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Allometric Relationship between Changes of Visceral Fat and Total Fat Mass

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Abstract

Objective—To elucidate the mathematical relationship between changes of visceral adipose tissue (VAT) and total body fat mass (FM) during weight loss.

Design—We hypothesized that changes of visceral adipose tissue (VAT) mass are allometrically related to changes of total fat mass (FM), regardless of the type of weight loss intervention, as defined by the differential equation $dVAT/dFM = k \times VAT/FM$ where k is a dimensionless constant. We performed a systematic search of the published literature for studies that included measurements of VAT changes via MRI or CT imaging along with measurements of FM changes by DEXA, hydrodensitometry, air-displacement plethysmography, or whole-body MRI or CT imaging. We then examined whether or not the data could be explained by the allometric model.

Results—We found 37 published studies satisfying our search criteria, representing 1407 men and women of various ethnicities, degrees of adiposity, and weight loss interventions. The hypothesized allometric equation relating changes of VAT and FM accurately modeled the data for both men and women and for all methods of weight loss studied. The best-fit value for the dimensionless constant was $k = 1.3 \pm 0.1$ and the resulting model had an $R^2 = 0.73$.

Conclusion—This is the first report to reveal an allometric relationship between changes of VAT and FM that holds for both genders as well as a wide variety of weight loss interventions including bariatric surgery, caloric restriction with or without exercise, and exercise alone. We conclude that changes of VAT are primarily determined by FM changes as well as the initial VAT to FM ratio.

Keywords

Weight loss; Visceral Adipose Tissue; Body Composition; Fat Mass; Allometry

Introduction

Fat accumulation in the visceral area is believed to be particularly dangerous because it is highly correlated with cardiovascular and metabolic risk factors such as elevated blood pressure, dyslipidemia, insulin resistance, and type 2 diabetes [1-4]. Thus, reduction of visceral adipose tissue (VAT) may be especially beneficial. Fortunately, negative energy balance appears to cause VAT to decrease to a greater degree than total fat mass (FM) [5] which may explain the metabolic benefits of weight loss. But are some weight loss methods better than others at generating a targeted or selective reduction of VAT?

Several years ago, Smith et al. addressed the issue of selective reduction of VAT by reviewing published studies that measured VAT as well as total fat mass (FM) changes during weight loss and found that most weight loss interventions caused a preferential loss of VAT [5]. These authors concluded that the absolute amount of VAT loss was related to both the amount of FM loss as well as the initial VAT [5], but a clear mathematical relationship between these variables was not determined.

Here we update and extend the observations of Smith et al. and test the hypothesis that changes of VAT mass and FM are allometrically related according to the following differential equation:

$$\frac{dVAT}{dFM} = k \frac{VAT}{FM} \quad (1)$$

where k is a dimensionless constant. This class of equation has a long and rich history and was first used by Huxley to describe the law of constant differential growth between various body parts of an organism [6]. We show that this allometric relationship accurately describes the published data on changes of VAT and FM and that the same relationship holds regardless of gender or the type of weight loss intervention.

Methods

Published studies were included in our analysis if FM and VAT were measured before and after a weight loss intervention in humans, regardless of the method of weight loss. Total fat mass was measured by dual energy X-ray absorptiometry (DEXA), underwater weighing, air displacement plethysmography, or via whole-body computed tomography (CT) or magnetic resonance imaging (MRI). Studies measuring FM changes using bioelectric impedance or anthropomorphic methods, such as skin-folds, were excluded. MRI or CT imaging was used to assess VAT changes.

Since the hypothesized allometric equation is an expression involving VAT mass, we converted cross-sectional VAT areas to volumes using the regression equations described by Shen [7]. (This procedure was unnecessary for studies that measured VAT volumes using multi-slice CT or MRI.) Since different regression equations are used to convert cross-sectional areas to volumes in men and women, we required that the studies report the VAT areas for men and women separately. Furthermore, the regression equations required that the slice location had to be either at L4-L5 for both genders, or 5 cm above L4-L5 for women and 10 cm above L4-L5 for men. We assumed an adipose tissue density of 0.93 kg/L.

We searched for studies matching the above inclusion criteria in both PubMed and Web of Science databases using the search term “weight loss visceral adipose tissue”. On July 4th 2007, the PubMed search returned 83 hits and the Web of Science search returned 335 hits, 65 of which were duplicates also found in the PubMed search. Examination of the abstracts reduced the number of studies possibly matching our search criteria to 131. Investigation of the methods sections of these remaining reports further narrowed the number of studies to a total of 34 that fulfilled our inclusion criteria. The citations from these 34 reports were then surveyed for studies not found by the initial search, resulting in an additional 3 studies such that 37 total studies matched our inclusion criteria.

