Stronger Associations of Sagittal Abdominal Diameter with Atherogenic Lipoprotein Subfractions than Waist Circumference in Middle-Aged U.S. White and Japanese Men

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Abstract

Objective—Both sagittal abdominal diameter (SAD) and waist circumference (WC) highly correlate with visceral adipose tissue (VAT) being linked to an atherogenic lipoprotein profile. However, it is uncertain whether SAD is a better correlate of atherogenic lipoprotein subfractions than WC. We examined relative associations of SAD versus WC with lipoprotein subfractions for U.S. white and Japanese men, concurrently examining the associations of VAT versus subcutaneous adipose tissue (SAT) with lipoprotein subfractions.

Methods—A population-based sample of 260 white and 282 Japanese men aged 40–49 was examined for VAT and SAT by computed tomography, SAD and WC by a portable sliding-beam caliper and a measuring tape, respectively, and lipoprotein subfractions by nuclear magnetic resonance spectroscopy.

Results—Both SAD and WC were significantly and positively associated with large VLDL and total and small LDL particle concentrations, and inversely associated with large HDL particle concentration for both white and Japanese men. In BMI-adjusted regression models, the significant associations of SAD remained for both white and Japanese men, whereas those of WC became non-significant for white men. When SAD and WC were simultaneously included into the BMI-adjusted models, the associations of SAD remained significant and statistically stronger than

those WC for both white and Japanese men. Furthermore, the pattern of the associations of SAD with those lipoprotein subfractions showed comparable to that of the associations of VAT.

Conclusion—SAD showed comparable to VAT and stronger than WC in the associations with atherogenic lipoprotein subfractions for middle aged, nondiabetic, white and Japanese men.

Keywords

adiposity; intra-abdominal fat; abdominal subcutaneous fat; sagittal abdominal diameter; waist circumference; lipoproteins

Lipoprotein subfractions may provide an atherogenic feature for prediction of the risk for coronary heart disease (CHD) (1–2). Epidemiological studies have demonstrated that total low-density lipoprotein (LDL) particle concentration is a more predictive measure for CHD risk than LDL cholesterol (1). Large high-density lipoprotein (HDL) particle concentration is protective against carotid atherosclerosis, coronary stenosis and cardiovascular events (1,3–4). Large very low-density lipoprotein (VLDL) and small LDL particle concentrations may be related to an increased prevalence of coronary calcification and cardiovascular risk (1,5).

Increased abdominal fat contributes to CHD risk (6–7). Of abdominal fat compartments, visceral adipose tissue (VAT) is an independent predictor of CHD risk (8–9), closely linked with metabolic abnormalities including elevated triglyceride levels (10). Compared to subcutaneous adipose tissue (SAT), VAT is more strongly associated with metabolic and cardiovascular factors, independent of overall obesity (11–12). More recently, VAT is more strongly associated with elevated atherogenic lipoprotein subfractions than SAT (13), including elevated concentrations of large VLDL and total and small LDL particles and a reduced concentration of large HDL particles (14). The elevated concentrations of atherogenic lipoprotein subfractions may be related to an increased secretion of triglyceride-rich lipoproteins induced by VAT-linked free fatty acids flux toward liver (15). Together with an increased activity of hepatic lipase, the elevation of triglyceride-rich lipoproteins (i.e., large VLDL particles) results in increased production of small LDL particles, which is concurrently responsible for decreased large HDL particles (16).

Abdominal adipose tissues including VAT and SAT can be measured by computed tomography which is not easily available in clinical practice to identify abdominally obese individuals. Waist circumference (WC) and sagittal abdominal diameter (SAD) are inexpensive and simple anthropometric measures of abdominal adipose tissues. WC is a major component of the diagnosis criteria of metabolic syndrome defined by the National Cholesterol Education Program's Adult Treatment Panel III and the International Diabetes Federation (17–18). SAD is a strong correlate of VAT (19–20). Several studies have suggested that SAD is a better correlate of cardiovascular and metabolic risk profile than WC, particularly including elevated triglycerides, reduced HDL cholesterol, and elevated apolipoprotein B levels (21–22). However, no previous studies have reported relative importance of SAD compared to WC in the associations with lipoprotein subfractions.

We hypothesized that SAD would be a better correlate of the profile of atherogenic lipoprotein subfractions than WC, concurrently examining the associations of VAT vs. SAT with those lipoproteins. We tested the hypothesis in each population-based sample of U.S. white men and Japanese men in Japan aged 40–49 years without cardiovascular disease and diabetes from the **E**lectron-beam tomography and **R**isk **A**ssessment in **J**apanese and **U**S men in the **p**ost-World War II birth (ERA-JUMP) cohort, a population-based cross-sectional study (23).

Methods

Study participants

During 2002 to 2006, a population-based sample of randomly-selected men aged 40 to 49 years was obtained: 310 whites from Allegheny County, Pennsylvania, U.S. and 313 Japanese men from Kusatsu, Shiga, Japan. (23) All the participants were without clinical cardiovascular disease, type 1 diabetes, cancer except skin cancer in the past 2 years, renal failure, and genetic familial hyperlipidemia. Of the original sample, we excluded men having lipid lowering medications (n=49), type 2 diabetes (n=26), and missing values (n=6). Type 2 diabetes was defined as fasting glucose ≥ 126 mg/dL or taking diabetes medication. The final sample was 542 (260 white and 282 Japanese men).

Written informed consents were obtained from all participants. The study was approved by the Institutional Review Boards of University of Pittsburgh, Pittsburgh, U.S. and Shiga University of Medical Science, Otsu, Japan.

All participants underwent a physical examination, and completed a lifestyle questionnaire (e.g., smoking and alcohol consumption) and a laboratory assessment as described previously (24). Venipuncture was performed early in the clinic visit after a 12-h fast, and samples were stored at −80°C and shipped on dry ice to the University of Pittsburgh. Data collection was standardized across research centers.

