Fat Segmentation on Abdominal CT

1. Introduction

This Quick Start guide describes semi-automatic segmentation of abdominal fat and muscle on abdominal CT images [1, 2].

The steps below use the commands under the main menu's **Workflows** > **CT Abdominal Fat Segmentation** group and create segmentation masks (ROI layers) with automatically assigned names, including: 1) whole fat (total adipose tissue, **TAT**), 2) subcutaneous fat (subcutaneous adipose tissue, **SAT**), 3) visceral fat (visceral adipose tissue, **VAT**), 4) muscle, 5) intramuscular fat (intramuscular adipose tissue, **MAT**), as well as auxiliary ROI layers, such as Abdominal Cavity (**AC**).

The initial step is the *automatic* total fat segmentation. The next step is the segmentation of subcutaneous and visceral fat (SAT and VAT, respectively), which can also be done automatically. Alternatively, this segmentation may be done *manually*, with the help of a user-defined Abdominal Cavity (AC) ROI. Segmentation of subcutaneous, visceral, and intramuscular fat and muscle can also be performed using the AC contour.

[1] Chandarana H, Dane B, Mikheev A, Taffel MT, Feng Y, Rusinek H. Visceral adipose tissue in patients with COVID-19: risk stratification for severity. Abdom Radiol (NY). 2021 Feb;46(2):818-825. doi: 10.1007/s00261-020-02693-2. Epub 2020 Aug 3. PMID: 32748252; PMCID: PMC7398639.

[2] Chandarana H, Pisuchpen N, Krieger R, Dane B, Mikheev A, Feng Y, Kambadakone A, Rusinek H. Association of body composition parameters measured on CT with risk of hospitalization in patients with Covid-19. Eur J Radiol. 2021 Dec;145:110031. doi: 10.1016/j.ejrad.2021.110031. Epub 2021 Nov 15. PMID: 34801878; PMCID: PMC8592118.

2. Load and display images

To load CT images in the DICOM format, start FireVoxel and use the main menu to select **File** > **Open DICOM Single Document**. This opens the **DICOM Tree dialog** (Figure 1) that allows the user to preview and select images to be loaded. Select (click on series name) or check (check box) the abdominal CT series and click **Load**. This will open the dialog titled **Load Volume value conversion**, specifying the options for the conversion from Hounsfield units (HU) to signal intensity. Accept the default settings, **Load as Unsigned Integer Volume**.

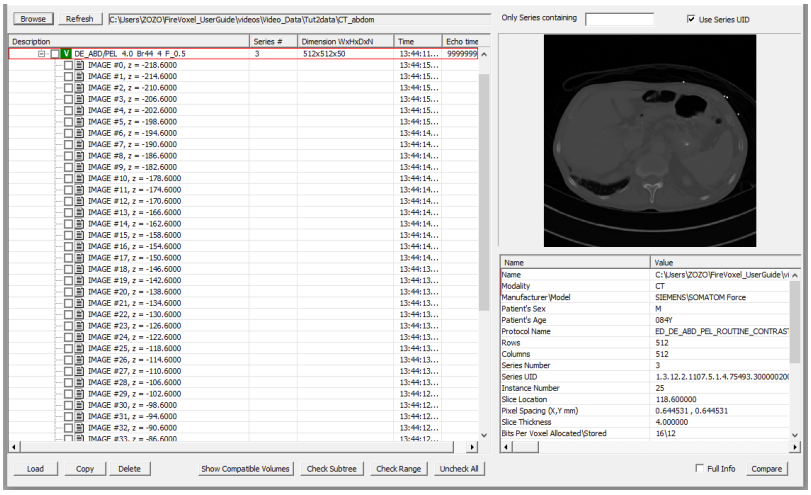

Figure 1. The DICOM Tree panel is opened when the user selects File > Open DICOM and navigates to a directory containing DICOM images. The list on the left contains available images, which are previewed in the top right corner of the panel. The bottom right part shows image properties from the DICOM headers.

With this transformation, air (-1024 HU or -1000 HU, depending on the manufacturer) is assigned 0 grayscale intensity and water is +1024.
Click **OK** to load the images.

Save the document by selecting on the main menu **File** > **Save FireVoxel Document**. The user may wish to save the document after each processing step to avoid losing results.

Images can be displayed in Film view or Slice view. To toggle between the views, double-right-click on the image. In Slice view, use Up and Down arrow keys on the keyboard or scroll the mouse wheel to scroll through slices.

