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REVIEW

Waist circumference and waist/hip ratio in relation to all-cause mortality, cancer and sleep apnea

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Abdominal obesity assessed by waist or waist/hip ratio are both related to increased risk of all-cause mortality throughout the range of body mass index (BMI). The relative risks (RRs) seem to be relatively stronger in younger than in older adults and in those with relatively low BMI compared with those with high BMI. Absolute risks and risk differences are preferable measures of risk in a public health context but these are rarely presented. There is a great lack of studies in ethnic groups (groups of African and Asian descent particularly). Current cut-points as recommended by the World Health Organization seem appropriate, although it may be that BMI-specific and ethnic-specific waist cut-points may be warranted. Waist alone could replace both waist–hip ratio and BMI as a single risk factor for all-cause mortality. There is much less evidence for waist to replace BMI for cancer risk mainly because of the relative lack of prospective cohort studies on waist and cancer risk. Obesity is also a risk factor for sleep apnoea where neck circumference seems to give the strongest association, and waist–hip ratio is a risk factor especially in severe obstructive sleep apnoea syndrome. The waist circumference and waist–hip ratio seem to be better indicators of all-cause mortality than BMI.
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Waist circumference, waist–hip ratio and all-cause mortality

What is the optimal cut-point for assessing risk of premature death?—purposes of cut-points

There are not very many studies that directly compare mortality risks by waist circumference and waist–hip ratio. Those who do usually show a continuous relationship between waist, waist/hip and mortality, making any decision about cut-points and classification rather arbitrary. It is also important to think about the uses for cut-points (WHO Expert Consultation, 2004). Cut-points can be applied to population data to describe prevalence and to provide information that may trigger policy actions, to facilitate prevention programmes and to measure the effect of interventions. They can also be used in epidemiological studies to describe the strength and effect size of relationships of determinants on health outcomes. Finally, they can be used to identify individuals who are at risk, to determine the type and intensity of treatment and to evaluate the effects of treatment.

The focus of this paper is to evaluate the nature and form of the relationships between waist, waist/hip and all-cause mortality in prospective epidemiological studies and to identify potential cut-points based on for example, statistical grounds (e.g. quintiles), the flexing of the curves or of absolute and relative risk (RR) estimates.

The evaluation of the impact of anthropometric measures on mortality can be done by calculating absolute risks (and rate or risk differences), RR or population attributable risk. The RR gives an impression of the slope of the association but has the disadvantage of being dependent on the level of background risk. The risk difference gives the best assessment of the impact on mortality but is rarely used in epidemiological studies. The population attributable risk is particularly useful for policy because it gives an estimate of the determinant on total mortality on a population level.

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For example, the RR of people with a large vs a small waist circumference may be higher in younger people than in older people. However, because mortality rates are higher in older people, the rate difference may be larger in older than in younger people. Finally, because the prevalence of a large waist circumference may be higher in older compared with younger people, the proportion of deaths attributable to abdominal obesity may also be higher in older than in younger people. Despite the usefulness of these different assessments of risk, almost universally the RR is presented in scientific papers as the main measure of impact.

There will also be a brief discussion about the association between body mass index (BMI) with waist and waist/hip as well as with mortality. Finally, a brief discussion of the association between measures of abdominal obesity and cancer and sleep apnoea will be presented.

Studies comparing waist, waist/hip and all-cause mortality in young adults and middle-aged subjects

The largest study in this respect is the EPIC (European Prospective Investigation on Cancer) study in 359 387 participants from nine European countries with 14 723 deaths during a follow-up of 9.7 years on average (Pischon *et al.*, 2008).

Table 1 shows the results for RRs by quintiles of waist and waist–hip ratio. Further, subgroup analyses revealed that the RRs for increased waist circumference and waist–hip ratio were more pronounced in the lower ranges BMI (see Figure 1). For instance, the RR in the upper quintile in men with a BMI <24.9 was 2.51 (95% CI: 1.59–1.96), whereas in men with a BMI⩾27.7 it was 0.87 (95% CI: 0.46–1.6). Similar results were observed in women and for waist–hip ratio.

