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Secular and longitudinal trends in body composition: The Tromsø Study, 2001 to 2016

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Abstract

Objective: Overweight, defined as excessive fat mass, is a long-standing worldwide public health challenge. Traditional anthropometric measures used to identify overweight and obesity do not assess body composition. The aim of this study was to examine population trends in general and abdominal fat mass during the past two decades.

Methods: This study included participants from one or more consecutive surveys of the population-based Tromsø Study, including Tromsø 5 (conducted in 2001, $n = 1{,}662$, age 40-84 years), Tromsø 6 (2007-2008, $n = 901$, age 40-88 years), and Tromsø 7 (2015-2016, $n = 3{,}670$, age 40-87 years), with total body dual-energy x-ray absorptiometry scans. Trends in total fat and visceral adipose tissue (VAT) were analyzed by generalized estimation equation models in strata of sex and age groups.

Results: Total fat and VAT mass increased during 2001 to 2016, with a larger increase during 2007 to 2016 than from 2001 to 2007 and among the youngest age group (40-49 years), particularly in women. Women had higher total fat mass than men, whereas men had higher VAT mass than women.

Conclusions: General and abdominal dual-energy x-ray absorptiometry-derived fat mass increased during the past two decades in this general population. Of particular concern is the more pronounced increase in the past decade and in the younger age groups.

INTRODUCTION

The obesity epidemic causes concern in all parts of the world, and almost 40% of the adult population worldwide had overweight in 2016 according to the World Health Organization (1). Obesity and overweight are major risk factors for noncommunicable diseases, including cardiovascular diseases, which are the leading cause of death globally (2).

The definition of overweight and obesity is "abnormal or excessive fat accumulation that may impair health" (1). Anthropometric measures such as BMI (weight in kilograms divided by height in meters squared) and waist circumference are currently the most frequently used measures of general and abdominal overweight and obesity, in lack of more precise but available methods. BMI and waist circumference do not distinguish between fat mass and fat free mass; therefore, these measures do not directly address the definition of obesity. Increased BMI indicates either increased muscle mass and/or increased fat mass, which have different effects on health. Most previous studies have used BMI to present increasing prevalence of overweight and obesity, but it is unknown whether body composition has changed over time.

There are several tools to examine body composition. The more accurate tools such as magnetic resonance imaging and computed tomography are expensive or resource demanding, or they involve considerable radiation exposure (3). Dual-energy x-ray absorptiometry (DXA) is a clinically applicable imaging method with negligible radiation exposure that also provides accurate measures of body fat, bone, and lean tissue (i.e., muscle and organs, bone and fat excluded) (3). In addition, the CoreScan application (EnCore version 17.0, GE Healthcare, Madison, Wisconsin) enables computation of visceral adipose tissue (VAT) from DXA scans, which is highly correlated with VAT derived from magnetic resonance imaging and computed tomography scans (4,5). VAT, located intra-abdominally and around organs, is regarded as the most metabolically active body fat component and is associated with cardiometabolic diseases and several types of cancers (6). Previous studies investigating DXA-measured changes in body composition mainly included older adults (≥65 years old) and had short follow-up (≤5 years) (7-12). To our knowledge, no studies have examined both secular and longitudinal changes in body composition and VAT mass in a general adult population sample measured by DXA.

The aim of this study was to examine trends in body composition during the past two decades using a population-based sample.

Study Importance

What is already known?

- Overall, overweight and obesity, usually measured by BMI, are increasing all around the world, and no efforts have been shown to be effective in halting this trend.
- BMI is a proxy measure of overweight and obesity that does not address the actual definition of overweight and obesity, which is "excessive fat accumulations that may impair health." Knowledge about trends in body composition and especially trends in the most harmful fat (visceral fat) is lacking.

What does this study add?

- Our manuscript contributes new knowledge about secular and longitudinal trends in body composition and, more specifically, body fat, visceral fat, and lean mass in a general adult population with a follow-up of 15 years.
- No other studies, to our knowledge, have presented trends in dual-energy x-ray absorptiometry-derived visceral adipose tissue in a general population.

How might these results change the direction of research or the focus of clinical practice?

- We believe that our results are of importance to researchers, clinicians, and public health workers as motivation for enhancing the battle against the obesity epidemic and especially for targeting the younger generations in which the increase in body fat and visceral fat was higher than in the older participants.

METHODS

Study sample

The Tromsø Study is an ongoing population-based study (13) conducted in the Tromsø municipality, a municipality with about 77,000 inhabitants in Northern Norway (14). The majority of the population is native Norwegian and similar to the general Norwegian population in regard to age and sex (14). The Tromsø Study consists of seven surveys (Tromsø 1 [conducted in 1974], Tromsø 2 [1979-1980], Tromsø 3 [1986-1987], Tromsø 4 [1994-1995], Tromsø 5 [2001], Tromsø 6 [2007-2008], and Tromsø 7 [2015-2016]) that invited complete birth cohorts and large representative samples of the population in the Tromsø municipality. The present study includes participants from Tromsø 5 through Tromsø 7 (2001-2016). The data collections comprised a basic examination (total sample) with questionnaires and interviews, biological sampling, and clinical examinations, as well as an extended examination (subsamples) with additional clinical examinations, including DXA scanning. The subsamples invited to the extended examination varied between studies: in Tromsø 5 (total number of participants in the basic examination = 8,130, age 30-89 years, total attendance = 79%), all participants attending the basic examination in Tromsø 5 and who had previously attended the extended examination in Tromsø 4 were invited; in Tromsø 6 (*n* = 12,984, age 30-87 years, total attendance = 66%), all participants who attended the extended examination in Tromsø 4, all participants who were aged 50 to 62 years or 75 to 84 years, and a 20% random sample aged 63 to 74 years were invited to the extended examination; and in Tromsø 7 (*n* = 21,083, age 40-99 years, total attendance = 65%), a random sample plus all participants attending DXA and eye examinations in Tromsø 6 were invited to the extended examination.