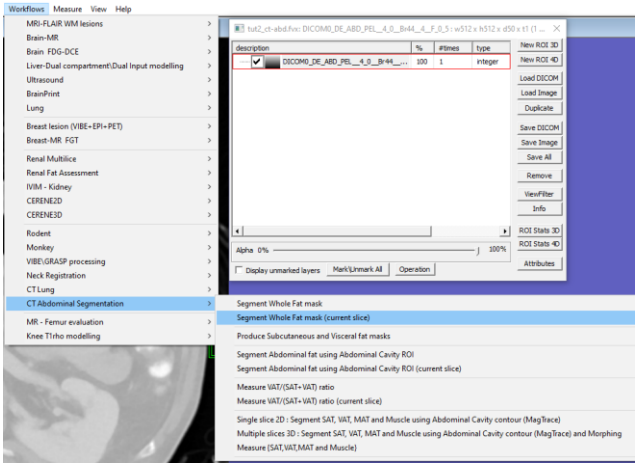

Figure 2. Open Workflows > CT Abdominal Fat Segmentation > Segment Whole Fat mask (single slice).

To view the layers in the document (essential in this procedure), double-left click on the image to open the **Layer Control** panel. After the images are loaded, only the **base image** layer is present.

3. Segment Whole Fat Mask (current slice)

Navigate to the slice to be segmented by scrolling the mouse wheel or pressing Up and Down arrow keys. The first step is the automatic segmentation of the total fat within the slice. On the main menu, select **Workflows** > **CT Abdominal Fat Segmentation** > **Segment Whole Fat mask (current slice)** (Figure 2). This command opens **CT Fat Segmentation Dialog** (Figure 3**)**. Accept the defaults and click **OK**. This command creates two new ROI layers (Figure 4):

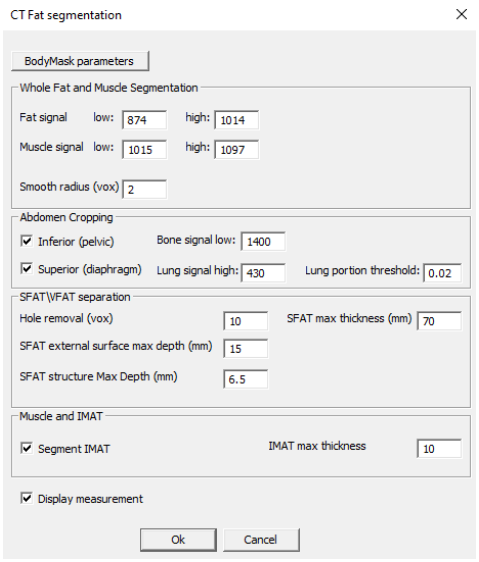

Figure 3. CT Fat Segmentation dialog with default parameters.

1) auto whole fat slice #[number] – the TAT layer mask, and
2) auto body slice #[number] – the whole body mask (vs background).

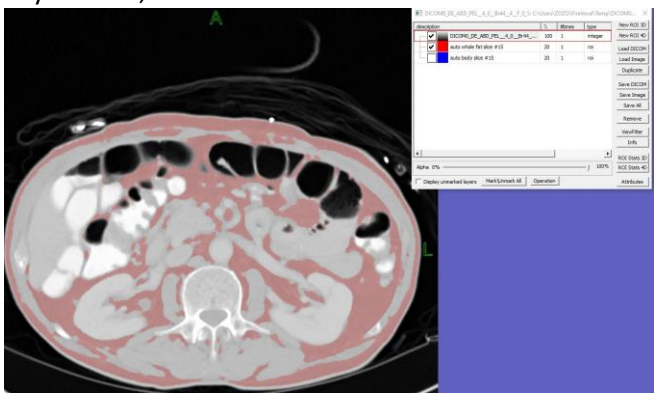

*Figure 4. The ROI layers created by **Segment Whole Fat mask** (whole fat mask (red) and body mask (blue, invisible)).*

4. Produce Subcutaneous and Visceral Fat Masks

This step automatically separates the total fat mask into subcutaneous and visceral fat masks (SAT and VAT, respectively).

Make sure that the **base image** and the **auto whole fat slice** #[number] (TAT) layer are

checked (visible). Select **Workflows** > **CT Abdominal Fat Segmentation** > **Produce Subcutaneous and Visceral Fat Masks (current slice)**. This opens the **CT Fat Segmentation Dialog**. Accept defaults and click **OK**. During processing, the status bar in the lower left corner of the software window will show the current processing step. When completed, the command creates two new ROI layers (Figure 5):

1) auto subcutaneous fat (SAT mask),
2) auto visceral fat (VAT mask).

