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Title: Estimation of abdominal fat compartments by bioelectrical impedance: The validity of the ViScan measurement system in comparison with MRI.

5 **Running title:** Measuring abdominal fatness: ViScan vs MRI

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Abstract

Background: Abdominal obesity, more specifically increased intra-abdominal adipose tissue is strongly associated with increased risk of metabolic disease. Bioelectrical impedance analysis (BIA) has been proposed as a potential method of determining individual abdominal fat compartments in the form of the commercially available ViScan™ measurement system (Tanita Corporation, Japan) but has yet to be independently validated.

Objective: To investigate the validity of the ViScan to assess adult abdominal adiposity, across a range of body fatness.

Subjects/Methods: Cross sectional study. 74 participants (40 female, 34 male; BMI: 18.5 and 39.6 kg/m²). Total abdominal adipose tissue (TAAT), subcutaneous abdominal adipose tissue (SAAT) and intra-abdominal adipose tissue (IAAT) were measured by MRI. In addition, intra-hepatocellular lipid (IHCL) was obtained by magnetic resonance spectroscopy (MRS). Estimates of abdominal adiposity (total and compartmental) were obtained from BIA and anthropometry.

Results: ViScan derived percentage trunk fat strongly and significantly related to TAAT and SAAT in both lean and overweight/obese individuals, and categorise individuals reliably in terms of total abdominal fat. ViScan derived “visceral” fat correlated significantly with IAAT but the strength of this relationship was much weaker in overweight/obese individuals, particularly those with higher SAAT, leading to less reliable classification of individuals for IAAT.

Conclusion: The ViScan may serve as a useful tool for predicting total abdominal fat, but prediction of visceral fat (IAAT) may be limited, especially in the abdominally obese.

Key words: Intra-abdominal adipose tissue, whole body MRI, intra-hepatocellular lipid, bioimpedance,

Introduction

Excess abdominal adiposity is known to predispose to diabetes and cardiovascular disease (Deprés & Lemieux, 2006). Abdominal adipose tissue may be divided into subcutaneous abdominal adipose tissue (SAAT) and intra-abdominal adipose tissue (IAAT), whereby increased IAAT (also referred to as “visceral fat”) is specifically associated with insulin resistance, dyslipidemia, systemic inflammation, diabetes, hypertension, myocardial infarction, and all-cause mortality (Misra & Vikram, 2003; Nicklas *et al.*, 2004; Kuk *et al.*, 2006; Fox *et al.*, 2007).

Various methodologies exist to measure whole body adiposity, ranging in complexity, cost and availability (see Lee & Gallagher, 2008; Chumlea & Guo, 2000 for review), however, methods for measuring regional adiposity are more limited. An elevated waist circumference may be an effective predictor of abdominal obesity (Clasey *et al.*, 1999), yet is not a direct measure of either SAAT or IAAT. Although health related cut-off values for waist circumference exist (WHO, 2000; NICE, 2006), Individuals with a waist circumference in the normal range may be classified as “healthy” despite elevated IAAT. In addition waist circumference alone is not sufficiently sensitive to detect changes in abdominal body composition (Kay & Fiatarone Singh, 2006).

Magnetic resonance imaging (MRI) and computed tomography (CT) represent the best reference methods for measurement of SAAT and IAAT (Thomas *et al.*, 1998), but both are high cost techniques, labour intensive, non-portable and of limited availability for wide application.

Bioelectrical impedance analysis (BIA) is a non-invasive, inexpensive and portable method of body composition assessment (Baumgartner, 1996; Kyle *et al.*, 2004) that has recently been suggested as a means of predicting abdominal adipose tissue compartments (i.e. IAAT and SAAT) (Scharfetter *et al.*, 2001; Demura *et al.*, 2007; Nagal *et al.*, 2008). This use of

bioelectrical impedance has culminated in the development of the commercially available ViScan™ measurement system (Tanita Corp, Tokyo, Japan).

To date, the ViScan measurement system has not been independently validated against a gold standard measure such as MRI. Therefore, the aim of this study is to compare ViScan predictions of total abdominal and regional adiposity with measures obtained by whole body MRI in lean and obese adults.

Methods

Participants & Study Design

74 adult (40 females, 34 males) participants, with a range of body mass index (BMI); between 18.5 and 39.6 kgm⁻² were studied. Whole Body MRI and regional BIA were undertaken on all subjects. In addition, full anthropometric measures were completed in 72 volunteers. All measurements were undertaken on a single visit following an overnight fast. The study was undertaken under the approval of the NHS medical ethics committee of the Hammersmith Hospital, London (ref nos: 07/Q0411/19 and 06/Q0411/173).

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Magnetic Resonance Imaging and (MRI) and Magnetic Resonance Spectroscopy (MRS)

Whole body MR images were obtained on a 1.5T Phillips Achieva system (Philips Medical Systems, Best, Netherlands) as previously described (Thomas et al 2005). Images were quantified by an independent data analysis company (Vardis Group), using SliceOmatic (Tomovision, Montreal, Canada). Volumes of IAAT and SAAT were calculated from the abdominal region defined as the volume between the slice containing the bottom of the lungs/top of the liver and the slice containing the femoral heads. Total abdominal adipose tissue (TAAT) was calculated as the sum of IAAT and SAAT. IAAT and SAAT were also estimated from single slices were taken from the whole body datasets for each individual at the level of the umbilicus.

