Comparison of three different adipose tissue segmentation methods at CT scans

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Aims and objectives

The numerical characterization of the subcutaneous and visceral adipose tissue volume can be very useful at CT studies. In recent years, at least three independent segmentation algorithms have been introduced which employ specific but different Hounsfield unit (HU) ranges [1,2,3]. One of the workgroups has also developed an algorithm to estimate the patient's BMI index along with their fat-tissue segmentation [3]. We aimed to examine and compare the reliability of these methods from the previously applied CT protocol at additional CT scanner and acquisition protocol.
Methods and materials

Examination of 51 males and 47 females were performed with Philips Brilliance 64 system, then three axial slices (L1 vertebra; hilus region of the right and the left kidney) were used for image processing. Two ROIs were drawn on these pictures (see in Figure 1), one ROI was placed on the body contour (green line) and one in the abdominal cavity (red line). Fat tissue segmentation was made according to these independent territories and in this way we got the subcutaneous adipose areas (sWAT) and the visceral ones (vWAT) for all three slices. To ensure an almost constant signal to noise ratio, different Xray exposures were used at different body weights for the CT device. 100, 150 and 200 mAs were set under 80kg, between 80kg-110 and above 110kg, respectively. The applied exposures are typical at the low-dose CT investigations, thus the protocol was greatly different from the one used in [2,3]. In all cases the tube voltage was set to 120kV.

We used the following ranges for the segmentations: [window level, window width] = [-110,160], [-95,110], [-120,150]; and we applied these ranges for both the sWAT and vWAT calculation. The corresponding areas shall be called sWAT1, sWAT2, sWAT3, vWAT1, vWAT2 and vWAT3. The actual BMI was calculated by

\[
\text{BMI} = \frac{\text{weight [kg]}}{\text{height}^2 [\text{m}]}.
\]

The BMI value was also estimated (BMlest) according to the following formula published in [3]:

\[
\begin{align*}
\text{BMlest male:} & \quad 2,069055+(0,037443*\text{SQA})-(0,050594*\text{age})+(0,984937*\text{BTD})-(2,647949*\text{L1APD}) \\
\text{BMlest female:} & \quad -9,163352+(0,252992*\text{BC})+(10,621081*\text{SQA/BA})-(0,080649*\text{age})+(0,597135*\text{BAPD})
\end{align*}
\]

This formula requires the horizontal and AP diameter of the body (BTD, BAPD), the diameter of the vertebral body (L1APD), body circumference (BC), the total body area (BA) of the axial slice, the subcutaneous fatty area (SQA) and the patient’s age.

All data evaluation and processing were performed with the Microsoft Office Excel and the Matlab programs.
Fig. 1: The subcutaneous fat tissue (sWAT) is defined by the space between the green and red ROI while the visceral fat tissue (vWAT) is defined by the region in the red ROI.

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Results

In the second figure representative results of the fat tissue segmentation are shown produced by the three different segmentation thresholds. There are no substantial differences between A, B and C, only minor and less pronounced differences can be found. It can also be noted that the most noisy result came from the narrowest segmentation method (Panel B). Data of all patients were used for correlation analysis of the three methods for both subcutaneous and intra-abdominal area, separately for men and women. The results are shown below, in Figure 3. The correlations were very high in all cases, thus only two typical cases are shown. The related correlation coefficients and the regression equations can be seen in Table 1. Although the correlations are very good, all intersections differ significantly from zero. Therefore it is expected that there may be differences between the absolute values of vWAT1,2,3 and also between the absolute values of sWAT1,2,3. These deviations were calculated and can be seen in Figure 4. It can be stated that the deviations are smaller in the case of the sWAT areas and larger for the vWAT values. For sWAT case, the deviation is less than 5% if the pixel number of the segmented sWAT is larger than 500-800, which is more than 80-90% of the all cases. On the other hand the related deviation is less than 10% for the vWAT areas if the segmented regions are larger than ~1000 pixels, which is about 60-80% of the all occurrences. Because of the very close correlation and the small differences between the sWAT1,2,3 and between the vWAT1,2,3 areas, we will only present the sWAT1 and the vWAT1 segmented parameters in the followings.

We also investigated the interrelationship between segmented areas and the patients’ weight, and the BMIest index. Figure 5 presents the resulted data where although the correlations are less extent but are larger than 0.6299 and 0.2729 for the sWAT1 and vWAT1 areas, respectively. The similar calculated data of the sWAT1 - BMIreal and vWAT1 - BMIreal are presented in Table 2 and can be concluded that the $R^2$ values are larger for the BMIreal than in the case of the BMIest. It is also generally stated that the correlations of the subcutaneous adipose areas to any other investigated parameters are always better than the related viscerals’ correlations. In the next step we studied the accuracy of the BMIest values. Figure 6 shows the correlations between the BMIest and the BMIreal index, where $R^2=0.7802$ (p<0.001) and $R^2=0.841$ (p<0.001) for the male and female, respectively, which corresponds to a good correlations. Similar significant correlations (p<0.001, $r^2=0.736$, $r^2=0.705$) were found by the authors of [3], in which the BMIest was defined, which shows that the correlations does not depend significantly on the actual CT protocol.