A total of 1,713, 905, and 3,670 participants underwent whole-body DXA scans in Tromsø 5, Tromsø 6, and Tromsø 7, respectively. All participants attending one or more surveys were included in the analyses. Furthermore, only participants aged 40 years and above were included in the analysis because of few participants with DXA scans below age 40 years in Tromsø 5 (*n* = 51) and Tromsø 6 (*n* = 5). After exclusions, the final sample for analysis consisted of 1,662 (62% women, age 40-84 years) participants from Tromsø 5, 901 (63% women, age 40-88 years) participants from Tromsø 6, and 3,670 (59% women, age 40-87 years) participants from Tromsø 7 (Figure 1).

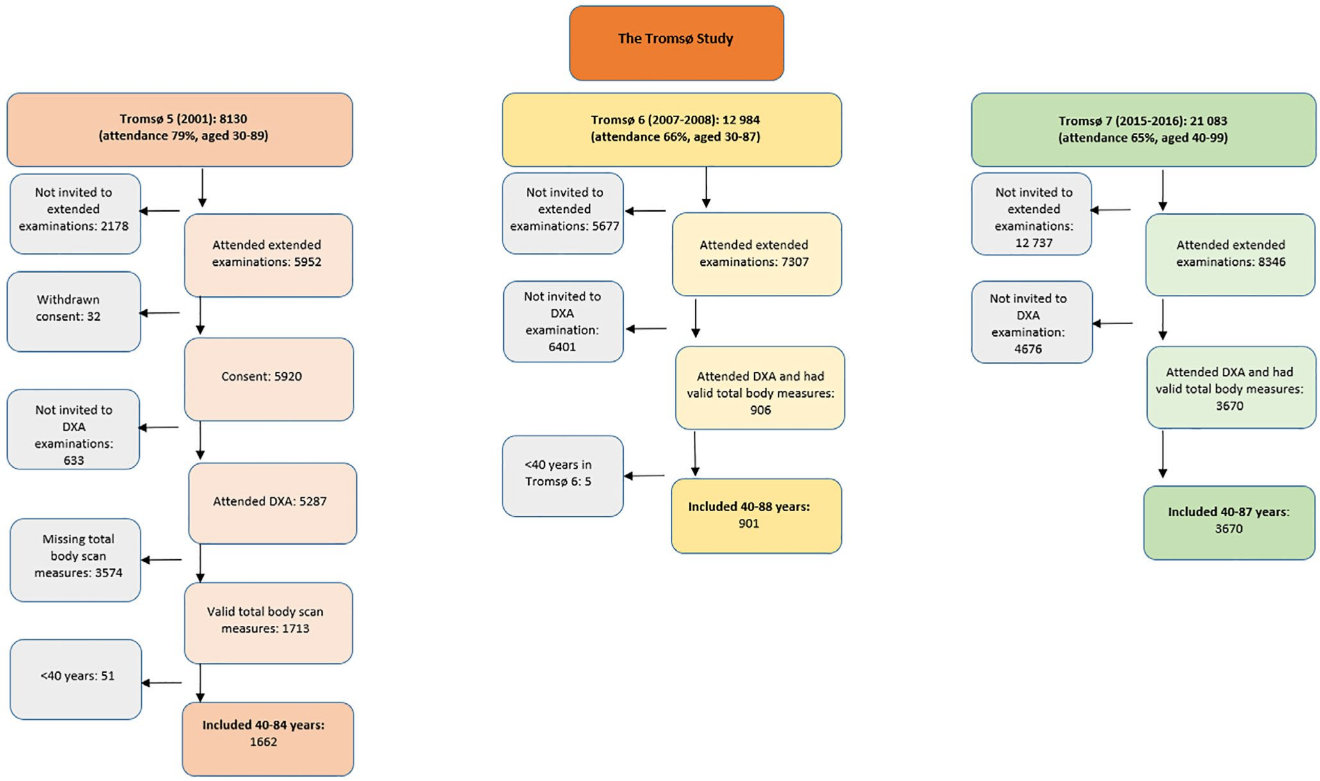

FIGURE 1 Inclusion of participants from Tromsø 5 (2001), Tromsø 6 (2007-2008), and Tromsø 7 (2015-2016). The Tromsø Study, 2001 to 2016. DXA, dual-energy x-ray absorptiometry

This project was approved by the Regional Committee for Medical Research Ethics (REC North reference 2017/1967). All participants gave written informed consent.

Body composition measures

In all three surveys, total body DXA scans were performed with Lunar Prodigy Advance (GE Medical Systems, Madison, Wisconsin) in accordance with protocols from the manufacturer. The DXA machine was calibrated each morning with a phantom. Post-scanned images were inspected by technicians and corrected if necessary. In order to ensure comparison between surveys, fat mass and lean mass were derived with Basic Mode Analysis, and VAT mass was derived with Enhanced Mode Analysis. Total body fat and lean and VAT mass were included directly from DXA scans from all three surveys. Total body fat and lean mass percentages were included directly from the DXA scans in Tromsø 6 and Tromsø 7, and they were calculated as total body fat or lean mass, respectively, divided by total body mass × 100 in Tromsø 5. Percentage of VAT was calculated as VAT mass divided by total body fat mass in the android area × 100. Total body fat mass in the android area was not available from Tromsø 5. Therefore, VAT in percentage was available only from Tromsø 6 and Tromsø 7; thus, analysis of trends in VAT was performed for VAT in grams only. It should also be noted that, of the 1,662 participants with total body DXA scans in Tromsø 5, VAT mass measures were available for 284 of them. All participants attending total body scans had valid VAT mass measures from Tromsø 6. In Tromsø 7, a total of 3,675 participants had valid VAT mass measures. Two participants with VAT percentage values > 100 in Tromsø 7 were excluded from analysis of VAT; therefore, a total of 3,673 participants with valid VAT measures were included in Tromsø 7. Participants with VAT mass equal to 0 had their values transformed into the lowest registered value of VAT mass in the sample, which was 2 g in both Tromsø 6 (n = 5) and Tromsø 7 (n = 10). There were no values of 0 for VAT in Tromsø 5.

