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TECHNICAL NOTE

Quantification of Intra-Abdominal Fat During Controlled Weight Reduction: Assessment Using the Water-Suppressed Breath-Hold MRI Technique

J. TINTĚRA, P. HARANTOVÁ, P. SUCHÁNEK, A. DVOŘÁKOVÁ, M. ADAMOVÁ, M. HÁJEK, R. POLEDNE

Institute of Clinical and Experimental Medicine, Prague, Czech Republic

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Summary

A group of 14 healthy female subjects was studied using MRI during 2 months of life-style intervention. A series of 21 water-suppressed images was used to determine the intra-abdominal fat volume before and after the controlled loss of weight. The average weight decrease was 8.2 %, but the average relative loss of visceral fat was 20.3 %, whereas subcutaneous fat decreased by 13.4 %. A small but significant increase of insulin sensitivity (decrease in fasting insulin and blood glucose) was observed, but no changes in lipoprotein parameters were demonstrated. There was a significant negative correlation ($r=-0.633$, $p=0.028$) between the relative abdominal fat decrease and the initial amount of subcutaneous fat.

Key words
Intra-abdominal adipose tissue • MRI • Weight loss

Introduction

In the past few years, there has been a growing interest in better understanding the role of abdominal fat. Several authors have demonstrated the possibility to use MRI for quantification of intra-abdominal fat volume (Terry *et al.* 1995, Sharma *et al.* 1996, Rofsky *et al.* 1999, Kockx *et al.* 1999, Kamel *et al.* 2000, Fox *et al.* 2000, Busseto *et al.* 2000). All these studies used a standard T1-weighted imaging protocol to quantify the fat volume, but this approach suffers from motion artifacts caused by subcutaneous fat movement during breathing. Also, given the need to keep repetition time TR short for sufficient T1-weighting, fat enhancement leads to limitation in the number of slices per measured volume. Consequently, the entire abdominal volume is acquired very sparsely and the missing volume must be estimated.

Here we present a different approach using a breath-hold water-suppressed imaging technique to monitor the visceral and subcutaneous fat volumes. The advantage of our approach is the acquisition of motion artifact-free images containing practically only the fat signal. Therefore, the subsequent segmentation is easy to perform with automatic thresholding and reproducible volume quantification. Our technique was used to quantify abdominal and subcutaneous fat during a

Fax +420 241 062 164
E-mail: physres@biomed.cas.cz http://www.biomed.cas.cz/physiolres

controlled loss of weight and a correlation with other laboratory samples was evaluated.

Methods

A single-slice breath-hold turbo spin-echo (TSE) sequence (turbo factor 5, echo time TE 12 ms, TR 200 ms, slice thickness 10 mm, field-of-view (FOV) 420-450 mm, total measurement time 11 s) was modified to suppress the water signal so that the images contained practically only the fat signal. This was realized in a similar manner as the usual fat suppression with spectral selective radio-frequency (RF) pulse. However, in this case the resonant frequency was manually shifted onto the fat frequency (a shift of 220 Hz) and a frequency selective RF pulse on the water frequency followed by a gradient spoiler served to suppress the water signal. The efficiency of the water suppression is demonstrated in Figure 1. Water suppressed images could be more easily segmented to quantify the entire fat volume. The TSE sequence with centrically acquired k-space was chosen to keep echo time TE short and also to shorten the measurement time so that the subject can easily hold the breath (11 s). The breath-hold technique is used to avoid any motion artifacts (ghosting due to the movement of subcutaneous fat regions with high signal intensity) which would cause difficulties during the data segmentation.

A complete volume of 210 mm in length was covered by 21 continuous axial slices acquired in a standard body coil to keep the fat signal constant over the image as much as possible. The in-plane FOV was individually adapted to the subject´s body size to ensure that the volume is scanned completely. The advantage of the short measurement time is that the scan can be simply repeated in any case of subject's movement without a significant time penalty. The whole examination was completed with 21 successful breath-holds and took less than 20 min in individual subjects.

Segmentation of the fat volume was performed with our internally developed software application written in PV-WAVE (Visual Numerics). Although the images principally contain the fat signal, the most important point for volume quantification is to find the proper threshold for the segmentation. We developed an automatic procedure to find the threshold of the fat signal using a histogram evaluation of the entire volume. This histogram was first smoothed to improve the signal-to-noise ratio and then signal threshold for segmentation was set as a minimum between noise voxels and a maximum representing voxels clearly containing fat.