Body mass index and abdominal adiposity indices

Body mass index (BMI) was calculated using body weight and height (kg/m^2). WC and SAD were measured in underwear. WC was measured twice at the umbilical level using a measuring tape while the participant was standing upright, and an average of the two measurements was taken. SAD was measured using a portable sliding beam caliper (Holtain-Kahn Abdominal Caliper; Holtain Ltd., Dyfed, Wales). While the participant was laying supine on an examining table with leg straight, the base of caliper was placed under the subject's back and then caliper's upper arm was slid down to a point midway between iliac crests without compression. Then, a SAD, so called a height of abdomen (i.e., anterioposterior diameter), was determined with a ruler to the nearest millimeter of the caliper. An intra-observer coefficient was 2.5%; an intra-class coefficient was 95.8% (25). Areas of the whole abdominal adipose tissue (AAT) and VAT were determined at the level between the fourth and fifth lumbar vertebrae, using computed tomography (CT) images (GE-Imatron C150; GE Medical Systems, South San Francisco, CA). Areas of SAT were calculated as AAT minus VAT. Intra-class correlation coefficients at our reading center are 99% for SAT and 99% for VAT (26).

Lipoprotein measurements

Nuclear magnetic resonance (NMR) spectroscopy (LipoScience, Inc., Raleigh, NC) was performed to quantify serum lipoproteins of different size (27). Particle concentrations of the following lipoproteins were determined: VLDL (large, >60 nm; medium, 35–60 nm; and small, 27–35 nm), LDL ([intermediate-density lipoprotein (IDL), 23–27 nm; large, 21.3–23 nm; small, 18.3–21.2 nm), and HDL (large, 8.8–13.0 nm; medium, 8.2–8.8 nm; and small, 7.3–8.2 nm) (28). Weighted average particle sizes were calculated from the subclass levels.

Statistical analyses

To examine the association between each abdominal adiposity index (a primary predictor variable) and each lipoprotein (an outcome variable), the multiple linear regression analysis was performed using 3 different models. In model I, age, pack years of smoking, and alcohol consumption were adjusted for. In "model II", BMI was further adjusted for. Then in "model

III", SAD and WC or VAT and SAT were simultaneously added to model II. To determine if there was any significant difference in β coefficients between SAD and WC or between VAT and SAT in associations with each lipoprotein, the linear combinations of coefficient estimators were performed. Statistical significance was considered to be $P<.05$. All statistical analyses were performed with STATA 10.0 for Windows (StataCorp LP, College Station, TX).

Results

Our cohort had mean BMIs of 28 kg/cm^2 for white men and 24 kg/cm^2 for Japanese men (Table 1). According to BMI category defined by the World Health Organization (29), 71% of white men and 27% of Japanese men were overweight or obese. White men had significantly greater levels of VAT (cm^2) and SAT (cm^2) than Japanese men.

SAD and WC correlated highly with each other (r=.82 for white men and r=.75 for Japanese men) (Table 2). Age-adjusted partial correlation analysis showed that SAD appeared comparable with WC in the correlations with VAT, whereas SAD appeared weaker than WC in the correlations with SAT for both white and Japanese men. For additional information, we performed the multiple regression analysis for which SAD and WC were simultaneously included as predictor variables into the adjusted models for age and BMI. The analysis showed that both SAD and WC explained VAT significantly (beta=.23 and beta =.43, all for $P<.01$ for white men; beta=.23 and beta=.52, for $P<.001$ for Japanese men), and the coefficients between SAD and WC in the associations with VAT did not differ significantly. On the other hand, WC, but SAD, explained SAT significantly (beta =.72 for white men; beta=.71 for Japanese men, all for $P<.001$) for both white and Japanese men.

Both SAD and WC were significantly and positively associated with total and large VLDL particle concentrations for both white and Japanese men (model I); after further adjustment for BMI (model II), WC was not significantly associated any more for white men, but remained significantly associated for Japanese men (Table 3). In model II for Japanese men, WC appeared to have smaller R^2 values than SAD in the associations with total and large VLDL particle concentrations (R^2=.10 vs. R^2=.12 for total VLDL particle concentration; R^2=.07 vs. R^2=.09 for large VLDL particle concentration). Furthermore, when SAD and WC were simultaneously included into model III, WC was not significantly associated any more even for Japanese men. Both VAT and SAT were significantly and positively associated with large VLDL particle concentrations for both white and Japanese men (model I) (Table 3). After further adjustment for BMI (model II), such associations of SAT did not remain for white or Japanese men; for white men, SAT was significantly and inversely associated with large VLDL particle concentration.

Both SAD and WC were significantly and positively associated with total and small LDL and IDL particle concentrations, and inversely associated with LDL size for both white and Japanese men (model I) (Table 4). When SAD and WC were simultaneously included into model III, the significant associations of SAD remained for both white and Japanese men, whereas those of WC became non-significant for white men and attenuated for Japanese men; the associations of WC with total LDL and IDL particle concentrations for Japanese men became non-significant, and those of WC with small LDL particle concentration and LDL size attenuated (β=−10.37 to −6.24 for small LDL particle concentration; β= −.05 to −.03 for LDL size). However, the associations of SAD with small LDL particle concentrations and LDL size were statistically stronger than those of WC (Δ β between SAD and WC, P=.012 for small LDL particle concentration and P=.005 for LDL size). VAT was significantly and positively associated with total and small LDL and IDL particle concentrations, and

inversely associated with LDL size for both white and Japanese men in models I, II and III (Table 4). However, when VAT and SAT were simultaneously included into BMI-adjusted models (model III), SAT was not significantly associated with total and small LDL particle concentrations for both white and Japanese men; in particular, for white men, SAT showed an inverse association with small LDL particle concentration and a positive association with LDL size.

