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Sagittal diameter in comparison with single slice CT as a predictor of total visceral adipose tissue volume

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BACKGROUND: Abdominal obesity has an important biological and epidemiological relationship to disease. The gold standard for measurement of visceral adipose tissue (VAT) is assessment by computerized tomography (CT) or magnetic resonance imaging (MRI), but because of simplicity and ease in collection, anthropometric variables are a desirable alternative to estimate VAT.
OBJECTIVE: To compare the abilities of a single slice CT scan through the L4-L5 interspace (L4-L5 VAT), sagittal diameter, and body mass index (BMI) to estimate total volume VAT. Total volume VAT (the gold standard) was measured by total abdominal CT scanning, with a mean of 42 CT slices per patient. Estimation of VAT in subjects of similar body size was emphasized.
DESIGN: Retrospective study of subjects undergoing complete abdominal and pelvic CT scanning for clinical reasons.
SUBJECTS: 40 subjects (20 men and 20 women) mean age 56.5 y, with a balanced selection for BMI <27 and >27.
RESULTS: In univariate regression models, L4-L5 VAT explained the largest proportion of the variance in total VAT ($R^2=0.87$ ($P<0.001$)), though age ($R^2=0.11$ ($P=0.04$)), BMI ($R^2=0.37$ ($P<0.001$)), and sagittal diameter ($R^2=0.50$ ($P<0.001$)) were also statistically significantly related to total VAT. When limited to individuals with a BMI ≥ 27 however, L4-L5 VAT explained a large proportion of the variance in total VAT ($R^2=0.87$ ($P<0.001$)) whereas sagittal diameter was only of borderline significance ($R^2=0.20$ ($P=0.06$)), and BMI was not associated with total VAT ($R^2=0.04$ ($P=$ NS)). In multiple regression analyses, L4-L5 VAT area explained a large proportion of the variance (0.84–0.90), and once in the model, BMI, sagittal diameter, and age did not additionally contribute significantly to the explained variance in total VAT.
CONCLUSIONS: Abdominal sagittal diameter is poorly correlated to total VAT for men and women with a BMI ≥ 27. Within a 2 cm range of sagittal diameter, there is nearly a three-fold variability in total VAT.

Keywords: computed tomography; visceral adipose tissue; obesity; anthropometry; body fat distribution

Introduction

Abdominal obesity has an important biological and epidemiological relationship to diabetes, cardiovascular,[1–6] and possibly neoplastic, disease.[7–10] The gold standard for measurement of visceral adipose tissue (VAT) is assessment by computerized tomography (CT)[11] or magnetic resonance imaging (MRI)[12] and thresholds for identifying individuals at risk have been identified.[13,14] Because of simplicity and ease in collection, anthropometric variables would be a desirable alternative to estimate VAT.

Models for predicting VAT using anthropometric measures including height, weight, body mass index (BMI), waist to hip ratio (WHR), waist circumference, and abdominal sagittal diameter have been developed by a number of investigators.[15–27] In all of these studies, there is significant correlation between anthropometric measurements of obesity and VAT. This is to be expected, especially when the sample includes subjects representing a wide range of 'body-fatness'.[18] It is not surprising that when someone who is obese is compared to someone who is thin, the obese person has more VAT, and that BMI, WHR, waist circumference or abdominal sagittal diameter will correlate to the measured amount of VAT. The critical issue in evaluating the necessity of CT or MRI determination of VAT, as opposed to anthropometric estimation of VAT, is the variability of VAT in relatively homogenous groups of adiposity. The essential question centers on how well anthropometric measurements distinguish VAT quantity in individuals of similar body size.

The correlation coefficients between WHR, waist circumference, BMI or sagittal diameter (measured by anthropometry or by CT scan) and VAT have varied between 0.38 and 0.87, with no one anthropometric variable consistently superior[15–28]. Some studies show waist circumference and abdominal sagittal diameter explaining a much higher percentage of the variance in VAT, such as $>85\%$, however they include individuals with a wide ranging BMI.[24,26]

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The error associated with estimation of VAT by anthropometry is estimated to be in the order of 25–30%.[8,9,29] However, previous studies examining the ability of anthropometry to predict VAT measured by CT scanning, use an estimation for the volume of VAT that has employed no more than 8–12 abdominal CT slices.[22,30] Error is introduced in the extrapolation from a limited number of abdominal CT slices to total VAT volume.

