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Body mass index and alternative indices of obesity in relation to height, triceps skinfold and subsequent mortality: the Busselton Health Study

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OBJECTIVES: The ideal index for leanness and obesity in epidemiological studies should correlate strongly with body weight and with a direct measure of fat while minimizing the influence of height. The preferred index is expected to show meaningful associations with subsequent mortality. Our aims were to compare weight/height, weight/height^2 (body mass index or BMI), and weight/height^3 as candidates for this index.
DESIGN: We analysed cross-sectional data from surveys of 6948 adults (3334 men (mean age 43 y, mean BMI 24.8 kg/m^2), and 3614 women (mean age 42 y, mean BMI 24.3 kg/m^2)) in Busselton, Australia whose weight, height, triceps skinfold, and cardiovascular risk factors were measured from 1966 through to 1978. In these same subjects we studied the mortality risks of indices of obesity using Cox regression analysis for survival time from first survey to death, or to follow up at the end of December 1995, after adjustment for age. Subjects dying within 5 y of the baseline survey were excluded from the analysis to avoid the bias of concurrent illness. We also studied subgroups including never smokers, subjects with no heart disease, and subjects<60 years of age at first survey.
RESULTS: In men, weight/height^2 met the criteria for a satisfactory index in that there was a very strong correlation with triceps skinfold, and a negligible correlation with height. For women, weight/height was as good a measure as weight/height^2, with both having strong correlations with triceps skinfold, and minimal correlations with height. Weight/height^2 as a predictor of mortality in men of all ages showed the typical U-shaped associations that were similar and consistent and of variable statistical significance. The significances of the hazard ratio curves were the strongest for cardiovascular disease deaths (all men P=0.001; men without heart disease at baseline P<0.001; never smoking men P=0.007). In never smoking men there was a near linear positive relationship with all-cause mortality (P=0.018). In women weight/height^2 showed no consistent associations with mortality. There was a shallow U-shaped relationship with all-cause mortality (P=0.087), also seen in never smoking women (P=0.075). In assessing 'ideal' weight for height in this population, a weight/height^2 of 25 kg/m^2 (range 22.5–27.5 kg/m^2) is appropriate. Weight/height and mortality showed very similar patterns in men to weight/height^2 with quite similar levels of statistical significance. In women much more pronounced U-shaped curves were apparent in all groups and subgroups, with a significant all-cause mortality trend for all women (P=0.029) and never smoking women (P=0.034). In assessing 'ideal' weight for height a weight/height of 42.5 kg/m (range 35–50 kg/m) appears appropriate for men and women.
CONCLUSIONS: Weight/height^2 is an appropriate index of leanness and obesity in males at all ages, whereas weight/height is at least as good an index for females. In mortality studies weight/height^2 and weight/height predict mortality similarly in males, but weight/height is a better discriminant of mortality in females.
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Introduction

Weight gain and obesity are recognized as an increasing public health problem in most societies, because of cardiovascular disease risk and associations with obesity-related cancers.[1–4] In epidemiological studies over three decades,[5–8] the ratio weight/height^2 or body mass index (BMI) has been the preferred measure for quantitating leanness vs obesity.[4–8] Ranges have been defined for ideal BMI (18.5–25 kg/m^2), underweight (< 18.5 kg/m^2), overweight (25–30 kg/m^2) and obesity (> 30 kg/m^2).[4] A more liberal upper limit for normal BMI (> 27 kg/m^2) has been suggested for middle-aged or elderly subjects.[9] BMI agrees very closely with actuarial tables of 'ideal body weight' for a given height.[10] However, both BMI and percentage desirable weight figures have some deficiencies and do not cater for individual frame size, muscularity, fat distribution and the changes of ageing.[4] BMI remains the preferred measure of fatness for epidemiological studies, although it

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does not reflect the distribution of obesity.[11,12] There are few Australian data on population measures of obesity. We undertook to evaluate a range of indices (weight/height, weight/height^2 and weight/height^3) from the data of the Busselton Health Study. We sought to establish that the ideal index will correlate closely with direct measures of fatness such as subcutaneous skinfolds, but show absent or negligible correlations with height. The best index should then be tested against subsequent morality, especially cardiovascular disease deaths, so as to identify true healthy weight ranges and departures from these.