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¹H MR spectra of the liver were acquired using a PRESS sequence without water suppression as previously described (Thomas et al 2005).. Spectra were analyzed using AMARES, lipid resonances were quantified with reference to water after correcting for T₁ and T₂ (Thomas *et al.*, 2005)

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Anthropometry

Body mass was measured using a calibrated digital scale (TANITA electronic Scale WB-110MA, Tanita Corporation, Japan) and recorded to the nearest 0.1kg. Height was assessed using a wall mounted stadiometer (Seca UK, Birmingham), and recorded to the nearest 0.1cm). Standing waist circumference was measured at 4 different sites with a non flexible anthropometric tape, and recorded to the nearest 0.1cm by a single trained observer. The sites included: midpoint (at the midpoint between the lower costal margin and the iliac crest), the umbilicus, the minimal waist (the observed minimal waist as viewed anteriorly) and iliac crest. In addition, supine waist circumference was also measured at the umbilicus. Hip circumference was measured in the standing position at the level of the greater trochanter. From these measures waist to hip ratio (WHR) and waist to stature ratio (WSR) were calculated.

Bioelectrical impedance analysis (BIA) of the trunk (VISCAN™)

With the subject lying supine, waist circumference was measured using the ViScan (Tanita Corporation, Japan), involving an infrared beam projected over the waist at the umbilical sagittal plane, detected by 2 infra red sensors on either side of the base unit. Impedance was then measured, by ViScan, essentially a tetrapolar impedance method involving 2 pairs of injecting and sensing electrodes (basically a wireless measurement “belt”) placed directly on the skin at the umbilicus in the sagittal plane. ViScan abdominal body composition values are derived from extrapolation of impedance measures (at 6.25 KHz and 50KHz) using inbuilt software. A photograph of the ViScan measurement system in operation can be seen in figure 1.

ViScan abdominal body composition values are sub-divided into: total abdominal adiposity (i.e. VAT + SAAT), expressed as % trunk fat (range 0-75%), whereas VAT is expressed as “visceral fat” (arbitrary units ranging from 1 to 59). The ViScan also rates these measures

using arbitrary band ratings of “low”, “average” and “high” for % trunk fat and “average”, “high” and “very high” for visceral fat.

Statistical Analysis

5 Agreement between methods of waist measurement (i.e. ViScan vs. manual measurement) was assessed according to Bland & Altman (1986) and systematic bias between methods was assessed via paired sample t-test. Pearson’s correlation coefficients were calculated to assess the association between MRI derived abdominal fat compartments and VISCAN BIA estimates. Differences in MRI derived total abdominal fat between the ViScan trunk fat
10 bandings and between IAAT and the ViScan visceral fat bandings were assessed using a one way ANOVA. Associations between other anthropometric measures and MRI derived abdominal fat compartments were assessed using Pearson’s correlation coefficients. All analyses were performed using SPSS version 16.0 (SPSS, Chicago, IL, USA). Level of significance was set at $p < 0.05$

Results

Taking the study population as a whole, body mass, and height were significantly greater in the male cohort ($P < 0.001$), whereas %BF was significantly greater in the females ($P < 0.001$), with no other significant gender differences in the group ($P \geq 0.06$). Subject characteristics and body composition compartments (MRI and ViScan) are shown in table 1, by gender and BMI group (lean vs. overweight/obese).

The ViScan significantly overestimated manual girth measurements; both supine ($P < 0.001$) and standing ($P < 0.001$), corresponding to a mean difference (bias) of 6.5cm against manual supine (95% limits of agreement -2.9 to 16.0cm) and 3.6cm against manual standing measurement (95% limits of agreement -5.9 to 13.9cm).

Pearson's correlation coefficients relating to MRI derived abdominal fat compartments in the whole population are shown in table 2. The ViScan derived % trunk fat most strongly associated with MRI derived total abdominal fat (IAAT + SAAT) expressed as a percentage of body weight ($r = 0.938$, $P < 0.001$), explaining 88% of the variance in total abdominal fat (figure 2A). Lower correlations were shown with total abdominal adiposity and manual anthropometric measures that singularly explained between 23% and 68% of the inter-individual variance. ViScan derived % trunk fat was the strongest single correlate with SAAT ($r = 0.884$, $P < 0.001$), explaining 78% of the inter-individual variance (figure 2B). Other anthropometric measures individually explained between 16% and 72% of the variance.

Midpoint waist circumference, was the single strongest correlate with IAAT ($r = 0.844$, $P < 0.001$), explaining 71% of inter-individual variance. The ViScan derived visceral fat rating correlated strongly with IAAT ($r = 0.731$, $P < 0.001$), (figure 2C), but only explained 53% of the variance, compared to between 59% and 73% of variance explained by the manual anthropometric measures incorporating a waist circumference. Separating the group by

gender, the ViScan measures correlated more strongly with IAAT (males, $r = 0.769$; females $r = 0.809$) explaining 59% of variance in the males and 65% of the variance in the females. However, midpoint waist circumference alone remained the strongest single correlate for both genders (males, $r = 0.794$; females, $r = 0.889$).

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Interestingly, taking MRI measurements of AT from a single slice at the level of the umbilicus, corresponding to the placement of the ViScan belt, rather than the whole volume, the correlations between the methodologies, although still significant, was weaker, particularly for SAAT (ViScan % visceral fat vs. MRI single slice IAAT $r = 0.703$, $p < 0.001$; ViScan % trunk fat vs. SAAT $r = 0.648$, $p < 0.0001$).