For all causes of death (cancer, circulatory, respiratory and 'other') there was a strong relationship between increased waist and waist–hip ratio in both men and women. In men, the causes of death, most strongly related to an increased waist or waist–hip ratio, were deaths related to respiratory diseases.

Tables 2 and 3 show relative all-cause mortality risks for waist circumference in middle-aged men and women from US studies (Baik *et al.*, 2000; Koster *et al.*, 2008; Zhang *et al.*, 2008).

Welborn and Dhaliwal (2007) showed in a study in 9309 Australian urban adults aged 20–69 years followed for 11 years that waist–hip ratio was superior to BMI, waist and waist–stature ratio in predicting all-cause mortality (male hazard ratio 1.25, *P*-0.003; female hazard ratio 1.24, $P<0.001$ for 1 standard deviation above the mean).

Simpson *et al.* (2007) followed 16 969 men and 24 344 women for 11 years who were participants in the Melbourne Collaborative Cohort Study and aged 27–75 years at baseline. Comparing the top quintile to the second quintile, there was an increased risk of between 20 and 30% for all-cause mortality for all anthropometric measures (BMI, waist circumference, waist–hip ratio, fat mass and percentage fat assessed by impedance). For women, there was an increased RR for waist (RR: 1.3; 95% CI: 1.1–1.6) and waist–hip ratio (RR: 1.5; 95% CI: 1.2–1.8).

Table 1 Multivariate relative risks of mortality according to quintiles of waist circumference and waist–hip ratio in men and women participating in the EPIC study (Pischon *et al.*, 2008)

All-cause mortality	*Quintiles*				
	I	*II*	*III*	*IV*	*V*
Men					
Waist (cm)	<86	86.0–91.5	91.5–96.5	96.5–102.7	⩾102.7
Relative risk[a]	1 (ref)	0.91*	0.94	1.05	1.33*
Relative risk[b]	1 (ref)	1.15*	1.35*	1.63*	2.05*
WHR	<0.89	0.89–0.92	0.92–0.95	0.95–0.99	⩾0.99
Relative risk[a]	1 (ref)	1.01	1.07	1.15*	1.44*
Relative risk[b]	1 (ref)	1.15*	1.26*	1.36*	1.68*
Women					
Waist (cm)	<70.1	70.1–75.6	75.6–81.0	81.0–89.0	⩾89.0
Relative risk[a]	1 (ref)	0.97	0.93	1.05	1.28*
Relative risk[b]	1 (ref)	1.16*	1.21*	1.46*	1.78*
WHR	<0.73	0.73–0.77	0.77–0.80	0.80–0.85	⩾0.85
Relative risk[a]	1 (ref)	1.06	1.07	1.16*	1.45*
Relative risk[b]	1 (ref)	1.09	1.12*	1.23*	1.51*

*$P<0.05$.
[a]Adjusted for smoking status, educational level, alcohol consumption, height.
[b]As above with further adjustment for BMI.

Bigaard *et al.* (2003) studied data of 27 178 Danish men and 29 875 women aged 50–64 years at baseline and followed for 5.8 years. Waist circumference among both men and women showed a strong dose–response type of relationship with mortality when adjusted for BMI, whereas the low range of BMI was inversely associated with mortality when adjusted for waist circumference (Bigaard *et al.*, 2003). A 10% larger waist circumference corresponded to a 1.48 (95% CI: 1.36–1.61) times higher mortality over the whole range of waist circumference. In another study, they adjusted for body composition (body fat and fat-free mass assessed by impedance measurements). Waist circumference was associated with an increased risk of all-cause mortality after adjustment for body composition; the mortality RR was 1.36 (95% CI: 1.17–1.44) per 10% larger waist and 1.30 (85% CI: 1.17–1.44) for women (Bigaard *et al.*, 2005). They also showed that, when mutually adjusted, waist and hip circumference showed opposite associations with all-cause mortality. They indicated that the waist–hip ratio should be used with caution in substituting waist and hip (Bigaard *et al.*, 2004).