In the Appendix, we show that the allometric hypothesis requires that the ratio of the change of VAT to the change of FM, $\Delta VAT/\Delta FM$, is proportional to the initial ratio of VAT to FM, VAT/FM . Therefore, we calculated these ratios and investigated whether or not a linear relationship existed. Typically, such an analysis would be completed using a weighted least-squares linear regression method that assumes that only the y coordinate has an associated

uncertainty. However, in the present case this cannot be assumed since the data had uncertainties in both the x and y coordinates. Therefore we combined the use of traditional weighted linear regression, which accounts for the uncertainties in the y direction, along with a Monte-Carlo strategy to take the uncertainties in the x direction into account. For each Monte-Carlo iterate, a random set of x variables was chosen such that each x value was normally distributed about the data point with a standard deviation given by the uncertainty of each data point. For each Monte-Carlo iteration, we performed a weighted least-squares regression procedure to fit to the line $y = k \cdot x$. The model parameter k was estimated as the average over 10000 Monte-Carlo simulations. All model statistics were then assessed based on this average linear model. Outlier assessment based on the Cook's distance and studentized residuals were calculated using the standard deviations of the data points.

The x variable (initial VAT/FM) and y variable ($\Delta VAT/\Delta FM$) in our analysis were transformations of the reported VAT and FM data. Since the initial VAT and FM measurements were included in both x and y variable calculations, the data transformation introduced dependencies between the variables that could possibly lead to spurious correlations [8]. We tested for spurious correlations by randomly shuffling the VAT and FM measurements 10000 times and calculated the coefficients of determination (i.e., the Pearson correlation coefficient squared, r^2) of the resulting x and y variables. If the data transformation procedure itself introduced significant correlations, then the r^2 calculated using the shuffled data should frequently exceed the r^2 determined from the un-shuffled data. We estimated the probability of a spurious correlation as the fraction of the 10000 r^2 values obtained using the shuffled data that exceeded the observed r^2 value of the original un-shuffled data.

Results

The systematic review produced a total of 37 weight loss intervention studies, representing 1407 subjects and 79 data points (Table 1). The population comprised 24% men and 73% women, of which 27% were postmenopausal. The number of men and women was not reported for 3% of the subjects. These studies investigated a wide range of weight loss interventions including caloric restriction [9-33], endurance exercise [9,15,20-23,25-28,31,34-41], resistance exercise [18,19,24,27,42], and bariatric surgery [43-45]. One study reported data from women with type 2 diabetes (T2DM) [15] and another study investigated HIV positive women [35].

We plotted the loss of visceral fat mass relative to the total loss of fat mass ($\Delta VAT/\Delta FM$) against the initial visceral fat mass divided by the total fat mass (VAT/FM). Figure 1A clearly shows a linear relationship between these two ratios which is consistent with our hypothesis that VAT and FM changes are allometrically related. The calculated dimensionless model parameter was $k = 1.3 \pm 0.1$ with an $R^2 = 0.73$ indicating that the model explained more than 70% of the variability in the reported data. We found no evidence of spurious correlations since none of the 10000 shuffled VAT and FM data sets produced a coefficient of determination higher than that observed for the original data. The residuals of the model are plotted in Figures 1B indicating no general trend. There were no outliers detected by examination of Cook's distance (maximum value was 0.04) or studentized residuals (maximum magnitude was 1.05). The chi-square was 4.6 and, based on an evaluation of the incomplete gamma function, the probability was less than 10^{-33} that the chi-square for a correct model should be less than the chi-square calculated for our model [48]. In other words, the allometric model provides an excellent fit to the data. Nevertheless, this measure of the model fit may be somewhat overestimated since the uncertainties for each data point were large due to the fact that we only had access to the reported group averages in each published study. (The average calculated uncertainty of the data points was $\hat{\sigma}_x = 0.05$ and $\hat{\sigma}_y = 0.3$ in the x and y directions, respectively.) For clarity, we have omitted the error bars from the figures.

Both men and women were described by the same allometric relationship, where $k = 1.3 \pm 0.2$ for both groups calculated separately which was the same as the overall best fit line with $k = 1.3 \pm 0.1$. On average, the male subjects had a higher initial VAT to FM ratio as indicated by the closed black diamonds (◆) in comparison to the open symbols (women) in Figure 1A. Crosses indicate studies that reported a mixture of men and women (+).