Both SAD and WC were significantly and inversely associated with large HDL particle concentration and HDL size for both white and Japanese men (model I) (Table 5). In further adjusted models II and III, SAD remained significantly associated, whereas WC was not significantly associated any more for white men, but still significantly associated for Japanese men. When SAD and WC were simultaneously included into model III, the associations of SAD with large HDL particle concentration and HDL size showed statistically stronger than those of WC (Δ β between SAD and WC, *P*=.037 for large HDL particle concentration and *P*=.025 for HDL size). VAT was significantly and inversely associated with large HDL particle concentration and HDL size for both white and Japanese men in models I, II, and III. When VAT and SAT were simultaneously included into BMI-adjusted models (model III), the significant associations of VAT remained, whereas those of SAT remained population-specific; significant and positive associations for white men vs. non-significant associations for Japanese men.

Discussion

In a cohort of middle-aged, non-diabetic men, both SAD and WC were significantly and positively associated with total and large VLDL and total and small LDL particle concentrations, and inversely associated with large HDL particle concentration and LDL and HDL sizes for both white and Japanese men. After further adjustment for BMI, the associations of SAD remained significant for both white and Japanese men, whereas those of WC became non-significant for white men. When SAD and WC were simultaneously included into the BMI-adjusted models, the associations of SAD were not only significant, but also statistically stronger than those of WC for both white and Japanese men. Furthermore, the pattern of the associations of SAD with those lipoprotein subfractions showed comparable to that of the associations of VAT.

Both SAD and WC correlate with VAT with similar magnitudes (30). However, concerning correlations with SAT, our finding suggests that SAD may correlate weakly with SAT, whereas WC may correlate strongly with SAT (see Results). Practically at the same height of abdomen (i.e., at the same SAD), an increase in WC may reflect increased fat slid transversely toward the sides of the waist in the supine position, being regarded as SAT. Kullberg et al. reported that transverse abdominal diameter correlated highly with SAT (20). The Framingham Heart Study reported that WC was a stronger correlate of SAT than VAT in middle-aged 1,984 men and women (31).

We found that, compared to SAT, VAT had stronger associations with higher particle concentrations of total, large, and medium VLDL and small LDL, and with a lower particle concentration of large HDL and lower average sizes of LDL and HDL for both white and Japanese men. These finding may support the notion that VAT is strongly linked with altered metabolism of triglyceride-rich lipoproteins, inducing non-esterified fatty acids flux to the liver (15). An increased secretion of triglyceride-rich lipoproteins (i.e., large VLDL particles) favors the transfer of triglyceride from triglyceride-rich lipoproteins to LDL and HDL through the action of cholesteryl ester transfer protein. During the process, hepatic lipase activity is increased, progressively lipolyzing the triglyceride-rich LDL and HDL to finally small LDL and HDL particles, respectively (32–33). Further, such process is also

related to the lowered HDL cholesterol which was noted to have a fairly linear relationship to lowered concentrations of large HDL particles (34–35).

We found that SAT showed weak associations with lipoprotein subfractions for both white and Japanese men, when VAT and SAT were simultaneously included into BMI-adjusted models. Even though VAT carries greater cardiovascular and metabolic risks (11–12), SAT has also been associated with the risks (11,36). However, increasing evidence indicates that the associations of SAT may be relatively weak (11,37–38) and possibly beneficial (39). Fox et al. reported that SAT showed weaker correlations with metabolic risk factors than VAT in Framingham Heart Study Offspring and Third-Generation Study Cohorts (11). Oka et al. that both VAT and SAT were significantly associated with metabolic risk factors in middle-aged Japanese men and women, but SAT did not remain significant when VAT and SAT were simultaneously included in the regression models (38). Furthermore, Sam et al. reported that SAT, unlike VAT, was not significantly associated with total VLDL and LDL particle concentrations in patients with type 2 diabetes in the CHICAGO trial Caucasian and African-American participants (13).

Additionally, we found that SAT had beneficially significant associations with large VLDL, small LDL and large HDL for white men. Recently, the Framingham Heart Study reported that, among individuals with high VAT (the highest tertile group of VAT), increased SAT was significantly associated with lower triglycerides levels, whereas, among individuals with low VAT (the lowest tertile group of VAT), increased SAT was significantly associated with higher triglycerides levels (39). Given the relation of hypertriglyceridemia to the lipoprotein metabolism as mentioned above, the beneficial associations of SAT with those lipoprotein subfractions found in our findings may parallel with the positive association of SAT with triglycerides levels found in the Framingham Heart Study. In this context, SAT may be protective against unfavorable redistribution of VLDL and LDL subfractions for white men who have a relatively greater absolute amount of VAT rather than for Japanese men who have a relatively less absolute amount of VAT.

We found that the pattern of the associations of SAD with atherogenic lipoprotein subfractions (i.e., large VLDL, total and small LDL, and large HDL particle concentrations) was comparable with that of VAT for both white and Japanese men. In our finding, SAD was a strong correlate of VAT for both white and Japanese men. Previous studies have revealed that SAD is the strongest correlate of VAT among other anthropometric abdominal adiposity measures including WC (20,40–41). Kvist et al. reported that, among anthropometric abdominal adiposity measures (i.e., WC and abdominal transverse diameters), SAD measured by a multiscan CT was the most predictive measure for the amount of visceral adipose tissue in both men and women with a wide range of body weights (40). Therefore, increased SAD may reflect a VAT-linked elevation of atherogenic lipoprotein subfractions well.

We found that SAD had stronger associations with atherogenic lipoprotein subfractions (i.e., large VLDL, total and small LDL, and large HDL particle concentrations) than WC for both white and Japanese men, independent of BMI. Previous studies have reported that SAD has stronger associations with insulin resistance and cardiometabolic risk factors known as being linked to VAT, than WC in the general population, middle-aged men and women, or obese men (21,42–43). To the best of our knowledge, our current study is the first to report stronger associations of SAD with atherogenic lipoprotein subfractions than WC, compared to relative associations of VAT vs. SAT across two ethnic population groups. This main finding may be possibly explained by relative contributions of SAD vs. WC to VAT vs. SAT, indicating a weaker contribution of SAD to SAT than WC as mentioned above. Therefore, to identify high risk abdominally visceral obese individuals linked with elevated

atherogenic lipoprotein subfractions, SAD may be a better measure than WC across white and Japanese men.