Katzmarzyk *et al.* (2002) studied the relationship between BMI, waist circumference and the sum of five skinfolds in relation to mortality in 10 232 adult participants 20–69 years of age from the Canada Fitness Survey who were followed for 13 years. Significant J-shaped associations in men and linear relationships in women were observed between BMI, waist circumference and sum of skinfolds and all-cause mortality rates.

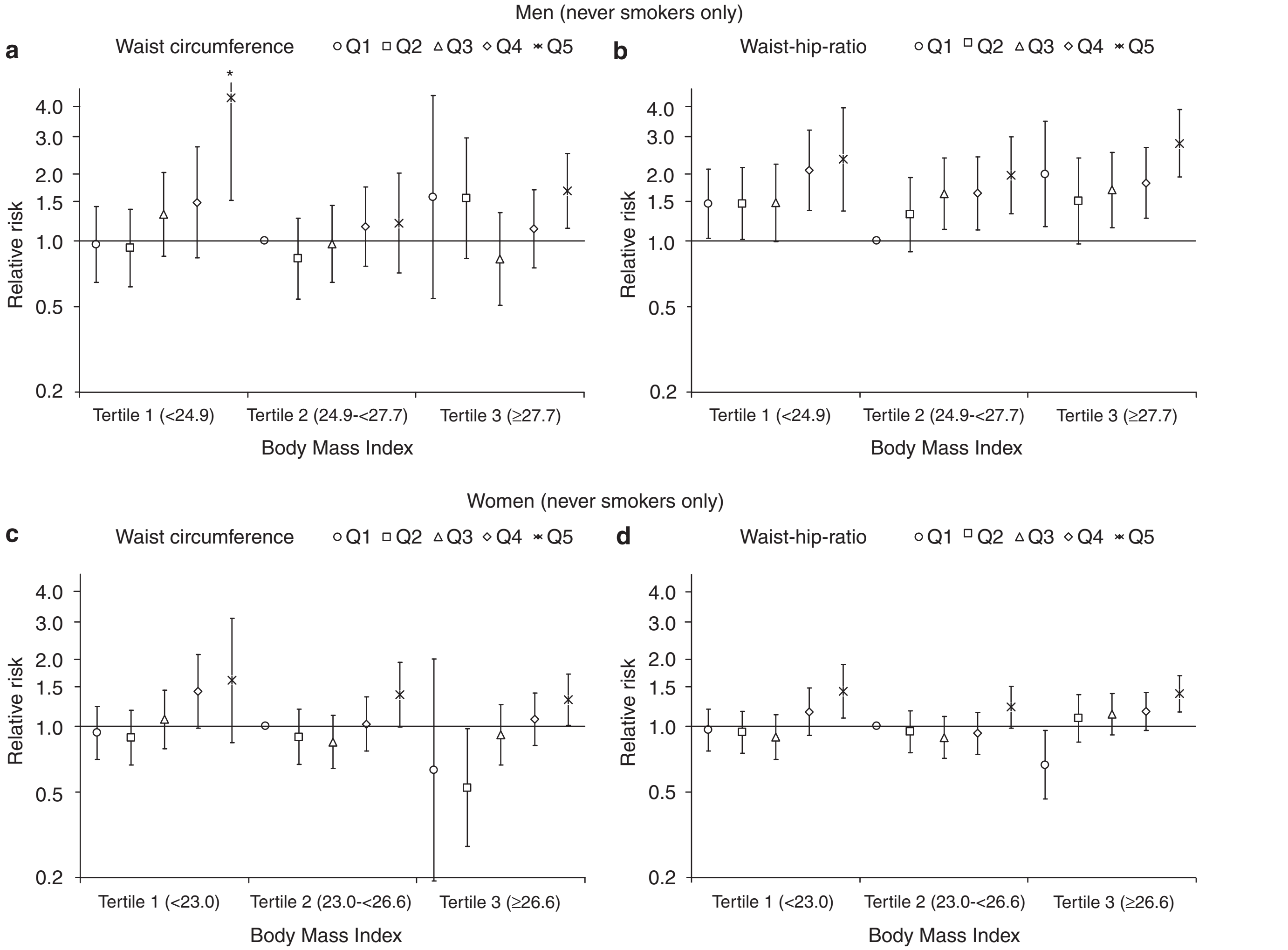

Figure 1 Adjusted relative risk of death among men and women who had never smoked according to thirds of BMI and quintiles of waist circumference or waist-to-hip ratio (Pischon *et al.*, 2008). (**a**) Men, waist circumference. (**b**) Men, waist-to-hip ratio. (**c**) Women, waist circumference. (**d**) Women, waist-to-hip ratio.

Flegal and Graubard compared excess mortality associated with BMI levels with other anthropometric measurements including waist circumference and waist–hip ratio in the third National Health and Nutrition Examination Survey (Flegal and Graubard, 2009).

These authors pointed out that the correlation between waist and BMI were high (0.89 in men and 0.88 in women) but considerably lower between BMI and waist/hip ratio (0.53 in men and 0.39 in women). The associations between BMI and mortality were weak as were those between mortality and waist/hip and waist.

Studies in elderly subjects

Dolan *et al.* (2007) studied the relation between waist and BMI with mortality in 8029 women aged 65 years and older (8 years of follow-up; 845 deaths). Mortality was lowest in the BMI's between 24.6 and 29.8 kg/m^2 but also in the middle of the distribution of waist circumference.