Figure 2A depicts the same data coded by weight loss intervention. The allometric relationship applied equally well to all weight-loss interventions since no particular intervention deviated systematically from the overall best fit line with $k = 1.3 \pm 0.1$. The calculated allometric constants determined separately for each intervention group were no different from the overall best fit value since $k = 1.2 \pm 0.2$ for caloric restriction alone (□), $k = 1.4 \pm 0.2$ for caloric restriction with aerobic exercise (◆), $k = 1.3 \pm 0.3$ for caloric restriction with resistance exercise (+), $k = 1.5 \pm 0.7$ for exercise alone (Δ), and $k = 1.4 \pm 1$ for bariatric surgery (○).

Discussion

VAT is often considered to be a labile fat depot based on the preferential loss of VAT with weight loss [5], along with the in vitro observations that visceral adipocytes are more lipolytically active than subcutaneous adipocytes [49,50], and are therefore believed to have a higher fat turnover rate. Others have hypothesized that VAT is a secondary fat storage pool that accumulates during positive energy balance only after subcutaneous stores are full [51]. Some have suggested that exercise specifically mobilizes VAT as a result of preferential stimulation of VAT lipolysis [52]. Here, we demonstrated that VAT and FM change in parallel and that the magnitude of VAT change is primarily determined by FM change according to an allometric relationship independent of the weight loss method.

Allometric equations have historically been used to describe relationships between the relative growth of various body parts of an organism [6]. To see this, equation 1 can be rearranged as follows:

$$\frac{1}{VAT} \frac{dVAT}{dt} = k \frac{1}{FM} \frac{dFM}{dt} \quad (2)$$

thereby indicating that the relative growth rates of VAT and FM are proportional to each other. The fact that the best fit value of the constant k was greater than 1 (i.e., $k = 1.3 \pm 0.1$) corresponds to the observation of preferential VAT changes versus FM changes. The fact that this same value for k adequately describes both genders as well as a wide variety of weight loss interventions suggests that differences between men and women can be explained by the initial VAT to FM ratio and there is no preferential benefit of one weight loss intervention over another.

The allometric model also suggests a way to determine whether or not an obesity therapy preferentially targets visceral adipose tissue. To show that the treatment in question has a special benefit for VAT reduction, one needs to show that the plot of $\Delta VAT/\Delta FM$ versus the initial VAT/FM lies above the best fit line described by a control group of subjects undergoing a standard obesity treatment (e.g., caloric restriction). Based on the results of the present study, we expect that the data from such a control group will be well described by a line with a slope of approximately 1.3. While the data from a treatment group targeted against visceral adiposity may not be well-described by the allometric relationship, the data must lie above the control group's line to claim that the treatment preferentially reduces visceral adiposity.

We also found data matching our inclusion criteria from two weight gain interventions, one examining recovery of anorexic women [46] and the other was an overfeeding study of healthy young men [47]. These weight gain data also appeared to follow the allometric relationship as

depicted by asterisks (*) in Figures 1 and 2, but they were not used in the model fitting procedure. Future work should investigate the applicability of the allometric relationship in weight gain studies.

In their 1999 review of VAT changes with weight loss, Smith et al. introduced a selectivity index to facilitate comparisons between weight loss interventions and quantify their ability to selectively target VAT [5]. The selectivity index was defined as the percent change of VAT mass divided by the percent change of FM which is mathematically identical to the allometric constant k . Our observation that the same value of k adequately represented various types of weight loss interventions conforms to Smith et al.'s conclusion that no clear pattern was detected for the selectivity index across the interventions [5]. However, Smith et al. claimed that the selectivity index depended on the initial proportion of visceral fat in a subset of studies that reported single slice area ratios of initial VAT to subcutaneous adipose tissue (SAT). In this subset of data, we also found weak positive correlations between the selectivity index with both the initial VAT/FM and VAT/SAT ($r^2 = 0.26$ and 0.29 , respectively). However, there is a high probability that these correlations were spurious since shuffled data produced higher r^2 values than the un-shuffled data 15% of the time. Furthermore, we found no significant correlations of the selectivity index as a function of initial VAT/FM in the full dataset ($r^2 = 0.03$). Thus, the data are consistent with a constant selectivity index identical to the allometric constant k which is independent of the initial proportion of VAT.