In this investigation, we compared sagittal diameter to single slice L4-L5 CT scanning for the ability to predict total VAT volume. By virtue of using a retrospective design, a mean of over 42 abdominal slices per patient were obtained and analyzed, to minimize error in measurement of total VAT volume. In order to examine the variability in VAT in relatively homogenous groups of adiposity, VAT volume was measured in subjects selected on the basis of BMI and gender.

Methods

Subjects

Inpatients and outpatients undergoing abdominal and pelvic CT scans at the University of Pittsburgh were eligible for inclusion. Over a six week period the CT scans and medical information on consecutive patients were retrospectively reviewed. Patients were included if: 1) CT scanning extended from above the diaphragm to the symphysis pubis; and 2) There was no evidence of ascites, abdominal wall edema, prior abdominal surgery (including bowel resection, cholecystectomy or splenectomy), metastatic disease or chronic hepato-renal disease. Most commonly, patients underwent CT scans for the evaluation of pain, with the majority of studies interpreted as normal. Twenty men and 20 women subjects were selected, ten of each gender with a BMI <27 and ≥ 27, determined by self report to the radiology technician prior to scanning.

Computed Tomography

Patients were scanned with a 9800 CT scanner (General Electric, Milwaukee, WI). Cross-sectional abdominal scan thickness ranged from 5–10 mm in size, determined by the clinical indications for the study, obtained at 120 kVp and 140–240 mA with a scanning time of 1–2 s/scan. The total slice number ranged from 32–52, with a mean of 42 slices per patient. Gaps between scan slices did not exceed 10 mm.

Abdominal adipose tissue was calculated using commercially available CT software (GE Medical Systems, Milwaukee, WI). Adipose tissue area was determined electronically by setting the region of interest for attenuation values within the range of -190 to -30 Hounsfield units.[31] Small alterations of the Hounsfield unit range do not significantly alter VAT measurements.[31,32,33] Using the trace function, the boundary separating subcutaneous and visceral fat was defined manually using a cursor, and the intra-abdominal adipose tissue area was recorded. Retroperitoneal adipose tissue was included in the visceral adipose tissue measurement. The equation

$$V = \Sigma \frac{a_i(b_i + c_i)}{2},$$

where V is the volume, a_i is the distance between two adjacent scans, and b_i and c_i are the adipose tissue areas from the adjacent cranial and caudal scans, developed by Kvist *et al*,[31] was used to calculate the intra-abdominal fat volume between scan slices. This formula is based on the underlying assumption that there is a linear change in adipose tissue area between adjacent scans. The total VAT volume was determined by summing the individual adipose tissue slice areas and gaps. Prior to determination of VAT volume, a radiologist (FLT) reviewed the images and scout films from the CT scans to identify which CT slice was located through the L4-L5 interspace. Sagittal diameter was determined *via* an electronic measurement using the L4-L5 CT image, with the cursor extending from skin to skin through the center of the abdomen.[15] For 1–3 CT slices near the level of the diaphragm, there is often a combination of visceral, pericardial and mediastinal adipose tissue. For each of these slices, the amount of VAT or adipose tissue below the diaphragm was estimated to the nearest 25%. This determination was made prior to the calculation of total VAT volume.

Statistics

BMI was calculated as weight in kg/(height in m)^2. Differences in variables by gender were assessed using *t* Tests. Regression analyses, (SAS Institute, Cary, NC) employing influence diagnostics and residual analysis were performed to assess univariate and multiple variate relationships to total VAT volume, the dependent variable. Cook's D statistic was computed to measure the influence of each observation on the parameter estimates.

Results

Forty patients were included in the analysis. For one woman, the BMI could not be verified, and she was deleted from analyses which required that measurement. The characteristics of the patient sample are displayed in Table 1. As one might expect from selection criteria based on BMI, there were no significant differences between men and women in BMI. Although men tended to have larger amounts of total VAT and L4-L5 VAT than women, these did not reach statistical significance.

