldwork for the studies spanned from March to November of 1998. While conducting the fieldwork, she was also working full time in the Department of Nutrition. In October 1998 she completed the International Course on Advanced Body Composition Techniques in Wageningen. She has presented findings from her studies at the 9th European Congress on Obesity, Advanced Course on Nutrition Assessments in Obesity and Asian BMI/Obesity Workshop (Milan, 1999), Workshop on Body Composition (Kuala Lumpur, 1999) and Scientific Symposium of the Institute of Health (Singapore, 1999). The last phase of the PhD started end February 2000.

She is currently appointed as medical consultant and deputy director in the Department of Nutrition. Upon completion of the PhD, she would resume her duties and participate in the restructuring of the Department into a statutory board.