Price *et al.* (2006) studied 14 833 subjects aged 75 years or older (follow-up 5.9 years, 649 deaths). In non-smoking men and women (90% of the cohort), compared with the lowest quintile, the hazard ratios were below 1.0 for all other quintiles of BMI. Increasing hazard ratios were observed with increasing waist–hip ratio. Waist circumference was not associated with all-cause mortality.

Kalmijn *et al.* (1999) observed an inverse association between BMI and all-cause mortality in 3741 Japanese-American men followed for 4.5 years (76 deaths). After adjustment for BMI, a higher waist–hip ratio steadily increased the risk of dying (RR highest vs lowest category: 1.5 95% CI: 1.1–2.0; *P*-trend = 0.004).

Visscher *et al.* (2001) observed in 6296 men and women aged 52–102 years at baseline with a follow-up of 5.4 years that high quintiles of waist, but not of waist–hip ratio or BMI

Table 2 Multivariate relative risks of mortality according to quintiles of waist circumference and waist–hip ratio in women

All-cause mortality	*Quintiles*				
	I	*II*	*III*	*IV*	*V*
Zhang *et al.*					
Waist (inches)	<28	28–29	30–31	32–34	⩾35
Relative risk[a]	1 (ref)	1.11	1.17*	1.31*	1.71*
Zhang *et al.*					
WHR	<0.73	0.73–0.75	0.76–0.79	0.80–0.83	⩾0.84
Relative risk[a]	1 (ref)	1.09	1.14*	1.33*	1.59*
Koster *et al.*					
Waist (cm)	<73	73–80	80–87	87–96	⩾96
Relative risk[b]	1.07	1 (ref)	0.99	1.00	1.28*

*$P<0.05$.
[a]44 636 women aged 30–55 years at baseline, 16 years of follow-up; relative risks adjusted for age, smoking status, physical activity, alcohol consumption, menopausal status, hormone use and body mass index (relative risk in highest vs lowest quintile: 1.44 (1.29–1.60) without adjustment for BMI.
[b]90 757 women aged 51–72 years at baseline; 9 years of follow-up; relative risks adjusted for age, racial/ethnic group, education, smoking status, physical activity, alcohol consumption, height and body mass index (relative risk in highest vs 2nd quintile: 1.36 (1.26–1.47) without adjustment for BMI).