Methods

This report describes data from the Caucasoid rural population of Busselton, Western Australia, a centre for farming, vineyards, timber and mineral sands industries. Cross-sectional health surveys were conducted in 1966, 1969, 1975 and 1978.[13,14] The response rates were 91%, 90%, 76% and 74%.[13] The mean of three triceps skinfolds were recorded using Harpenden calipers in the recommended manner.[15] Because of the markedly skewed distribution of skinfold values, logarithmic conversion was used in he analysis. A wide range of cardiovascular risk factor data and other physical and laboratory measures were documented.[13] Persons with coronary heart disease (CHD) were identified by doctor-confirmed positive Rose questionnaires for angina pectoris and/or past myocardial infarction, or by definite ECG abnormalities using the Minnisota Code.[14]

Statistical methods

Participants in he 1966–1978 triennial surveys were studied at their first attendance and followed to mortality until 31 December 1995. The indices (weight/height, weight/height^2 and weight/height^3) were analysed as continuous variables using quadratic equations to identify curvilinear relationships between the indices and subsequent mortality. We analysed all-cause mortality, cardiovascular disease deaths (ICD codes 390–459) and coronary heart disease deaths (ICD codes 410–414). Cox proportional hazards regression[16] was used to estimate the effect of the weight indices on the mortality rates, after adjustment for age. Two degrees of freedom *P*-values for the quadratic relationship were used to assess the significance of the U-shaped trends. Survival times from first survey to death or to the end of follow-up on 31 December 1995 were ascertained for all subjects. Those who died within 5 y of baseline were excluded in order to minimize the bias of concurrent illness causing underweight and contributing to mortality.

We also studied subgroups of the survey populations including younger persons < 60 y at baseline, persons with no coronary heart disease at baseline, and persons who had never smoked.

Results

The number of persons in the cohort and in various subgroups, together with the number of observed deaths until 31 December 1995 are shown in Table 1. There were 3334 men with 1026 deaths, and 3614 women with 813 deaths.

The characteristics of the subjects at baseline including the mean weights, heights, indices of obesity calculated from weight and height, triceps skinfold, and the cardiovascular risk factors measured are shown in Table 2.

Table 2 Characteristics of subjects at baseline. Entries are the mean (s.d.) for continuous variables, and percentage (%) for categorical variables

Characteristic	*Men*	*Women*
Age (y)	42.8 (16.9)	42.5 (16.8)
Weight/height^2 (kg/m^2	24.8 (3.3)	24.3 (4.1)
Weight/height (kg/m	43.0 (5.8)	39.1 (6.5)
Weight/height^3 (kg/m^3	14.3 (2.0)	15.2 (2.8)
Smoker	68%	36%
Serum cholesterol (mmol/l	5.7 (1.2)	5.9 (1.3)
Systolic blood pressure (mmHg)	133 (20)	130 (24)
Diastolic blood pressure (mmHg)	77 (13)	76 (14)
Mid triceps skin fold (mm)	10.5 (4.9)	21.6 (8.0)
Log mid triceps skin fold	2.3 (0.4)	3.0 (0.4)

Table 1 Number of persons in the Busselton cohort and the number of observed deaths (after excluding people who died during first 5 y)

			No. of deaths		
Sex	*Group*	*No. of persons*	*All*	*CVD*	*CHD*
Male	All	3334	1026	509	314
	Age < 60 y	2634	466	204	136
	Without heart disease	3086	878	418	251
	Never smokers	1059	187	105	69
Female	All	3614	813	450	242
	Age < 60 y	2927	317	135	78
	Without heart disease	3353	679	356	194
	Never smokers	2306	540	316	171

