Available online at www.sciencedirect.com

ScienceDirect

Journal of Sport and Health Science 8 (2019) 17−22

www.jshs.org.cn

Original article

Waist circumference thresholds and cardiorespiratory fitness

Sindre M. Dyrstad [a,*], Elisabeth Edvardsen [b,c], Bjørge H. Hansen [b], Sigmund A. Anderssen [b]

[a] *Department of Education and Sport Science, University of Stavanger, Stavanger 4036, Norway*
[b] *Department of Sports Medicine, Norwegian School of Sport Sciences, Oslo 0806, Norway*
[c] *Department of Pulmonary Medicine, Oslo University Hospital, Oslo 0424, Norway*

Received 16 November 2016; revised 14 December 2016; accepted 7 February 2017
Available online 6 April 2017

Abstract

Purpose: This study's purpose was to examine whether established risk categories of waist circumference (WC)—normal, high risk, and very high health risk—reflected significant differences in cardiorespiratory fitness (CRF) and physical activity (PA) level.
Methods: CRF was directly measured as maximal oxygen uptake during a progressive graded treadmill test to exhaustion in 722 individuals (349 women) aged 20−85 years. WC was measured between the lower rib and the iliac crest. Objectively measured PA was assessed using an accelerometer.
Results: Men in the normal risk group (WC < 94 cm) had a 31% higher CRF and 43% higher level of moderate-to-vigorous PA than men in the very high risk group (with a WC > 102 cm). Corresponding numbers for women within normal (WC < 80 cm) and very high risk group (WC > 88 cm) were 25% and 18% ($p < 0.05$). There was a high negative correlation between CRF and WC in men ($r = -0.68$), and a moderate correlation for women ($r = -0.49$; $p < 0.001$). For each cm increase in WC, CRF was reduced by 0.48 and 0.27 mL/kg/min in men and women, respectively ($p < 0.001$).
Conclusion: The recommended WC thresholds for abdominal obesity reflected significant differences in CRF for both men and women, and could serve as a useful instrument for estimating health-related differences in CRF.

Keywords: Abdominal obesity; Fit fat; Maximal oxygen uptake; Obesity; Public health; Waist circumference

1. Introduction

Central or abdominal obesity, measured as waist circumference (WC), is one of 5 risk factors constituting a diagnosis of metabolic syndrome.[1] WC is found to explain obesity-related health risks,[2] and for a given body mass index (BMI), an increase of WC by 5 cm has been associated with an increased risk of death of 17% for men and 13% for women.[3]

As stated by Alberti et al.[4] defining thresholds for abdominal obesity is complicated, in part because of differences in the relationship between abdominal obesity and other metabolic risk factors and because differences in WC occur between sexes and ethnic groups. Current recommended WC thresholds for abdominal obesity (high and very high risk for cardiovascular disease and diabetes) are set at 80 cm and 88 cm in Caucasian women and 94 cm and 102 cm in Caucasian men, respectively.[4−6] However, other WC thresholds are also recommended for white and African-American adults.[7]

Cardiorespiratory fitness (CRF) appears to be one of the most important indicators of overall health status, and a decline in CRF level predicts the development of metabolic syndrome, hypertension, and hypercholesterolemia[8] as well as all-cause and cardiovascular disease mortality.[9] CRF, which is best measured by direct measurement of maximal oxygen uptake (VO_{2max}), reflects the ability of the respiratory, circulatory, and muscular systems to supply oxygen during physical activity (PA).[10] An inverse relationship has been found between WC and CRF,[11] and this relationship was more pronounced than the relationship between BMI and CRF.[12] Unfortunately, in those studies CRF was estimated rather than directly measured, and estimation can be highly inaccurate.[13] To the best of our knowledge, no studies have examined the relationship between directly measured CRF and WC in a large population, nor studied whether the recommended WC thresholds for abdominal obesity reflect any health-related differences in CRF.

Peer review under responsibility of Shanghai University of Sport.
* Corresponding author.
E-mail address: sindre.dyrstad@uis.no (S.M. Dyrstad).

https://doi.org/10.1016/j.jshs.2017.03.011
2095-2546/© Cite this article: Dyrstad SM, Edvardsen E, Hansen BH, Anderssen SA. Waist circumference thresholds and cardiorespiratory fitness. *J Sport Health Sci* 2019;8:17−22. (http://creativecommons.org/licenses/by-nc-nd/4.0/)

Therefore, the main purpose of the present study was to examine whether categories of WC (normal, high, and very high health risk) reflected significant differences in CRF and PA level, and to examine the association between CRF and WC in a large sample of the national population.

