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Sedentary Behavior, Physical Activity, and Abdominal Adipose Tissue Deposition

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Abstract

Purpose—We examined whether sedentary lifestyle habits and physical activity level are associated with abdominal visceral adipose tissue (VAT), subcutaneous adipose tissue (SAT), intermuscular adipose tissue (IMAT), and liver attenuation, independently of each other and potential confounders.

Methods—Analysis of 3,010 African American and Caucasian men and women, aged 42–59 years, from the Coronary Artery Risk Development in Young Adults (CARDIA) study who completed multiple-slice abdominal computed tomography (CT) in 2010–2011. Participants reported average hours per day sitting (television, computing, paperwork, music, telephone, car). Physical activity was assessed with the CARDIA Physical Activity History. VAT, SAT, IMAT, and liver attenuation were estimated from CT. Multivariable general linear regression models regressed means of fat depots on total sedentary time, task-specific sedentary time, and total physical activity.

Results—Television-viewing was positively, and physical activity inversely, associated with fat depots. For each 1 SD increment in television-viewing (1.5 hours/day), VAT, SAT, and IMAT were greater by 3.5 cm^3, 3.4 cm^3, and 3.9 cm^3, respectively ($p<0.03$ for all). For each 1 SD increment in physical activity (275 exercise units), VAT, SAT, and IMAT were lower by 7.6 cm^3, 6.7 cm^3, and 8.1 cm^3, respectively, and liver attenuation was greater (indicating more liver fat) by 0.5 Hounsfield Units ($p<0.01$ for all). Total sedentary time was associated with VAT, IMAT, and liver attenuation in White men only after controlling for physical activity, SAT, and other potential confounders ($p\leq0.01$ for all). No other task-specific sedentary behaviors were associated with fat depots.

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Conflict of Interest:

The authors report no conflicts of interest. The results of the present study do not constitute endorsement by the American College of Sports Medicine. The results of the study are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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Conclusions—Sedentary behaviors, particularly television viewing, and physical activity levels have distinct, independent associations with fat deposition.

Keywords

visceral adipose tissue; subcutaneous adipose tissue; intermuscular adipose tissue; liver attenuation

Introduction

Abdominal obesity is an established risk factor for both metabolic and cardiovascular diseases (7). Excess levels of fat located within the intra-abdominal cavity in particular, including visceral adipose tissue (VAT), intermuscular adipose tissue (IMAT) and liver fat, are associated with an increased risk of insulin resistance, dyslipidemia, glucose intolerance, hypertension, and cardiovascular disease (23, 27, 32, 33). Subcutaneous adipose tissue (SAT) on the other hand may be relatively less important in the pathophysiology of chronic disease development (15).

General adiposity has a number of putative contributors, and level of physical activity is considered a key factor. The health benefits of physical activity are well established, and include a reduction in risk for many common chronic diseases, as well as reducing fat deposition, independent of body mass index (BMI) (19). Recent studies have identified associations between sedentary behaviors (e.g. sitting or lying down) and adverse health outcomes, including cardiovascular disease, diabetes, cancer, and all-cause mortality (3). Cross-sectional evidence also suggests that meeting guidelines for physical activity may not be sufficient for chronic disease prevention if accompanied by high levels of sedentary time (11). A potential pathway through which sedentary behavior may independently predict chronic disease progression is body composition, particularly amount and type of intra-abdominal fat depots.

Few studies have examined the associations between sedentary behavior and intra-abdominal fat depots, with mixed results. Some evidence suggests a positive association between sedentary time and VAT (13, 26, 31), while other studies report no association (20, 22, 29). To our knowledge, only one study has examined the associations between sedentary behavior and liver fat (13), or sedentary behavior and abdominal IMAT (20), two fat depots that may be independent predictors of metabolic risk (27, 33). Previous studies examining sedentary behavior and intra-abdominal fat depots have been limited by small samples with little racial/ethnic diversity.

We address these important gaps in the literature by studying a large sample of Black and White men and women who completed a detailed sedentary behavior questionnaire and had computed tomography (CT) measured abdominal VAT, SAT, IMAT and liver attenuation (a diagnostic method to assess liver fat). The aim of this study was to examine whether sedentary lifestyle habits and physical activity level are associated with abdominal fat depots (VAT, SAT, and IMAT) and liver attenuation, independent of each other and potential confounders. We hypothesized that sedentary time would be positively, and physical activity level inversely, associated with abdominal fat depots, and that sedentary time and physical activity would be independent and additive in their prediction of abdominal fat depots.

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Given the known race and sex differences in abdominal adipose distribution (18, 30) and the potential differential effects on cardiovascular disease risk (1, 9), we also examined if these associations vary by sex and race.

Methods

Coronary Artery Risk Development in Young Adults (CARDIA) is an ongoing prospective cohort study of 5,115 Black and White men and women who were initially recruited in 1985–1986 from four urban centers: Birmingham, Alabama; Minneapolis, Minnesota; Chicago, Illinois; and Oakland, California. Participants completed additional measurement visits in 1987–1988 (Year 2), 1990–1991 (Year 5), 1992–1993 (Year 7), 1995–1996 (Year 10), 2000–2001 (Year 15), 2005–2006 (Year 20), and 2010–2011 (Year 25). A total of 3,173 participants who underwent abdominal computed tomography (CT) scans in year 25 had complete data on VAT, SAT, and IMAT. Of those with complete VAT, SAT, and IMAT data, 36 participants did not complete a sedentary behavior or physical activity questionnaire, and 127 were missing data on study covariates, resulting in a final sample size of 3,010 for analyses of VAT, SAT, and IMAT. After the above exclusions, data on liver attenuation was available for 2,995 participants. Heavy alcohol consumption (>4 drinks per day for men and >3 drinks per day for women), but not moderate alcohol consumption (>2 drinks per day for men, >1 drink per day for women), was associated with lower liver attenuation. We therefore excluded an additional 78 participants who reported heavy alcohol consumption, resulting in a final sample of 2,917 for analyses of liver attenuation. Written informed consent was obtained from all participants at each exam, and the institutional review board at each of the clinical centers approved all study protocols.