Statistical analyses

We used Stata version 16 (StataCorp LLC, College Station, Texas) to analyze both secular and longitudinal trends in body composition across surveys. Total body mass consists of fat mass and lean mass; therefore, we present results from lean mass analysis in online Supporting Information. Mean values are presented with standard deviations (SD) or 95% confidence intervals (CI). In order to examine whether there were systematic differences in study population characteristics between those who re-participated in two or three of the surveys compared with those who participated in only one of the surveys, we present sex-adjusted mean values and proportions of cardiometabolic risk factors in 10-year age groups (Supporting

TABLE 1 Mean total body fat (kilograms and percentage) in Tromsø 5, Tromsø 6, and Tromsø 7 in women and men by 10-year age groups: The Tromsø Study, 2001 to 2016

	Tromsø 5 (2001, n = 1,662)					Tromsø 6 (2007-2008, n = 901)					Tromsø 7 (2015-2016, n = 3,670)				
Age (y)	*n*	Body fat (kg)	Body fat (%)	BMI (kg/m^2)	Weight (kg)	*n*	Body fat (kg)	Body fat (%)	BMI (kg/m^2)	Weight (kg)	*n*	Body fat (kg)	Body fat (%)	BMI (kg/m^2)	Weight (kg)
Women															
40-49	46	22.6 (8.5)	32.8 (7.8)	25.1 (4.23)	67.8 (11.7)	32	22.8 (10.7)	32.5 (8.7)	25.3 (5.28)	67.8 (14.6)	128	26.4 (9.7)	35.9 (7.6)	26.0 (4.46)	71.9 (13.3)
50-59	216	26.5 (9.8)	36.3 (7.6)	26.7 (4.95)	71.6 (13.8)	31	26.7 (9.6)	36.9 (7.3)	26.6 (4.94)	71.4 (14.6)	283	27.0 (9.7)	36.9 (7.5)	26.5 (4.87)	71.7 (13.3)
60-69	407	25.6 (8.0)	36.8 (7.0)	26.5 (4.21)	69.9 (11.0)	278	26.4 (9.2)	36.7 (7.5)	26.9 (4.81)	70.6 (13.1)	931	27.7 (9.4)	38.2 (7.2)	26.6 (4.59)	71.3 (12.8)
70-79	313	26.5 (9.3)	37.8 (7.9)	27.2 (4.67)	68.7 (12.1)	187	26.1 (8.0)	37.2 (7.2)	27.0 (4.01)	69.1 (11.0)	690	28.6 (9.6)	39.3 (7.2)	27.5 (4.89)	71.9 (13.2)
80+	39	25.7 (8.3)	37.4 (6.8)	27.2 (3.90)	68.0 (11.5)	39	25.8 (10.2)	36.5 (8.8)	27.3 (5.26)	68.9 (13.7)	117	25.3 (7.9)	37.9 (7.1)	26.3 (3.88)	66.2 (10.8)
Overall	1,021	26.0 (8.9)	36.8 (7.5)	26.7 (4.52)	69.4 (12.1)	567	26.0 (9.0)	36.6 (7.6)	26.9 (4.63)	69.9 (12.6)	2,149	27.7 (9.5)	38.2 (7.3)	26.8 (4.70)	71.3 (13.0)
Men															
40-49	20	19.6 (6.9)	23.3 (6.2)	26.0 (2.41)	83.3 (12.4)	18	17.0 (6.3)	20.4 (6.0)	25.9 (2.85)	81.4 (11.4)	101	26.6 (11.1)	27.8 (7.7)	28.8 (4.59)	93.1 (17.2)
50-59	100	21.9 (7.0)	25.0 (5.7)	27.8 (3.01)	86.4 (11.1)	32	19.9 (7.3)	23.7 (6.6)	26.7 (2.68)	82.5 (9.69)	188	23.5 (7.9)	26.5 (6.3)	27.5 (3.39)	87.1 (11.8)
60-69	273	20.7 (7.6)	24.8 (6.4)	26.8 (3.43)	82.0 (12.5)	111	22.0 (7.0)	25.8 (6.1)	27.5 (3.11)	84.6 (10.0)	721	24.0 (8.6)	27.3 (6.8)	27.6 (3.69)	86.4 (12.3)
70-79	219	19.8 (7.7)	24.8 (7.1)	26.2 (3.67)	78.3 (12.0)	142	20.2 (7.9)	24.7 (6.5)	26.6 (3.62)	80.3 (12.6)	417	24.2 (8.1)	28.4 (6.4)	27.5 (3.60)	84.4 (12.3)
80+	29	19.5 (8.4)	24.7 (7.2)	25.3 (4.23)	75.4 (13.5)	31	24.0 (7.1)	29.1 (5.8)	27.2 (3.34)	81.8 (12.2)	94	22.4 (8.1)	28.0 (7.0)	26.3 (3.42)	78.8 (11.7)
Overall	641	20.5 (7.6)	24.8 (6.6)	26.6 (3.51)	81.2 (12.5)	334	21.0 (7.5)	25.1 (6.5)	26.9 (3.31)	82.1 (11.5)	1,521	24.1 (8.6)	27.6 (6.7)	27.6 (3.71)	85.9 (13.2)

Numbers are presented as mean (SD) in 10-year age groups and overall.

Information Table S1; all participants in Tromsø 6 attended Tromsø 5 and/or Tromsø 7).

Secular trends

We used descriptive analysis to present mean total body fat (kilograms and percentage), lean mass (kilograms and percentage), VAT mass (grams and percentage), BMI (kilograms/meters squared), body weight (kilograms), and waist circumference (centimeters) in strata of 10-year age groups for all three surveys (Tables 1 and 2 and Supporting Information Table S2). We used kernel density plots to present distributions of total body fat, lean mass, and VAT mass from all three surveys (Figures 2 and 3 and Supporting Information Figure S1). In order to visualize secular trends in total body fat and lean mass, we plotted mean values from birth year-adjusted generalized estimation equation (GEE) analyses of each body composition measure from each survey (Figure 4 and Supporting Information Figure S2).