Table 3 Multivariate relative risks of mortality according to quintiles of waist circumference and waist–hip ratio in men

All-cause mortality	*Quintiles*				
	I	*II*	*III*	*IV*	*V*
Baik *et al.*					
Waist (inches)	<34.5	34.5–36.2	36.3–37.9	38.0–40.2	⩾40.3
Relative risk[a]	1 (ref)	0.98	0.89	1.07	1.37*
Baik *et al.*					
WHR	<0.90	0.90–0.91	0.92–0.94	0.95–0.97	⩾0.98
Relative risk[a]	1 (ref)	0.67*	0.88	1.05	1.15
Koster *et al.*					
Waist (cm)	<88.9	88.9–94.0	94.0–99.1	99.1–106.7	⩾106.7
Relative risk[b]	1.10	1 (ref)	1.00	1.01	1.22*

*$P<0.05$.
[a]25 684 men aged 40–75 at baseline; 10 years of follow-up; relative risks adjusted for age, smoking, family history of myocardial infarction or colon cancer, profession, marital status, height, alcohol, calorie-adjusted intakes vitamins A, E and dietary fibre.
[b]154 776 men aged 51–72 years at baseline; 9 years of follow-up; relative risks adjusted for age, racial/ethnic group, education, smoking status, physical activity, alcohol consumption, height and body mass index (relative risk in highest vs 2nd quintile: 1.30 (1.15–1.29) without adjustment for BMI).

were associated with an increased risk of all-cause mortality in men who had never smoked. No associations were seen in women or in men who smoked.

Baik *et al.* (2000) stratified their analyses into men younger and older than 65 years of age. Increased RRs for all-cause mortality by quintiles of waist and waist–hip ratio were more pronounced in the younger men and not significant in the older men.

Studies in Asian populations

A WHO expert consultation recognized that most studies on overweight, obesity and fat distribution and health are based on studies from the North America and Europe. It was concluded that Asian populations have different associations between BMI, percentage of body fat and health risks than American and European populations. On the basis of the studies from, for example Taiwan, it was concluded from studies on all-cause mortality that Asians showed risks equivalent to Caucasians' at lower BMI (about 5 units). It has been proposed that, therefore, the definition of obesity in Asian populations should be based on a cut-point of 25 kg/m^2 rather than 30 kg/m^2. In Taiwan, this would raise the prevalence of obesity from about 4 to 27% (Wen *et al.*, 2009). There is a lack of prospective epidemiological studies in Asian population where BMI, waist and waist/hip are compared.

Zhang *et al.* (2007) studied the relationship of waist/hip and all-cause mortality in 72 773 non-smoking Chinese women followed for 5.7 years. They observed a strong association of waist/hip ratio and RR of all-cause mortality after adjustment for BMI. When stratified into tertiles of BMI, they observed the steepest association in the leanest women. There were no differences in association between WHR and mortality by age or level of physical activity. They did not present data on waist circumference in detail but noted that the RR of all-cause mortality in the highest vs lowest quintile of waist was 1.95 (95% CI: 1.46–2.60) after adjustment for BMI. The effect of waist on RR of mortality was greater in younger than in older women and stronger at the lower range of BMI (Figure 2).

Is one indicator better for assessing risk for mortality?

It seems that waist circumference and waist–hip ratio are not very different in their associations with all-cause mortality. Both are better predictors of death than BMI, particularly in elderly subjects where often an inverse association between BMI and mortality was observed. Waist circumference is a good choice as a single preduictor of death. It is difficult to derive a single cut-point that is optimal but the level of 102 cm (40 inch) in men and 88 cm in women (35 inch) seems appropriate.

Can waist, waist/hip be used to predict cancer and sleep apnoea?

Abdominal obesity and cancer

In the report 'Food, Nutrition, physical activity, and the prevention of Cancer—a global perspective' by the World Cancer Research Fund (World Cancer Research Fund, 2007), it is concluded that the evidence for a causal association between general obesity was 'convincing' for cancer of the