Measures

Sedentary behavior was assessed with a self-reported questionnaire. Participants were asked how much time they spend sitting while engaging in six separate sedentary tasks: (1) watching television; (2) using the computer for non-work activities or playing video games; (3) doing non-computer office work or paperwork; (4) listening to music, reading a book or magazine, or doing arts and crafts; (5) talking on the phone or texting; and (6) sitting in a car, bus, train or other mode of transportation. Time spent in these sedentary tasks was queried separately for the average weekday and average weekend day. Response options were none, 15 minutes or less, 30 minutes, 1 hour, 2 hours, 3 hours, 4 hours, 5 hours, or 6 hours or more. Average sedentary hours per day for each of the six different tasks (television, computer, paperwork, music, phone, and car) was computed by multiplying the reported time spent in each activity on a weekday by five, and time spent in each activity on a weekend day by two, summing these two values to get average hours in each sedentary activity per week. The number of hours spent per week in each sedentary task, separately, was then divided by seven to get average sedentary hours per day. Total sedentary time per day was then calculated by summing the averages across the six different tasks.

Physical activity was assessed by self-report with the validated CARDIA Physical Activity History (8, 16, 17). Participants were asked to report the frequency of participation in 13 different activities (eight vigorous, five moderate) related to recreational sports, exercise,

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leisure, and occupational activities. Vigorous activities included: jogging or running; racket sports; bicycling faster than 10 miles per hour; swimming; vigorous exercise classes; lifting, carrying, or digging while on the job; snow shoveling, moving heavy objects or weight lifting; and other strenuous sports (e.g. basketball). Moderate or more leisurely activities included: non-strenuous sports (e.g. softball); walks or hikes; bowling or golf; home exercise or calisthenics; and home maintenance or gardening. Total moderate and vigorous physical activity was calculated by multiplying the number of months the activity was performed by the intensity of the activity, weighting activities performed more frequently, and then summing across all activities. Details on frequency or duration of physical activity was not directly assessed; therefore physical activity is expressed in exercise units, with separate scores for moderate and heavy intensity activity, and for total physical activity. Approximately 300 exercise units are roughly equivalent to meeting physical activity recommendations, or 30 minutes of moderate intensity activity, 5 days per week (8). A validation study of the CARDIA Physical Activity questionnaire found that heavy physical activity was significantly associated with maximal oxygen consumption ($r=0.63$), accelerometer measured activity ($r=0.31$), and total 4-week activity history ($r=0.54$; all $p<0.05$) (16). Inverse associations have also been reported between total physical activity, assessed by the CARDIA physical activity history, and metabolic risk factors (5).

Abdominal adipose tissue depots were measured using CT scans, which were conducted at each of the CARDIA field centers at year 25. A non-contrast CT scan of the abdomen was performed with multidetector CT scanners (GE 750HD and GE LightSpeed VCT models were used at the Birmingham and Oakland Centers, respectively; GE Healthcare, Waukesha WI; Siemens Sensation 64 models were used at both Chicago and Minneapolis Centers; Siemens Medical Solutions, Erlangen, Germany). The images were electronically transmitted to a CT reading center for image analysis and quality control at Wake Forest University School of Medicine, Winston-Salem, NC. CT scans of the abdomen were reconstructed into 5 mm slices with a maximum 50 cm field-of-view to include the whole abdomen. Adipose tissue depots were measured volumetrically from two adjoining five mm slices located at the level of the lumbar disk between the 4th and 5th vertebra (L3-L4 for IMAT, to avoid interference with a pelvic bone). Tissues with attenuation between -190 to -30 Hounsfield units were defined as adipose tissue. Analysts segmented the images based on anatomical boundaries into the entire abdomen, abdominal wall, and intra-abdominal compartments using the Medical Image Processing, Analysis, and Visualization application (http://mipav.cit.nih.gov/index.php). VAT, SAT, and IMAT were quantified in each compartment.

Liver attenuation, a diagnostic method to assess liver fat, was measured using non-contrast CT images of the upper abdomen while in axial scan mode. Averages of three distinct CT slices at the level of the T12-L1 intervertebral space were calculated to provide mean hepatic attenuation in Hounsfield Units (HU). Analysts were trained to avoid regions that included common hepatic lesions and hepatic vasculature. Liver attenuation is inversely related to liver fat content, such that lower levels of liver attenuation indicate higher levels of liver fat (10).

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Study covariates assessed at year 25 included age, sex, race, education (years completed), study center, smoking (never, former, current), alcohol consumption (ml/day), fast food intake (frequency/week), sugar-sweetened beverage consumption, including regular soda and sweetened fruit drinks, sports, or energy drinks (frequency/week), and body mass index (BMI, kg/m^2). For anthropometric measures, participants were dressed in light clothing without shoes. Body weight was measured to the nearest 0.2 kg using a calibrated balance beam scale. Height was measured using a vertical rule to the nearest 0.5 cm. BMI was calculated as weight in kilograms divided by height in meters squared.

Statistical analyses

All statistical analyses were conducted using SAS, version 9.4 (SAS Institute, Inc., Cary, North Carolina). Distributions of variables were examined; all dependent variables were approximately normal with low skewness and kurtosis. Total sedentary behavior and total physical activity were categorized into tertiles for descriptive purposes. A linear trend over sedentary and physical activity tertiles was tested using linear regression or Chi-square test of independence, as appropriate. Differences by race and sex were tested using one-way ANOVA. Due to skewed distributions of independent variables (sedentary behaviors and physical activity), spearman correlation coefficients were used to examine bivariate associations between abdominal adiposity measures, sedentary behaviors, and physical activity.