Longitudinal trends

Owing to the fact that we did not have complete repeated measures for all included participants and to account for repeated measures in the 940 participants attending two or more of the three surveys (of which, 382 attended all three), we used GEE analysis (which estimates values for all participants attending one of the surveys) to examine the longitudinal trends overall and in 10-year age groups (attained age in Tromsø 5 [2001]). Longitudinal change in total body fat, lean mass, and VAT mass across surveys was presented by adjusting for birth year using GEE analysis (Table 3 and Supporting Information Table S3). Furthermore, we assessed whether longitudinal change in body composition differed between age groups by performing GEE analysis in strata of age groups in 2001 (40-49 years, 50-59 years, 60-69 years, and 70-79 years). Only participants < 80 years old were included in these analyses because few participants were aged 80 years and older (n = 74). In separate models, we included two-way interaction terms between indicator variables of 10-year age groups in 2001 and an ordinal variable of time (Table 4 and Supporting Information Tables S4 and S5). All analyses are presented for women and men separately. $P < 0.05$ was considered statistically significant.

RESULTS

There was a higher proportion of women (58%-63%) than men in all three surveys and a higher mean age in Tromsø 6 (mean age = 68.5 and 69.9 years in women and men, respectively) compared with Tromsø 5 (mean age = 65.2 and 66.5 years in women and men, respectively) and Tromsø 7 (mean age = 66.7 and 66.2 years

TABLE 2 Mean total visceral adipose tissue (grams) in Tromsø 5, Tromsø 6, and Tromsø 7 and percentage of VAT in Tromsø 6 and Tromsø 7 in women and men, by 10-year age groups: The Tromsø Study, 2001 to 2016

	Tromsø 5 (2001, n = 284)				Tromsø 6 (2007-2008, n = 901)				Tromsø 7 (2015-2016, n = 3,673)			
Age (y)	*n*	VAT (g)	VAT (%)	WC (cm)	*n*	VAT (g)	VAT (%)	WC (cm)	*n*	VAT (g)	VAT (%)	WC (cm)
Women												
40-49	10	442 (221)	NA	78.6 (9.79)	32	470 (467)	20.2 (13.1)	88.3 (13.8)	128	515 (435)	22.7 (11.1)	86.6 (11.2)
50-59	35	826 (664)	NA	84.9 (13.0)	31	797 (770)	28.2 (16.5)	90.2 (13.0)	284	832 (651)	32.7 (13.2)	89.6 (12.8)
60-69	64	895 (548)	NA	85.1 (10.4)	278	917 (621)	33.7 (12.5)	91.9 (12.3)	932	935 (635)	36.5 (13.5)	90.8 (12.2)
70-79	43	951 (665)	NA	86.5 (12.9)	187	956 (569)	37.9 (13.6)	92.2 (10.6)	691	1,064 (625)	42.3 (11.8)	93.5 (12.6)
80+	10	1,085 (442)	NA	88.5 (8.41)	39	871 (507)	37.2 (12.3)	92.4 (11.8)	117	920 (542)	43.1 (12.8)	89.6 (10.5)
Overall	162	878 (597)	NA	85.3 (11.6)	567	895 (607)	34.7 (13.6)	91.7 (11.9)	2,152	937 (632)	37.1 (13.6)	91.2 (12.4)
Men												
40-49	4	874 (789)	NA	88.5 (13.5)	18	851 (599)	42.5 (28.4)	91.7 (7.01)	102	1,471 (919)	48.7 (14.3)	101.2 (12.5)
50-59	24	1,561 (698)	NA	97.2 (6.06)	32	1,283 (762)	50.4 (20.1)	94.8 (7.87)	187	1,448 (744)	55.5 (13.0)	98.7 (9.63)
60-69	52	1,354 (769)	NA	95.3 (9.36)	111	1,560 (767)	56.3 (16.1)	100.8 (9.00)	722	1,687 (891)	60.5 (13.7)	100.5 (10.7)
70-79	35	1,434 (836)	NA	93.8 (10.8)	142	1,462 (880)	57.6 (14.3)	99.2 (10.0)	417	1,775 (886)	63.8 (13.9)	101.3 (9.92)
80+	7	1,590 (1075)	NA	99.4 (11.5)	31	1,828 (644)	64.1 (13.6)	104.7 (9.41)	93	1,571 (827)	62.6 (12.5)	99.8 (10.1)
Overall	122	1,415 (793)	NA	95.2 (9.57)	334	1,479 (819)	56.9 (16.0)	99.4 (9.67)	1,521	1,660 (877)	60.1 (14.2)	100.5 (10.5)

Numbers are presented as mean (SD) in 10-year age groups and overall.

Abbreviations: VAT, visceral adipose tissue; WC, waist circumference.

