IndoseCT

Version 20.b

Software for Calculating and Managing Radiation Dose of Computed Tomography for an Individual Patient

Manual-English

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I. INTRODUCTION

1.1. About IndoseCT

IndoseCT 15.a is the first version of **IndoseCT**, while **IndoseCT 20.b** is the second version. **IndoseCT** was first developed in 2015. **IndoseCT** has been recorded in the Letter of Registration of Creation, Ministry of Law and Human Rights (Kementerian Hukum dan HAM), Republic of Indonesia, Number 000217029, on August 12, 2020.

IndoseCT is software to calculate and manage the radiation dose of a patient undergoing computed tomography (CT) examination. It does not only calculate the radiation output dose of CT machines (in terms of volume CT dose index, $CTDI_{vol}$), but also the individual dose received by each patient (in terms of size-specific dose estimate, SSDE) either based on the effective diameter (D_{eff}) or water-equivalent diameter (D_w). This software can also calculate radiation output and patient dose for CT equipped with tube current modulation (TCM) technique.

Until 2011, CT doses had been expressed in terms of $CTDI_{vol}$, whereas that metric is only able to quantify CT radiation output. The $CTDI_{vol}$ value is influenced by almost all input parameters, such as tube voltage (kVp), tube current (mA), rotation time (s), pitch, collimation width, and others. It was noted, since its introduction, that $CTDI_{vol}$ was not meant to indicate the radiation dose received by the patient. This is because the dose within each scanner is influenced by not only the radiation output from the CT machine, but also by the characteristics of the patient undergoing the examination, such as the size of the patient and the composition of the body part being examined. To quantify a patient's radiation dose, the size-specific dose estimate (SSDE) was introduced.

IndoseCT software estimates the radiation dose directly for each individual patient using the patient's image or by entering patient data manually. **IndoseCT** can also be used for the estimation of organ dose and effective dose. The effective dose is the dose commonly used to estimate the risk of developing cancer in the future from CT examinations. **IndoseCT** is also equipped with tools to store patient dosimetry data in a database. From this database, the software can process patient dosimetry data and easily display its graphs so that it becomes useful information for dose optimization for the use of ionizing radiation for stakeholders, whether for medical physicists, radiology doctors, hospital management or regulatory agencies.

1.2. Features

IndoseCT 15.a software features are as follows:

1. Calculates the radiation output of CT devices as $CTDI_{vol}$ for several manufacturers of CT and scanners (for various parameters of tube current (mA), tube voltage (kV), pitch, and beam collimation) (Data adopted from ImPACT 1.04)
2. Calculates the radiation output of CT devices as $CTDI_{vol}$ for scanners equipped with tube current modulation (TCM) or automatic exposure control (AEC) techniques (Anam et al. Int J Rad Res. 2018; 16(3): 289-297).
3. Calculates the effective diameter (D_{eff}) for variations in age, lateral (LAT) diameter, anterior-posterior (AP) diameter, and combined LAT+AP). This feature is similar to previous available calculators. The user only inputs patient data (in the form of patient

age, and LAT diameter AP diameter, or a combination of LAT+AP) and the D_{eff} value is immediately obtained (Data adopted from AAPM TG 204)