A manual selection (delineation) of the whole abdominal as well as subcutaneous volume was performed by two independent observers; in both cases, evaluation of the first and second set of data was done simultaneously to suppress the difference in volume definition. In addition, to evaluate the inter-observer variability of the segmentation, all subjects were analyzed twice by independent observers. A common correlation of variables extracted from MRI volumetry (e.g. relative changes in abdominal and subcutaneous fat, fat volumes in the baseline examination, abdominal volume fat filling factor) with clinical data was searched for by calculating a covariate matrix. All MR measurements were done on a Siemens Vision 1.5 T scanner, and the MR examination was performed once at the beginning of the study and again after 2 months.

A group of 14 healthy young overweight or obese females (age 25-35 years) was selected with the criteria of a minimal body mass index (BMI) of 28 kg/m^2 and willingness to participate in life-style intervention representing individual dietary recommendation and supervised increased physical activity for 9 weeks (before the study one woman had BMI 25 kg/m^2, two women had BMI 29 kg/m^2 and 11 women had BMI values greater than 30 kg/m^2). None of these volunteers smoked and there was only a slight decrease of average alcohol consumption during the life-style intervention period. The increased physical activity consisted of 6 sessions a week comprising 2-3 supervised exercise sessions in a fitness center (45 min) and 2-3 additional controlled physical activities (bicycling, jogging or brisk walking for 45 min). Daily dietary records were reviewed and supervised to decrease total energy intake, as well as to limit a high fat intake and the proportion of saturated fats in the diet, if necessary. Lipoprotein concentrations were analyzed using a Cobas Mira autoanalyzer with an enzymatic method (Hoffmann-LaRoche). Fasting lipoprotein and glucose concentrations were measured before and after the intervention period.

Results

The use of the breath-hold technique in conjunction with water suppression provided excellent image quality of abdominal fat (Fig. 1). Water suppression leads to an increase of signal difference (ratio) between fat and muscle from 4.3 up to 17.7 so the fat contrast is more than four times better using water suppression compared to standard T1-weighted images. Better image contrast makes the segmentation procedure much easier and probably also more reproducible.

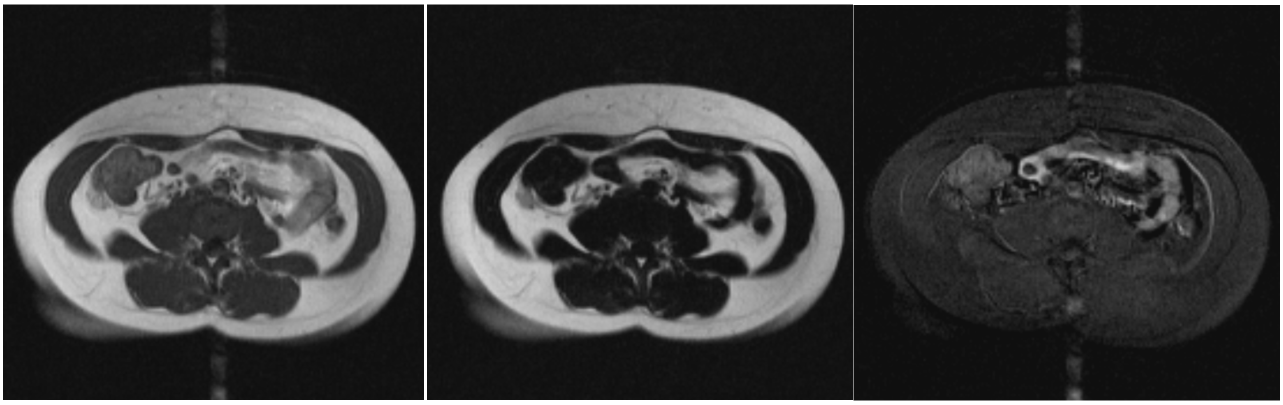

Fig. 1. An axial image without (left) and with water suppression (middle) (all other parameters remain the same) and the difference image (right) showing the effect of water suppression.