2. Methods

2.1. Participants

This multicenter study involved 9 regional test centers throughout Norway. A comprehensive description of the study can be found elsewhere.[14,15] Briefly, a representative sample of 11,515 adults (aged 20−84 years) from the areas surrounding each test center was drawn from the Norwegian population registry. Written informed consent was obtained from 3867 participants (34%). These participants wore an accelerometer for 7 consecutive days. From the sample that completed the accelerometer measurements, 1930 were randomly selected and invited to undergo a cardiopulmonary exercise test and measurement of height, body weight, body fat, and WC. A total of 1030 participants accepted the invitation, 904 persons met at the lab and 722 participants (349 women) completed the tests successfully 5 to 8 months after the accelerometer measurements. The study was approved by the Regional Ethics Committee for Medical Research (REK Sør-Øst B, S-08046b) and the Norwegian Social Science Data Services.

2.2. Measurement of anthropometrics

The anthropometric measures of body weight, height, WC, and skinfold thickness were all conducted by trained investigators following a detailed test protocol, and all measuring instruments were calibrated.

Height was measured to the nearest 0.5 cm using a stadiometer. The participants were instructed to stand upright without shoes, heels touching the wall, and with a straight body facing forward. Body weight were measured to the nearest 0.1 kg, with participants wearing light clothes and no shoes.

WC was recorded following a protocol developed by the World Health Organization,[16] and was measured twice, using a measuring band in standing position from the point midway between the inferior margin of the last rib and the iliac crest at the end of a normal expiration. If the difference between the first and second measurement was larger than 2 cm, a third measurement was made. The mean of the 2 closest measurements was used. As reported by Kjaer et al.,[17] WC has shown acceptable inter-rater reliability (technical error of measurement: 2.35%−2.50%)[18] and good correlation with dual-energy X-ray absorptiometry measures of trunk fat mass percentage (partial Pearson's correlations $r = 0.76-0.86$, $p < 0.05$).[19] The participants were divided into 3 groups according to their WC: Group 1 had WC <94 and <80 cm (normal health risk for men and women, respectively), Group 2 had WC 94−102 and 80−87 cm (high health risk for men and women, respectively), and Group 3 had WC >102 and >87 cm (very high health risk for men and women, respectively).

The percentage of body fat was determined using 3-site skinfold measurements by a Harpenden caliper (Baty International, Burgess Hill, UK) or Lange skinfold caliper (Beta Technology Inc., Santa Cruz, CA, USA), depending on availability. Because fat distribution differs by gender,[20,21] the measurements were recorded at the chest, abdomen, and thigh for the men and at the triceps, suprailium, and thigh for the women. The mean of 2 measures were recorded to the nearest millimeter and the summed skinfold values were used to calculate body density.[22,23] The following equation was used for percentage of fat: (495/body density)−450.[24] The intra-variation between the Harpenden caliper and the Lange caliper is found to be small, accounting for ~1.5% of the variation in fat percentage.[25] The inter-rater reliability of skinfold measures have been found to vary from 3% to 9% in fat percentage.[26] To minimize the bias of inter-rater reliability, a detailed test protocol was developed combined with a thorough technician training.

2.3. Cardiopulmonary exercise test

CRF was measured using a modified Balke graded maximal exercise test. Gas exchange and ventilatory variables were sampled as the subjects breathed into a Hans Rudolph two-way breathing mask (2700 series; Hans Rudolph Inc., Shawnee, KS, USA). During the last part of the cardiopulmonary exercise test, the subject's effort was encouraged by the technician until voluntary termination. Rating of perceived exertion was obtained using the Borg Scale.[27] Gas exchange variables were reported as 30 s averages. The CRF test was accepted if the respiratory exchange ratio was ≥1.10 or the Borg score was ≥17. CRF was expressed in units of mL/kg/min or L/min. Each day, the gas analyzers used were calibrated for volume and gas and corrected for barometric pressure, temperature, and humidity. A detailed description of measurement accuracy between gas analyzers was provided elsewhere together with the participants' cardiorespiratory response during maximal exercise.[15]