4. Calculates the effective diameter (D_{eff}) from a CT image for 2D or 3D, both manually and fully automatically. Manual calculation means that the user performs measurements manually with the **line** tool on the patient image. Fully automatic calculation means that the D_{eff} value of the patient image is determined without intervention from the user (Anam et al. Adv Sci Eng Med. 2015; 7: 892-896). In fully automatic calculations, the user can also select the diameter at the maximum position, the diameter at the center position, or directly use the cross-sectional area of the patient image (Anam et al. Atom Indonesia. 2017; 43(1): 55-60).
5. Calculates the water-equivalent diameter (D_w) of CT images for 2D or 3D (manually and automatically) (Anam et al. J Appl Clin Med Phys. 2016; 17(4): 320-333)
6. Calculates the D_w value for a truncated image that is cut off at the edges. Truncated images are common in clinical applications. **IndoseCT** is equipped with a correction factor for truncated images (Anam et al. Radiat Prot Dosim. 2017; 175(3): 313-320).
7. Calculates and displays the D_{eff} and D_w profiles along the longitudinal axis for all images. D_{eff} and D_w calculations for all 3D CT images may require a relatively long computational time. **IndoseCT** also allows the user to select the number of images to be calculated or use certain intervals (eg images 1, 10, 30, and so on).
8. Calculates patient dose in terms of size-specific dose estimate (SSDE) from the $CTDI_{vol}$ and D_{eff} (or D_w) values entered by the user, or directly from CT images for 2D or 3D (manually and automatically) (Anam et al. .J Phys Conf Ser. 2016;694:012030).
9. Calculates the total radiation dose as the metric of dose-length product (DLP), either as standard or corrected by patient size.
10. Calculates organ doses based on patient size taken directly from patient CT images for various protocols (data and equations adopted from Sahbaee et al. Med Phys. 2014;41(7):072104).
11. Calculates the effective patient dose based on patient size for various examination protocols (data and equations adopted from Sahbaee et al. Med Phys. 2014; 41(7): 072104).
12. Extracts some patient data from the DICOM info and stores it in the database. This data storage and processing will be very beneficial for the institution, so that it can manage doses and other data locally, and can take strategic steps related to the application of CT in the institution. This data is relatively small and is stored separately from patient images which require very large storage media.
13. Analyzes patient dosimetry data and displays it as needed. There are many data options that can be displayed, such as $CTDI_{vol}$, DLP, D_{eff}, D_w, SSDE profiles, as well as relationships between metrics such as the relationship between D_{eff} and SSDE, or the relationship between $CTDI_{vol}$ and SSDE, and so on.

The development features of **IndoseCT 20.b** are as follow:

1. **IndoseCT 20.b** can be run without having to install the main program (Matlab). Users can directly install or uninstall **IndoseCT** from the computer easily.
2. The display of I**ndoseCT 20.b** is very user-friendly so that it is easier to use.
3. **IndoseCT 20.b** is faster at performing calculations than the previous version.

4. Access options to open files using folders, while earlier versions only had a file-based option. Opening an image within a folder is faster than as a file. In this case there are no other files in the folder other than the patient image file.
5. Sample images have been added in the form of anthropomorphic phantom images from the base of the pelvis to the top of the head. These samples are very useful for practice in using **IndoseCT**.
6. It has been equipped with several window options to display images with higher contrast between objects, such as soft tissue, bone, and so on.
7. To move from the image of one slice to another, the arrow keys on the keyboard can be used in this version so that it is more practical.
8. The image can be zoomed-in, zoomed-out, and shifted using the keyboard.
9. DICOM info is easy to access. Users sometimes want to access such information, for example information about the field of view (FOV).
10. A database of scanner types and $CTDI_{vol}$ values for several manufacturers and scanners has been added (Data adopted from ImPACT 1.04 and WAZA-ARI).
11. There is an option to display tube current profiles, $CTDI_{vol}$, and SSDE (Anam et al. Information. 2017; 20(1): 377-382)
12. It has been equipped with an additional option to adjust the $CTDI_{vol}$ value in the TCM technique. For example, for the image taken with the TCM technique the CTDIvol value does not fluctuate with the current, but we have added an option to adjust the CTDIvol value.
13. In some cases $CTDI_{vol}$ value, may not be contained in the DICOM info, so then other parameters (such as tube current, tube voltage, etc.) can be taken automatically from the DICOM info to calculate the $CTDI_{vol}$ value. With this facility, $CTDI_{vol}$ calculation becomes faster.
14. D_{eff} calculations have been complemented by options for correcting for the presence of lung (As introduced by Mihailidis et al. Br J Radiol. 2020; 93: 20200473) and bone.
15. For the calculation of D_w, a new algorithm has been developed to detect the patient's body as a whole, even though there are several separate parts, for example when there are two patient arms on the thoracic image (Anam et al. J Appl Clin Med Phys. 2021;1-11). This is different from the previous version which only uses the largest patient object selection, so that when there are two patient arms in the thoracic image, only one part is segmented, namely the thorax, while the two arms are not segmented.
16. For D_w calculations, there is an option to calculate D_w from the entire image (without segmentation) and there is a further option to remove the patient table from the image automatically (Anam et al. Radiat Prot Dosim. 2019; 185(1): 42-49)
17. For 3D (Z-axis) options in the calculation of D_{eff} and D_w, it is equipped with **Regional** options, so the user can determine the calculated slice, for example calculating the value from the 51st slice to the 100th slice. This is useful for calculating organ doses (Anam et al. J Biomed Phys Eng . 2021)
18. There is a new size-conversion value option (from CTDIvol to SSDE) for head examinations (Data adopted from AAPM TG 293).
19. A system has been equipped for calculating dose distribution within a patient (dose-map) and calculating organ doses (Anam et al. J X Ray Sci Med. 2020; 28: 695-708), although the contouring process should be still done manually by the user.