The first set of multivariable general linear regression models regressed means of VAT, SAT, IMAT, and liver attenuation on total sedentary time, followed separately by task-specific sedentary time (i.e. television, computer, paperwork, music, phone, and car). Model 1 adjusted for center, age, sex, race, education, smoking, alcohol, fast food intake and sugar-sweetened beverage consumption. Model 2 additionally adjusted for total physical activity. Model 3 additionally adjusted for SAT in the models for VAT, IMAT, and liver attenuation. The betas for sedentary time in model 3 can be interpreted as the unique statistical effects of intra-abdominal fat depots, independent of any effects on total abdominal fat. The SAT models were adjusted for VAT. In model 4, we additionally adjusted for BMI (in addition to SAT or VAT) in order to further test for independence from effects of sedentary time on overall body size.

The second set of linear regression models regressed means of VAT, SAT, IMAT, and liver attenuation on total physical activity, followed separately by moderate and then heavy physical activity. The physical activity models followed the same pattern of adjustment as the sedentary behavior models; however, models 2–4 adjusted for total sedentary time, not total physical activity. All four models are displayed for total sedentary time. Because the addition of BMI beyond that of SAT or VAT did not appreciably alter study findings, only final models are included for task-specific sedentary time and physical activity. The beta regression coefficients for sedentary behaviors and physical activity models were standardized (e.g. 1 standard deviation [SD] total sedentary behavior = 4.0 hours/day, 1 SD television time = 1.5 hours/day, 1 SD total physical activity = 275 exercise units). As activity levels and abdominal fat vary significantly by race and sex, we also examined interactions with race and sex by including cross-product terms in the models. Interactions were

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statistically significant for race and sex categories ($p<.05$), therefore stratified results are reported. Given variation in the SD for sedentary behaviors and physical activity level by race/sex categories, the beta regression coefficients for the stratified models reflect the SD specific to each race/sex category.

Results

As seen in Table 1, an inverse linear trend over sedentary tertiles was observed for age, years of education, alcohol consumption, physical activity (total, moderate, and heavy), and liver attenuation (indicating a positive association between sedentary time and liver fat). A positive trend over sedentary tertiles was found for fast food and sugar-sweetened beverage consumption, BMI, VAT, SAT, and IMAT. Current smokers reported greater levels of sedentary time as compared to those who never smoked. An inverse linear trend over physical activity tertiles was observed for BMI, VAT, SAT, and IMAT, and a positive trend was found for liver attenuation (see Table, Supplemental Digital Content 1, participant characteristics by tertiles of total physical activity).

Averages for total sedentary time, task-specific sedentary time, physical activity, and abdominal fat depots, stratified by sex and race are located in Table 2. Differences by sex and race were statistically significant ($p<0.001$) across all categories. Black participants reported more hours per day engaged in sedentary behaviors than Whites. Men reported higher levels of physical activity than women, with White men reporting the highest levels of activity and Black women reporting the lowest levels. Blacks had significantly lower VAT and IMAT, and greater SAT and liver attenuation than Whites. This difference by race in VAT and IMAT was driven by the large difference in abdominal fat depots among Black and White men, as the difference in VAT and IMAT among Black and White women was non-significant. Overall, VAT and IMAT were higher in men than women, while SAT and liver attenuation were higher in women.

Total sedentary time and time spent watching television or using the computer were significantly associated with VAT, SAT, IMAT and liver attenuation in bivariate analyses ($p<0.001$; see Table, Supplemental Digital Content 2, spearman correlations and p-values between abdominal fat depots, sedentary behaviors, and physical activity). Total physical activity, moderate physical activity, and heavy physical activity were also significantly associated with VAT, SAT, and IMAT ($p<0.001$), but not liver attenuation. Importantly, correlations were weak between sedentary time and physical activity ($\rho = -0.18$ to 0.02), consistent with previous reports in the literature (12), indicating that these are unique independent behaviors.

Sedentary Behavior and Abdominal Adipose Depots

The associations of total sedentary time with abdominal adipose depots and liver attenuation are shown in Table 3. Total sedentary time was positively associated with VAT after adjustment for demographics and lifestyle factors (Models 1 and 2); however, this association was attenuated after adjustment for SAT (Model 3) and BMI (Model 4). When stratified by sex and race, the association between sedentary time and VAT was significant in White men only, and remained significant in all models. For a 1 SD increment in total

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sedentary time per day for White men (2.9 hours/day), VAT was greater by 6.0 cm^3 (p=0.007). A similar pattern was observed for IMAT and liver attenuation, with significant associations observed in White men only (β=5.9 cm^3, p=0.010; β=−1.3, p=0.003, respectively). Total sedentary time was positively and significantly associated with SAT in the total sample after adjustment. After stratifying, the association remained significant in all groups with the exception of Black men.

When examining task-specific sedentary time (i.e. television, computer, paperwork, music, phone, and car) we observed strong associations between time spent watching television and abdominal adipose depots in the total sample after adjustment for all covariates (see Table 4). No other task-specific sedentary behaviors were associated with abdominal adipose depots or liver attenuation (data not shown). Television viewing was significantly and positively associated with VAT, SAT, and IMAT after adjustment. No associations were observed between television viewing and liver attenuation in the total sample. After stratifying by sex and race, VAT, IMAT, and liver attenuation were significantly associated with television viewing in White men only. For each 1 SD increment spent watching television (1.2 hours/day), VAT increased by 4.8 cm^3 (p=0.037), IMAT increased by 5.0 cm^3 (p=0.031), and liver attenuation decreased by 1.8 HU (p<0.001) in White men. Television viewing and SAT were significantly associated in White women only, fully adjusted (β=6.4 cm^3, p=0.016).

Physical Activity and Abdominal Adipose Depots

A robust inverse association was observed for total physical activity and VAT, SAT, and IMAT in the total sample after adjustment for all covariates (Table 5). For each 1 SD increment in physical activity (275 exercise units), VAT, SAT, and IMAT were lower by 7.6 cm^3, 6.7 cm^3, and 8.1 cm^3, respectively (p<.001 for all). This finding was consistent by race and sex, with the exception of the association between physical activity and SAT in Black women (β=−2.6, p=0.396). Physical activity was positively associated with liver attenuation after adjustment in the total sample. After stratifying, the association was significant in White men only (β=1.1, p=0.013). Results were similar when examining physical activity volume by intensity category (moderate and heavy) across race and sex groups (data not shown).