Table 1 Characteristics of the sample

	Men (n = 20)			Women (n = 20)		
	Mean	± s.d.	Range	Mean	± s.d.	Range
Age (y)	57.5	± 16.3	24–84	55.5	± 16.6	24–83
BMI	27.8	± 5.9	17.6–41.0	29.0	± 8.7[a]	15.5–50.2
Sagittal diameter (cm)	24.7	± 5.5	16.5–37.0	24.7	± 5.7	18.0–37.5
L_4–L_5 VAT (cm^2)	137.6	± 78	20–280	126.4	± 110	17.3–507
Total VAT (l)	4.7	± 2.6	0.6–9.6	3.2	± 2.5	0.3–9.1

[a] $n = 19$.
BMI = body mass index; VAT = visceral adipose tissue.

Table 2 Regression analyses

Model	Age	BMI	Sagittal Diameter	L_4-L_5 VAT	Total R^2
Simple R^2 With Outlier Removed[a]					
1A. Full Sample	0.11 (0.04)[b]	0.37 (< 0.001)	0.50 (< 0.001)	0.87 (< 0.001)	
1B. BMI < 27	0.31 (0.01)	0.49 (< 0.0001)	0.66 (< 0.001)	0.87 (< 0.001)	
1C. BMI ≥ 27	0.01 (NS)	0.04 (NS)	0.20 (0.06)	0.81 (< 0.001)	
Multiple regression analysis/partial R^2: Volume VAT with age, BMI, sagittal diameter and L4-L5-VAT					
2A. Full Sample	0	0	0	0.87 (< 0.001)	0.87
2B. BMI < 27	0.01 (NS)	0.01 (NS)	0.01 (NS)	0.87 (< 0.001)	0.90
2C. BMI ≥ 27	0	0.03 (NS)	0	0.81 (< 0.001)	0.84

[a] Univariate models with the dependent variable total VAT volume.
[b] Displayed are the percent explained variance (R^2) and the corresponding P value.
BMI = body mass index; VAT = visceral adipose tissue; NS = not satistically significant.

Using regression analysis, models employing age, BMI, sagittal diameter, and L4-L5 VAT were constructed to examine the relative contribution of each of these variables to the percent of the explained variance of total VAT volume. Influence diagnostics revealed that a woman 1.5 meters tall, who weighed 86.4 Kg, with a total VAT of 9.1 liters and an L4-L5 VAT area of 507 cm^2 was an outlier, with a Cook's D influence statistic of 4.9, whereas the Cook's D for all other observations was < 0.8. This subject was excluded from all subsequent analyses but inclusion of the outlier did not significantly alter the results. The results of the regression analyses are displayed in Table 2.

In univariate analysis with the dependent variable total VAT volume, age, BMI, abdominal sagittal diameter and L4-L5 VAT, were examined independently for their relationship to total VAT. All four variables were statistically significantly associated with total VAT, but the L4-L5 adipose tissue area explained the largest proportion of the variance in total VAT, with the R^2 for age 0.11 ($P = 0.04$), BMI 0.37 ($P < 0.001$), sagittal diameter 0.50 ($P < 0.001$), and for L4-L5 VAT 0.87 ($P < 0.001$) (Table 2, 1A).

To examine the relationship of these variables to total VAT volume in homogenous groups of adiposity, regression models in groups stratified by BMI were performed. In individuals with a BMI < 27 all the variables were statistically associated with total VAT, with the explained variance highest for L4-L5 VAT ($R^2 = 0.87$ ($P < 0.001$)) (Table 2, 1B). For individuals with a BMI ≥ 27, L4-L5 VAT was highly associated with total VAT, with an $R^2 = 0.81$ ($P < 0.001$). In contrast, BMI did not explain a significant portion of the variance in total VAT ($R^2 = 0.04$, $P =$ NS) and sagittal diameter was not well associated with total VAT, with an $R^2 = 0.20$ ($P = 0.06$) (Table 2, 1C).

In multiple regression analysis (Table 2, 2A–C), once the L4-L5 VAT area was in the model, BMI, sagittal diameter and age did not contribute significantly to the explained variance, and the explained variance for these models was high, (total $R^2 = 0.84 - 0.90$).