Strengths of our study include the incorporation of different ethnic population groups as well as the analysis of the relative associations of SAD vs. WC compared to those of VAT vs. SAT. Limitations of our study include the cross-sectional nature of the study design and generalizability to female, elderly or other race population groups.

In a cohort of middle-aged, non-diabetic men, the pattern of the associations of SAD showed comparable to that of the associations of VAT. Most notably, SAD had stronger associations with atherogenic lipoprotein subfractions, i.e., large VLDL, total and small LDL, and large HDL particle concentrations than WC for both white and Japanese men.

Acknowledgments

References

1. Mora S, Otvos JD, Rifai N, Rosenson RS, Buring JE, Ridker PM. Lipoprotein particle profiles by nuclear magnetic resonance compared with standard lipids and apolipoproteins in predicting incident cardiovascular disease in women. Circulation 2009 Feb 24;119(7):931–9. [PubMed: 19204302]

2. Kathiresan S, Otvos JD, Sullivan LM, Keyes MJ, Schaefer EJ, Wilson PW, et al. Increased small low-density lipoprotein particle number: a prominent feature of the metabolic syndrome in the Framingham Heart Study. Circulation 2006 Jan 3;113(1):20–9. [PubMed: 16380547]

3. Rosenson RS, Otvos JD, Freedman DS. Relations of lipoprotein subclass levels and low-density lipoprotein size to progression of coronary artery disease in the Pravastatin Limitation of Atherosclerosis in the Coronary Arteries (PLAC-I) trial. The American journal of cardiology 2002 Jul 15;90(2):89–94. [PubMed: 12106834]

4. Mora S, Szklo M, Otvos JD, Greenland P, Psaty BM, Goff DC Jr, et al. LDL particle subclasses, LDL particle size, and carotid atherosclerosis in the Multi-Ethnic Study of Atherosclerosis (MESA). Atherosclerosis 2007 May;192(1):211–7. [PubMed: 16765964]

5. Mackey RH, Kuller LH, Sutton-Tyrrell K, Evans RW, Holubkov R, Matthews KA. Lipoprotein subclasses and coronary artery calcium in postmenopausal women from the healthy women study. The American journal of cardiology 2002 Oct 17;90(8A):71i–6i.

6. Iribarren C, Darbinian JA, Lo JC, Fireman BH, Go AS. Value of the sagittal abdominal diameter in coronary heart disease risk assessment: cohort study in a large, multiethnic population. American journal of epidemiology 2006 Dec 15;164(12):1150–9. [PubMed: 17041127]

7. Rexrode KM, Carey VJ, Hennekens CH, Walters EE, Colditz GA, Stampfer MJ, et al. Abdominal adiposity and coronary heart disease in women. Jama 1998 Dec 2;280(21):1843–8. [PubMed: 9846779]

8. Fujimoto WY, Bergstrom RW, Boyko EJ, Chen KW, Leonetti DL, Newell-Morris L, et al. Visceral adiposity and incident coronary heart disease in Japanese-American men. The 10-year follow-up results of the Seattle Japanese-American Community Diabetes Study. Diabetes care 1999 Nov; 22(11):1808–12. [PubMed: 10546012]

9. Nicklas BJ, Penninx BW, Cesari M, Kritchevsky SB, Newman AB, Kanaya AM, et al. Association of visceral adipose tissue with incident myocardial infarction in older men and women: the Health, Aging and Body Composition Study. American journal of epidemiology 2004 Oct 15;160(8):741–9. [PubMed: 15466496]

10. Despres JP. Health consequences of visceral obesity. Annals of medicine 2001 Nov;33(8):534–41. [PubMed: 11730160]

11. Fox CS, Massaro JM, Hoffmann U, Pou KM, Maurovich-Horvat P, Liu CY, et al. Abdominal visceral and subcutaneous adipose tissue compartments: association with metabolic risk factors in the Framingham Heart Study. Circulation 2007 Jul 3;116(1):39–48. [PubMed: 17576866]

12. Pou KM, Massaro JM, Hoffmann U, Vasan RS, Maurovich-Horvat P, Larson MG, et al. Visceral and subcutaneous adipose tissue volumes are cross-sectionally related to markers of inflammation and oxidative stress: the Framingham Heart Study. Circulation 2007 Sep 11;116(11):1234–41. [PubMed: 17709633]

13. Sam S, Haffner S, Davidson MH, D'Agostino RB Sr, Feinstein S, Kondos G, et al. Relationship of abdominal visceral and subcutaneous adipose tissue with lipoprotein particle number and size in type 2 diabetes. Diabetes 2008 Aug;57(8):2022–7. [PubMed: 18469202]

14. Okazaki M, Usui S, Ishigami M, Sakai N, Nakamura T, Matsuzawa Y, et al. Identification of unique lipoprotein subclasses for visceral obesity by component analysis of cholesterol profile in high-performance liquid chromatography. Arteriosclerosis, thrombosis, and vascular biology 2005 Mar;25(3):578–84.

15. Despres JP. Is visceral obesity the cause of the metabolic syndrome? Annals of medicine 2006;38(1):52–63. [PubMed: 16448989]

16. Krauss RM. Lipids and lipoproteins in patients with type 2 diabetes. Diabetes care 2004 Jun;27(6): 1496–504. [PubMed: 15161808]

17. Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) final report. Circulation 2002 Dec 17;106(25):3143–421. [PubMed: 12485966]

18. International Diabetes Federation. IDF worldwide definition of the metabolic syndrome. 2008. [cited 2008 March 4]; Available from: http://www.idf.org/home/index.cfm?node=1429

19. Asayama K, Dobashi K, Hayashibe H, Kodera K, Uchida N, Nakane T, et al. Threshold values of visceral fat measures and their anthropometric alternatives for metabolic derangement in Japanese obese boys. Int J Obes Relat Metab Disord 2002 Feb;26(2):208–13. [PubMed: 11850752]

20. Kullberg J, von Below C, Lonn L, Lind L, Ahlstrom H, Johansson L. Practical approach for estimation of subcutaneous and visceral adipose tissue. Clinical physiology and functional imaging 2007 May;27(3):148–53. [PubMed: 17445065]