Dividing the study population by BMI (as in table 1), ViScan derived visceral fat was the strongest correlate with IAAT ($r = 0.786$, $P < 0.001$), in the lean group ($BMI < 25 \text{ kgm}^{-2}$), explaining 62% of the variance. However, in the overweight/obese group ($BMI \geq 25 \text{ kgm}^{-3}$), waist circumference was the strongest single correlate with IAAT ($r = 0.774$, $P < 0.001$). Moreover, although the ViScan measure correlated significantly with IAAT ($r = 0.523$, $P = 0.002$), it only explained 27% of the variance seen in the overweight/obese. Splitting the group into two by measured SAAT at the 50th percentile provided a high SAAT and a low SAAT group. Again, the ViScan was the strongest correlate with IAAT in the low SAAT group ($r = 0.859$, $P < 0.001$) explaining 74% of the variance in IAAT. In the high SAAT group, despite the ViScan correlating significantly with MRI derived IAAT ($r = 0.406$, $P = 0.011$), it only explained 16% of the variance.

As well as attempting to quantify abdominal fat compartments the ViScan also categorises individuals into bandings of adiposity both for % trunk fat (“low”, “average” or “high”) and for visceral fat (“average”, “high” or “very high”). The relationship between these categories and MRI measured AT compartments are shown in figure 3 for both total abdominal fat (figure 3A)

and IAAT (figure 3B). Following one way ANOVAs there was a significant difference in MRI derived total abdominal fat between the three ViScan categories of % trunk fat ($P < 0.001$), with the “low” group significantly less than the “average” group ($P < 0.001$) and the “average” group significantly less than the “high” group ($P < 0.001$). There was also a significant difference between ViScan visceral fat categories in terms of MRI derived IAAT (5 $P < 0.001$). However, following post-hoc tests IAAT was only significantly different between the “average” and the “high” groups ($P < 0.001$) with no differences seen between the “high” and the “very high” groups.

10 A further factor that was investigated in reference to the comparison between MRI and ViScan measures of visceral fat was the presence of fat in the liver. Subjects were divided into two groups according to their liver fat correlation between MRI and ViScan measures of visceral fat was stronger in the subjects with low liver fat content ($r = 0.83$, $p < 0.001$) compared to those with high liver fat content ($r = 0.69$, $p < 0.001$).

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Discussion

In this cohort of subjects the ViScan appears to systematically overestimate waist circumference when compared to manual measurements (both standing and supine), in the order of 4-6cm. This is far in excess of the within-subject variation of manual measurement, generally in the order of 5-9mm (Wang et al 2003). This may be explained by considering that the ViScan calculates waist circumference on the basis of abdominal width, calculated from the distance between the abdomen and the base unit on both sides as determined by a near infrared reflection method. Ascertaining circumference from diameter relies on the assumption of that an individual's waist is uniformly circular or elliptical, both of which are problematic. Moreover, waist circumference may be a predominant factor in prediction of abdominal adiposity from transimpedance, as cross-sectional area of the trunk (crudely estimated as waist circumference squared) is required, assuming a relationship between impedance and either; the ratio of total fat to the cross sectional area (when predicting % trunk fat), or, the ratio of IAAT to cross sectional area (when predicting "visceral fat").

Traditional multifrequency BIA has been used by various authors to estimate regional fat mass as measured by DXA (Baumgartner et al 1989, Fuller et al 2002, Braco et al 1996, Demura and Sato 2007), with a SEE of 1.5-2.0 kg, equating to approximately +/- 10% of measured trunk fat mass. Unlike whole body BIA, the ViScan is directly measuring abdominal transimpedance, and should therefore better reflect the local conducting tissue compartments. Most of the current flux in the abdomen is likely to be through extracellular (6.25 kHz) and intracellular (50kHz) fluid; representing the FFM of the trunk (water, muscle (superficial and deep), organs and connective tissue), and from this FM of the trunk can be inferred. A strong

relationship between ViScan measured % trunk fat and DXA derived FM of the trunk has been reported previously by authors associated with the manufacturers (Minaguchi et al 2007), and our study represents the first time this association has been independently confirmed against a reference method of abdominal fat compartments, MRI. Despite this verification, direct comparisons cannot be made with MRI, as the ViScan does not express adiposity in terms of absolute mass or volume, hence we can only confidently confirm the ViScan as a valid predictor of total abdominal adiposity.

10 Distinguishing total fat or specific AT compartments in the abdomen by transimpedance requires an understanding of the different structures in the abdomen, their depth from the surface, composition and relative conductance. The relative placement of the electrodes also influences the path of current flux in the abdomen. Baker (1989) demonstrated that impedance between electrodes close together (as with the ViScan) mainly reflects structures just below the surface. In the abdomen, subcutaneous abdominal fat (SAAT) represents the closest compartment to the surface which is 5-10x less conductive than other tissues (e.g. muscle) (Geddes & Baker 1967, Gabriel et al 1999), hence, much of the inter-individual difference in transimpedance could be explained by differing volumes (or depths) of SAAT. Indeed, SAAT explains the most variance in % trunk fat in our study, an observation that confirms the original observations of Scharfetter et al (2001).

The idea that transimpedance is influenced by fat content of the mesentery (i.e. IAAT), was first suggested by Scharfetter (2005). Our study showed a strong relationship between ViScan derived “visceral fat” and MRI derived IAAT similar to that reported in the developmental studies of the ViScan against CT (Yamaguchi et al 2006), however, waist circumference alone explained more of the variance in our

cohort. Reliable prediction of IAAT using transimpedance would depend on the depth of the IAAT as well as the relative volumes, depths and conductance of other abdominal tissues (e.g. muscle, mesentery, spine, liver and other internal organs), all of which are difficult to quantify and correct for. For example, it is likely that much of the current flux is through superficial muscle, the conductance of which is dependant on muscle fibre direction relative to injection point, as well as presence of lipid within the muscle (Gielen et al 1984). The observed weaker relationship between MRI and ViScan in those with high liver fat also suggests an influence of organ mass/composition as higher liver fat is closely associated with increased liver volume (Thomas et al 2005).