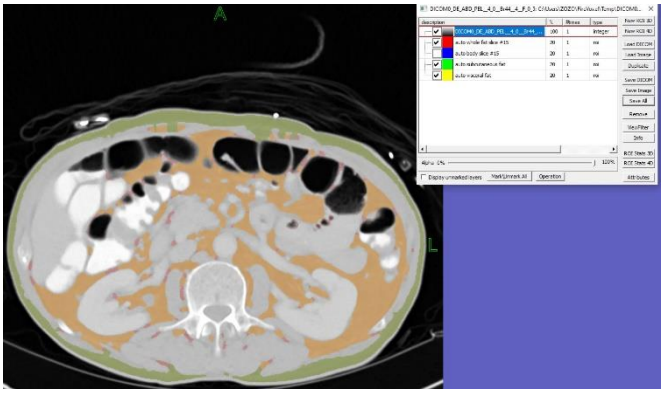

Figure 5. The ROI layers created by Produce Subcutaneous and Visceral Fat Masks (subcutaneous fat (green) and visceral fat (yellow).

5. Segment Abdominal fat using Abdominal Cavity ROI (current slice)

This step describes a method to create SAT and VAT fat masks with the help of a user-defined Abdominal Cavity (AC) ROI layer. Here, this method and its results are labeled *manual segmentation*.

5.1 Define Abdominal Cavity using MagTrace

The Abdominal Cavity ROI may be created using the Magnetic Trace tool (MagTrace, **Trace** group). The user draws a MagTrace vector contour around the abdominal cavity (AC), including the abdominal organs and visceral fat inside the contour and leaving the muscle, bones, and subcutaneous fat outside (Figure 6).

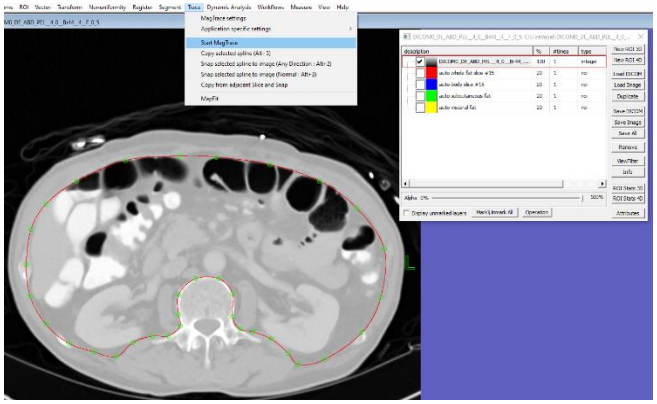

Figure 6. MagTrace contour enclosing abdominal cavity.

To start MagTrace, on the main menu, select **Trace** > **Start MagTrace**. Click along the boundary of AC to place about 20 anchor points (green circles in Figure 6). Press **Esc** to finish and exit from the MagTrace tool.

To reposition an anchor point, click the contour to display the anchor points, hover the mouse over the point and drag it to the new location. To add an anchor point, hover the cursor over the contour and press Alt+1.

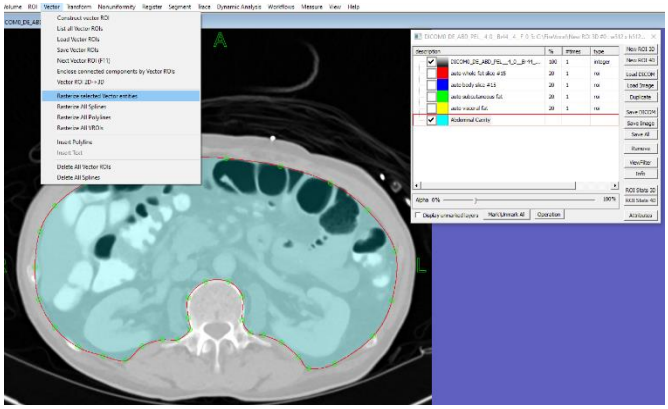

Figure 7. Abdominal Cavity ROI layer and Rasterize commands in the Vector group.

To delete an anchor point, hover the cursor over the point and press Alt+4. To activate the contour click on the contour; to deactivate, click anywhere outside the contour. All anchor point adjustments are done after exiting from the MagTrace tool.