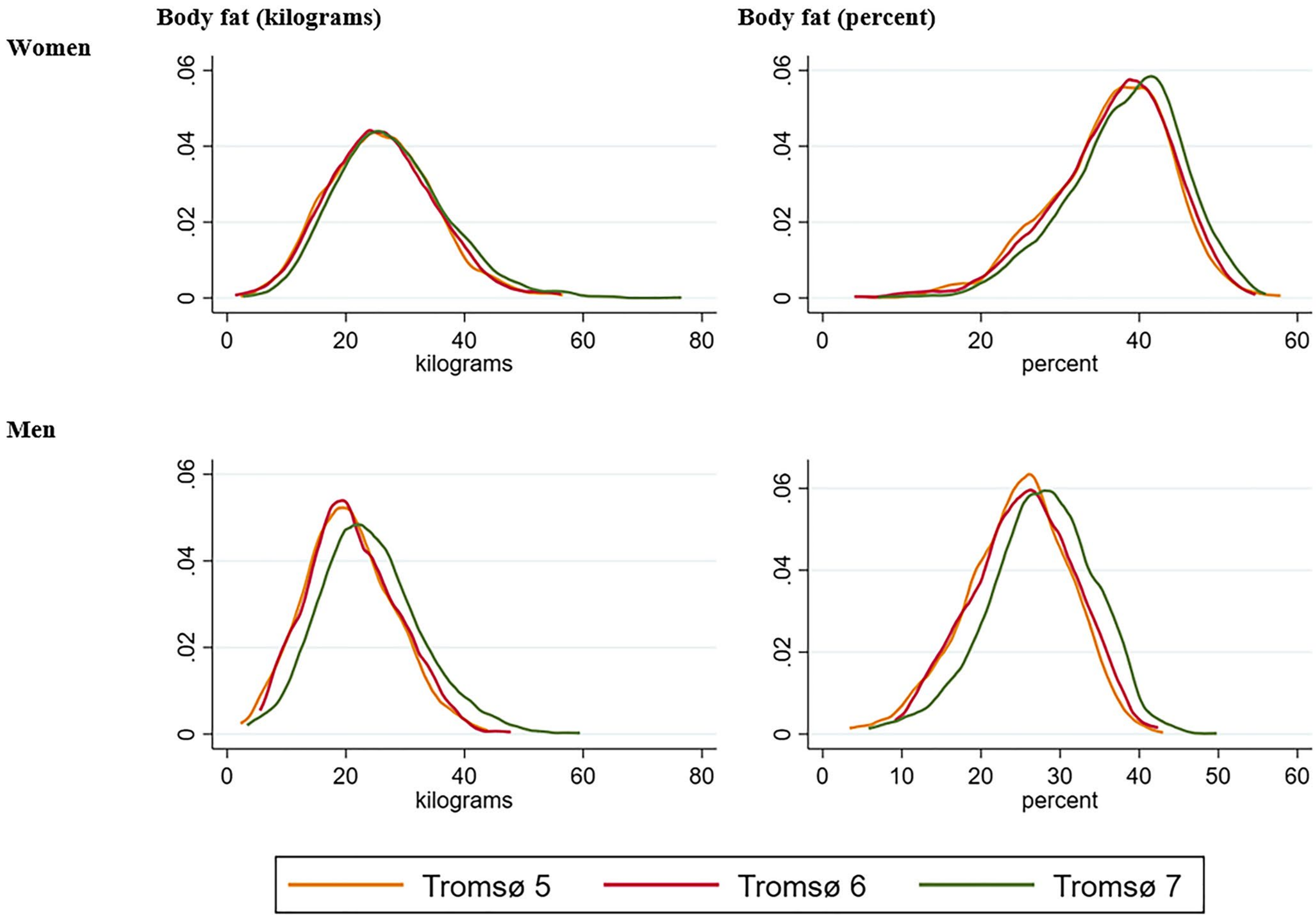

FIGURE 2 Kernel density plots of the distribution of body fat (kilograms and percentage) in women and men age ≥ 40 years in Tromsø 5 (2001; orange line), Tromsø 6 (2007-2008; red line), and Tromsø 7 (2015-2016; green line). The Tromsø Study, 2001 to 2016

in women and men, respectively). There were minor differences in cardiometabolic risk factors between those attending one compared with two or more DXA scans (Supporting Information Table S1).

Secular trends

Overall, mean total body fat and VAT mass increased across the three surveys (Tables 1 and 2). Correspondingly, percentage of total body lean mass was slightly lower in Tromsø 7 than in Tromsø 5 and Tromsø 6 (Supporting Information Table S2). Overall, BMI and waist circumference in women increased between 2001 and 2007-2008 but remained relatively stable between 2007-2008 and 2015-2016. In men, BMI and waist circumference increased across the three surveys. Overall body weight increased between the three surveys in both women and men (Tables 1 and 2). The kernel density plots indicate that, for each survey added, the distributions for fat and VAT shifted to the right in both women and men. Density plots for lean mass in kilograms were slightly shifted to the right in men only, whereas density plots for lean mass in percentage were shifted to the left for each added survey (Figures 2 and 3 and Supporting Information Figure S1).

Figure 4 shows that both total body fat and VAT mass increased from Tromsø 5 to Tromsø 6, and a much steeper increase was observed from Tromsø 6 to Tromsø 7. Total body fat mass was higher in women compared with men, whereas VAT mass was higher in men compared with women across all surveys ($p < 0.001$ for both). VAT mass increased more rapidly in men than in women over time ($p < 0.001$). Overall, absolute body lean mass was higher in men than in women, and lean mass (kilograms) remained stable across surveys in both women and men (Supporting Information Figure S2). Percentage of lean mass, on the other hand, decreased across surveys, especially from Tromsø 6 to Tromsø 7, which aligns with the increased absolute values of fat mass and the stable trend in lean mass (Supporting Information Figure S2).

Longitudinal trends

Results from GEE analyses (Table 3) show that total body fat mass increased across all surveys. There was a small increase from Tromsø