Distinguishing IAAT and SAAT using transimpedance would have to assume that for a given trunk volume there is a constancy of non-adipose tissue in terms of mass and conductivity. Given that SAAT is the closest structure to the surface it is credible that the absolute amount of SAAT dictates the relative depth of IAAT and hence its contribution to transimpedance. Gender will also have an influence since, as shown by us and other authors, women exhibit a significantly higher SAAT:IAAT ratio (Ross et al 1994, Kuk et al 2005, Demerath et al 2007). Indeed, as like waist circumference, gender may be a key component in the prediction of abdominal fat.

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Across a range of adiposity, as in our study, degree of abdominal adiposity itself is a possible influence on prediction of adipose tissue compartments. Fat (or more specifically adipose tissue) is known to contribute more significantly to overall conductance in the obese (Baumgartner et al 1998), potentially contributing to error in transimpedance interpretation in the abdominally obese. Depth of IAAT is likely increased in the abdominally obese, and in the very obese IAAT and SAAT compartments may also be anatomically bridged further adding to problems in

distinguishing abdominal adipose tissue compartments. Relative electrode placement in the abdominally obese is also a factor as Nagal et al (2008) noted that when determining deeper structures there should be a greater relative distance between sensing and injecting electrodes. In the ViScan system the distance between electrodes is fixed but the relative positions of these compared to anatomical landmarks differ depending on abdominal girth, hence a lean individual, with a smaller waist girth will have the electrodes spanning proportionally more of the abdomen.

To help illustrate these, and other points, figure 4 shows representative MRI images and discrepancy between MRI and ViScan derived values for adipose tissue compartments for two male subjects of similar overall abdominal adiposity.

ViScan may be a useful predictor of abdominal adipose tissue compartments in leaner individuals, similar to those recruited in the original developmental study of Yamaguchi et al (2006). However, across a range of adiposity the ViScan may be capable of predicting total abdominal adiposity, but the use of this system to predict “visceral fat” (IAAT) remains limited. Further studies using reference methods such as MRI are needed to investigate the influence of structural differences, tissue hydration and musculature on transimpedance, which may improve prediction models. More studies are also needed to investigate reliability of the ViScan, in particular its ability to predict changes in abdominal fat compartments. Nevertheless, the ViScan system may still prove to be a valuable motivational instrument for the health practitioner, with a possible future role in screening for abdominal obesity.

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Table 1: Measured subject characteristics and body composition compartments, split by BMI (lean group represents BMI $\leq 25 \text{ kgm}^{-2}$, the overweight/obese group represents individuals with a BMI above 25 kgm^{-2}).

	Lean		Overweight/obese [†]	
	males (n=13)	females (n=18)	males (n=21)	females (n=22)
Age (y)	36.7 \pm 13.0	29.3 \pm 10.4	42.1 \pm 14.6	49.1 \pm 15.1
Body Mass (kg)	71.0 \pm 7.2	58.8 \pm 5.4*	91.4 \pm 11.8	82.7 \pm 14.2*
BMI (kgm⁻²)	22.7 \pm 2.0	21.5 \pm 1.8	29.2 \pm 3.3	32.0 \pm 3.6
Mid waist circumference (cm)	81.4 \pm 6.5	71.8 \pm 5.1*	97.0 \pm 12.0	99.6 \pm 12.3
WHR	0.86 \pm 0.07	0.76 \pm 0.04*	0.92 \pm 0.07	0.90 \pm 0.09
<u>MRI</u>				
total body fat (%)	19.8 \pm 5.7	28.1 \pm 6.4*	24.8 \pm 8.0	47.0 \pm 4.8*
total abdominal fat (IAAT + SAAT) (kg)	4.5 \pm 1.8	4.2 \pm 1.3	8.3 \pm 4.0	13.4 \pm 3.7*
SAAT (l)	3.1 \pm 1.3	3.8 \pm 1.1	5.9 \pm 3.1	10.8 \pm 3.1*
IAAT (l)	1.9 \pm 1.1	0.9 \pm 0.4*	3.3 \pm 2.0	4.2 \pm 1.9
IAAT:SAAT ratio	0.65 \pm 0.35	0.23 \pm 0.07*	0.58 \pm 0.3	0.39 \pm 0.18
IHCL (%)	0.8 \pm 1.0	0.4 \pm 0.7	6.4 \pm 9.2	10.6 \pm 13.8
<u>ViScan (BIA)</u>				
ViScan % trunk fat (%)	20.2 \pm 5.2	24.1 \pm 7.3	28.9 \pm 9.1	45.2 \pm 4.6*
ViScan visceral fat (no units)	6.8 \pm 1.8	3.6 \pm 1.3*	13.2 \pm 6.2	10.9 \pm 2.4*

WHR= waist hip ratio. ; IAAT, intra-abdominal adipose tissue,: SAAT, subcutaneous abdominal adipose tissue: IHCL, intra-hepatocyte lipid.

* Significant gender difference within the same BMI group ($P < 0.05$)

5 † All variables significantly different from lean group of the same gender ($P < 0.05$)

Table 2: Pearson's correlation coefficients for associations with MRI abdominal fat compartments. All variables correlated at a significance of $P < 0.001$ unless otherwise stated.