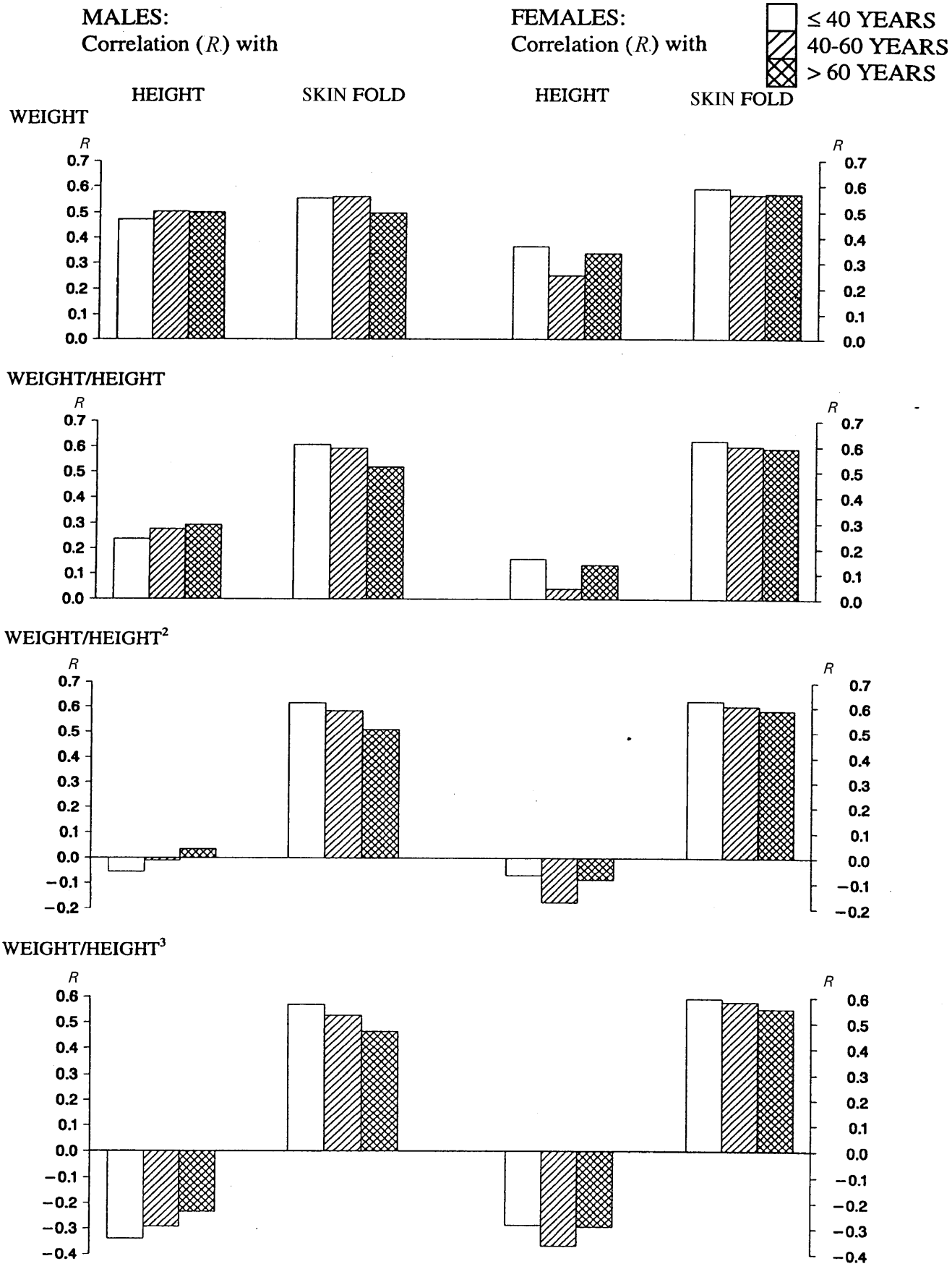

Figure 1 The correlation coefficients (*R*) for indices of obesity and height and the logarithm of mid triceps skinfold by age groups. The actual *R* values and their significance are shown in Table 3.