2.4. Measurement of PA

The ActiGraph GT1M (ActiGraph, LLC, Pensacola, FL, USA) was used to assess participants' PA levels. Participants with a minimum of 4 days of at least 10 h of daily recordings were included in the analysis. Data were collected in 10 s epochs, which were collapsed into 60 s epochs for comparison with other studies. The data were reduced using an SAS-based macro (SAS Institute Inc., Cary, NC, USA). Wear time was defined by subtracting non-wear time from 18 h since all data between 00:00 and 06:00 were excluded to avoid potential bias due to participants forgetting to remove the monitor when going to bed at night. Non-wear time was defined as intervals of at least 60 consecutive minutes with 0 count, with allowance for 1 min with counts greater than 0.[28] For analysis of sedentary behavior, ActiLife 6.11.4 software (ActiGraph) was used to analyze the accelerometer data. The first sedentary break of each day was ignored to avoid a misclassification of non-wear time during evening as a sedentary break.

Average counts per minute (cpm) was expressed as the total number of registered counts for all valid days divided by wear

Table 1
Characteristics (mean ± SE) for men and women participating in the study.

Variable	Men ($n = 373$)	Women ($n = 349$)
Age (year)	49.3 ± 0.8	50.1 ± 0.8
WC (cm)	94.6 ± 0.6*	85.1 ± 0.6
Body fat (%)#	23.5 ± 0.5*	31.4 ± 0.4
BMI (kg/m^2)	26.3 ± 0.3*	25.2 ± 0.2
CRF (mL/kg/min)	39.8 ± 0.5*	32.3 ± 0.5
MVPA (≤2020 cpm, min/day)	38.3 ± 1.1	36.2 ± 1.2

* $p < 0.001$, compared with women.
\# According to valid data, n for body fat is lower due to missing data (men, $n = 219$; women, $n = 208$).
Abbreviations: BMI = body mass index; cpm = counts per minute; CRF = cardiorespiratory fitness; MVPA = moderate-to-vigorous physical activity; WC = waist circumference.

time. To identify PA of different intensities, count thresholds corresponding to the energy cost of the given intensity were applied to the data set. Sedentary time was defined as all activity below 100 cpm, a threshold that corresponds to sitting, reclining, or lying down.[29,30] Moderate-to-vigorous physical activity (MVPA) was defined as cpm ≤2020.[28] Mean min/day at different intensities was calculated as the sum of all minutes where the count met the criterion for that intensity, divided by the number of valid days.

2.5. *Statistics*

An independent sample *t* test was used for testing differences among sexes in Table 1, while a multivariate general linear model, adjusted for age and accelerometer wear time, was used to assess differences within the 3 groups of WC (Table 2). Correlations between MVPA, WC, BMI, body fat, and CRF were assessed by Pearson correlation coefficient (Table 3). A correlation <0.3 was defined as low, 0.3−0.49 as moderate, 0.5−0.7 as high, and >0.7 as a very high correlation.[31] To analyze the relationships between CRF and the correlates of sex, age, WC, and MVPA, hierarchical regression with enter procedure was applied. Preliminary analyzes of normal distribution were conducted to ensure that there was no violation of the assumptions of linear regression. The analysis contained 3 models with the biological variables of sex and age in the first, WC in the second, and MVPA in the third (Table 4). Data are presented as mean ± SE unless otherwise specified. The numbers of participants vary in tables according to valid data. A *p* value of less than 0.05 was regarded as statistically significant. All statistical analyzes were performed using IBM SPSS Statistics Version 21.0 (IBM Corp., Armork, NY, USA).

3. Results

Participant anthropometrics, CRF, and PA levels are presented in Table 1. CRF differed significantly across the 3 risk

Table 2
Cardiorespiratory fitness and physical activity variables for men and women within the 3 WC groups based at thresholds for abdominal obesity (mean ± SE).