	IAAT	SAAT	IHCL	Total abdominal fat (kg)	Total abdominal fat (% of body weight)
ANTHROPOMETRY					
Waist (mid)	0.844	0.690	0.630	0.821	0.651
Waist (umbilicus)	0.805	0.765	0.582	0.861	0.697
Waist (supine umbilicus)	0.796	0.773	0.597	0.860	0.698
Hip	0.613	0.846	0.461	0.844	0.670
WHR	0.783	0.400	0.601	0.583	0.480
WSR	0.82	0.798	0.606	0.889	0.825
BMI	0.702	0.843	0.520	0.875	0.733
VISCAN					
ViScan % Trunk fat	0.688	0.884	0.447	0.899	0.938
Viscan Visceral fat	0.731	0.622	0.567	0.725	0.742

Abbreviations: Waist (mid), midpoint between lower rib and greater trochanter; Waist (umbilicus), waist circumference at the level of the umbilicus; Waist (umbilicus supine), waist measured at the level of the umbilicus with the subject laying supine; WHR, waist hip ratio, WSR, waist-stature ratio; IAAT, intra-abdominal adipose tissue, SAAT, subcutaneous abdominal adipose tissue; IHCL, intra-hepatocyte lipid.

FIGURE LEGENDS

Figure 1: The ViScan measurement system in operation (see text for description of the method)

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Figure 2: Relationships between MRI derived abdominal adipose tissue compartments and the ViScan measurement system. All relationships statistically significant ($P < 0.001$).

10 *Figure 2A:* Relationship between MRI derived total abdominal adipose tissue (IAAT + SAAT) expressed as a % of body weight, and % trunk fat as measured by the ViScan™ Measurement system

15 *Figure 2B:* Relationship between MRI derived subcutaneous abdominal adipose tissue (SAAT), and % trunk fat as measured by the ViScan™ Measurement system (n = 74)

Figure 2C: Relationship between MRI derived IAAT (litres), and “visceral fat” as measured by the ViScan™ Measurement system (n=74).

20

Figure 3: Resultant boxplots to show the ViScan derived banding of individuals in terms of abdominal fat compartments and MRI derived abdominal adipose tissue (n=74).

25 *Figure 3A:* ViScan categorised percentage trunk fat.

Figure 3B: ViScan categorised visceral fat.

Figure 4: A single slice MRI image for two subjects of the same gender with near identical ViScan visceral fat scores (4a = 20; 4b = 19.5 arbitrary units), but differing IAAT as assessed by MRI (4a = 6.3; 4b = 3.2 litres). Interestingly, when abdominal subcutaneous fat is considered (4a = 9.2; 4b = 13.6 litres) these two subjects exhibited similar overall levels of total abdominal adiposity (4a = 15.5; 4b = 16.8 litres)