Comparisons of correlations in cross-sectional data

The correlation coefficients between the indices of obesity (weight/height, weight/height^2, weight/height^3) with height and with the logarithmic value for triceps skinfold for each individual's baseline study are shown in Table 3 and Figure 1. These results are based on the measures obtained at the first survey attended. Similar results were seen when measures from each survey were analysed separately. Correlation coefficients are shown in age groups < 40 y, 40–60 y and > 60 y. For men, the correlations are consistent across all age groups. There is a strong correlation between all of the weight indices and triceps skinfold. Only weight/height^2 fulfils the criterion of having a negligible correlation with height. Weight/height has a highly significant positive correlation, and weight/height^3 a highly significant negative correlation with height.

For women the correlations between all obesity indices and triceps skinfold are very strong. Weight/height shows small positive correlations with height and weight/height^2 shows small negative correlations with height in all three age groups. Weight/height^3 shows large negative correlations with height. Thus for women, in contrast to men, there is no clearly preferred measure of obesity, with weight/height fulfilling the criteria as well as weight/height^2. If anything weight/height is better than weight/height^2 for women 40–60 years of age.

Weight/height^2 and mortality

We examined the relationships between weight/height^2 (body mass index) as a continuous quadratic variable and all-cause mortality, and cardiovascular disease and coronary heart disease mortality. The results are shown in Figure 2.

Weight/height^2 in all men showed a fairly consistent U-shaped relationship for all three mortality outcomes, significant for cardiovascular disease mortality ($P = 0.001$) and coronary heart disease deaths ($P = 0.011$). The U-shaped relationship is mirrored in the subgroups of men < 60 y at baseline (although none were significant) and in men with no coronary heart disease at baseline ($P = 0.062$, $P < 0.001$, $P = 0.004$ for all-cause, cardiovascular disease and coronary heart disease deaths respectively). Only in the subgroup of never smoking men is there a more linear positive association for all-cause mortality whereas U-shaped curves are retained for cardiovascular disease ($P = 0.007$) and coronary heart disease ($P = 0.316$) mortality.

In the women, weight/height^2 does not show any convincing trends in relation to mortality. There are shallow U-shaped associations seen for all women and never smoking women but none of these reach statistical significance. In women aged < 60 y at baseline there is a positive near-linear relationship, and in women without heart disease at baseline there is essentially no relationship with weight/height^2.

Where U-shaped relationships exist between weight/height^2 and mortality, the nadir of the curve is a body mass index close to 25.0 kg/m^2 in both men and women, and the range of values associated with the lowest mortality is approximately 22.5–27.5kg/m^2.

Weight/height and mortality

The relationship of weight/height was also explored to pursue the relevance of this index, especially in women. These analyses are summarized in Figure 3

For men, the weight/height mortality curves were very similar to the curves for weight/height^2 and with similar levels of significance.

In the women, more pronounced U-shaped curves for weight/height were apparent in all groups except for women < 60 y of age, however, only the all-cause mortality trend was significant ($P = 0.029$ in all women and $P = 0.034$ in never smoking women).

Additional analyses

The effect of weight/height^2 on mortality was assessed using an estimation of peak adult height[17] with little change in the nature of the associations. The effect of weight/height^2 was also analysed after adjustment for coronary heart disease risk factors (total cholesterol, systolic and diastolic blood pressure, smoking) as well as for age, without altering the relationships qualitatively, although the significance levels were reduced.

Discussion

Weight/height^2, or body mass index, has been the accepted standard measure for leanness and obesity in epidemiological studies for the past four decades.[4–8] It provides the most convenient way of expressing fatness or thinness in populations. Much of this early epidemiological work focused on young and middle-aged adults. When obesity is being assessed as a risk factor for mortality and cardiovascular disease, very large population numbers are required to assess its true contribution.[18] Body mass index does show significant trends in relation to subsequent mortality,[18,19] but these are of moderate order compared with cardinal risk factors such as hypertension, hypercholesterolaemia and smoking, and rarely are they independent of these factors. In recent studies, body mass index has also been used as the more appropriate measure of fatness in children and adolescents.[4] In the elderly there are very few detailed assessments of body mass index as a measure of fatness and a predictor of mortality, but in general the mortality risk is less.[18]

The U-shaped relationship generally described between weight and height^2 in larger population cohorts illustrates that obesity contributes to increased