Now this vector contour can be used to create a raster ROI layer. **Uncheck all ROI layers**. With **only the base image visible**, click on the contour to activate it and select **Vector** > **Rasterize selected Vector entities**. This creates a new ROI layer, named New ROI 3D #[roi number], with the voxels inside the MagTrace contour filled with color (Figure 7). Rename this layer **Abdominal Cavity** (double-click the layer name in the **Layer Control**, type in a new name in the box that opens and click **OK**).

Alternatively, the user can *first* create a new ROI layer (**Layer Control** > **New ROI 3D**), rename it Abdominal Cavity, make it the active ROI layer, and then use **Vector** > **Rasterize selected Vector entities** command to create the raster AC ROI in this layer.

5.2 Define Abdominal Cavity ROI using Paintbrush

The Abdominal Cavity ROI can also be created using the **Paintbrush** and **ROI** tools. Some users may prefer this method to using MagTrace.

Create a new layer (**Layer Control** > **New ROI 3D**) and rename it Abdominal Cavity. Activate the **Paintbrush** tool by holding down Ctrl key and the left mouse and draw a rough contour around the abdominal organs. The outside boundary of this contour must follow the AC boundary. The shape of the inside boundary does not matter. Once the contour is completed, release the Ctrl key and mouse button. Make corrections using the **Paintbrush** and **Eraser** (Ctrl + right mouse button). Next, on the main menu, select **ROI** > **Fill 2D Contours**. This command fills the inside of the contour and completes the Abdominal Cavity ROI.

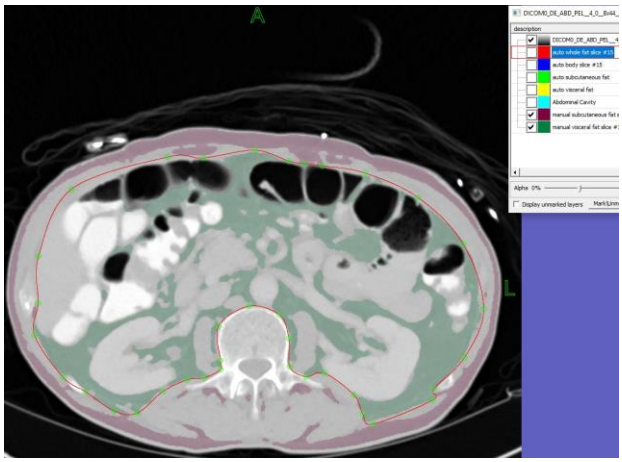

Figure 8. The ROIs created by Segment Abdominal fat using Abdominal Cavity ROI: subcutaneous fat (maroon) and visceral fat (dark green).

To define the AC ROI for 3D segmentation, the user may use the **Paintbrush** to draw the perimeter of the ROI skipping several slices (e.g., on every 5th slice) and then use **ROI** > **Morphology** > **Fill 2D Contours and Morph Convex** to complete the AC ROI.

5.3 Segment subcutaneous and visceral fat using AC ROI

Check the boxes next to the **base image**, **auto whole fat slice**, and **Abdominal Cavity** layers.

Select **Workflows** > **CT Abdominal Fat Segmentation** > **Segment Abdominal fat using Abdominal Cavity ROI (current slice)**. This command creates two new ROI layers (Figure 8):

1) manual subcutaneous fat slice #[number],
2) manual visceral fat slice #[number].

6. Measure VAT/(SAT+VAT) ratio (current slice)

This step allows the user to measure the volumes of visceral and subcutaneous fat compartments (in cm^3) and the visceral fat fraction VAT/(SAT+VAT).

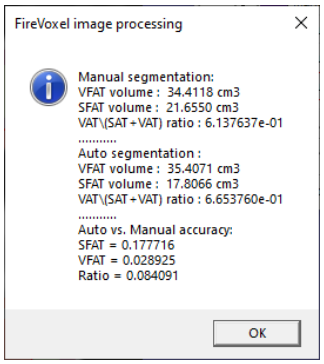

Figure 9. Measure VAT/(SAT+VAT) results.

This step will return the measurements for all segmentation layers present in the document, both automatic and manual, visible or invisible.

On the main menu, select **Workflows** > **CT Abdominal Fat Segmentation** > **Measure VAT/(SAT+VAT) ratio (current slice)**. This opens a dialog displaying the results: VAT volume (cm^3), SAT volume (cm^3), and VAT/(SAT+VAT) ratio. If both automatic and manual segmentation ROIs are present in the document, the SAT, VAT and VAT fraction are returned for each segmentation type (Figure 9). In addition, the relative difference between the automatic and manual segmentation is also shown for the volumes and the ratio: |auto - manual|/manual. If layers from only one segmentation type (manual or automatic) are present, the results are shown only for that type.