21. Ohrvall M, Berglund L, Vessby B. Sagittal abdominal diameter compared with other anthropometric measurements in relation to cardiovascular risk. Int J Obes Relat Metab Disord 2000 Apr;24(4):497–501. [PubMed: 10805508]

22. Richelsen B, Pedersen SB. Associations between different anthropometric measurements of fatness and metabolic risk parameters in non-obese, healthy, middle-aged men. Int J Obes Relat Metab Disord 1995 Mar;19(3):169–74. [PubMed: 7780492]

23. Sekikawa A, Curb JD, Ueshima H, El-Saed A, Kadowaki T, Abbott RD, et al. Marine-derived n-3 fatty acids and atherosclerosis in Japanese, Japanese-American, and white men: a cross-sectional study. J Am Coll Cardiol 2008 Aug 5;52(6):417–24. [PubMed: 18672160]

24. Sekikawa A, Ueshima H, Kadowaki T, El-Saed A, Okamura T, Takamiya T, et al. Less subclinical atherosclerosis in Japanese men in Japan than in White men in the United States in the post-World War II birth cohort. American journal of epidemiology 2007 Mar 15;165(6):617–24. [PubMed: 17244636]

25. Williamson D, Kahn H, Worthman C, Burnette J, Russell C. Precision of recumbent anthropometry. American Journal of Human biology 1993;5(2):159–67.

26. Kadowaki T, Sekikawa A, Murata K, Maegawa H, Takamiya T, Okamura T, et al. Japanese men have larger areas of visceral adipose tissue than Caucasian men in the same levels of waist circumference in a population-based study. International journal of obesity (2005) 2006 Jul;30(7): 1163–5. [PubMed: 16446744]

27. Otvos JD. Measurement of lipoprotein subclass profiles by nuclear magnetic resonance spectroscopy. Clin Lab 2002;48(3–4):171–80. [PubMed: 11934219]

28. Freedman DS, Otvos JD, Jeyarajah EJ, Shalaurova I, Cupples LA, Parise H, et al. Sex and age differences in lipoprotein subclasses measured by nuclear magnetic resonance spectroscopy: the Framingham Study. Clinical chemistry 2004 Jul;50(7):1189–200. [PubMed: 15107310]

29. World Health Organization. Global database on body mass index: BMI classification. 2008. [cited 2008 April 23]; Available from: http://www.who.int/bmi/index.jsp?introPage=intro_3.html

30. Clasey JL, Bouchard C, Teates CD, Riblett JE, Thorner MO, Hartman ML, et al. The use of anthropometric and dual-energy X-ray absorptiometry (DXA) measures to estimate total abdominal and abdominal visceral fat in men and women. Obes Res 1999 May;7(3):256–64. [PubMed: 10348496]

31. Paynter, NP.; Fox, CS.; Hoffman, U.; Pou, KM.; Vasan, RS.; D'Agostino, RB., et al. Waist circumference does not differentially detect visceral adipose tissue. American Heart Association: Nutrition, physical activity, and metabolism conference; March 11–13, 2008; Corolado Springs, Corolado: American Heart Association; 2008. p. 109(Abstract)

32. Zambon A, Hokanson JE, Brown BG, Brunzell JD. Evidence for a new pathophysiological mechanism for coronary artery disease regression: hepatic lipase-mediated changes in LDL density. Circulation 1999 Apr 20;99(15):1959–64. [PubMed: 10208998]

33. Carr MC, Ayyobi AF, Murdoch SJ, Deeb SS, Brunzell JD. Contribution of hepatic lipase, lipoprotein lipase, and cholesteryl ester transfer protein to LDL and HDL heterogeneity in healthy women. Arteriosclerosis, thrombosis, and vascular biology 2002 Apr 1;22(4):667–73.

34. Couture P, Otvos JD, Cupples LA, Wilson PW, Schaefer EJ, Ordovas JM. Association of the A-204C polymorphism in the cholesterol 7alpha-hydroxylase gene with variations in plasma low density lipoprotein cholesterol levels in the Framingham Offspring Study. Journal of lipid research 1999 Oct;40(10):1883–9. [PubMed: 10508208]

35. Otvos JD, Jeyarajah EJ, Cromwell WC. Measurement issues related to lipoprotein heterogeneity. The American journal of cardiology 2002 Oct 17;90(8A):22i–9i.

36. Abate N, Garg A, Peshock RM, Stray-Gundersen J, Grundy SM. Relationships of generalized and regional adiposity to insulin sensitivity in men. J Clin Invest 1995 Jul;96(1):88–98. [PubMed: 7615840]

37. Pou KM, Massaro JM, Hoffmann U, Lieb K, Vasan RS, O'Donnell CJ, et al. Patterns of abdominal fat distribution: the Framingham Heart Study. Diabetes care 2009 Mar;32(3):481–5. [PubMed: 19074995]

38. Oka R, Miura K, Sakurai M, Nakamura K, Yagi K, Miyamoto S, et al. Impacts of visceral adipose tissue and subcutaneous adipose tissue on metabolic risk factors in middle-aged Japanese. Obesity (Silver Spring) 2010 Jan;18(1):153–60. [PubMed: 19498348]

39. Porter SA, Massaro JM, Hoffmann U, Vasan RS, O'Donnel CJ, Fox CS. Abdominal subcutaneous adipose tissue: a protective fat depot? Diabetes care 2009 Jun;32(6):1068–75. [PubMed: 19244087]

40. Kvist H, Chowdhury B, Grangard U, Tylen U, Sjostrom L. Total and visceral adipose-tissue volumes derived from measurements with computed tomography in adult men and women: predictive equations. The American journal of clinical nutrition 1988 Dec;48(6):1351–61. [PubMed: 3202084]

41. Despres JP, Prud'homme D, Pouliot MC, Tremblay A, Bouchard C. Estimation of deep abdominal adipose-tissue accumulation from simple anthropometric measurements in men. The American journal of clinical nutrition 1991 Sep;54(3):471–7. [PubMed: 1877502]