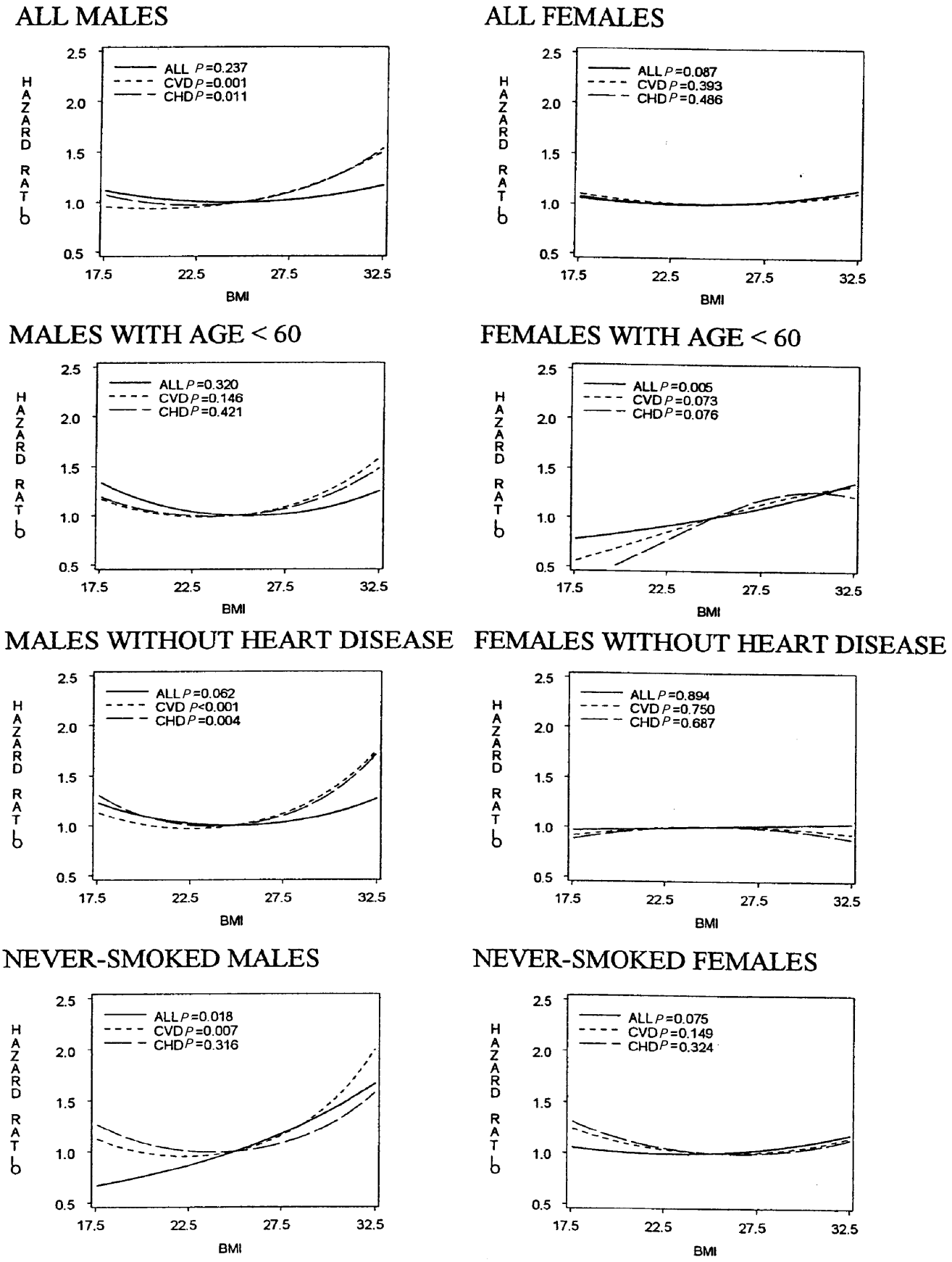

Figure 2 The relationships between weight/height^2 (body mass index) as a continuous quadratic variable and all-cause mortality, cardiovascular disease mortality, and coronary heart disease mortality.