The allometric equation 1 can be integrated to give a power law relationship:

$$VAT = bFM^k \quad (3)$$

where b is a parameter that sets the baseline amount of VAT for a given initial FM. Unlike many reported allometric relationships, the value of b is not a universal constant in our case. Rather, b depends on gender, ethnicity, as well as other potential factors that contribute to determining the initial VAT. Thus, the typical log-log plots often used to assess allometric relationships in our case produces a scatter of points since the values of the parameter b vary widely across ethnicity and gender groups (not shown). However, since our analysis used the initial VAT and FM as model variables, the dependence of the parameter b on gender and ethnicity was automatically accounted for.

The most obvious limitation of the present analysis was that the calculated uncertainties of the data points were quite large due to the fact that we only had access to the reported average values from the published studies. Future studies should investigate these relationships using data on body composition change in individual subjects. Despite this limitation, a clear relationship was apparent in the data and the allometric model described this relationship remarkably well. Our analysis therefore suggests that changes of VAT mass are determined primarily by FM changes as well as the initial ratio of VAT to FM and is independent of gender or the method of weight loss intervention.

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APPENDIX

We hypothesized that the VAT and FM changes are allometrically related according to the following differential equation involving the infinitesimal changes $dVAT$ and dFM :

$$\frac{dVAT}{dFM} = k \frac{VAT}{FM} \quad (A1)$$

However, only macroscopic changes ΔVAT and ΔFM can be measured, so we must therefore determine the expected relationship for macroscopic changes ΔVAT and ΔFM if the system is described by the allometric equation. Equation A1 has the general solution:

$$VAT = bFM^k \quad (A2)$$

Therefore, a macroscopic change of VAT is given by:

$$\Delta VAT = b(FM + \Delta FM)^k - bFM^k \quad (A3)$$

Using the binomial expansion we obtain:

$$\begin{aligned} \Delta VAT &= b \sum_{j=0}^{\infty} \binom{k}{j} FM^{k-j} \Delta FM^j - bFM^k \\ &= bFM^k + k \frac{bFM^k}{FM} \Delta FM + b \sum_{j=2}^{\infty} \binom{k}{j} FM^{k-j} \Delta FM^j - bFM^k \\ &= k \frac{VAT}{FM} \Delta FM + VAT \sum_{j=2}^{\infty} \binom{k}{j} \left(\frac{\Delta FM^j}{FM^j} \right) \end{aligned} \quad (A4)$$

Therefore,

$$\frac{\Delta VAT}{\Delta FM} = k \frac{VAT}{FM} + VAT \sum_{j=2}^{\infty} \binom{k}{j} \left(\frac{\Delta FM^{j-1}}{FM^j} \right) \quad (A5)$$

ΔFM is typically small compared with FM , and for the data examined in this study $\Delta FM/FM = -0.2 \pm 0.08$. Therefore, the sum contains terms that become progressively smaller and the first term of the sum is proportional to $|\Delta FM/FM|^2 \ll 1$. Therefore, the allometric equation is well approximated by the relationship studied in the present report:

$$\frac{\Delta VAT}{\Delta FM} \approx k \frac{VAT}{FM}. \quad (A6)$$

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Figure 1.

A) Changes of visceral fat mass relative to the change of total fat mass ($\Delta \text{VAT} / \Delta \text{FM}$) versus the initial visceral fat mass divided by the total fat mass (VAT / FM) as compiled from 37 published studies of weight loss representing 1407 subjects. On average, male subjects (◆) had higher initial VAT to FM ratios compared to healthy pre-menopausal women (□), post-menopausal women (△), HIV positive women (◇), or women with type 2 diabetes (○). Crosses (+) indicate studies that reported a mixture of men and women. The line corresponds to the best fit allometric relationship to the weight loss data with $k = 1.3 \pm 0.1$ and $R^2 = 0.73$. Data from two weight gain interventions (*) are also plotted. B) Residuals of the best fit allometric model versus the initial VAT to FM ratio.

Figure 2.

A) The same data as in Figure 1 are represented according to the type of weight loss intervention as follows: caloric restriction alone (□), caloric restriction with aerobic exercise (◆), caloric restriction with resistance exercise (+), exercise alone (△), and bariatric surgery (○). Data from two weight gain interventions (*) are also plotted. B) Residuals of the best fit allometric model versus the initial VAT to FM ratio.