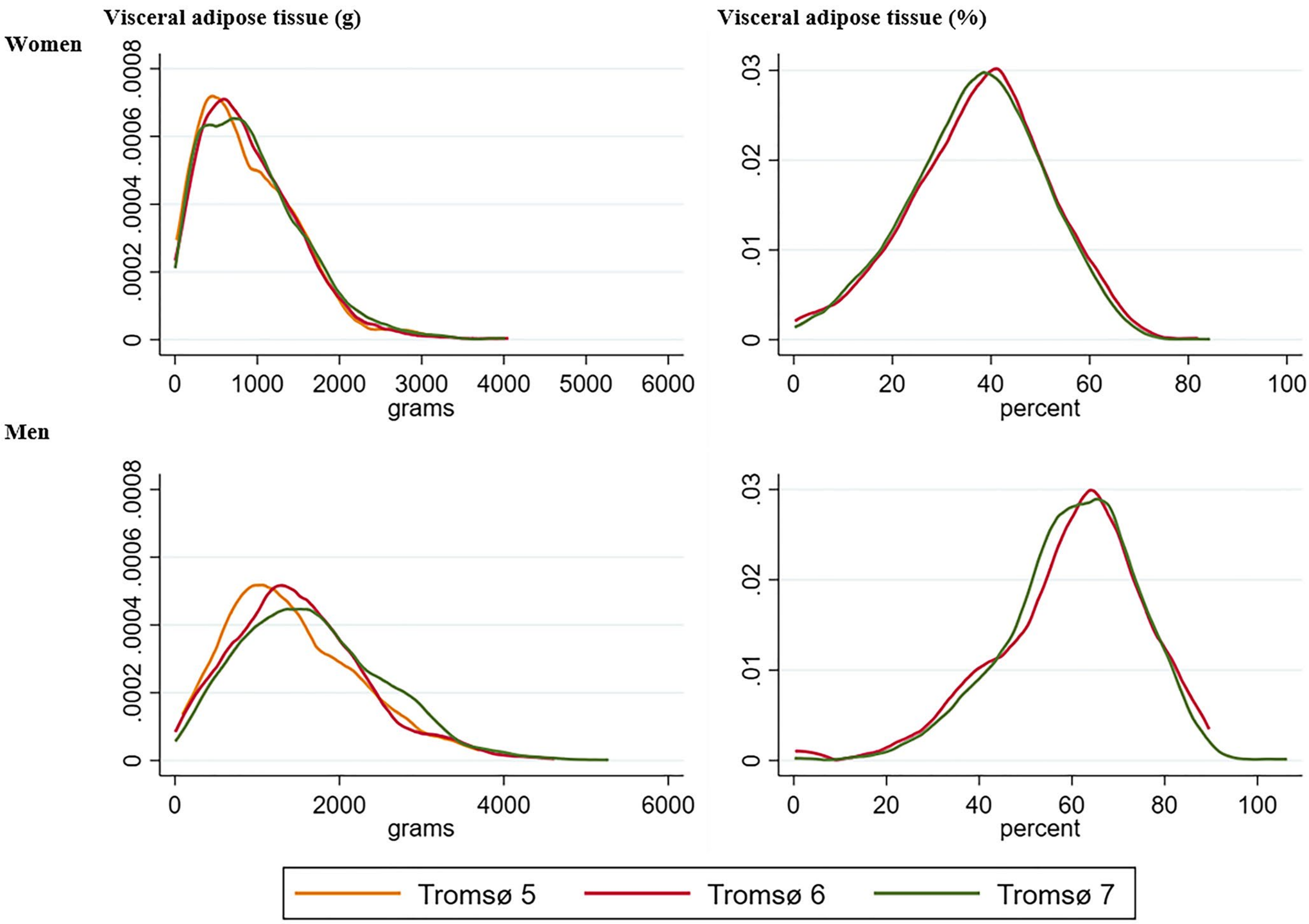

FIGURE 3 Kernel density plots of the distribution of visceral adipose tissue (grams and percentage) in women and men age ≥ 40 years in Tromsø 5 (2001; orange line), Tromsø 6 (2007-2008; red line), and Tromsø 7 (2015-2016; green line). The Tromsø Study, 2001 to 2016

5 to Tromsø 6 (0.2 kg and 0.1% body fat increase in women and 0.5 kg and 0.6% body fat increase in men), whereas the increase from Tromsø 5 to Tromsø 7 was more pronounced (1.8 kg and 2.3% body fat increase in women and 3.0 kg and 3.7% body fat increase in men). Also, VAT mass increased across the follow-up period from Tromsø 5 to Tromsø 7 (200 g and 365 g in women and men, respectively), whereas a smaller increase was observed between Tromsø 5 and Tromsø 6 (48 g and 103 g in women and men, respectively). From Tromsø 6 to Tromsø 7, VAT percentage increased by 5% in both women and men.

Table 4 shows that mean total body fat and VAT mass were lowest in the youngest age group (40-49 years) in Tromsø 5. The largest estimated increase in fat and VAT mass between Tromsø 5 and Tromsø 7 was observed in the same age group (40-49 years), with an increase of 3.9 kg (4.0%) in fat mass and 293 g in VAT mass in women and 4.5 kg (4.1%) in fat mass and 806 g in VAT mass in men. The difference in the estimated increase between age groups was not significant in men for fat or for VAT mass (Table 4). In sensitivity analyses including only participants with repeated DXA scans from all three ($n = 382$) or from two or three surveys ($n = 940$), the results in longitudinal trends did not change (not presented).

DISCUSSION

In these secular and longitudinal analyses using a population-based sample, we found that both total body fat and VAT mass increased over the past two decades in both women and men. The increases in total body fat and VAT mass were more pronounced in the past decade and in the youngest age groups (but were statistically significantly different in women only).

Secular trends

We observed an increase in mean body fat and VAT mass across time. Previous literature on the secular trend in DXA-derived fat and VAT mass in adults is scarce; therefore, we were unable to compare our results with other studies. Overall, body weight increased across time, and, in men, there was an increasing trend in both BMI and waist circumference across time. In women, neither BMI nor waist circumference increased between 2007-2008 and 2015-2016. However, the differences in mean BMI and waist circumference were clinically minor between the two latter surveys. In addition,