	Men			Women		
	Normal risk <94 cm ($n = 188$)	High risk 94−102 cm ($n = 95$)	Very high risk >102 cm ($n = 90$)	Normal risk <80 cm ($n = 116$)	High risk 80−88 cm ($n = 109$)	Very high risk >88 cm ($n = 124$)
WC (cm)	86.5 ± 0.4	97.5 ± 0.5	108.2 ± 0.6	73.7 ± 0.5	83.5 ± 0.5	97.1 ± 0.5
CRF (mL/kg/min)	43.9 ± 0.5**	37.5 ± 0.7	33.5 ± 0.7**	36.0 ± 0.5**	32.1 ± 0.5	28.9 ± 0.5**
CRF (L/min)	3.37 ± 0.04	3.26 ± 0.06	3.29 ± 0.06	2.17 ± 0.04	2.17 ± 0.04	2.29 ± 0.04*
Total activity (count/min/day)	329 ± 5	331 ± 2	321 ± 8	353 ± 6	343 ± 6	342 ± 6
MVPA (≤2020 cpm, min/day)	43 ± 2	38 ± 2	30 ± 2*	39 ± 2	37 ± 2	33 ± 2#
Sedentary time (<100 cpm, min/day)	556 ± 5	554 ± 8	564 ± 8	526 ± 6	536 ± 6	537 ± 6

* $p < 0.02$, ** $p < 0.001$, compared with other groups within the same sex.
\# $p < 0.02$, compared with normal risk group within the same sex.
Abbreviations: cpm = counts per minute; CRF = cardiorespiratory fitness; MVPA = moderate-to-vigorous physical activity; WC = waist circumference.

Table 3
Correlation coefficients between CRF and WC, body fat, BMI, and MVPA in men ($n = 373$) and women ($n = 349$).

	CRF (mL/kg/min)		WC (cm)		Body fat (%)		BMI (kg/m^2)	
	Men	Women	Men	Women	Men	Women	Men	Women
CRF (mL/kg/min)	—	—						
WC (cm)	−0.66*	−0.49*	—	—				
Body fat (%)#	−0.64*	−0.45*	0.66*	0.64*	—	—		
BMI (kg/m^2)	−0.51*	−0.42*	0.78*	0.76*	0.57*	0.60*	—	—
MVPA (min/day)	0.28*	0.33*	−0.24*	−0.15*	−0.20*	−0.10	−0.23*	−0.13*

* $p < 0.01$;
\# n for body fat is lower due to missing data (men, $n = 219$; women, $n = 208$).
Abbreviations: BMI = body mass index; CRF = cardiorespiratory fitness; MVPA = moderate-to-vigorous physical activity; WC = waist circumference.

Table 4
Hierarchical regression analysis of variables of relative cardiorespiratory fitness (mL/kg/min) ($n = 722$).

Variable	Model 1			Model 2			Model 3		
	B	SE	R^2	B	SE	R^2	B	SE	R^2
Constant	43.77	1.27*		68.39	1.75*		63.68	1.81*	
Sex (female *vs*. male)	7.18	0.54*		10.85	0.49*		10.43	0.48*	
Age (year)	−0.37	0.02*		−0.29	0.02*		−0.29	0.02*	
WC (cm)				−0.38	0.02*		−0.35	0.02*	
MVPA (min/day)							−0.07	0.01*	
			0.46*			0.62*			0.65*

* $p < 0.01$.
Abbreviations: MVPA = moderate-to-vigorous physical activity; WC = waist circumference.

groups of WC for both men and women (Table 2). Men in the normal risk WC had a 31% higher CRF than men with the very high risk WC. The corresponding number for women was 25%. One percent of the men, and 10% of the women in the very high risk group had a CRF ≥ the mean CRF of the normal risk group.

There were no significant differences in daily PA (cpm), or in sedentary time (min/day) between the same 3 groups. Participants in the normal risk group performed 43% and 18% more MVPA than participants in the very high risk group for men and women, respectively.

Among the correlation coefficients between CRF and WC/percent body fat/BMI/MVPA, the highest correlation coefficient was found between CRF and WC in both men and women (Table 3). The correlation coefficient between CRF (in L/min) and WC was −0.28 ($p < 0.001$) for men and non-significant for women. The correlation coefficient between WC and body weight (kg) was 0.79 and 0.76 for men and women, respectively ($p < 0.001$).