Study	Ref	Intervention	N	Sex	Weight loss [kg]	Total fat measurements	Visceral fat measurements	Notes
Brochu, et al (2003)	11	Calorie restriction	15	F	11.5	DEXA	CT - L4-L5	Postmenopausal
		Calorie restriction	10	F	16.21			
Busetto, et al (2002)	43	Bariatric surgery	6	F	9.9	MRI - Whole body	MRI - 7 slices inc. L4-L5	
		Bariatric surgery	-	F	7.2			
Chowdhury, et al (1993)	12	Calorie restriction	9	M	4.4	CT - Whole body	CT - Multi-slice inc. L4-L5	
Despres, et al. (1991)	34	Exercise	13	F	3.7	Hydrodensitometry	CT - L4-L5	
Doucet, et al. (2000)	10	Calorie restriction	19	M	10.7	Hydrodensitometry	CT - L4-L5	Fenfluramine or placebo
Doucet, et al. (2002)	13	Calorie restriction	23	F	7.9	Hydrodensitometry	CT - L4-L5	
Engelson, et al (2006)	35	Calorie restriction	17	M	11.6	Hydrodensitometry	CT - L4-L5	
		Calorie restriction	17	F	9.7			
Fujioaka, et al (1991)	14	Diet + exercise	18	F	6.7	DEXA	MRI - Multi-slice	HIV
		Calorie restriction	14	F	12.0	CT - Whole body	CT - Umbilicus (app. L4-L5)	VAT obese
Giannopoulos, et al. (2005)	15	Calorie restriction	26	F	12.3	Hydrodensitometry	MRI - Multi-slice	SAT obese
		Calorie restriction +Exercise	11	F	5.4			Postmenopausal - T2DM
Gleits, et al (2005)	44	Calorie restriction	11	F	3.7			
		Exercise	11	F	1.7			
Goodpaster, et al (1999)	16	Bariatric surgery	15	F	12.1	Air-displacement plethysmography	CT - Multi-slice from L1 to L5	
		Bariatric surgery	-	F	21.2	DEXA	CT - L4-L5	
Gower, et al (2002)	17	Calorie restriction	15	M	17.6	DEXA		
		Calorie restriction	17	F	12.2			
Janssen and Ross (1999)	19	Calorie restriction	18	F	13.1	DEXA		
		Calorie restriction	19	F	12.7			
Janssen, et al (2002)	18	Calorie restriction	10	M	11.7	MRI - Whole body	CT - Umbilicus (app. L4-L5)	
		Calorie restriction +Aerobic exercise	10	M	11.4		MRI - 5 slices inc. L4-L5	
Larson-Mayer (2006)	20	Calorie restriction + Resistance exercise	10	M	12.7			
		Calorie restriction	10	F	10.7			
Lin, et al. (2007)	45	Calorie restriction +Aerobic exercise	10	F	11.5			
		Calorie restriction	10	F	10.0			
Lynne, et al. (2001)	36	Calorie restriction	10	F	10.0			
		Calorie restriction +Aerobic exercise	10	F	10.0			
Nicklas, et al. (2003)	37	Calorie restriction	13	F	10.0			
		Calorie restriction +Resistance exercise	11	F	11.1			
Niklas, et al. (2003)	37	Calorie restriction	14	F	10.0			
		Calorie restriction +Resistance exercise	14	F	10.0			
Niklas, et al. (2003)	37	Control	11	M/	0.1	DEXA	CT - Multi-slice	Number of men & women not reported
		Calorie restriction	12	F	8.4			
Niklas, et al. (2003)	37	Calorie restriction	12	M/	8.1			
		Calorie restriction +Exercise	12	F	11			
Niklas, et al. (2003)	37	Calorie restriction	11	M/	11			
		Calorie restriction	11	F	11.5			
Niklas, et al. (2003)	37	Bariatric surgery	28	F	22.8	Air-displacement plethysmography	CT - Multi-slice from L1 to L5	Postmenopausal
		Bariatric surgery	-	F	6.0	DEXA	CT - L4-L5	
Niklas, et al. (2003)	37	Calorie restriction	40	F	6.0	DEXA	CT - L4-L5	Postmenopausal
		Calorie restriction +Walking	57	F	6.0			
Niklas, et al. (2003)	37	Calorie restriction	19	F	4.0	DEXA	CT - L4-L5	Postmenopausal
		Calorie restriction +Walking	19	F	4.0			