Sedentary Behavior, Physical Activity, and Abdominal Adipose Depots

Given that the association between total sedentary behavior and abdominal adipose depots appears to be driven by time spent watching television, we depict the adjusted means of abdominal fat depots and liver attenuation by tertiles of television viewing and total physical activity (low, moderate, and high) in Figure 1. Individuals reporting the lowest levels of television viewing and the highest levels of physical activity (referent group) had significantly lower VAT (118.4 cm^3), SAT (316.6 cm^3), IMAT (136.2 cm^3) compared to all other groups, and higher liver attenuation (56.4 HU). Those reporting the highest levels of television viewing and lowest levels of physical activity had the highest average VAT (147.5 cm^3), IMAT (167.2), and lowest liver attenuation (54.2 HU). The Figure in Supplemental Digital Content 3 illustrates the adjusted means for VAT, SAT, IMAT, and liver attenuation by tertiles of total sedentary time and physical activity. Findings were similar across

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abdominal fat depots, with the referent group having the lowest average VAT, SAT, and IMAT and the highest average liver attenuation values.

Discussion

In this population-based cohort study, we found that sedentary time and physical activity were differentially associated with abdominal fat depots and liver attenuation. While significant associations between television viewing, physical activity, and fat depots were observed in the entire cohort, the relationship between total sedentary time and VAT, IMAT, and liver attenuation was significant in White men only after controlling for physical activity and other potential confounders. Our findings add to the existing literature by demonstrating independent associations between sedentary behavior, physical activity, and various measures of abdominal adiposity, in a large population of Black and White adult men and women. These findings indicate potential differences in the magnitude of the association between sedentary behaviors and abdominal fat deposition by sex and race.

Our findings are consistent with other, smaller studies that have also reported sex differences when examining the association between sedentary behaviors and abdominal fat deposition (13, 26, 31). For example, Henson and colleagues reported positive associations between accelerometer measured sedentary time and magnetic resonance imaging measured VAT and liver fat in a sample of 66 White men and women at risk for type 2 diabetes (13). In their study, sedentary time had a stronger association with VAT in men than in women, similar to our findings among Whites. In a cross-sectional sample of Chinese adults (N=398), significant associations were observed for men, but not women, in self-reported hours per day of television viewing and CT measured VAT and SAT (26). One other study to date has examined both sex and race differences in the associations of sedentary behaviors, physical activity and abdominal fat depots. A multi-ethnic analysis of 539 older adults found stronger associations between physical activity, but not sedentary behavior, and VAT and IMAT in White men as compared to White, African American, and Filipino women (20).

The stronger associations observed in White men in our study and others may be partly explained by the greater absolute amount and variation of VAT and IMAT in this sub-population as compared to Black men or women of either race. Alternately, it is possible that White men have different behavioral patterns than other groups, which may explain the stronger association. There may also be differences in how sedentary behaviors are recalled or reported by race and sex. Although it is unclear why we observed differences by race and sex, there is a clear need to further explore this heterogeneity to avoid inappropriately generalization of findings.

Interestingly, when examining associations between different sedentary behaviors and fat deposition, significant findings were observed for television viewing only, and not for time spent engaging in other sedentary tasks. To our knowledge, this is the first study to examine the associations of various types of sedentary behavior with CT-measured abdominal fat depots. Hu and colleagues also reported stronger associations between television viewing and BMI as compared to time spent sitting at work, at home, or while driving in a sample of women from the Nurses' Health Study (14). Television viewing may have a unique effect on

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fat deposition and health risks as a result of increased snacking behaviors (4). Other potential mechanisms explaining the association between television viewing and abdominal fat deposition may include reduced resting metabolic rate or the influence of food and beverage advertisements on food consumption (6). It is also possible that recall of television viewing may be more accurate than other sedentary behaviors since time can be more easily quantified within the context of 30 or 60 minute television programming.

We observed a robust association between physical activity and VAT, SAT, and IMAT. A weaker, but statistically significant association was observed for physical activity and liver attenuation. The relationships observed between physical activity and abdominal fat depots are consistent with many (20, 21, 24, 28), but not all studies in the literature (20, 22, 26). The associations between physical activity and fat depots did not differ when examining moderate and heavy intensity physical activity separately, indicating a potentially protective effect of physical activity on fat deposition at either intensity level. Furthermore, the association between physical activity and VAT was independent of both SAT and BMI, indicating that the relationship between physical activity and VAT cannot be fully explained by total adiposity.

Our findings make a novel contribution by examining the associations of sedentary behaviors and physical activity with IMAT and liver attenuation, two understudied abdominal fat depots that may be independent risk factors for cardiometabolic disease. A study by Yim and colleagues found stronger associations between IMAT and glucose, protein bound glucose, and total cholesterol than observed for VAT (33). Adverse associations have also been reported between liver fat and fasting glucose and triglycerides, independent of other fat depots (31). In our study, we found that among White men, total sedentary time and television viewing were adversely associated with IMAT and liver attenuation, while the opposite associations were observed for physical activity and these fat depots in the entire cohort. Only one other study to date has examined the associations of physical activity with abdominal IMAT (20). The authors also reported an inverse association between physical activity and IMAT; however, this was attenuated after adjustment for BMI. Our findings suggest that reducing sedentary time and increasing physical activity may result in lower levels of IMAT and liver fat, independent of total body adiposity, thus reducing cardiometabolic risk.

When we examined the combined association of television viewing and physical activity, we found that those reporting high levels of television viewing and low levels of physical activity had the highest levels of VAT, a strong risk factor for cardiometabolic diseases (2). While television viewing and physical activity were independently associated with abdominal fat deposition, it appears that their relationship may be additive. Those who reported high levels of television viewing and low levels of physical activity had a 29 cm^3 greater average VAT volume compared to those reporting low levels of television viewing and high levels of physical activity. This amount of VAT is equivalent to 39% of the population standard deviation of VAT. Of note, we found that television viewing and physical activity were jointly associated with VAT, independent of SAT and BMI. It therefore appears that the associations of inactivity and activity with VAT may act through an independent mechanism beyond total body adiposity. Thus, when making

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recommendations related to adipose deposition, it appears important to emphasize both reducing sedentary time, particularly television viewing, and increasing physical activity.