42. Gustat J, Elkasabany A, Srinivasan S, Berenson GS. Relation of abdominal height to cardiovascular risk factors in young adults: the Bogalusa heart study. American journal of epidemiology 2000 May 1;151(9):885–91. [PubMed: 10791561]

43. Riserus U, Arnlov J, Brismar K, Zethelius B, Berglund L, Vessby B. Sagittal abdominal diameter is a strong anthropometric marker of insulin resistance and hyperproinsulinemia in obese men. Diabetes care 2004 Aug;27(8):2041–6. [PubMed: 15277437]

Table 1

Basic characteristics of the study participants in 2002–2006 (N=542)

	Mean (standard deviation) or Median (25th – 75th percentile)		
	White (n=260)	Japanese (n=282)	P
Age (years)	44.9 (2.8)	45.1 (2.8)	.343
BMI (kg/m²)	27.5 (3.9)	23.5 (3.0)	<.001
<25	75 (28.9)	206 (73.1)	
25–<30	122 (46.9)	68 (24.1)	
≥30	63 (24.2)	8 (2.8)	
VAT (cm²)	99.6 (42.2)	78.3 (30.8)	<.001
SAT (cm²)	145.8 (62.9)	79.3 (34.5)	<.001
WC (cm)	97.5 (10.8)	84.7 (8.0)	<.001
SAD(cm)	20.3 (2.7)	18.7 (1.8)	<.001
Systolic BP (mmHg)	122.6 (11.4)	124.5 (15.7)	.107
Diastolic BP (mmHg)	73.1 (8.9)	76.2 (11.7)	<.001
Hypertension (n (%))	33 (12.7).	68 (24.1)	.001
Hypertension medication (n (%))	15 (5.8)	12 (4.3)	.418
Pack years of smoking (years)	.3.5 (8.3)	19.8 (16.7)	<.001
Alcohol consumption (g/d)	10.3 (12.3)	26.2 (27.6)	<.001
Lipids			
Total cholesterol (mg/dL)	215.4 (37.1)	216.0 (34.8)	.844
Triglycerides (mg/dL)	148.9 (102.6) 124 (91 – 184.5)	151.2 (73.5) 134.5 (102 – 180)	.077
LDL-C (mg/dL)	137.7 (33.2)	131.6 (35.9)	.042
HDL-C (mg/dL)	48.5 (12.9)	54.2 (13.8)	<.001
Lipoprotein subfractions			
VLDL (nmol/L)			
Total	92.5 (43.7) 84.0 (61.2–117.9)	89.8 (44.9) 88.1(55.5–121.5)	.695
Large	4.4 (6.6) 1.6 (0.6–5.7)	2.5 (4.6) 0.4 (0.1–2.8)	<.001
Medium	40.7 (32.0) 33.8 (16.6–57.8)	44.5 (35.4) 39.6 (18.3–58.1)	.173
Small	47.4 (21.3) 45.6 (33.8–58.4)	42.8 (24.1) 40.9 (26.1–55.4)	.007
LDL (nmol/L)			

| | Mean (standard deviation) or Median ($25^{th} - 75^{th}$ percentile) | | | | |
	White (n=260)		Japanese (n=282)		P
Total	.1,472.7 (398.5)	1467.1(1171.3–1738.5)	1,382.9 (439.2)	1343 (1054–1677)	
Intermediate	52.1 (49.1)	41.8 (11.2–78.7)	32.9 (41.7)	16 (0–50)	.006
Large	.535.0 (278.4)	519.0 (311.6–725.0)	512.4 (230.0)	501(352–674)	<.001
Small	884.9 (505.8)	799.7 (482.2–1271.3)	837.6 (508.7)	806.5(471–1179)	.484
HDL (µmol/L)					
Total	31.3 (5.9)	30.9 (27.5–34.6)	35.2 (6.5)	34.8 (30.5–39.5)	.277
Large	5.1 (3.2)	4.7 (2.8–7.0)	8.7 (4.1)	8.4 (5.5–11.7)	<.001
Medium	1.1 (2.2)	0.03 (0–1.0)	2.8 (4.4)	1 (0–3.4)	<.001
Small	25.10 (4.47)	25.2 (22.0–28.3)	23.8 (5.5)	24.2 (20.2–27.5)	.003
Size (nm)					
VLDL	49.75 (7.76)	48.0 (44.7–53.0)	44.0 (7.5)	42.4 (39.2–48.5)	<.001
LDL	21.0 (.9)	21.0 (20.3–21.7)	21.1 (0.8)	21.1 (20.4–21.7)	.281
HDL	8.6 (.5)	8.5 (8.3–9.0)	9.1 (0.5)	9.1 (8.8–9.4)	<.001

Values are means (SD, standard deviation) and median ($25^{th} - 75^{th}$ percentile) for continuous variables and number (percentages) for categorical variables.

Difference between white and Japanese men: P values for categorical variables were obtained from χ^2 tests. P values for continuous variables were obtained from the t-test or Wilcoxon rank sum test

BP = blood pressure; BMI = body mass index; VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue; WC = waist circumference; SAD = sagittal abdominal diameter; VLDL = very low density lipoprotein; LDL = low-density lipoprotein; HDL = high-density lipoprotein.