We were also interested in the change of results if the analysed slice would be the one after or before the originally selected one (L1 vertebra), thus all parameter calculations (vWAT, sWAT areas and BMIest values) were performed in three independent slices. For
charaterizing the stability of the calculated parameters between the slices we defined the CV (coefficient of variation) for a parameter in % as

\[ CV = \frac{\text{std}(\text{parameter})}{\text{mean}(\text{parameter})} \times 100. \]

The histograms of the CV values can be seen in Figure 7 and Figure 8. It can be concluded that stability of the calculated sWAT and vWAT values are worse for the female patients and the related stability of the BMIest is surpassing irrespectively the gender. The mean values of the above histograms were the following: CV_vWAT=5,8, CV_sWAT=8,79, CV_BMIest=2,07 for the male; and CV_vWAT=12,55, CV_sWAT=10,43, CVBMI=1,5 for the female patients. The smallest CVmean corresponds to the higher stability, of course.
Images for this section:

![Images](image1.png)

**Fig. 2:** Represented sWAT and vWAT areas: \(wl_1, ww_1 = -110, 160\) (A), \(wl_2, ww_2 = -95, 110\) (B) és \(wl_3, ww_3 = -120, 150\) (C).

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<table>
<thead>
<tr>
<th>regression type</th>
<th>(R^2)</th>
<th>regression equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>sWAT1-sWAT3 (male)</td>
<td>0.9996</td>
<td>(y = 0.9937x - 351.01)</td>
</tr>
<tr>
<td>sWAT1-sWAT2 (male)</td>
<td>0.9882</td>
<td>(y = 0.9319x + 225.64)</td>
</tr>
<tr>
<td>sWAT1-sWAT2 (female)</td>
<td>0.9999</td>
<td>(y = 0.9946x - 233.74)</td>
</tr>
<tr>
<td>sWAT1-sWAT3 (female)</td>
<td>0.9998</td>
<td>(y = 0.996x - 306.44)</td>
</tr>
<tr>
<td>vWAT1-vWAT3 (male)</td>
<td>0.9987</td>
<td>(y = 0.9589x - 741.95)</td>
</tr>
<tr>
<td>vWAT1-vWAT2 (male)</td>
<td>0.9976</td>
<td>(y = 0.9525x - 376.3)</td>
</tr>
<tr>
<td>vWAT1-vWAT2 (female)</td>
<td>0.9987</td>
<td>(y = 0.9612x - 529.01)</td>
</tr>
<tr>
<td>vWAT1-vWAT3 (female)</td>
<td>0.9998</td>
<td>(y = 0.996x - 306.44)</td>
</tr>
</tbody>
</table>

**Table 1:** Results of the regression among the different vWAT and sWAT areas.

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Table 2: Regression data between the BMIreal and sWAT/vWAT areas.

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Fig. 3: Correlation plots of sWAT1-sWAT2, sWAT1-sWAT3 (lower graph) and vWAT1-vWAT2, vWAT1-vWAT3 (upper graph) in the case of female.

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Fig. 4: Percentage differences between the sWAT1,2,3 and between the vWAT1,2,3 values. The (A), (C) panels refer to the female and (B), (D) to the male population. Each X axis represents the vWAT1 or the sWAT1 values.

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Fig. 5: The relationships of the vWAT1/sWAT2 to the weight and the BMIest. The red and the blue labelled markers refer to the male and female population.

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Fig. 6: Correlations between the BMIest and BMIreal index.

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Fig. 7: The frequency distribution of the CVs for the sWAT (right panel) and wWAT (left panel) parameters.

Fig. 8: CV histogram of BMlest parameter.

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Conclusion

The published three different fat tissue segmentation thresholds and the related methods do not significantly affect the calculated sWAT, vWAT adipose tissue areas and the estimated BMI index. The error of calculated sWAT and vWAT values are usually not greater than 5% and 10%, respectively. In addition, the actual position of the selected slice in the region between the L1 vertebra and hilus of the kidneys does not influence largely the sWAT, vWAT and BMIest parameters. The minimum stability is characterized by the vWAT data of the female patients. The BMIest correlates well with the BMIreal index, thus the BMI can be determined by using rather thin slices. In general it can be stated that the result of the fat tissue segmentation is not significantly dependent on the settings of the actual CT scanner.
References