A major strength of this study is the large sample size which allows for comparisons by sex and race. Additionally, while sedentary behavior was self-reported, the questionnaire used in this study was more detailed than previous studies, allowing us to examine the associations of various types of sedentary behavior (e.g. television, computer) with intra-abdominal fat depots. Furthermore, we examined the associations of sedentary behavior and physical activity with multiple measures of adipose tissue, including IMAT and liver attenuation, which are understudied fat depots, and may play an independent role in cardiometabolic risk.

While this study contributes novel findings to the existing literature, multiple limitations must be noted. This study was limited to Black and White adults; therefore study findings cannot be generalizable to individuals from other racial/ethnic backgrounds. The cross-sectional study design limits inference on causality between sedentary behavior, physical activity, and abdominal adipose depots. Future studies are needed that follow individuals over time to assess the longitudinal effects of sedentary behavior and physical activity on adipose depots. It is also possible that unmeasured variables may have confounded the observed associations. For example, we were not able to fully control for diet quality or snacking behaviors. However, we did assess fast food frequency and sugar-sweetened beverage consumption which are associated with unhealthy dietary patterns (25). Both sedentary behavior and physical activity were assessed through self-report, and sedentary time at work was not queried. It is therefore possible that subjects may have underreported their sedentary behavior and over-reported their physical activity. Finally, we estimated liver fat using CT-measured liver attenuation, which is a less direct measurement method than biopsy or magnetic resonance techniques.

In conclusion, this study provides evidence that sedentary behavior, particularly television viewing, and physical activity have distinct, independent associations with abdominal adipose tissue deposition patterns. Importantly, the associations of television viewing in the entire sample and total sedentary time in White men remained after controlling for physical activity, SAT, and BMI. These findings suggest that sedentary behavior, particularly television viewing, may have a unique, independent influence on intra-abdominal fat depots that is not explained by total adiposity or total physical activity level.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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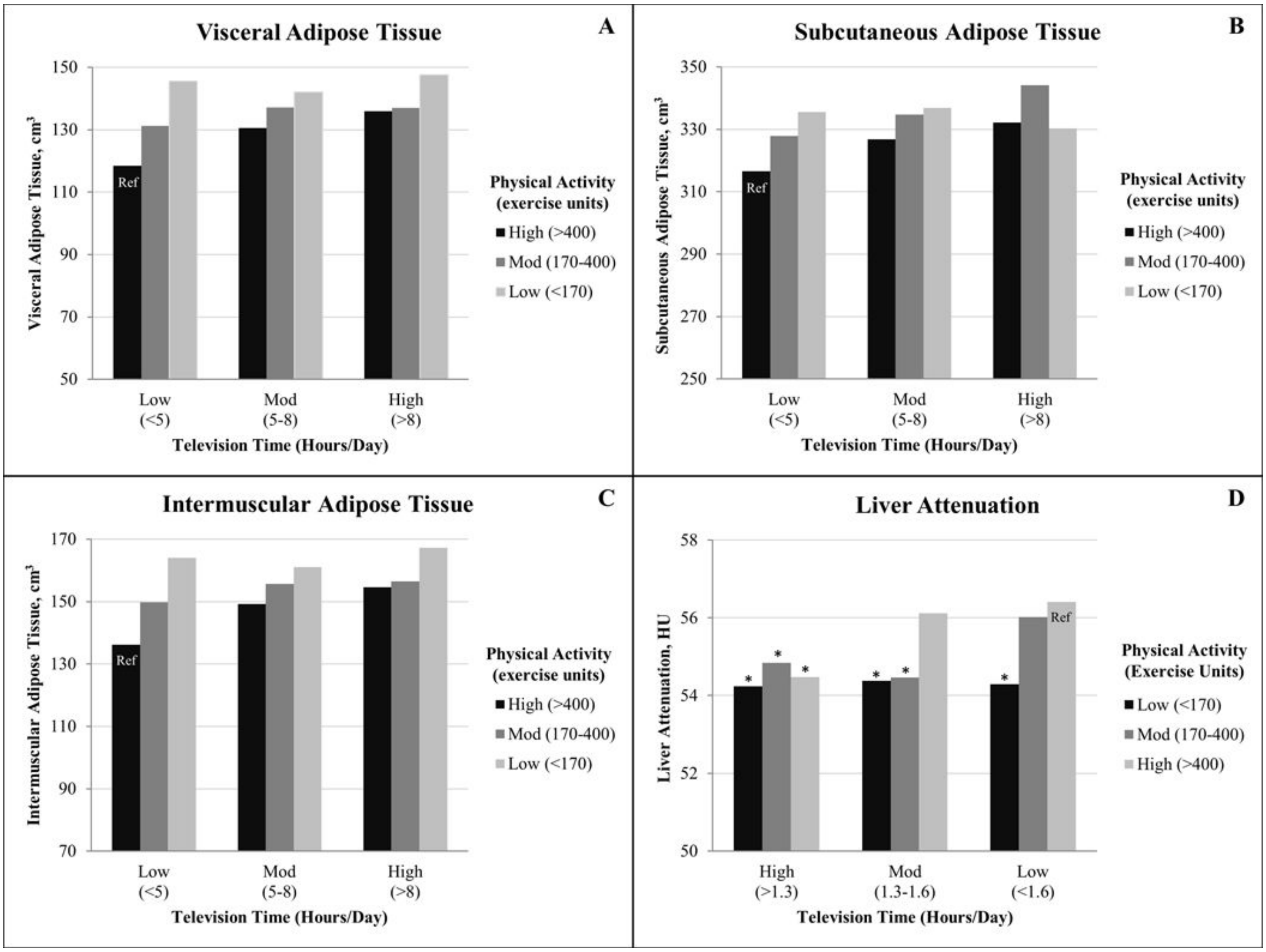