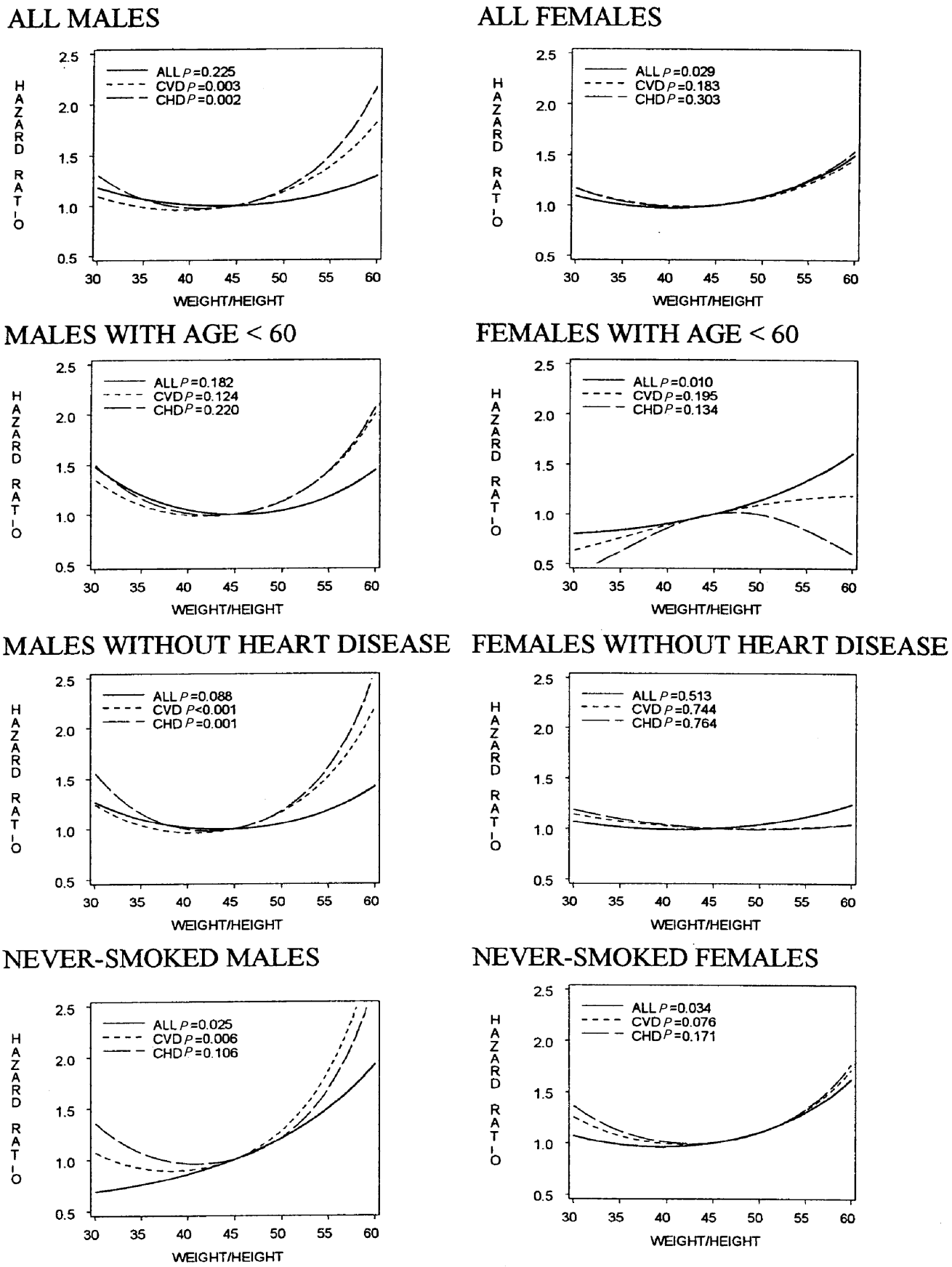

Figure 3 The relations between weight/height as a continuous quadratic variable and all-cause mortality, cardiovascular disease mortality, and coronary heart disease mortality.