Fig. 2A

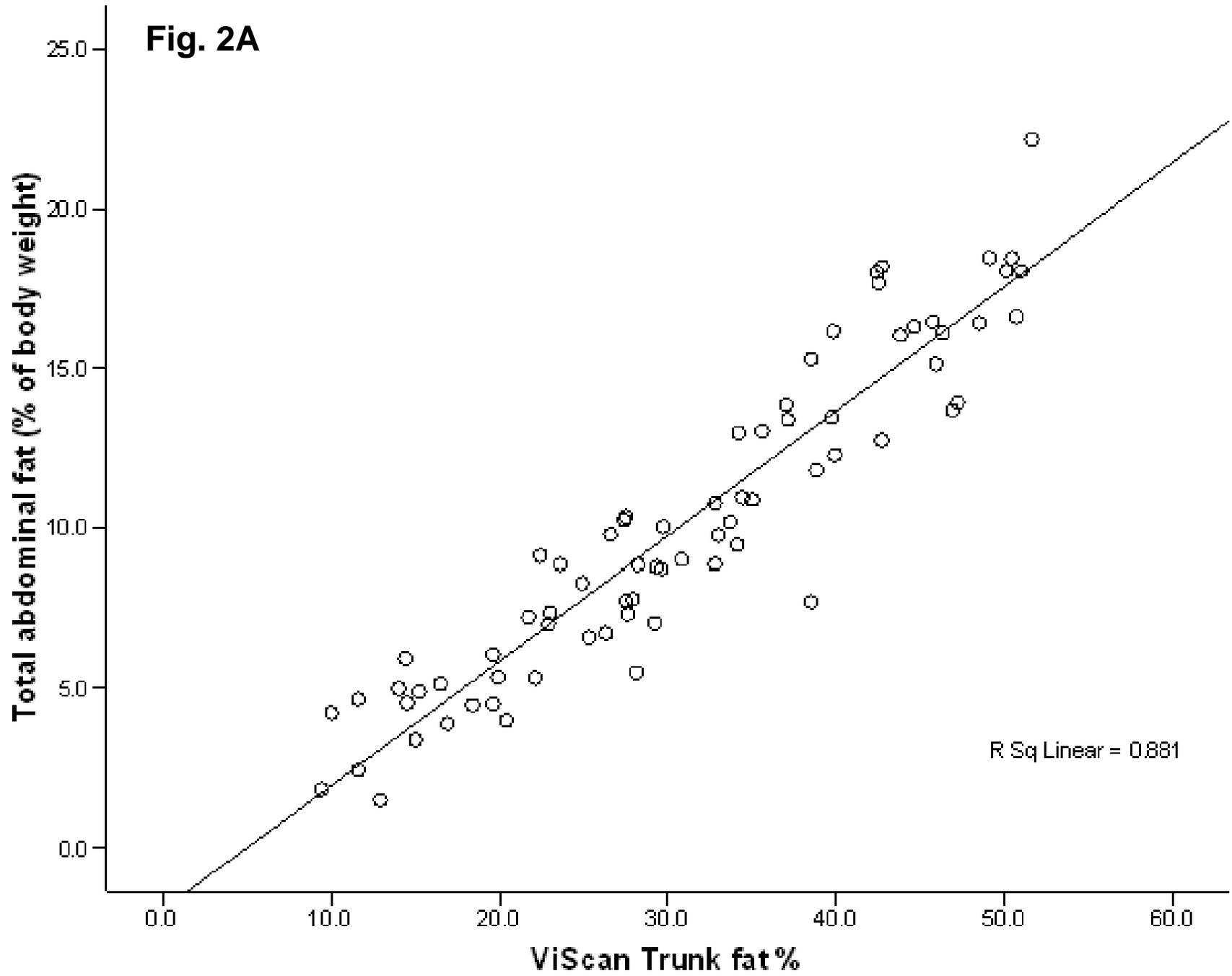


Fig. 2B

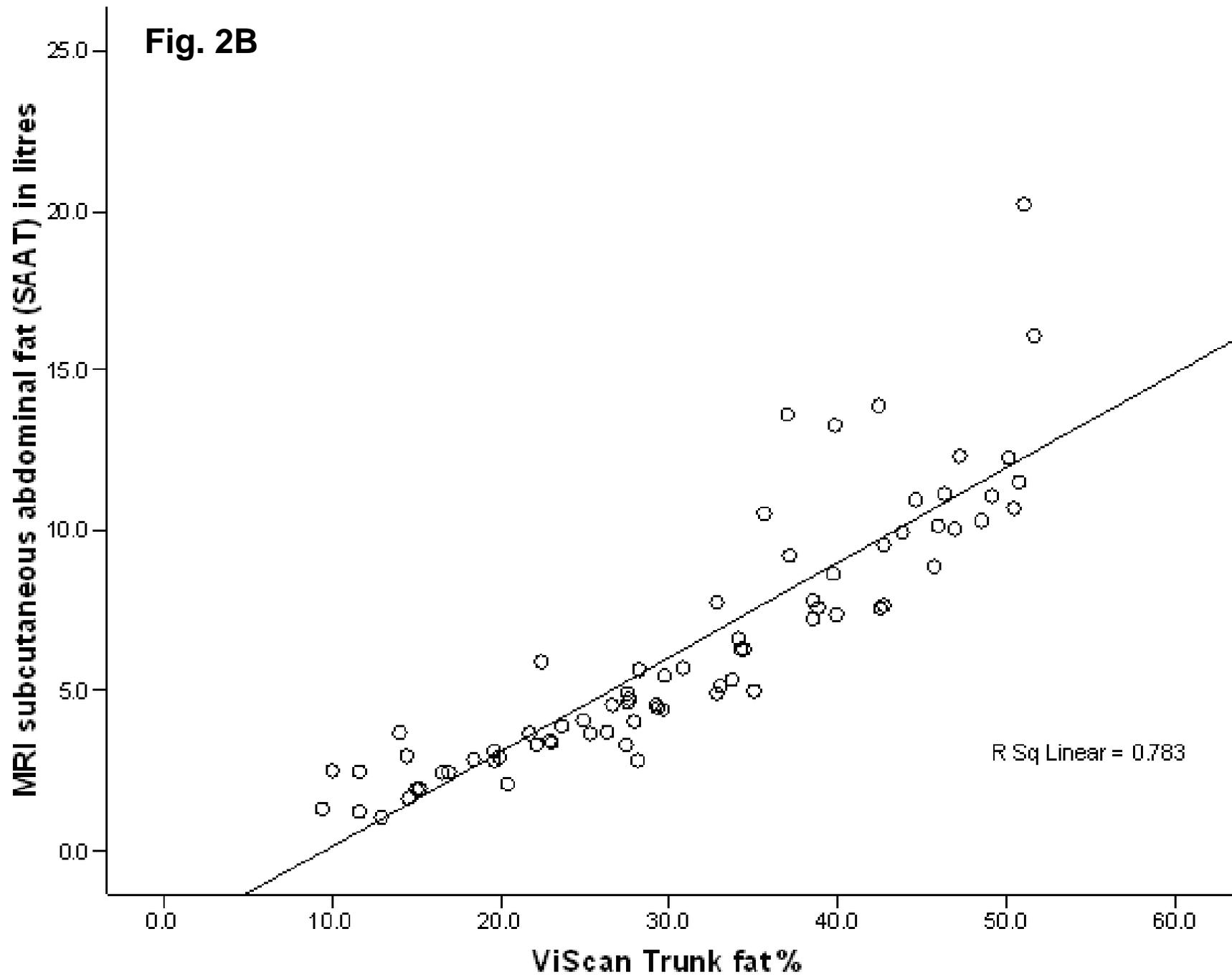