Figure 1. Abdominal fat depots by tertiles of television viewing and physical activity at CARDIA year 25 (2010–2011)

Adjusted means for visceral adipose tissue (A), subcutaneous adipose tissue (B), intermuscular adipose tissue (C), and liver attenuation (D) by tertiles of television viewing and total physical activity. Means adjusted for center, age, sex, race, education, smoking, alcohol, fast food intake, sugar-sweetened beverage consumption, BMI, subcutaneous adipose tissue (panels A, C, D), and visceral adipose tissue (panel B). In panels A–C, all groups have significantly greater adipose tissue than the referent group (low sedentary time, high physical activity). In panel D, groups denoted by the * have significantly lower liver attenuation (indicating more liver fat) than the referent group. Panel D excludes individuals categorized as heavy drinkers (>4 drinks/day for men and >3 drinks/day for women).

Table 1

Participant characteristics at CARDIA year 25 (2010–2011) by tertiles of sedentary time

		Sedentary Tertiles			
	Total (N=3010)	<5 hrs/day (N=1001)	5–8 hrs/day (N=1075)	>8 hrs/day (N=934)	
Characteristic	Mean ± SD or N (%)				p-value[b]
Sex					0.555
Female	1696 (56.4)	556 (55.5)	600 (55.8)	540 (57.8)	
Male	1314 (43.6)	445 (44.5)	475 (44.2)	394 (42.2)	
Age, years	50.1 ± 3.6	50.3 ± 3.4	50.2 ± 3.6	49.8 ± 3.8	<.001
Education, years	15.0 ± 2.7	15.5 ± 2.7	15.1 ± 2.6	14.4 ± 2.5	<.001
Smoking					<.001
Never	1864 (61.9)	665 (66.4)	659 (61.3)	540 (57.8)	
Former	667 (22.2)	234 (23.4)	248 (23.1)	185 (19.8)	
Current	479 (15.9)	102 (10.2)	168 (15.6)	209 (22.4)	
Alcohol, mg/day	11.7 ± 23.7	12.5 ± 23.9	11.9 ± 23.8	10.6 ± 23.3	0.077
Physical activity, exercise units[c]					
Total	336.6 ± 274.8	376.0 ± 281.5	330.1 ± 265.3	301.7 ± 273.2	<.001
Moderate intensity	136.0 ± 108.8	150.6 ± 112.6	134.2 ± 105.5	122.4 ± 106.6	<.001
Heavy intensity	200.8 ± 211.5	225.7 ± 219.4	196.2 ± 204.2	179.5 ± 208.7	<.001
Fast food intake (frequency per week)	2.2 ± 3.1	1.7 ± 2.9	2.0 ± 2.7	2.9 ± 3.6	<.001
Sugar-sweetened beverages (frequency per week)	4.1 ± 8.0	2.6 ± 6.3	3.8 ± 7.1	5.9 ± 9.9	<.001
Body mass index, kg/m^2	30.3 ± 7.1	28.3 ± 6.4	30.7 ± 7.2	31.9 ± 7.4	<.001
VAT, cm^3	131.9 ± 73.6	121.4 ± 70.5	138.8 ± 75.9	135.3 ± 73.1	<.001
SAT, cm^3	336.1 ± 169.9	288.1 ± 151.8	342.4 ± 166.9	380.1 ± 178.7	<.001
IMAT, cm^3	150.2 ± 80.0	138.4 ± 76.1	157.8 ± 82.2	154.0 ± 80.3	<.001
Liver attenuation, HU[d]	55.5 ± 11.8	57.1 ± 10.7	54.5 ± 11.9	54.8 ± 12.7	<.001

Abbreviations: VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue; IMAT = intermuscular adipose tissue; HU = Hounsfield Units

[a]Tertiles of sedentary time were created using the total sedentary time estimate

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[b] A linear trend over sedentary tertiles was tested using linear regression (continuous variables) or Chi-square test of independence (categorical variables)

[c] Physical activity was assessed using the CARDIA physical questionnaire

[d] Sample size for liver attenuation = 2,917; lower HU in liver indicates more fat

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Table 2

Sedentary time, physical activity and abdominal fat depots at CARDIA year 25 (2010–2011) by sex and racial group[a]

	Total (N=3010)	Black Men (N=570)	White Men (N=744)	Black Women (N=855)	White Women (N=841)
			Mean (SD)		
Sedentary behaviors, hours/day					
Total sedentary time	7.1 (4.0)	8.2 (4.5)	6.0 (2.9)	8.8 (4.7)	5.7 (2.7)
Television time	2.2 (1.5)	2.8 (1.6)	1.9 (1.2)	2.7 (1.6)	1.7 (1.2)
Computer time	1.2 (1.3)	1.2 (1.3)	1.1 (1.1)	1.3 (1.5)	1.0 (1.1)
Paperwork	0.7 (0.8)	0.7 (0.9)	0.6 (0.7)	0.9 (1.0)	0.6 (0.7)
Listening to music	1.1 (1.1)	1.2 (1.2)	0.8 (0.8)	1.4 (1.3)	1.0 (0.8)
Talking on the phone	0.8 (1.0)	0.9 (1.1)	0.5 (0.7)	1.2 (1.3)	0.5 (0.5)
Sitting in a car	1.2 (1.1)	1.5 (1.5)	1.1 (0.9)	1.3 (1.2)	1.0 (0.7)
Physical activity, exercise units[b]					
Total	336.6 (274.8)	373.0 (299.0)	429.1 (285.1)	228.8 (223.4)	339.6 (258.9)
Moderate intensity	136.0 (108.8)	133.1 (111.0)	163.4 (110.0)	100.1 (98.4)	150.4 (106.1)
Heavy intensity	200.8 (211.5)	240.0 (231.0)	266.0 (225.4)	129.0 (167.3)	189.6 (201.5)
Abdominal Fat Depots					
VAT, cm^3	131.9 (73.6)	133.6 (74.6)	170.8 (80.1)	115.5 (59.1)	113.2 (66.8)
SAT, cm^3	336.1 (169.9)	297.7 (154.4)	258.4 (120.9)	442.5 (176.4)	322.7 (157.1)
IMAT, cm^3	150.2 (80.0)	149.6 (81.4)	190.5 (86.0)	132.7 (65.4)	132.8 (74.2)
Liver attenuation, HU[c]	55.5 (11.8)	54.9 (11.0)	52.0 (12.9)	56.7 (11.2)	57.6 (11.2)