The biological factors of sex and age included in the regression analysis displayed the largest amount of explanatory power, explaining 46% of the variance in CRF (Table 4). By including WC, the explanatory power increased to 62%, while a further inclusion of MVPA added only 3 more percent points to explanatory power of CRF (Table 4). For every centimeter increase in WC, CRF was reduced by 0.48 and 0.27 mL/kg/min in men and women, respectively ($p < 0.001$).

4. Discussion

This study examined whether the 3 WC groups—normal risk group, high risk group, and very high risk group—also reflected significant differences in CRF. The main findings were that men and women in the normal risk group had 31% and 25% higher CRF, respectively, than men and women in the very high risk group, and that small differences in WC reflected large differences in CRF.

The difference in CRF found between 3 different risk groups varied between 3.2 and 10.4 mL/kg/min. For every increase in CRF of approximately 3.5 mL/kg/min, there is convincing evidence that the risk of death is reduced by 17% in women[32] and 12% in men.[33] An 8% decline in CRF per decade after age 30 years in both sexes[15] has been found, meaning that the differences in CRF between participants in the normal risk group and in the very high risk group represented around 3−4 decades of aging. Thus, the current recommended WC thresholds for abdominal obesity are a useful instrument for detecting significant health-related differences in CRF.

No differences in overall PA and sedentary time were found within the 3 WC groups; however, participants with smaller WC performed significantly more MVPA. A stronger negative correlation coefficient was also found between WC and PA with increasing PA intensity (data not shown). These results suggest that participants with higher WC and lower CRF were not more sedentary or less physically active overall, but participated in less intense PA.

In the present study a moderate-to-high negative correlation was found between CRF and WC in both men ($r = -0.66$) and women ($r = -0.49$), indicating that a large WC is associated with low CRF. This is higher than previously reported for men (−0.38[11] and −0.65[12]), but is in line with corresponding data for women. Kim and So[12] adjusted the correlation coefficient for age in their analysis. Similar adjustments in the present study did not significantly change the correlation coefficient (data not shown). Importantly, both of these studies[11,12] have a large potential bias due to indirect estimation of CRF, in contrast to the present study, which directly measured CRF. In addition, the present study had twice as many participants. Our results support the finding of Kim and So,[12] and confirm a high correlation between CRF and WC, and that this relationship is stronger in men than women.

"Fit fat" is a term that is used to describe overweight people who nevertheless have good fitness. In the present study the fit fat group included the very high risk group participants (those with the highest WC) who had a CRF corresponding to the mean CRF (or higher) of the participants in the normal risk group. While 10% of the women in the very high risk group were defined as fit fat, the corresponding number of men was only 1%. Even after adjusting for a larger difference in CRF between the normal risk group and very high risk group in men, the proportion of fit fat men was less than half compared to women. This could be related to the finding of a stronger negative correlation between CRF and WC in men than women. Men tend to have a more abdominal obesity (apple shaped obesity) than women, who have a higher fat prevalence around thighs and bottom (pear shaped obesity).[34] However, the finding of 10 times more fit fat women than men in the very high risk group (who all had large waists) was surprising and could suggest that a sex independent WC threshold for CRF could be appropriate. Central obesity may reduce the pulmonary function and increase the work of breathing,[35,36] which may have a negative effect on ventilatory capacity, thereby reducing CRF.

MVPA is strongly correlated to general health and it is highly recommended to participate in MVPA on a daily basis.[37] However, the correlation between MVPA and CRF was much lower than between WC and CRF. Further analysis of data showed that differences in CRF were far greater between quartiles of WC than between quartiles of MVPA (data not shown). This could be explained by at least 2 factors. First, relative CRF (mL/kg/min) is absolute CRF (L/min) divided by body weight. The correlation between absolute CRF and WC was much lower than between relative CRF and WC, because WC and body weight were highly correlated. Second, MVPA is a more complex factor with higher measuring bias than WC, which is an easily measured and precise biological variable. Even though a standard accepted protocol for measurement of WC is missing, WC measurement protocol has no substantial influence on the association between WC and health risk factors.[38,39]