Study	Ref	Intervention	N	Sex	Weight loss [kg]	Total fat measurements	Visceral fat measurements	Notes
Okura, et al. (2002)	22	Calorie restriction	14	F	7.3	DEXA	CT - L4-L5	SAT obese
		Calorie restriction	12	F	7.2			VAT obese
		Calorie restriction +Exercise	14	F	8.7			SAT obese
		Calorie restriction +Exercise	15	F	10.2			VAT obese
Okura, et al. (2003)	21	Calorie restriction	35	F	7.7	DEXA	MRI - L4-L5	
		Calorie restriction +Arobic exercise	22	F	9.1			
		Calorie restriction +Walking	33	F	10.2			
		Exercise	45	M	4.0			
Paré, et al. (2001)	38	Exercise	45	M	4.0	Hydrodensitometry	CT - L4-L5	
Redman, et al. (2007)	23	Calorie restriction	6	M	9.2	DEXA	CT - 8 slices inc. L4-L5	
		Calorie restriction +Exercise	5	M	9.0			
		Calorie restriction	6	F	7.6			
		Calorie restriction +Exercise	7	F	7.8			
Rice, et al (1999)	24	Calorie restriction	9	M	12.1	MRI - Whole body	MRI - Multi-slice	
		Calorie restriction +Arobic exercise	10	M	11.5			
		Calorie restriction	10	M	13.6			
		+Resistance exercise	10	M	13.6			
Ross & Rissanen (1994)	42	Calorie restriction	14	F	10.1	MRI - Whole body	MRI - 7 slices inc. L4-L5	
		+Resistance exercise	10	F	10.9			
		Calorie restriction +Arobic exercise	10	F	10.9			
		Calorie restriction	10	F	10.9			
Ross, et al. (1996) a	27	Calorie restriction	11	M	11.4	MRI - Whole body	MRI - Multi-slice	
		Calorie restriction + Arobic exercise	11	M	11.6			
		Calorie restriction	11	M	13.2			
		+Resistance exercise	11	M	13.2			
Ross, et al. (1996) b	9	Calorie restriction +Exercise	20	M	12.2	MRI - Whole body	MRI - 5 image around L4-L5	
		Calorie restriction +Exercise	38	F	10.2			
		Calorie restriction	14	M	7.4			
		Exercise	16	M	7.6			
Ross, et al. (2000)	25	Calorie restriction	14	M	7.4	MRI - Whole body	MRI - Multi-slice	
Ross, et al. (2004)	26	Calorie restriction	15	F	6.5	MRI - Whole body	MRI - Multi-slice	
		Exercise	17	F	5.9			
		Calorie restriction +Exercise	37	F	6.1			
		Calorie restriction	16	F	5.2			
Ryan & Nicklas (2004)	39	Calorie restriction +Exercise	37	F	6.1	DEXA	CT - L4-L5	
Ryan, et al. (2006)	28	Calorie restriction	17	F	7.4	DEXA	CT - L4-L5	Postmenopausal
Santosa et al (2007)	29	Calorie restriction	42	F	6.1	MRI - Whole body	MRI	Post & pre menop.
		Calorie restriction	42	F	6.1			
		Calorie restriction +Exercise	19	M/	11.7			M - 10 & F - 9
		Calorie restriction	19	F	11.7			
Shadid & Jensen, (2003)	40	Calorie restriction +Exercise	19	M/	11.7	DEXA	DEXA + CT	
Tchernof, et al. (2000)	30	Calorie restriction	11	F	16.4	DEXA	CT - L4-L5	Tn64Arg carrier
Thamer, et al. (2007)	41	Calorie restriction	13	F	14.1	MRI - Whole body	MRI - Multi-slice	Postmenopausal
		Calorie restriction +Exercise	112	M/	2.7			M - 48 & F - 69
		Calorie restriction	14	M	7.4			
		Calorie restriction +Exercise	14	M	7.6			
Thong, et al. (2002)	31	Calorie restriction	14	M	7.4	MRI - Whole body	MRI - Multi-slice	
van Rossum, et al. (2000)	32	Calorie restriction	54	F	5.8	DEXA	CT - L4-L5	Postmenopausal
		Calorie restriction	54	F	5.8			
		Calorie restriction	54	F	5.8			
		Calorie restriction	54	F	5.8			
Weinsier, et al. (2001)	22	Calorie restriction	23	F	13.1	DEXA	CT - L4-L5	White
		Calorie restriction	23	F	12.6			Black
		Calorie restriction	23	F	12.6			
		Calorie restriction	23	F	12.6			