Within a 2 cm range of sagittal diameter in men and women, there was nearly a three-fold variability in total VAT. Similarly, there was a nearly three-fold variability in total VAT within a narrow range of BMI. For example, two men with sagittal diameters of 26.0 and 27.9 cm, had a total VAT of 7.3 and 2.5 l, respectively, and two women with a BMI of 31.3 and 32.4 had a total VAT of 6.2 and 2.2 l, respectively.

Discussion

In order to examine the variability in VAT in relatively homogenous groups of adiposity, we measured total VAT in subjects selected on the basis of BMI and gender. By virtue of using a retrospective design, a mean of over 42 abdominal CT slices per patient were obtained and analyzed. In previous studies measuring total VAT, no more than 8–12 abdominal slices have been performed.[22,30] Therefore, we report the most complete and accurate measurement of total VAT to date using CT scanning. This accurate quantification of total VAT volume allows us to compare the predictive ability of abdominal sagittal diameter to L4-L5 VAT area, for estimation of total VAT volume, with minimal error.

In our investigation, the abdominal sagittal diameter explained only 50% of the variance for the group as a whole, and only 20% of the variance in individuals with a BMI ≥ 27. We found a substantial three-fold variation in total VAT within a narrow range of sagittal diameter or BMI. The L4-L5 VAT area however remained highly correlated to total VAT and explained a high percentage of the variance, regardless of body size (Table 2).

When anthropometric variables are evaluated across a wide range of adiposity, the percentage of the explained variance will be high, exceeding 80% in some studies.[24,26] However, when samples are restricted to obese individuals, the results are not nearly as impressive. Our work is similar to what others have shown for the WHR. In a study restricted to 51 premenopausal obese women, the correlation coefficients between WHR or BMI and L4-L5 VAT area were only 0.55 and 0.70, respectively.[17] In a study of 46 obese men, the correlation coefficient between WHR or BMI and L4-L5 VAT area was only 0.47 and 0.15, respectively,[18] and regression analyses employing a combination of anthropometric variables raised the explained variance to only 43%.

Thus, the subcutaneous and deep abdominal fat compartments may expand independently of each other and there is no simple metric relationship between VAT and total adiposity.[17,31,34] In particular, it is the subgroup of individuals with a larger BMI (≥ 27) where radiological quantification of VAT is required for research purposes. Although a variety of predictive equations using anthropometric variables have been offered, when tested in different populations, these models have not performed that well.[19,28,35] Furthermore, the models should be evaluated in subgroups of individuals with similar body size, or a false sense of their predictive ability will ensue.

Several limitations of this study should be noted. We used a measure for abdominal sagittal diameter determined from electronic imaging. However sagittal diameter measured by imaging has been shown to be highly correlated to that measured by anthropometry.[28,35] A retrospective sample was used in this analysis because of the radiation hazard of total abdominal and pelvic CT scanning, and because of cost. Although the sample was screened for factors which could contribute to an unusual reduction or accumulation in VAT, the sample may include individuals with disorders that influence body composition. Similarly, as subjects were selected from a population referred for CT scanning for clinical diagnostic purposes, they may not be representative of a random selection of normal subjects. Our measure of BMI was based on self report, however several studies show that self-reported weight and height are sufficiently precise.[36] Finally, because the sample was accrued retrospectively, waist circumference and WHR were not measured. Therefore, we could not measure their relationship to total VAT nor could we determine the effect of combining multiple anthropometric measures of adiposity to predict total VAT.

In summary, intra-abdominal adipose tissue is an important, independent, and specific risk factor for cardiovascular disease, diabetes and cancer. Studies of the association between intra-abdominal adipose tissue and disease require an accurate and reliable measure. Our analysis shows that indirect measures, such as sagittal diameter or BMI, are not sufficiently precise. The considerable variability in VAT for men and women with a BMI ≥ 27 mandates direct measurement for accurate quantification. Within a narrow range of sagittal diameter or BMI, there is an approximate three-fold variation in total VAT, whereas the L4-L5 VAT area is an accurate predictor of total VAT across gender and a wide range of BMI.