Table 3 shows that the correlations between WC, percent body fat, and BMI were between 0.57−0.78. The high internal correlations confirm that these factors are highly related and describe different aspects of obesity. BMI relates body weight with height. Body fat describes the proportion between fat and lean muscle mass, and WC describes the body shape by estimating abdominal fat. WC was the variable with the strongest correlation to CRF in both men and women, and was therefore used as the single factor in Model 2 in the regression analysis (Table 4). WC increased the explained variance (R^2) of CRF by 16%. By including an interaction term of sex and WC in the regression analysis (data not shown), WC for men had a 6% higher explained variance of CRF than women. The regression analysis also revealed that, for women, a 1-cm increase in WC reduced CRF just as much as 1 year of aging. For men, every 1-cm increase in WC reduced CRF by 0.5 mL/kg/min, which was 0.2 mL/kg/min or 60% more than 1 year of aging. This indicates that high WC has a major negative impact on CRF, especially for men. The CRF for men increased by around 1 mL/kg/min for every 2-cm reduction in WC, which was twice as much as for women, making it easy to estimate changes in CRF due to changes in WC.

The explained variance of CRF increased by only 3% by including MVPA in the regression analysis, which was surprisingly low. This could partly be explained by a low number of participants performing any significant amount of vigorous PA.

The strengths of the study include an objective measure of PA and the large sample size recruited from a wide age range throughout Norway. In addition, CRF was directly measured on a treadmill by gas analysis during a maximal exercise test and strict end criteria for CRF were used. The study has some limitations. First, the data are cross-sectional, therefore causality cannot be assumed. Second, 9 different test laboratories were used, with 3 different gas analyzer models, which may have increased the possibility of different test methods and measurement accuracies across the test laboratories. To minimize these differences all gas analyzers were compared and calibrated to an artificial lung. Further, a detailed test manual with instructions was written and all test personnel were rigorously trained in all test procedures. One test leader visited all test centers several times to ensure a uniformed test procedure. Third, the CRF and WC measurements were completed 5−8 months after the accelerometer-measured PA level. Participants' PA level could therefore have changed prior CRF testing. However, the largest seasonal variation in PA level in Norway is found between winter and summer (14% less PA during winter), with small differences between spring and autumn.[40] Because the accelerometer measurements were equally spread between autumn, winter and spring, and none of the participants were tested during the summer, the non-systematic bias due to seasonal variations seems low. A stable PA level over years among Norwegian adults is also supported by a longitudinal study over 6 years, reporting no secular change in accelerometer measured PA (total PA and MVPA) in a large Norwegian sample.[40] Finally, the study is limited by the lack of inter-rater reliability of the measurements. However, thorough staff training was performed and detailed test protocols were distributed to limit inter-tester variability.

5. Conclusion

This study indicates that a large WC is strongly negatively associated with CRF, especially for men. The recommended WC thresholds for abdominal obesity reflect significant health related differences in CRF, and enhance the value of WC as a useful, easily measured preliminary screening tool for health. WC showed higher correlation to CRF than BMI and body fat in both men and women. A 2-cm increase in WC reduced CRF by around 1 mL/kg/min in men, and 0.5 mL/kg/min in women, making WC suitable for estimating changes in CRF. The finding of 10 times more fit fat women than men in the very high risk group could suggest that a sex independent WC threshold for CRF could be appropriate, and should be further studied.

Acknowledgments

The authors thank all the test personnel at the 9 institutions involved in the study for their work during the data collection: Finnmark University College, Hedmark University College, NTNU Social Research AS, Sogn og Fjordane University College, University of Agder, University of Nordland, University of Stavanger, Telemark University College, and Norwegian School of Sport Sciences. The study was funded by The Norwegian Directorate of Health and the Norwegian School of Sport Sciences.

Authors' contributions

SMD was active in the planning of the study, analyzed and interpreted the data, and drafted the manuscript; EE was active in the planning of the study, controlled the equipment and quality of the test procedures, collected and interpreted the data, and reviewed the manuscript critically; BHH contributed to the conception and design of the study, coordinated the data collection, analyzed the data and reviewed the manuscript critically; SAA was project manager of the study, was active in design and conception of the study, discussed the interpretation of the data and reviewed the manuscript critically. All authors have read and approved the final version of this manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