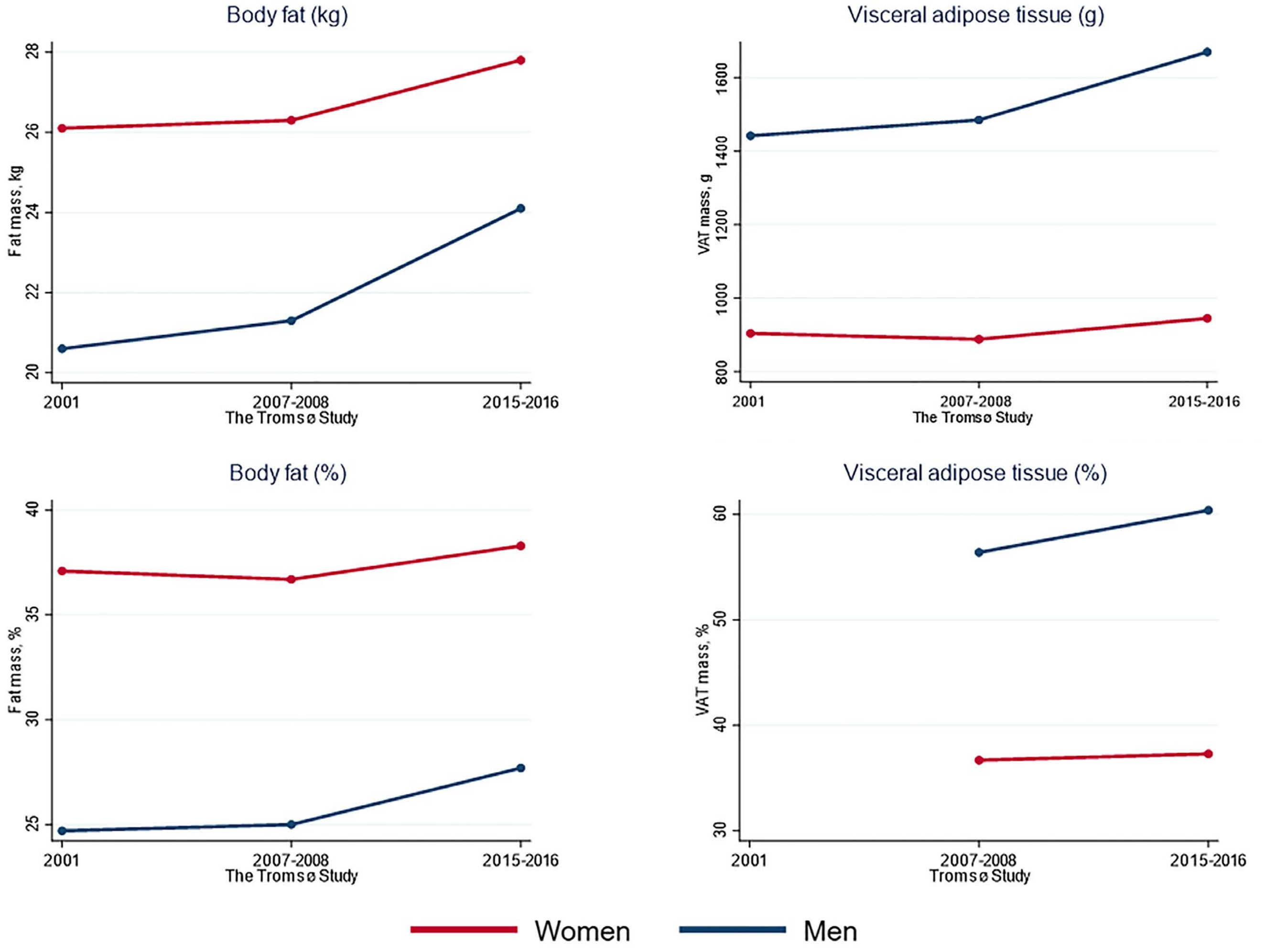

FIGURE 4 Trends in age-adjusted mean body fat (kilograms and percentage) and VAT (grams and percentage) mass in women (red line) and men (blue line). The Tromsø Study, 2001 to 2016. Each dot represents mean fat mass or mean VAT mass in Tromsø 5 (2001), Tromsø 6 (2007-2008), and Tromsø 7 (2015-2016). Percentage of VAT was available only from Tromsø 6 and Tromsø 7. VAT, visceral adipose tissue

TABLE 3 Estimated mean body fat (kilograms and percentage) and VAT (grams and percentage) in Tromsø 5 (2001) and subsequent change to Tromsø 6 (2007-2008) and Tromsø 7 (2015-2016) using generalized estimating equation models: The Tromsø Study, 2001 to 2016

	Body fat (kg)	Body fat (%)	VAT (g)	VAT (%)
Women				
Intercept (Tromsø 5, 2001)[a]	26.3 (25.8 to 26.8)	37.2 (36.8 to 37.6)	920 (863 to 977)	NA
Tromsø 6	0.2 (−0.3 to 0.7)	0.1 (−0.3 to 0.5)	47.5 (−1.4 to 96.3)	40.2 (39.2 to 41.2)[a]
Tromsø 7	1.8 (1.3 to 2.4)	2.3 (1.9 to 2.7)	200 (148 to 251)	4.9 (4.0 to 5.7)
Men				
Intercept (Tromsø 5, 2001)[a]	20.4 (19.8 to 21.0)	24.6 (24.2 to 25.1)	1,428 (1,313 to 1543)	NA
Tromsø 6	0.5 (−0.2 to 1.3)	0.6 (0.1 to 1.2)	103 (−11.1 to 217)	61.9 (60.7 to 63.1)[a]
Tromsø 7	3.0 (2.3 to 3.8)	3.7 (3.1 to 4.3)	365 (247 to 483)	4.6 (3.9 to 5.3)

Estimates are presented with 95% CI and are adjusted for birth year.

Abbreviations: NA, not applicable; VAT, visceral adipose tissue.

[a]Intercept represents means in Tromsø 5, but for the analyses of percentage of VAT, the intercept is for Tromsø 6.