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References

1 Folsom AR, Kaye SA, Sellers TA, Hong C-P, Cerhan JR, Potter JD, Prineas RJ. Body fat distribution and 5-year risk of death in older women. *JAMA* 1993; **269**: 483–487.
2 Larsson B, Svardsudd K, Welin L, Wilhelmsen L, Björntorp P, Tibblin G. Abdominal adipose tissue distribution, obesity, and risk of cardiovascular disease and death: 13 years follow-up of participants in the study of men born in 1913. *BMJ* 1984; **288**: 1401–1404.
3 Lapidus L, Bengtsson C, Larsson B, Pennert K, Rybo E, Sjöström L. Distribution of adipose tissue and risk of cardiovascular disease and death: a 12 year follow-up of participants in the population study of women in Gothenburg, Sweden. *BMJ* 1984; **289**: 1257–1261.
4 Prineas RJ, Folsom AR, Kaye SA. Central adiposity and increased risks of coronary artery disease mortality in older women. *Ann Epidemiol* 1993; **3**: 35–41.
5 Kaye SA, Folsom AR, Sprafka JM, Prineas RJ, Wallace RB. Increased incidence of diabetes mellitus in relation to abdominal adiposity in older women. *J Clin Epidemiol* 1991; **44**: 329–334.
6 Ohlson LO, Larsson B, Svardsudd K, Welin L, Eriksson H, Wilhelmsen L, Bjorntorp P, Tibblin G. The influence of body fat distribution on the incidence of diabetes mellitus: 13.5 years of follow-up of the participants in the study of men born in 1913. *Diabetes* 1985; **34**: 1055–1058.
7 Sellers TA, Kushi LH, Potter JD, Kaye SA, Nelson CL, McGovern PG, Folsom AR. Effect of family history, body fat distribution, and reproductive factors on the risk of postmenopausal breast cancer. *N Engl J Med* 1992; **326**: 1323–1329.