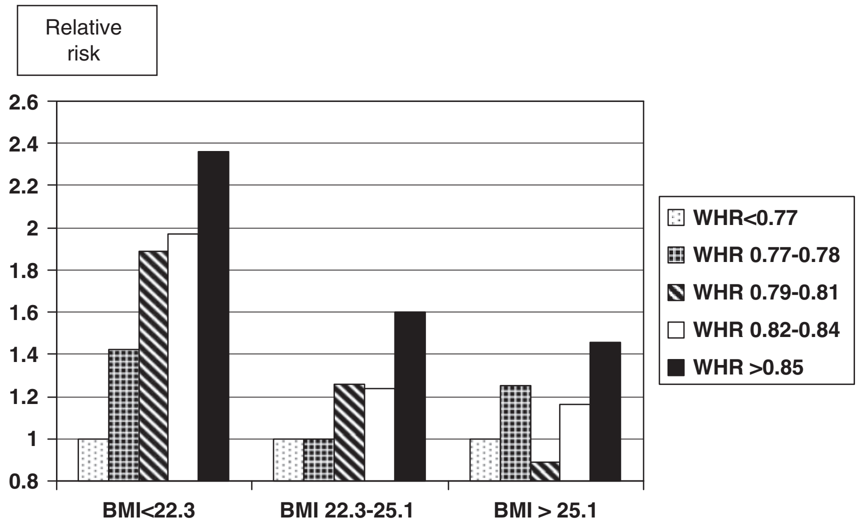

Figure 2 Relative risks by increasing waist-to-hip circumference ratio (WHT) by categories of body mass index (BMI) in Chinese women (Zhang *et al.,* 2007).

oesophagus, pancreas, colorectum, breast cancer (after menopause), endometrium, cervix and kidney and 'probable' for gallbladder cancer. The association between abdominal obesity and colorectal cancer was judged to be 'convincing' and 'probable' for cancer of the pancreas, breast cancer (after menopause) and endometrium.

Colon cancer

Moghaddam *et al*. (2007) reviewed the risks of obesity-related indicators and colorectal cancer in a meta-analysis of 31 studies with 70 000 events. After pooling and correcting for publication bias, the estimated RR of colorectal cancer was 1.19 (95% CI: 1.11–1.29), comparing obese (BMI $\geq 30\,kg/m^2$) with normal weight (BMI $<25\,kg/m^2$) people; and 1.45 (95% CI: 1.31–1.61), comparing those with the highest, to the lowest, level of central obesity. After correcting for publication bias, the risk of colorectal cancer was 1.41 (95% CI: 1.30–1.54) in men compared with 1.08 (95% CI: 0.98–1.18) for women (P(heterogeneity) <0.001). There was evidence of a dose–response relationship between BMI and colorectal cancer: for a $2\,kg/m^2$ increase in BMI, the risk of colorectal cancer increased by 7% (4–10%). For a 2-cm increase in waist circumference, the risk increased by 4% (2–5%).

Breast cancer

Harvie *et al*. (2003) performed a large systematic review on central obesity and breast cancer. Five cohort studies with 72 1705 person years of observation (453 pre-menopausal and 2684 post-menopausal cases), and three case–control studies comprising 276 pre-menopausal cases with 758 pre-menopausal controls and 390 post-menopausal cases with 1071 post-menopausal controls were included. Pooled results from cohort studies using the most adjusted data (but without adjustment for weight or BMI) suggest a 39% lower risk of breast cancer in post-menopausal women with the smallest waist (compared with the largest) and a 24% lower risk in women with the smallest WHR. In pre-menopausal women, however, pooled results suggest that measurement of waist or WHR have little effect on risk of breast cancer. Adjustment for BMI abolished the relationship between waist or WHR and risk of post-menopausal breast cancer, but introduced such a relationship amongst pre-menopausal women. The relationship between a smaller measurement of waist or WHR and lower risk of post-menopausal breast cancer appears to result from the associated correlation with BMI. Amongst pre-menopausal women, central (not general) obesity may be specifically associated with an increased risk of breast cancer.