Table 3 Comparisons of indices of obesity and their correlations with height and with the logarithm of triceps skinfold by age groups

	Correlation (R)											
	Men						*Women*					
	≤ 40 y		*40–60 y*		*> 60 y*		*≤ 40 y*		*40–60 y*		*> 60 y*	
Index of obesity	*Height*	*LogSF*	*Height*	*LogSF*	*Height*	*LogSF*	*Height*	*LogSF*	*Height*	*LogSF*	*Height*	*LogSF*
Weight	0.47***	0.55***	0.50***	0.56***	0.50***	0.50***	0.36***	0.59***	0.25***	0.56***	0.34***	0.57***
Weight/height	0.24***	0.61***	0.28***	0.59***	0.29***	0.52***	0.16***	0.62***	0.04	0.60***	0.13***	0.59***
Weight/height^2	− 0.06*	0.62***	− 0.01	0.58***	0.03	0.51***	− 0.07**	0.62***	− 0.18**	0.60***	− 0.09*	0.59***
Weight/height^3	− 0.34***	0.57***	− 0.29***	0.53***	− 0.23***	0.47***	− 0.29***	0.59***	− 0.37***	0.58***	− 0.29***	0.55***

***$P < 0.001$; **$P < 0.01$; *$P < 0.05$.

cardiovascular disease deaths.[2,3] The increased mortality associated with excessive leanness is thought to be mediated by smoking-related deaths, cancers and other chronic illnesses.[18,19]

In the Busselton cross-sectional data we sought to establish whether weight/height^2 was the preferred index of leanness and fatness in the population in terms of achieving the desired criteria of a strong association with actual weight and with a direct measure of fatness, namely triceps skinfold, and an absent or negligible association with height. These criteria were consistently met in adult men.

In women, weight/height was as good a measure of fatness as weight/height^2, showing equally strong correlations with triceps skinfold, and very minor correlations with height. Explanations for this phenomenon can only be speculative. Females have an increasing adipose tissue mass, less muscle bulk, and they show increased loss of height with ageing (through spinal curvature and osteoporosis).

Weight/height^3 showed an untoward influence of height in both men and women and therefore was not included in any further analysis.

Having established weight/height^2 as the preferred measure of body weight in men, and either weight/height or weight/height^2 for women, we applied these indices to the study of subsequent mortality. We excluded all deaths occurring within 5 y of baseline so as to minimize the influence of coexisting chronic diseases in the lean subjects.

In all men the typical U-shaped mortality curves with weight/height^2 were demonstrated, and were also quite consistent in the subgroups. The more linear and positive relationship between body mass index and all-cause mortality, seen in the subgroup of never smoking men, indicates the profound effect of smoking as a risk factor. In women, weight/height^2 failed to show any significant U-shaped relationship with mortality, but in the subgroup of women aged < 60 y at baseline, near-linear relationships between body mass index and mortality were seen.

It is of interest that, as a risk factor for mortality, weight/height performed at least as well as weight/height^2 in males, and it was a somewhat better predictor in females. This may reflect the confounding effect of height and its influence on mortality. Barker and his colleagues[20] have demonstrated a strong, consistent, graded association between increased height and reduced rates of total mortality, cardiac mortality and deaths from bronchitis. More recent reports suggest that height is an independent negative risk factor for coronary height disease[21,22] and for type 2 diabetes.[23] This issue should be pursued, for it invites the question: when used as a risk factor should an index of obesity be corrected for height, or should height and weight be analysed as separate variables?

The profound influence of distribution of body fat is now acknowledged,[11,12] and a variety of ways of assessing this for epidemiological purposes have been described, without complete agreement. These include waist–hip ratios, waist measures, anthropometry including multiple subcutaneous fat fold measures, and more sophisticated techniques such as dual photon absorptiometry and CT scanning. Ultimately, there will have to be a simple set of measures that incorporate weight and height and some assessment of abdominal fat. This is still an evolving field.

In this Australian population we can say that our findings suggest an ideal weight/height^2 or body mass index of 25 kg/m^2 with a range of 22.5–27.5 kg/m^2 is appropriate in men and women; and in women a weight/height measure of 45 kg/m with a range 40–50 kg/m, is appropriate as an index of leanness and fatness in the population.

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