Abbreviations: VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue; IMAT = intermuscular adipose tissue; HU = Housfield Units

[a]Differences by sex and racial group were tested using one-way ANOVA's, all associations were significant ($p < .001$)

[b]Physical activity was assessed using the CARDIA physical questionnaire

[c]Sample size for liver attenuation = 2,917; lower HU in liver indicates more fat

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Table 3

Associations of total sedentary time (per one standard deviation) with abdominal fat depots at CARDIA year 25 (2010–2011), stratified by sex and racial group

	Total Sedentary Time									
	Total (N=3010)		**Black Men (N=570)**		**White Men (N=744)**		**Black Women (N=855)**		**White Women (N=841)**	
	Beta[a] (95% CI) p-value									
VAT[b]										
Model 1	6.8 (4.1, 9.5)	**<.001**	2.1 (−4.0, 8.2)	0.492	13.6 (7.7, 19.5)	**<.001**	2.8 (−1.2, 6.8)	0.166	7.1 (2.7, 11.6)	**0.002**
Model 2	6.2 (3.6, 8.8)	**<.001**	1.6 (−4.5, 7.7)	0.604	13.6 (7.9, 19.3)	**<.001**	2.4 (−1.5, 6.3)	0.234	6.2 (1.9, 10.6)	**0.005**
Model 3	1.3 (−0.9, 3.5)	0.240	1.9 (−3.1, 7.0)	0.452	5.8 (0.9, 10.7)	**0.021**	−1.5 (−4.9, 1.9)	0.400	−1.2 (−4.5, 2.1)	0.473
Model 4	1.4 (−0.6, 3.4)	0.163	0.6 (−4.0, 5.3)	0.787	6.0 (1.6, 10.5)	**0.007**	−0.7 (−3.7, 2.4)	0.677	−1.3 (−4.2, 1.7)	0.391
SAT[b]										
Model 1	20.5 (14.6, 26.4)	**<.001**	−0.2 (−12.8, 12.4)	0.971	22.1 (13.2, 30.9)	**<.001**	23.4 (11.6, 35.3)	**<.001**	28.2 (17.7, 38.7)	**<.001**
Model 2	19.4 (13.6, 25.2)	**<.001**	−1.3 (−13.8, 11.2)	0.839	22.1 (13.4, 30.9)	**<.001**	22.4 (10.7, 34.1)	**<.001**	25.8 (15.7, 35.9)	**<.001**
Model 3	11.6 (6.8, 16.4)	**<.001**	−3.1 (−13.6, 7.4)	0.561	11.0 (3.6, 18.4)	**0.004**	18.7 (8.7, 28.8)	**<.001**	16.0 (8.5, 23.6)	**<.001**
Model 4	5.1 (2.2, 8.0)	**0.001**	−4.0 (−10.6, 2.6)	0.236	6.6 (2.1, 11.2)	**0.004**	9.3 (3.4, 15.1)	**0.002**	5.8 (0.6, 11.0)	**0.028**
IMAT[b]										
Model 1	7.7 (4.8, 10.6)	**<.001**	2.5 (−4.1, 9.2)	0.460	14.7 (8.4, 21.1)	**<.001**	3.4 (−1.0, 7.8)	0.127	8.4 (3.5, 13.3)	**<.001**
Model 2	7.1 (4.2, 9.9)	**<.001**	1.9 (−4.7, 8.5)	0.574	14.8 (8.7, 20.9)	**<.001**	2.9 (−1., 7.3)	0.183	7.4 (2.6, 12.1)	**0.003**
Model 3	1.3 (−1.0, 3.6)	0.255	2.3 (−3.1, 7.7)	0.401	5.7 (0.6, 10.7)	**0.027**	−1.6 (−5.3, 2.1)	0.391	−1.2 (−4.6, 2.3)	0.505
Model 4	1.4 (−0.6, 3.5)	0.176	0.9 (−4.0, 5.7)	0.732	5.9 (1.4, 10.4)	**0.010**	−0.7 (−4.0, 2.6)	0.669	−1.3 (−4.4, 1.7)	0.394

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	Total Sedentary Time									
	Total (N=3010)		**Black Men (N=570)**		**White Men (N=744)**		**Black Women (N=855)**		**White Women (N=841)**	
	Beta[a] (95% CI) p-value									
	Total (N=2917)[c]		**Black Men (N=542)**		**White Men (N=711)**		**Black Women (N=838)**		**White Women (N=826)**	
	Beta[c] (95% CI) p-value									
Liver Attenuation[d]										
Model 1	−0.8 (−1.3, −0.3)	**<.001**	0.3 (−0.7, 1.2)	0.539	−2.2 (−3.1, −1.2)	**<.001**	−0.6 (−1.3, 0.2)	0.131	−0.7 (−1.5, 0.0)	0.063
Model 2	−0.8 (−1.2, −0.3)	**<.001**	0.3 (−0.7, 1.2)	0.488	−2.2 (−3.1, −1.3)	**<.001**	−0.5 (−1.3, 0.2)	0.165	−0.6 (−1.4, 0.1)	0.091
Model 3	−0.2 (−0.7, 0.2)	0.262	0.3 (−0.6, 0.9)	0.452	−1.3 (−2.1, −0.4)	**0.005**	−0.2 (−0.9, 0.5)	0.631	0.2 (−0.5, 0.8)	0.633
Model 4	−0.2 (−0.6, 0.2)	0.273	0.3 (−0.5, 1.2)	0.338	−1.3 (−2.1, −0.4)	**0.003**	−0.2 (−0.9, 0.5)	0.516	0.2 (−0.5, 0.8)	0.585