Sleep apnoea

The prevalence of OSA among obese patients exceeds 30%, reaching as high as 50–98% in the morbidly obese population. Obesity is probably the most important risk factor for the development of OSA. Some 60–90% of adults with OSA are overweight, and the RR of OSA in obesity (BMI $>29\,kg/m^2$) is $\geqslant 10$. Numerous studies have shown the development or worsening of OSA with increasing weight, as opposed to substantial improvement with weight reduction. There are several mechanisms responsible for the increased risk of OSA with obesity. These include reduced pharyngeal lumen size due to fatty tissue within the airway or in its lateral walls, decreased upper airway muscle protective force due to fatty deposits in the muscle, and reduced upper airway size secondary to mass effect of the large abdomen on the chest wall and tracheal traction. These mechanisms emphasize the great importance of fat accumulated in the abdomen and neck regions compared with the peripheral one. It is the abdomen much more than the thighs that affect the upper airway size and function. Hence, obesity is associated with increased upper airway collapsibility (even in nonapneic subjects), with dramatic improvement after weight reduction. Conversely, OSA may itself predispose individuals to worsening obesity because of sleep deprivation, daytime somnolence and disrupted metabolism. OSA is associated with increased sympathetic activation, sleep fragmentation, ineffective sleep and insulin resistance, potentially leading to diabetes and aggravation of obesity (Pillar and Shehadeh, 2008). The association between obesity and OSA has been noted in cross-sectional and longitudinal studies. Young *et al.* (2005) reviewed the few population studies that have investigated the role of weight change in sleep disordered breathing (SDB) occurrence and progression over time. Findings consistently point to the importance of body habitus in predicting the occurrence and progression of SDB. In the Wisconsin sleep cohort, 690 men and women were studied with laboratory polysomnography at baseline and at 4-year follow-up; a 10% weight gain was associated with a sixfold increase in the odds of developing moderate or worse SDB (AHI $\geqslant$15). Similar to the findings from clinical studies, each 1% change in weight was associated with a 3% change in AHI. The 5-year incidence of SDB was investigated in the Cleveland Family Study. Of 286 men and women (mean age = 36.8 years) who had no SDB (indicated by AHI $<$5) at baseline, the incidence of new SDB (defined by developing AHI $>$ 15 at follow-up) was 3.3% for those whose baseline BMI was $<$24 and 22% for those whose baseline BMI was $\geqslant$31. Most recently, longitudinal data from the Sleep Heart Health Study were used to examine 5-year changes in weight and AHI based on in-home polysomnography of 2968 men and women aged 40–95 years. Results indicated that, although weight loss predicted a decrease in AHI, the effect was weaker than that of weight gain on an increase in AHI. For example, in men, the odds ratio for a 5-year increase in AHI of $\geqslant$15 with a gain of at least 10 kg was 5.2, but the odds ratio for a loss in AHI of at least 15 with a loss of $\geqslant$10 kg was 2.9.

Martinez-Rivera *et al.* (2008) compared different anthropometric indicators in relation to obstructive sleep apnoea syndrome (AHI $>$ 10). In a multiple logistic regression model, BMI (obese vs non-obese) was not associated with OSAS but a high waist–hip ratio (cut-points 1 for men and 0.85 for women) was associated with an odds ratio of 2.6 (1.2–5.8). Davidson and Patel (2008) concluded that waist circumference is a better measure than BMI or neck circumference to predict SDB. Even with an AHI of 5 or more, only half of SDB patients in this study were clinically obese. An abnormal waist circumference for men and women is 102 cm (40 inches) or more.

Conclusions

Abdominal obesity assessed by waist or waist/hip ratio are both related to increased risk of all-cause mortality throughout the range of BMI but particularly strong in younger adults and in those with relatively low BMI. Current cut-points seem appropriate. Waist alone could replace both waist–hip ratio and BMI as a single risk factor for all-cause mortality. There is much less evidence for waist to replace BMI for cancer risk mainly because of the relative lack of prospective cohort studies on waist and cancer risk. Obesity is also a risk factor for sleep apnoea, where neck circumference seems to give the strongest association and waist–hip ratio is a risk factor especially in severe obstructive sleep apnoea syndrome.

There is a great lack of studies in ethnic groups (groups of African and Asian descent particularly).

Conflict of interest

The author declares no conflict of interest.

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