Table 2

Age-adjusted partial correlations between adiposity indices for white and Japanese men (N=542)

	r (P<.001 for all)							
	White (n=260)				Japanese (n=282)			
	VAT	SAT	BMI	WC	VAT	SAT	BMI	WC
SAD	.69	.73	.81	.82	.69	.66	.72	.75
WC	.73	.88	.87		.78	.89	.89	
BMI	.69	.82			.72	.84		
SAT	.56				.70			

VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue; BMI = body mass index; WC = waist circumference; SAD = sagittal abdominal diameter;

Table 3

Multivariate-adjusted associations between abdominal adiposity indices and VLDL subfractions for white and Japanese men (N=542)

Outcome variables: VLDL particles	White β(R²) SAD	WC	Δ(SAD-WC) P	Japanese β(R²) SAD	WC	Δ(SAD-WC) P	White β(R²) VAT	SAT	Δ(VAT-SAT) P	Japanese β(R²) VAT	SAT	Δ(VAT-SAT) P
Total												
Model I	4.33* (.09)	.70‡ (.04)		8.20* (.12)	1.65* (.10)		.26* (.08)	.07 (.02)		.50* (.13)	.32* (.07)	
Model II	5.24† (.09)	.06 (.05)		7.41* (.12)	1.78‡ (.10)		.23† (.08)	−.13 (.06)		.49* (.13)	.14 (.08)	
Model III	6.21† (.09)	−.72 (.09)	.001	6.41† (.12)	.97 (.12)	.035	.23† (.09)	−.12 (.09)	.002	.49* (.13)	<.01 (.13)	.022
Large												
Model I	1.06* (.21)	.18* (.11)		.62* (.09)	.12* (.07)		.06* (.18)	.02† (.06)		.04* (.11)	.02† (.05)	
Model II	1.01* (.21)	−.04 (.16)		.64† (.09)	.16‡ (.07)		.05* (.20)	−.03† (.19)		.05* (.12)	.01 (.06)	
Model III	1.29* (.24)	−.21† (.24)	<.001	.54‡ (.09)	.09 (.09)	.094	.05* (.23)	−.03† (.23)	<.001	.06‡ (.12)	−.01 (.12)	.003
Medium												
Model I	2.58* (.07)	.43‡ (.04)		5.30* (.07)	1.04* (<.01)		.15† (.06)	.03 (.02)		.38* (.11)	.20† (.04)	
Model II	2.12 (.07)	−.29 (.06)		4.89† (.07)	1.08 (.06)		.09 (.06)	−.15† (.08)		.44* (.11)	.06 (.05)	
Model III	3.03‡ (.08)	−.67 (.08)	.017	4.34‡ (.08)	.53 (.08)	.067	.09 (.09)	−.15† (.09)	.005	.46* (.11)	−.07 (.11)	.002
Small												
Model I	.68 (.01)	.08 (.01)		2.28† (.06)	.49† (.05)		.05 (.01)	.02 (.01)		.08 (.04)	.11‡ (.05)	
Model II	2.11‡ (.03)	.40 (.02)		1.88 (.06)	.54 (.05)		.09‡ (.02)	.05 (.01)		−.01 (.05)	.07 (.05)	
Model III	1.89‡ (.03)	.16 (.03)	.097	1.52 (.06)	.35 (.06)	.411	.10‡ (.03)	.06 (.03)	.487	−.02 (.05)	.08 (.05)	.378
Size												
Model I	.88* (.12)	.18* (.09)		.25 (.04)	.06 (.04)		.06* (.12)	.02† (.05)		.03 (.05)	.01 (.04)	
Model II	.47 (.13)	−.05 (.12)		.21 (.04)	.08 (.04)		.04‡ (.14)	−.03‡ (.14)		.04 (.05)	−.01 (.04)	
Model III	.65‡ (.14)	−.13 (.14)	.032	.15 (.04)	.06 (.04)	.848	.03‡ (.16)	−.03‡ (.16)	.001	.04‡ (.06)	−.01 (.06)	.120

*P<0.001,

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[†] $P<0.01$,

[‡] $P<0.05$

SAD= sagittal abdominal diameter; WC= waist circumference; VAT = visceral adipose tissue; SAT= subcutaneous adipose tissue For models, the outcome variable is lipoprotein concentration or size; the primary predictor variable is each abdominal adiposity index (SAD, WC, VAT or SAT). Model I: adjusted models for age, pack years of smoking, and alcohol consumption. Model II: adjusted models for further BMI. Model II: BMI-adjusted models when SAD and WC were simultaneously included.

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Table 4

Multivariate-adjusted associations between abdominal adiposity indices and LDL subfractions for white and Japanese men (N=542)

Outcome variables: LDL particles	Predictor variables: abdominal adiposity indices															
	White				Japanese				White				Japanese			
	β (R²)		Δ (SAD-WC)	P	β (R²)		Δ (SAD-WC)	P	β (R²)		Δ (VAT-SAT)	P	β (R²)		Δ (VAT-SAT)	P
	SAD	WC			SAD	WC			VAT	SAT			VAT	SAT		
Total																
Model I	38.18*(.09)	7.08†(.05)			102.52*(.20)	23.19*(.21)			2.75*(.10)	.77(.03)			6.39*(.23)	4.99*(.18)		
Model II	33.11‡(.09)	−.91(.07)			70.23‡(.22)	19.93†(.21)			2.41*(.10)	−1.24(.08)			4.93*(.24)	2.79‡(.19)		
Model III	41.41‡(.09)	−6.10(.09)	.013		57.02†(.23)	12.73(.23)	.061		2.38†(.11)	−1.20(.11)	<.001		4.60*(.24)	1.45(.24)	.104	
Intermediate																
Model I	5.27*(.11)	.81†(.05)			5.56*(.07)	1.07†(.05)			.30*(.09)	.08(.03)			.39*(.09)	.21†(.04)		
Model II	6.25†(.11)	−.15(.07)			6.10†(.07)	1.68‡(.06)			.24‡(.09)	−.18‡(.09)			.49*(.10)	.18(.04)		
Model III	7.79*(.12)	−1.13(.12)	<.001		5.01‡(.08)	1.05(.08)	.107		.24‡(.11)	−.18‡(.11)	.001		.48*(.10)	.03(.10)	.026	
Large																
Model I	−22.82*(.06)	−3.78‡(.03)			−39.41*(.11)	−7.81*(.09)			−1.44*(.06)	−.30(.01)			−2.73*(.15)	−1.38*(.06)		
Model II	−22.41‡(.06)	1.40(.04)			−39.20*(.11)	−10.37†(.09)			−1.14‡(.06)	1.10‡(.06)			−3.23(.15)	−.46(.07)		
Model III	−29.32‡(.07)	5.07(.07)	.011		−32.72†(.12)	−6.24(.12)	.045		−1.12‡(.08)	1.08‡(.08)	.002		−3.34*(.15)	.51(.15)	<.001	
Small																
Model I	55.73*(.11)	10.04†(.07)			136.36*(.24)	29.93*(.23)			3.89*(.12)	.99‡(.04)			8.74*(.29)	6.16*(.19)		
Model II	49.27†(.11)	−2.15(.09)			103.30*(.25)	28.62*(.23)			3.31†(.13)	−2.15‡(.11)			7.67*(.29)	3.08‡(.20)		
Model III	62.95†(.12)	−10.05(.12)	.002		84.69*(.27)	17.93‡(.27)	.012		3.25†(.15)	−2.09‡(.15)	.000		7.46*(.29)	.91(.29)	.003	
Size																
Model I	−.11*(.12)	−.02*(.07)			−.22*(.23)	−.05*(.20)			−.01*(.13)	−.01‡(.04)			−.01*(.29)	−.01*(.16)		
Model II	−.10†(.12)	<.01(.09)			−.19†(.24)	−.05*(.20)			−.01†(.13)	<.01‡(.11)			−.01*(.29)	−.01(.17)		
Model III	−.12†(.13)	.02(.13)	.001		−.16†(.25)	−.03‡(.25)	.005		−.01†(.15)	<.01‡(.15)	<.001		−.01*(.29)	−.01(.29)	<.001	