Fig. 2C

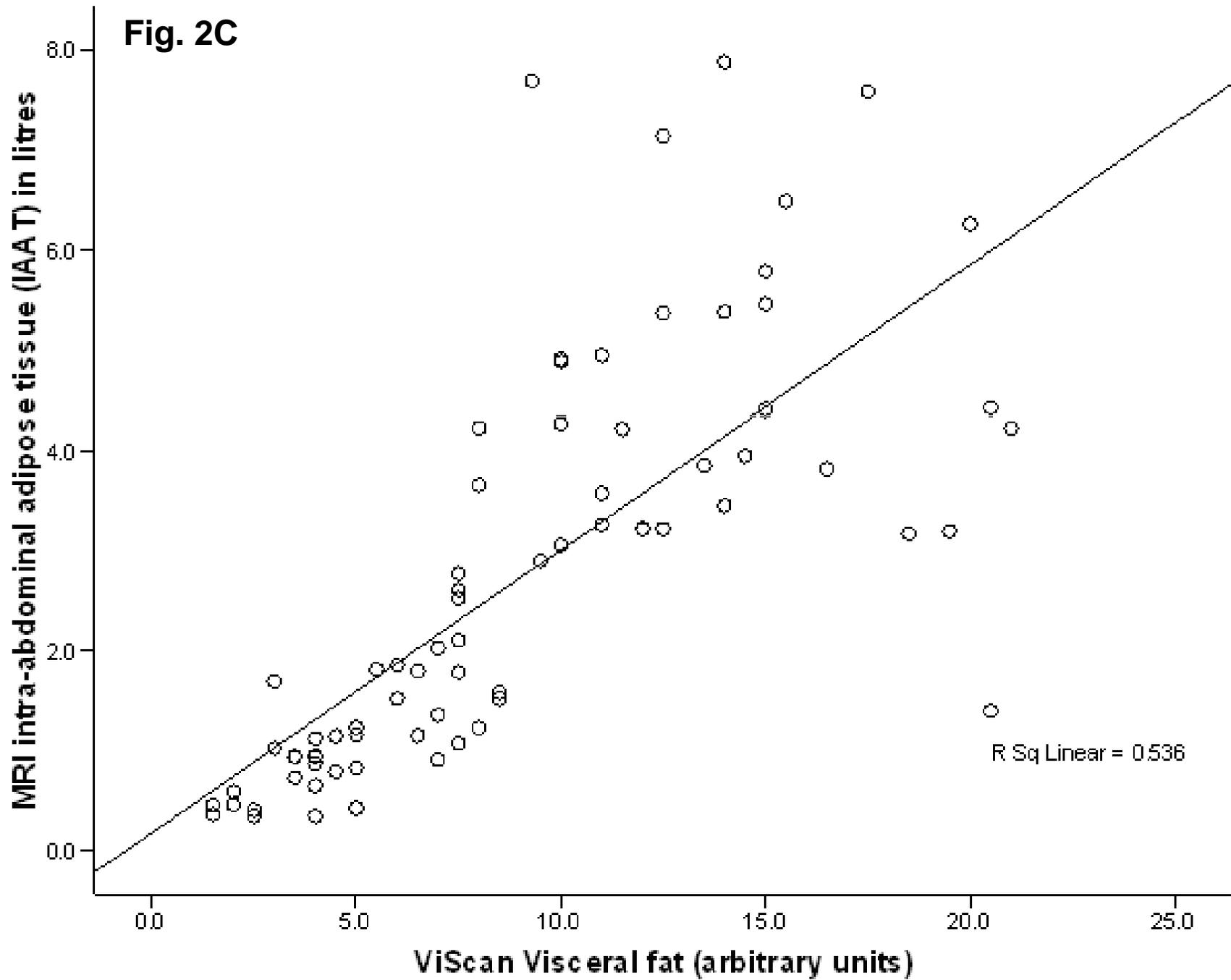


Fig. 3A