TABLE 4 Estimated means of body fat (kilograms and percentage) and VAT (grams) in Tromsø 5 (2001) and estimated change to Tromsø 7 (2015-2016) using generalized estimating equation by gender and 10-year age groups: The Tromsø Study, 2001 to 2016

Age in 2001 (y)	Body fat (kg)		Body fat (%)		VAT (g)	
	Tromsø 5 (2001)	Estimated change[a]	Tromsø 5 (2001)	Estimated change[a]	Tromsø 5 (2001)	Estimated change[a]
Women						
40-49	23.0	3.9 (1.9 to 5.8)	33.3	4.0 (2.5 to 5.5)	547	293 (150 to 436)
50-59	26.7	2.3 (1.3 to 3.2)	36.5	2.7 (2.0 to 3.4)	785	271 (194 to 347)
60-69	25.7	0.9 (0.06 to 1.7)	36.7	1.5 (0.9 to 2.2)	806	176 (111 to 241)
70-79	26.5	−1.6 (−3.8 to 0.6)	37.8	−1.5 (−3.1 to 0.1)	973	13.0 (−181 to 207)
p value[b]		<0.001		<0.001		0.047
Men						
40-49	19.3	4.5 (1.4 to 7.5)	22.8	4.1 (1.7 to 6.6)	783	806 (388 to 1,224)
50-59	21.8	2.6 (1.2 to 4.0)	24.8	2.9 (1.8 to 4.0)	1,364	394 (188 to 599)
60-69	20.5	2.7 (1.6 to 3.7)	24.5	3.7 (2.8 to 4.5)	1,382	300 (150 to 449)
70-79	19.8	3.1 (0.3 to 5.9)	24.7	3.7 (1.5 to 5.9)	1,385	370 (−62.0 to 802)
p value[b]		0.72		0.69		0.21

Abbreviation: VAT, visceral adipose tissue.

[a]Estimated change between 2001 and 2015-2016 presented with 95% CI.

[b]*p* value for equality between age groups.

we have previously shown that DXA-derived VAT mass strongly correlates with the more commonly available anthropometric measures, and we then concluded that these measures are satisfactory substitutes for the DXA-derived measures (15).

Longitudinal trends

The longitudinal trends showed that fat and VAT mass increased in both women and men in all age groups, except for body fat in women aged 70 to 79 years. Furthermore, the trends in fat (kilograms and percentage), VAT mass, and lean mass were more prominent in men than in women. This corresponds with findings from a previous study of 2,040 older individuals (age 70-79 years) with a follow-up of 2 years (11). Previous longitudinal studies have shown that body fat increases and lean mass decreases with increasing age (7,8,10-12). The trends in body composition were also present after adjusting for age, which implies that change in body composition may not only be an effect of age but also an effect of time. The changes in body composition differed between age groups, and the younger part of the population had a more unfavorable change in body composition over time, although age group differences in men were nonsignificant. These generational differences also have been observed in studies with longer follow-up of participants in the Tromsø Study (16-19) and other studies (20-23) in which the younger birth cohorts experienced larger increases in weight, BMI, and waist circumference than the older birth cohorts. The more pronounced increase in overweight in younger populations is a cause of concern for this generation's future health.

Body composition trends and the paradox with cardiometabolic risk

Contrasting the documented increase in overweight, other cardiometabolic risk factors such as total cholesterol (24,25), blood pressure (26,27), and overall burden of cardiometabolic risk (28-31) have decreased both in this study population as well as in other high-income countries. In this study population, leisure-time physical activity levels (32) and grip strength (improved physical function) (33) have increased over time. Therefore, the population seems to be in overall better health, whereas the trend in body composition suggests a health hazard. It is a paradox that the population is becoming physically stronger while, simultaneously, muscular mass remains stable, and, furthermore, that the cardiometabolic risk profile health improves while, simultaneously, the most metabolically harmful fat (VAT mass) increases. We may speculate that recent improvements in cardiometabolic health can be obstructed by the increase in prevalence of obesity in the younger generations.

Strengths and limitations

To our knowledge, no other study has presented secular trends in DXA-derived body composition in a general adult population, and, although previous longitudinal studies have found similar results, these studies examined changes in body composition by DXA in mostly older participants (age 65 years and older) and with shorter follow-up (a maximum of 5 years) (8,10-12). We have included participants aged 40 to 88 years with 14 years of follow-up (1,662, 901, and

3,670 participants in Tromsø 5, Tromsø 6, and Tromsø 7, respectively). Notably, we do not have repeated measures for all participants. A total of 940 participants attended two or more of the DXA scans (two or more repeated measures), and only 382 participants attended all three DXA scans (three repeated measures). We performed separate analyses for both those who attended two or more times as well as for those who attended all three DXA scans and found similar results. Furthermore, we examined cardiometabolic risk factors in those attending only one survey and in those attending two or more surveys and found that the clinical differences were minor. Of the 1,662 participants in Tromsø 5, only 284 participants had valid VAT measures. The CoreScan EnCore software application (GE Healthcare) for VAT extraction was not available in Tromsø 5 (2001). Therefore, the images were reanalyzed in 2019, and, at this point, many total body images were unavailable for extraction of VAT measures.

As for all population-based studies, selection bias may influence the results. Attenders in population studies tend to have a more favorable health profile than the nonattenders (34,35). This implicates that mean values of fat mass and VAT mass in the three surveys may be lower in the present study than in the general population.

Another limitation is the potential measurement error of the DXA equipment. Although Lunar Prodigy DXA (GE Medical Systems) was used in all three surveys, the more advanced Lunar iDXA machine could potentially have provided higher precision. Owing to the fact that all measurements were performed using identical protocols and equipment, we do not believe that our results are distorted by measurement error. Furthermore, the inconsistency in VAT measures increase with increasing obesity (36). However, the least significant change for VAT mass is reported to be ±130 g, meaning that observed changes larger than 130 g, as mostly observed in our study, can be considered actual changes (36). The results from this study are generalizable to similar populations measured with the same equipment as used in the current study.

CONCLUSION

During 2001 to 2016, fat mass and VAT mass increased whereas lean mass remained stable in both sexes and all age groups in this Norwegian general population. The findings confirm the observed unhealthy increase in general and abdominal obesity measured by traditional anthropometric measures. Particularly worrying is the more pronounced increase in the past decade and in the younger age groups.

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CONFLICT OF INTEREST

The authors declared no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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