*P<0.001,

†$P<0.01$,

‡$P<0.05$

SAD = sagittal abdominal diameter; WC = waist circumference; VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue For models, the outcome variable is lipoprotein concentration or size; the primary predictor variable is each abdominal adiposity index (SAD, WC, VAT or SAT). Model I: adjusted models for age, pack years of smoking, and alcohol consumption. Model II: adjusted models for further BMI. Model II: BMI-adjusted models when SAD and WC were simultaneously included.

Table 5

Multivariate-adjusted associations between abdominal adiposity indices and HDL subfractions for white and Japanese men (N=542)

| Outcome variables: HDL particles | Predictor variables: abdominal adiposity indices | | | | | | | | | | | | | | | |
| | White | | | | Japanese | | | | White | | | | Japanese | | | |
	β (R²) SAD	WC	Δ (SAD-WC)	P	β (R²) SAD	WC	Δ (SAD-WC)	P	β (R²) VAT	SAT	Δ (VAT-SAT)	P	β (R²) VAT	SAT	Δ (VAT-SAT)	P
Total																
Model I	−.35† (.13)	−.10† (.14)			−.16 (.24)	−.06 (.24)			−.02† (.13)	−.01‡ (.12)			.01 (.24)	−.01 (.24)		
Model II	−.13 (.14)	−.08 (.14)			.10 (.24)	−.03 (.24)			−.01 (.14)	<.01 (.14)			.04‡ (.26)	−.01 (.24)		
Model III	−.02 (.14)	−.08 (.14)	.843		.15 (.24)	−.05 (.24)	.565		−.01 (.14)	<.01 (.14)	.404		.04‡ (.26)	−.01 (.26)	.047	
Large																
Model I	−.44* (.20)	−.09* (.15)			−1.04* (.26)	−.23* (.26)			−.03* (.19)	−.01* (.11)			−.06* (.28)	−.05* (.21)		
Model II	−.31† (.21)	.02 (.19)			−.79* (.27)	−.25* (.26)			−.02† (.21)	.01‡ (.20)			−.05* (.29)	−.03‡ (.22)		
Model III	−.41† (.22)	.07 (.22)	.001		−.61† (.29)	−.17† (.29)	.037		−.02† (.23)	.01‡ (.23)	<.001		−.05* (.29)	−.01 (.29)	.015	
Medium																
Model I	.02 (.01)	−.01 (.01)			.05 (.16)	−.01 (.16)			<.01 (.01)	−.01 (.01)			.01 (.17)	<.01 (.17)		
Model II	.03 (.01)	−.05‡ (.03)			.23 (.17)	.04 (.17)			−.01 (.01)	−.01 (.02)			.03† (.19)	.02 (.18)		
Model III	.12 (.03)	−.07‡ (.03)	.080		.21 (.17)	.02 (.17)	.424		−.01 (.02)	−.01 (.02)	.416		.03† (.20)	.02 (.20)	.032	
Small																
Model I	.07 (.04)	.01 (.04)			.83* (.11)	.18* (.10)			.01 (.04)	−.01 (.04)			.06* (.14)	.03† (.07)		
Model II	.15 (.04)	−.05 (.04)			.66† (.17)	.18‡ (.10)			.01 (.04)	−.01 (.04)			.06* (.14)	−.01 (.09)		
Model III	.26 (.05)	−.08 (.05)	.121		.55‡ (.11)	.11 (.11)	.161		.01 (.04)	−.01 (.04)	.289		.06* (.14)	−.02 (.14)	.001	
Size																
Model I	−.07* (.22)	−.01* (.15)			−.13* (.28)	−.03* (.29)			−.01* (.19)	−.01* (.12)			−.01* (.35)	−.01* (.24)		
Model II	−.06* (.23)	−.01 (.18)			−.08* (.31)	−.03* (.30)			−.01† (.21)	<.01 (.18)			−.01* (.36)	−.01‡ (.27)		
Model III	−.07* (.23)	.01 (.23)	<.001		−.07† (.33)	−.02‡ (.33)	.025		−.01† (.21)	<.01 (.21)	.005		−.01* (.36)	−.01 (.36)	.001	

*P<0.001,

[†]$P < 0.01$,

[‡]$P < 0.05$

SAD = sagittal abdominal diameter; WC = waist circumference; VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue For models, the outcome variable is lipoprotein concentration or size; the primary predictor variable is each abdominal adiposity index (SAD, WC, VAT or SAT). Model I: adjusted models for age, pack years of smoking, and alcohol consumption. Model II: adjusted models for further BMI. Model II: BMI-adjusted models when SAD and WC were simultaneously included.