8 Schapira DV, Kumar NB, Lyman GH, Cavanagh D, Roberts WS, LaPolla J. Upper-body fat distribution and endometrial cancer risk. *JAMA* 1991; **266**: 1808–1811.
9 Giovannucci E, Ascherio A, Rimm EB, Colditz GA, Stampfer MJ, Willett WC. Physical activity, obesity, and risk for colon cancer and adenoma in men. *Ann Intern Med* 1995; **122**: 327–334.
10 Gann PH, Daviglus ML, Dyer AR, Stamler J. Heart rate and prostate cancer mortality: Results of a prospective analysis. *Cancer Epi Bio Prev* 1995; **4**: 611–616.
11 Kooy KVD, Seidell JC. Techniques for the measurement of visceral fat: a practical guide. *Int J Obes* 1993; **17**: 187–196.
12 Ross R. Magnetic resonance imaging provides new insights into the characterization of adipose and lean tissue distribution. *Can J Physiol Pharmacol* 1996; **74**: 778–785.
13 Hunter GR, Snyder SW, Kekes-Szabo T, Nicholson C, Berland L. Intra-abdominal adipose tissue values associated with risk of possessing elevated blood lipids and blood pressure. *Obes Res* 1994; **2**: 563–568.
14 Williams MJ, Hunter GR, Kekes-Szabo T, Trueth MS, Snyder S, Berland L, Blandeau T. Intra-abdominal adipose tissue cutpoints related to elevated cardiovascular risk in women. *Int J Obes* 1996; **20**: 613–617.
15 Kvist H, Chowdhury B, Grangard U, Tylén U, Sjöström L. Total and visceral adipose-tissue volumes derived from measurements with computed tomography in adult men and women: predictive equations. *Am J Clin Nutr* 1988; **48**: 1351–1361.
16 Seidell JC, Oosterlee A, Deurenberg P, Hautvast JGAJ, Ruijs JHJ. Abdominal fat depots measured with computed tomography: effects of degree of obesity, sex, and age. *Eur J Clin Nutr* 1988; **42**: 805–815.
17 Ferland M, Després J-P, Tremblay A, Pinault S, Nadeau A, Moorjan S, Lupien PJ, Thériault G, Bouchard C. Assessment of adipose tissue distribution by computed axial tomography in obese women: association with body density and anthropometric measurements. *Br J Nutr* 1989; **61**: 139–148.
18 Després J-P, Prud'homme D, Pouliot M-C, Tremblay A, Bouchard C. Estimation of deep abdominal adipose-tissue accumulation from simple anthropometric measurements in men. *Am J Clin Nutr* 1991; **54**: 471–477.
19 Svendsen OL, Hassager C, Bergmann I, Christiansen C. Measurement of abdominal and intra-abdominal fat in postmenopausal women by dual energy X-ray absorptionetry and anthropometry: comparison with computerized tomography. *Int J Obes* 1993; **17**: 45–51.
20 Tornaghi G, Raiteri R, Pozzato C, Rispoli A, Bramani M, Cipolat M, Craveri A. Anthropometric or ultrasonic measurements in assessment of visceral fat: A comparative study. *Int J Obes* 1994; **18**: 771–775.
21 Armellini F, Zamboni M, Robbi R, Todesco T, Rigo L, Bergamo-Andreis IA, Bosello O. Total and intra-abdominal fat measurements by ultrasound and computerized tomography. *Int J Obes* 1993; **17**: 209–214.
22 Armellini F, Zamboni M, Castelli S, Micciolo R, Mino A, Turcato E, Rigo L, Bergamo-Andreis A, Bosello O. Measured and predicted total and visceral adipose tissue in women. Correlations with metabolic parameters. *Int J Obes* 1994; **18**: 641–647.
23 Weits T, Van Der Beek EJ, Wedel M, Ter Haar Romeny BM. Computed tomography measurement of abdominal fat deposition in relation to anthropometry. *Int J Obes* 1988; **12**: 217–225.
24 Pouliot M-C, Despres J-P, Lemieux S, Moorjani S, Bouchard C, Tremblay A, Nadeau A, Lupien PJ. Waist circumference and abdominal sagittal diameter: best simple anthropometric indexes of abdominal visceral adipose tissue accumulation and related cardiovascular risk in men and women. *Am J Cardiol* 1994; **73**: 460–468.
25 Ross R, Shaw KD, Martel Y, de Guise J, Avruch L. Adipose tissue distribution measured by magnetic resonance imaging in obese women. *Am J Clin Nutr* 1993; **57**: 470–475.
26 Kekes-Szabo T, Hunter GR, Nyikos I, Nocholson C, Snyder S, Berland L. Development and validation of computed tomography derived anthropometric regression equations for estimating abdominal adipose tissue distribution. *Obes Res* 1994; **2**: 450–57.
27 Treuth MS, Hunter GR, Kekes-Szabo T. Estimating intraabdominal adipose tissue in women by dual-energy X-ray absorptiometry. *Am J Clin Nutr* 1995; **62**: 527–32.
28 Van der Kooy K, Leenen R, Seidell JC, Deurenberg P, Visser M. Abdominal diameters as indicators of visceral fat: comparison between magnetic resonance imaging and anthropometry. *Br J Nutr* 1993; **70**: 47–58.
29 Ross R, Rissanen J, Hudson R. Sensitivity associated with the identification of visceral adipose tissue levels using waist circumference in men and women: effects of weight loss. *Int J Obes* 1996; **20**: 533–538.
30 Chowdhury B, Sjöström L, Alpsten M, Kostanty J, Kvist H, Löfgreb R. A multicompartment body composition technique based on computerized tomography. *Int J Obes* 1994; **18**: 219–234.
31 Kvist H, Sjöström L, Tylén U. Adipose tissue volume determinations in women by computed tomography: technical considerations. *Int J Obes* 1986; **10**: 53–67.
32 Rössner S, BO WJ, Hiltbrandt E, Hinson W, Karstaedt N, Santago P, Sobol WT, Crouse JR. Adipose tissue determinations in cadavers–A comparison between cross-sectional planimetry and computed tomography. *Int J Obes* 1990; **14**: 893–902.
33 Borkan GA, Gerzof SG, Robbins AH, Hults DE, Silbert CK, Silbert JE. Assessment of abdominal fat content by computed tomography. *Am J Clin Nutr* 1982; **36**: 172–177.
34 Tokunaga K, Matsuzawa Y, Ishikawa K, Tarui S. A novel technique for the determination of body fat by computed tomography. *Int J Obes* 1983; **7**: 437–445.
35 Koester RS, Hunter GR, Snyder S, Khaled MA, Berland LL. Estimation of computerized tomography derived abdominal fat distribution. *Int J Obes* 1992; **16**: 543–554.
36 Willett W. Anthropometric Measures and Body Composition. Nutritional Epidemiology. Oxford University Press: New York, 1990, 217–244.