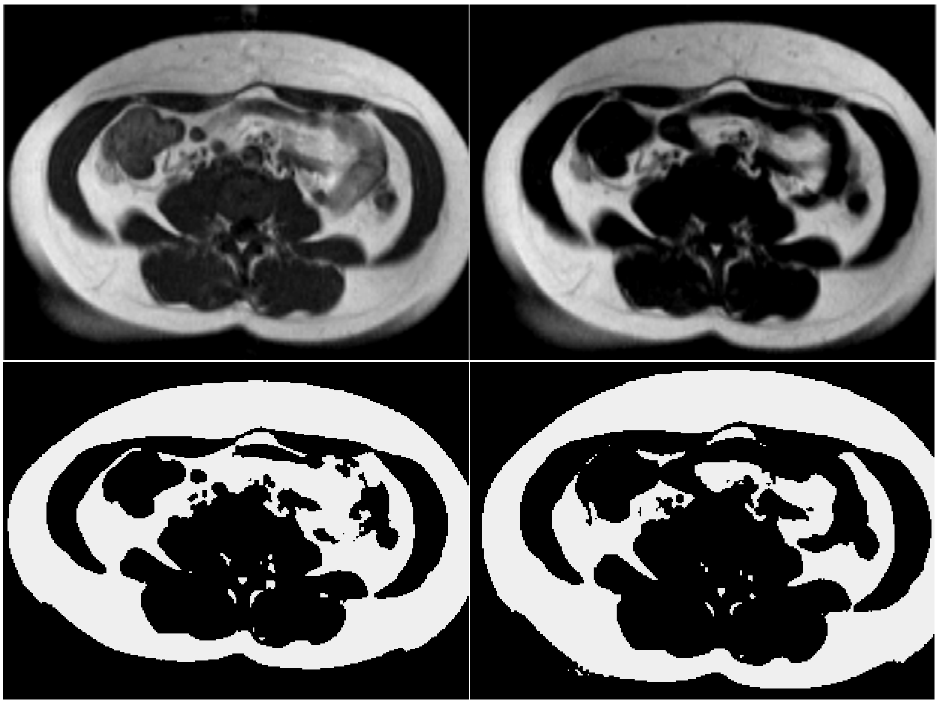

Fig. 2. An axial image and the result of automatic thresholding for measurement without water suppression (left column) and with water suppression (right column). The automatic segmentation gives a more realistic fat volume in the case of water suppression.

The comparison of segmented images with and without water suppression can be seen in Figure 2. The most important point of volume segmentation is the selection of the signal intensity threshold. Voxels containing fat have the highest intensities so that only the lower edge of signal intensities still corresponding to fat has to be found (segmentation threshold). Of course, some voxels partly contain fat molecules but also water molecules (partial volume effect) so that the signal distribution of fat containing voxels has a Gauss-like shape in the upper part of the histogram. Our automated procedure searches for the minimum in the histogram located in the lower intensity part of the Gaussian distribution of fat signals.

The maximal difference between thresholds automatically set in two measurements of the same subject was 126 (24 %), but the average value in the whole group was only 11 (2.6 %). A large difference in the searched value indicates usually insufficient water suppression in one of the measurements (e.g. because of the insufficient magnetic field homogeneity). Using a paired t-test, we did not identify a significant difference between thresholds automatically set in the first and second examinations.

After automatic thresholding, the region of interest (either abdominal or subcutaneous) has to be defined interactively by the observer. This regional selection could be partly subjective (we used pre-defined anatomical landmarks) and could thus be another source of systematic error. Therefore, the data were evaluated by two independent observers to estimate this influence. The mean difference between fat volumes segmented by the two observers was only 2±9 % (S.D.).

MRI quantification of abdominal and subcutaneous fat by the above described method was used to measure changes in fat volumes and to compare these changes with laboratory data in a group of volunteers who participated in a two-month weight loss program. A typical example of the image from the first and second examination (after two months of life-style intervention) is depicted in Figure 3. The changes of main anthropometric measures and biochemical parameters are shown in Table 1.

Table 1. Body and blood composition of 14 women before and after the life-style intervention.

14 Women	Before	After	T-test
Weight (kg)	86.4 ± 9.1	78.9 ± 8.0	p<0.0001
BMI (kg/m^2)	30.7 ± 2.4	28.0 ± 2.5	p<0.0001
Waist (cm)	93.2 ± 9.5	84.0 ± 6.2	p<0.005
Hip (cm)	111.4 ± 4.0	104.8 ± 5.7	p<0.0001
WHR	0.84 ± 0.07	0.80 ± 0.07	NS
Blood glucose (mmol/l)	5.44 ± 0.46	5.24 ± 0.43	p<0.05
Total cholesterol (mmol/l)	5.36 ± 0.85	5.05 ± 1.05	NS
TG (mmol/l)	1.41 ± 0.42	1.29 ± 0.52	NS
LDL (mmol/l)	3.04 ± 0.94	2.81 ± 0.96	NS
HDL (mmol/l)	1.41 ± 0.24	1.35 ± 0.25	NS
HDL/TC (%)	31.1 ± 8.6	32.3 ± 12.5	NS
Insulin (µIU/ml)	8.04 ± 2.43	6.34 ± 2.13	p<0.05
Visceral fat (cm^3)	1438 ± 653	1121 ± 542	p<0.0001
Subcutaneous fat (cm^3)	667 ± 123	572 ± 136	p<0.0001

Data are mean ± S.D., WHR – waist-hip ratio, TG – triglycerides, LDL – LDL cholesterol, HDL – HDL cholesterol