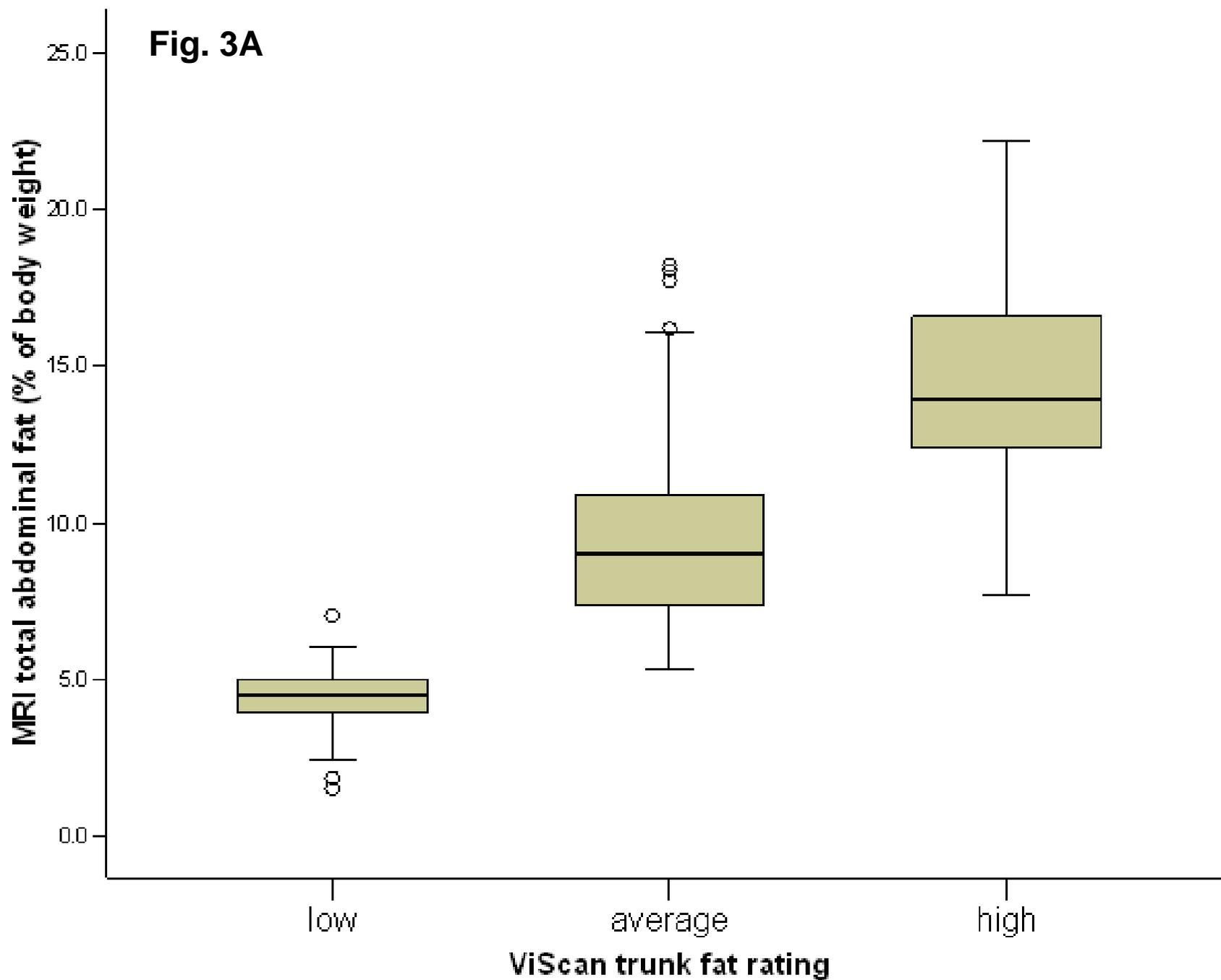
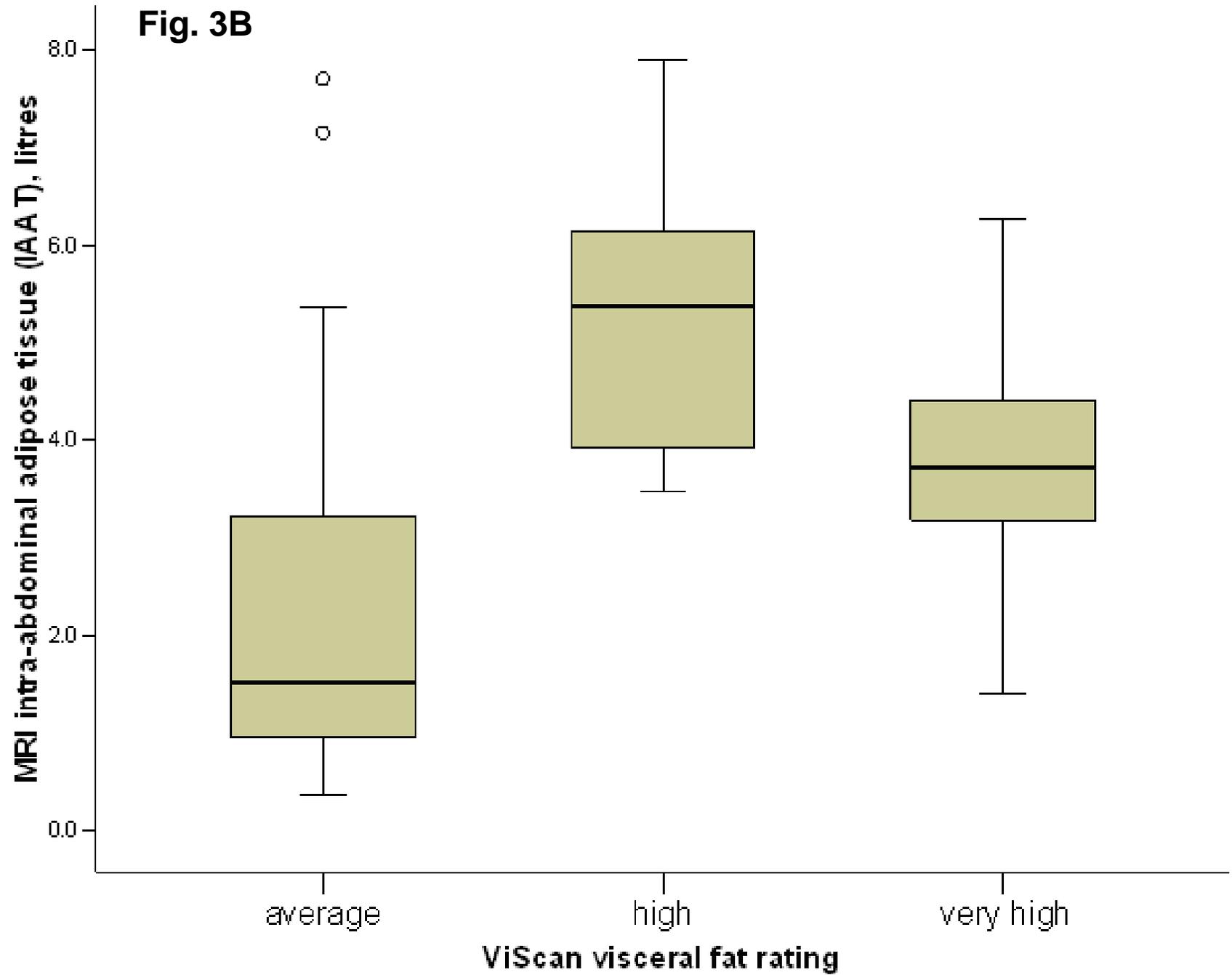


Fig. 3B



4a





4b