References

1. Grundy SM, Cleeman JI, Daniels SR, Donato KA, Eckel RH, Franklin BA, et al. Diagnosis and management of the metabolic syndrome—an American Heart Association/National Heart, Lung, and Blood Institute Scientific Statement. *Circulation* 2005;**112**:2735–52.
2. Janssen I, Katzmarzyk PT, Ross R. Waist circumference and not body mass index explains obesity-related health risk. *Am J Clin Nutr* 2004;**79**:379–84.
3. Pischon T, Boeing H, Hoffmann K, Bergmann M, Schulze MB, Overvad K, et al. General and abdominal adiposity and risk of death in Europe. *N Engl J Med* 2008;**359**:2105–20.
4. Alberti KG, Eckel RH, Grundy SM, Zimmet PZ, Cleeman JI, Donato KA, et al. Harmonizing the metabolic syndrome. A joint interim statement of the International Diabetes Federation Task Force on epidemiology and prevention. *Circulation* 2009;**120**:1640–5.
5. World Health Organization (WHO). *Obesity: preventing and managing the global epidemic. Report of a WHO consultation*. Geneva: WHO; 2000.
6. Han TS, van Leer EM, Seidell JC, Lean ME. Waist circumference action levels in the identification of cardiovascular risk-factors—prevalence study in a random sample. *BMJ* 1995;**31**:1401–5.
7. Katzmarzyk PT, Bray GA, Greenway FL, Johnson WD, Newton Jr RL, Ravussin E, et al. Ethnic-specific BMI and waist circumference thresholds. *Obesity (Silver Spring)* 2011;**19**:1272–8.
8. Lee DC, Sui X, Church TS, Lavie CJ, Jackson AS, Blair SN. Changes in fitness and fatness on the development of cardiovascular disease risk factors hypertension, metabolic syndrome, and hypercholesterolemia. *J Am Coll Cardiol* 2012;**59**:665–72.
9. Lee DC, Sui X, Artero EG, Lee IM, Church TS, McAuley PA, et al. Long-term effects of changes in cardiorespiratory fitness and body mass index on all-cause and cardiovascular disease mortality in men the aerobics center longitudinal study. *Circulation* 2011;**124**:2483–90.
10. Lee DC, Artero EG, Sui X, Blair SN. Mortality trends in the general population: the importance of cardiorespiratory fitness. *J Psychopharmacol* 2010;**24**:27–35.
11. Dagan SS, Segev S, Novikov I, Dankner R. Waist circumference vs body mass index in association with cardiorespiratory fitness in healthy men and women: a cross sectional analysis of 403 subjects. *Nutr J* 2013;**12**:12. doi:10.1186/1475-2891-12-12.
12. Kim JH, So WY. Correlation of waist circumference and body mass index with VO_{2max} in Korean adults. *Healthmed* 2012;**6**:1632–5.
13. Åstrand PO, Rodal K, Dahl HA, Strłmme SB. Evaluation of physical performance on the basis of tests. *Textbook of work physiology*. Champaign, IL: Human Kinetics; 2002.p.284–8.
14. Hansen BH, Kolle E, Anderssen SA. *Physical activity level among adults and the elderly in Norway. Updated analyzes based on new national recommendations in 2014*. Oslo: Norwegian Directorate of Health; 2014. Report number IS-2183.
15. Edvardsen E, Hansen BH, Holme IM, Holme IM, Dyrstad SM, Anderssen SA. Reference values for cardiorespiratory response and fitness on the treadmill in a 20- to 85-year-old population. *Chest* 2013;**144**:241–8.
16. World Health Organization (WHO). *Waist circumference and waist-hip ratio: a report of a WHO expert consultation*. Geneva: WHO; 2008.
17. Kjaer IGH, Kolle E, Hansen BH, Anderssen SA, Torstveit MK. Obesity prevalence in Norwegian adults assessed by body mass index, waist circumference and fat mass percentage. *Clin Obes* 2015;**5**:211–8.
18. Barber J, Palmese L, Chwastiak LA, Ratliff JC, Reutenauer EL, Jean-Baptiste M, et al. Reliability and practicality of measuring waist circumference to monitor cardiovascular risk among community mental health center patients. *Community Ment Health J* 2014;**50**:68–74.