Abbreviations: VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue; IMAT = intermuscular adipose tissue

Model 1 adjusts for center, age, sex, race, education, smoking, alcohol, fast food frequency, and sugar-sweetened beverage consumption (stratified models do not adjust for sex or race)

Model 2 adjusts for all variables in Model 1, in addition to total physical activity

Model 3 adjusts for all variables in Model 2, in addition to subcutaneous fat (the subcutaneous fat model adjusts for visceral fat)

Model 4 adjusts for all variables in Model 3, in addition to BMI

[a]Beta regression coefficients are interpreted as the estimated difference in adipose depots (cm^3) per 1 SD of total sedentary time (total sample = 4.0 hours/day; Black men = 4.5 hours/day; White men = 2.9 hours/day; Black women = 4.7 hours/day; White women = 2.7 hours/day)

[b]Abdominal fat depots measured in cm^3

[c]Liver attenuation models exclude individuals categorized as heavy drinkers (>4 drinks/day for men and >3 drinks/day for women)

[d]Liver attenuation measured in Hounsfield Units, lower values indicate higher liver fat content

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Table 4

Associations of television time (per one standard deviation) with abdominal fat depots at CARDIA year 25 (2010–2011), stratified by sex and racial group

	Television Time									
	Total (N=3010)		**Black Men (N=570)**		**White Men (N=744)**		**Black Women (N=855)**		**White Women (N=841)**	
	Beta[a] (95% CI) p-value									
VAT[b]										
	3.5 (1.4, 5.5)	**0.001**	2.4 (−2.3, 7.2)	0.316	4.8 (0.2, 9.2)	**0.037**	2.9 (−0.3, 6.1)	0.077	0.1 (−2.9, 3.1)	0.946
SAT[b]										
	3.4 (0.4, 6.4)	**0.027**	−1.7 (−8.5, 5.0)	0.612	4.2 (−0.4, 8.8)	0.075	3.9 (−2.3, 10.0)	0.221	6.4 (1.2, 11.6)	**0.016**
IMAT[b]										
	3.9 (1.8, 6.1)	**<.001**	3.1 (−1.8, 8.1)	0.213	5.0 (0.5, 9.6)	**0.031**	3.0 (−0.5, 6.4)	0.089	0.7 (−2.4, 3.8)	0.661
Liver Attenuation[c]	−0.4 (−0.8, 0.0)	0.078	0.6 (−0.3, 1.4)	0.178	−1.8 (−2.7, −0.9)	**<.001**	−0.2 (−0.9, 0.5)	0.621	0.1 (−0.5, 0.8)	0.674

Abbreviations: VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue; IMAT = intermuscular adipose tissue

Models adjusted for center, age, sex, race, education, smoking, alcohol, fast food intake, sugar-sweetened beverage consumption, total physical activity, subcutaneous fat (the subcutaneous fat model adjusts for visceral fat), and BMI

[a]Beta regression coefficients are interpreted as the estimated difference in adipose depots (cm^3) per 1 SD of television time (total sample = 1.5 hours/day; Black men = 1.6 hours/day; White men = 1.2 hours/day; Black women = 1.6 hours/day; White women = 1.2 hours/day)

[b]Abdominal fat depots measured in cm^3

[c]Liver attenuation measured in Hounsfield Units, lower values indicate higher liver fat content; liver attenuation models exclude individuals categorized as heavy drinkers (>4 drinks/day for men and >3 drinks/day for women)

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Table 5

Associations of total physical activity with abdominal fat depots at CARDIA year 25 (2010–2011), stratified by sex and racial group

	Total Physical Activity									
	Total (N=3010)		**Black Men (N=570)**		**White Men (N=744)**		**Black Women (N=855)**		**White Women (N=841)**	
	Beta[a] (95% CI) p-value									
VAT[b]	−7.6 (−9.5, −5.6)	**<.001**	−5.4 (−10.2, −0.7)	**0.025**	−13.4 (−17.7, −9.2)	**<.001**	−4.8 (−7.9, −1.7)	**0.002**	−3.4 (−6.4, −0.5)	**0.023**
SAT[b]	−6.7 (−9.6, −3.8)	**<.001**	−8.4 (−15.1, −1.7)	**0.015**	−7.6 (−12.1, −3.1)	**0.001**	−2.6 (−8.6, 3.4)	0.396	−8.9 (−14.1, −3.7)	**0.001**
IMAT[b]	−8.1 (−10.1, −6.0)	**<.001**	−6.2 (−11.2, −1.2)	**0.015**	−13.8 (−18.2, −9.5)	**<.001**	−5.2 (−8.5, −1.9)	**0.002**	−3.8 (−6.9, −0.7)	**0.017**
Liver Attenuation[c]	0.5 (0.1, 0.9)	**0.007**	0.2 (−0.6, 1.0)	0.663	1.1 (0.2, 1.9)	**0.013**	0.6 (−0.1, 1.3)	0.101	−0.1 (−0.8, 0.5)	0.714

Abbreviations: VAT = visceral adipose tissue; SAT = subcutaneous adipose tissue; IMAT = intermuscular adipose tissue

Models adjusted for center, age, sex, race, education, smoking, alcohol, fast food intake, sugar-sweetened beverage consumption, sedentary time, subcutaneous fat (the subcutaneous fat model adjusts for visceral fat), and BMI

[a]Beta regression coefficients are interpreted as the estimated difference in adipose depots (cm^3) per 1 SD of total physical activity (total sample = 275 exercise units [EU]; Black men = 299 EU; White men = 285 EU; Black women = 223 EU; White women = 259 EU)

[b]Abdominal fat depots measured in cm^3

[c]Liver attenuation measured in Hounsfield Units, lower values indicate higher liver fat content; liver attenuation models exclude individuals categorized as heavy drinkers (>4 drinks/day for men and >3 drinks/day for women)