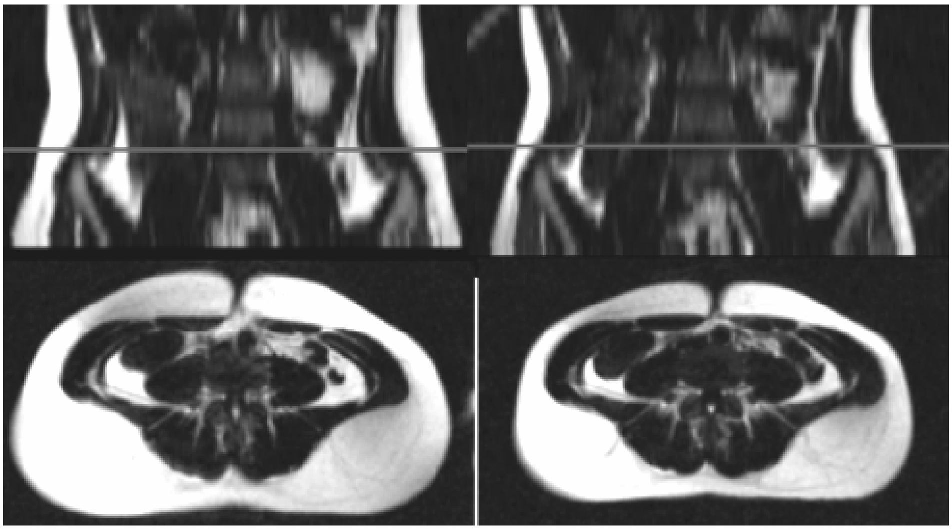

Fig. 3. A frontal (upper) and axial (bottom) fat image in the baseline examination (left) and after 2 months of life-style intervention (right). For this subject the most pronounced decrease of visceral fat volume was observed.

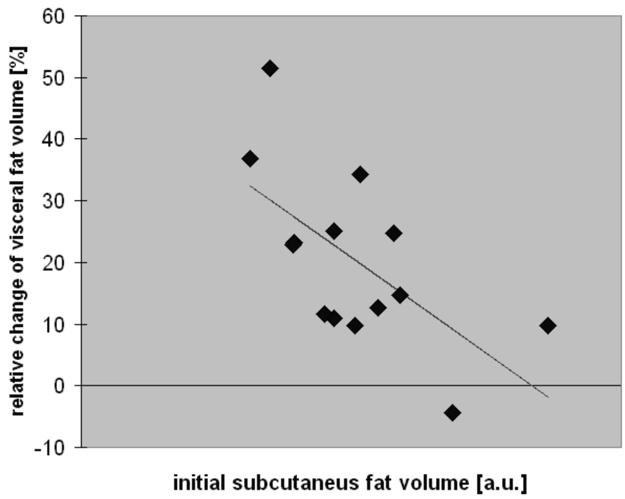

Fig. 4. Correlation between the relative change of visceral fat and the amount of subcutaneous fat at the start of the study (r=–0.633, n=14, p=0.028).

The average weight loss in the volunteer group was 8.2 % (7.5 kg) after a two-month life style intervention. The weight loss corresponds to an average relative loss of intra-abdominal fat volume of 20.3 %, whereas the decrease in subcutaneous fat volume was only 13.4 %. In all subjects, both visceral fat volume and subcutaneous fat volume decreased. A substantial drop of BMI, waist and hip circumference were documented (Table 1). A small but significant increase of insulin sensitivity (decrease in fasting insulin and blood glucose) was observed, but no changes in lipoprotein parameters were demonstrated. There was a significant negative correlation between the relative intra-abdominal fat decrease and the amount of subcutaneous fat at the beginning of the study (Fig. 4.).

Discussion

Our results in this group of volunteers indicate that the technique presented here is capable of measuring volume changes of abdominal fat with an error certainly below 10 %. The study shows that the loss of visceral fat volume is more than twice as fast as compared to the body weight loss (20 % compared to 8 %) and the decrease of subcutaneous fat is also greater than body weight loss (13 % compared to 8 %). Moreover, according to the correlation shown in Figure 4, the decrease of visceral fat is more pronounced in subjects having a lower overall subcutaneous fat volume at the initiation of the diet. We can speculate that there is a mechanism controlling the loss of body fat in such a way that the loss of subcutaneous fat dominates, given the generally higher volume of this fat, but a faster decrease of visceral fat occurs if initial volumes of subcutaneous fat are lower.

We developed a robust and time-efficient technique to quantify abdominal fat. Using this method we have found that the decrease in visceral fat was higher than the change in subcutaneous fat during the life-style intervention and that also this change in visceral fat depends on the initial amount of subcutaneous fat.

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Reprint requests

J. Tintěra, PhD., Institute of Clinical and Experimental Medicine, Vídeňská 1958/59, 140 00 Prague 4, Czech Republic. Fax: +420 2 4172 8224. E-mail: jati@medicon.cz