19. Sun Q, van Dam RM, Spiegelman D, Heymsfield SB, Willett WC, Hu FB. Comparison of dual-energy x-ray absorptiometric and anthropometric measures of adiposity in relation to adiposity-related biologic factors. *Am J Epidemiol* 2010;**172**:1442–54.
20. Kuk JL, Lee S, Heymsfield SB, Ross R. Waist circumference and abdominal adipose tissue distribution: influence of age and sex. *Am J Clin Nutr* 2005;**81**:1330–4.
21. Stevens J, Katz EG, Huxley RR. Associations between gender, age and waist circumference. *Eur J Clin Nutr* 2010;**64**:6–15.
22. Jackson AS, Pollock ML. Generalized equations for predicting body density of men. *Br J Nutr* 1978;**40**:497–504.
23. Jackson AS, Pollock ML, Ward A. Generalized equations for predicting body density of women. *Med Sci Sports Exerc* 1980;**12**:175–81.
24. Siri WE. The gross composition of the body. *Adv Biol Med Phys* 1956;**4**:239–80.
25. Gruber JJ, Pollock ML, Graves JE, Colvin AB, Braith RW. Comparison of Harpenden and Lange calipers in predicting body-composition. *Res Q Exerc Sport* 1990;**61**:184–90.
26. Lohman TG, Pollock ML, Slaughter MH, Brandon LJ, Boileau RA. Methodological factors and the prediction of body fat in female athletes. *Med Sci Sports Exerc* 1984;**16**:92–6.
27. Borg GA. Perceived exertion. *Exerc Sport Sci Rev* 1974;**2**:131–53.
28. Troiano RP, Berrigan D, Dodd KW, Mâsse LC, Tilert T, McDowell M. Physical activity in the United States measured by accelerometer. *Med Sci Sports Exerc* 2008;**40**:181–8.
29. Healy GN, Dunstan DW, Salmon J, Cerin E, Shaw JE, Zimmet PZ, et al. Objectively measured light-intensity physical activity is independently associated with 2-h plasma glucose. *Diabetes Care* 2007;**30**:1384–9.
30. Matthews CE, Chen KY, Freedson PS, Buchowski MS, Beech BM, Pate RR, et al. Amount of time spent in sedentary behaviors in the United States, 2003−2004. *Am J Epidemiol* 2008;**167**:875–81.
31. Field A. *Discovering statistics using IBM SPSS statistics: and sex and drugs and rock "n" roll*. 4th ed. Los Angeles, CA: Sage; 2013.
32. Gulati M, Pandey DK, Arnsdorf MF, Lauderdale DS, Thisted RA, Wicklund RH, et al. Exercise capacity and the risk of death in women: the St James Women Take Heart Project. *Circulation* 2003;**108**:1554–9.
33. Myers J, Prakash M, Froelicher V, Do D, Partington S, Atwood JE. Exercise capacity and mortality among men referred for exercise testing. *N Engl J Med* 2002;**346**:793–801.
34. Tchoukalova YD, Koutsari C, Votruba SB, Tchkonia T, Giorgadze N, Thomou T, et al. Sex- and depot-dependent differences in adipogenesis in normal-weight humans. *Obesity (Silver Spring)* 2010;**18**:1875–80.
35. Chen Y, Rennie D, Cormier YF, Dosman J. Waist circumference is associated with pulmonary function in normal-weight, overweight, and obese subjects. *Am J Clin Nutr* 2007;**85**:35–9.
36. Wadstrom C, Mullersuur R, Backman L. Influence of excessive weight-loss on respiratory-function—a study of obese patients following gastroplasty. *Eur J Surg* 1991;**157**:341–6.
37. Haskell WL, Lee IM, Pate RR, Powell KE, Blair SN, Franklin BA, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc* 2007;**39**:1423–34.
38. Ross R, Berentzen T, Bradshaw AJ, Janssen I, Kahn HS, Katzmarzyk PT, et al. Does the relationship between waist circumference, morbidity and mortality depend on measurement protocol for waist circumference? *Obes Rev* 2008;**9**:312–25.
39. Mason C, Katzmarzyk PT. Waist circumference thresholds for the prediction of cardiometabolic risk: is measurement site important? *Eur J Clin Nutr* 2010;**64**:862–7.
40. Hansen BH, Anderssen SA, Steene-Johannessen J, Ekelund U, Nilsen AK, Andersen ID, et al. *Physical activity and sedentary time among adults and elderly in Norway. National results 2014-15*. Oslo: Norwegian Directorate of Health; 2015. Report number IS-2367.