To copy these results to clipboard, click on the dialog box and press Ctrl+C, then press Ctrl+V to paste the results into another application.

The volumes of each layer in voxels and cubic centimeters can also be obtained by activating the corresponding layer and using **ROI Stats 3D** command on **Layer Control**.

7. Single Slice 2D: Segment SAT, VAT, MAT and Muscle using Abdominal Cavity contour (MagTrace)

This step automatically segments muscle and intramuscular fat in addition to the subcutaneous and visceral fat using the Abdominal Cavity *contour* (rather than raster AC ROI layer).

Check the boxes for **base image** and **auto whole fat slice #[number]**. Make sure that the AC vector contour is present. On the main menu, select **Workflows** > **CT Abdominal Fat Segmentation > Single Slice 2D: Segment SAT, VAT, MAT and Muscle using Abdominal Cavity contour (MagTrace)**. This opens the **CT Fat Segmentation Dialog** (Figure 3). Click **OK** to accept the defaults.

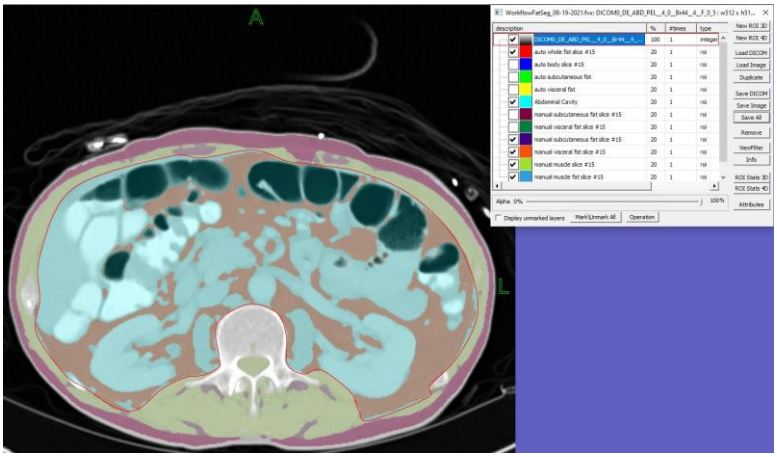

*Figure 10. The ROI layers created by **Single Slice 2D: Segment SAT, VAT, MAT and Muscle**.*

This commands creates four new ROI layers (Figure 10):

1) manual subcutaneous fat slice #[number]
2) manual visceral fat slice #[number]
3) manual muscle slice #[number]
4) manual muscle fat slice #[number].

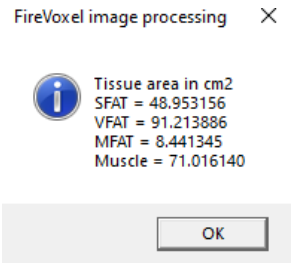

*Figure 11. Tissue area measurements created by **Single Slice 2D** command.*

This command will also show a dialog with the area measurements (in cm^2) for SAT, VAT, MAT and muscle compartments (Figure 11).

To copy these results to clipboard, click on the dialog box and press Ctrl+C, then press Ctrl+V to paste the results into another application. Then click **OK** to close the results box.

These results can also be retrieved using **Measure SAT, VAT, MAT and Muscle** described next.
The volumes of each ROI can also be obtained by activating each layer, opening **Layer Control** and using **ROI Stats 3D**.

8. Measure SAT, VAT, MAT and Muscle

This steps allows the user to measure and display the areas of the ROIs segmented by the **Single Slice 2D** command (*manual segmentation*).

Check the boxes for the **base image**, **manual subcutaneous fat slice #xx**, **manual visceral fat slice #xx**, **manual muscle slice #xx**, **manual muscle fat slice #xx**.

Select **Workflows** > **CT Abdominal Fat Segmentation** > **Measure {SAT, VAT, MAT and Muscle}**. The information dialog with the area measurements (in cm^2) of SAT, VAT, MAT and muscle will be displayed, as in the previous step (Figure 11). These results can be copied to clipboard (Ctrl+C) and pasted elsewhere (Ctrl+V).

Note that this command returns the ROI areas rather than their volumes, in contrast to Measure VAT/(SAT+VAT command).