20. Patient data stored in the database can be deleted easily. It can also be exported to Microsoft Excel easily.
21. Data stored in databases such as institutional data, vendors, and scanner types, can be mixed with data from various scanners from one institution (hospital) or several institutions for comparison. **IndoseCT** will differentiate the data and process it according to the needs and preferences of users.
22. The **IndoseCT** can display graphs (e.g. SSDE and D_w relationships), and it is equipped with trendline options such as linear equations, quadratic equations, polynomial equations, exponential equations and others.
23. The displayed graph is equipped with the option to display the average value and standard deviation. The x-axis and y-axis values can be adjusted as needed. Graphics can also be shifted for a more optimal display.
24. The displayed graph can be saved in various image formats (such as jpeg and bitmap) or exported to Microsoft Excel.

1.3. Developers

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- Fahmi R. Mahdani (*Diponegoro University*)
- Freddy Haryanto (*Bandung Institute of Technology*)
- Rena Widita (*Bandung Institute of Technology*)
- Idam Arif (*Bandung Institute of Technology*)
- Khoerun N. Syaja'ah (*Bandung Institute of Technology*)
- Geoff Dougherty (*California State University Channel Islands*)

1.4. Publications

For those who want to delve deeper into the scientific aspects of **IndoseCT**, please refer to the following list of publications:

1. Anam C, Haryanto F, Widita R, Arif I. *Automated estimation of patient's size from 3D image of patient for size specific dose estimates (SSDE)*. **Adv Sci Eng Med.** 2015; 7(10): 892-896.
2. Anam C, Haryanto F, Widita R, Arif I, Dougherty G. *The evaluation of effective diameter (D_{eff}) calculation and its impact on size-specific dose estimate (SSDE)*. **Atom Indonesia.** 2017; 43(1): 55-60.
3. Anam C, Haryanto C, Widita R, Arif I, Dougherty G. *Automated calculation of water-equivalent diameter (D_W) based on AAPM report TG. 220*. **J Appl Clin Med Phys.** 2016; 17(4): 320-333.
4. Anam C, Mahdani FR, Dewi WK, Sutanto H, Triadyaksa P, Haryanto F, Dougherty G. *An improved method for automated calculation of the water-equivalent diameter for estimating size-specific dose in CT*. **J Appl Clin Med Phys**. 2021; 22(9): 313–323.
5. Anam C, Haryanto F, Widita R, Arif I, Dougherty G. *A fully automated calculation of size-specific dose estimates (SSDE) in thoracic and head CT examinations*. **J Phys Conf Ser.** 2016; 694: 012030.
6. Anam C, Haryanto F, Widita R, Arif I, Dougherty G. *The size specific dose estimates (SSDE) for truncated computed tomography images.* **Radiat Prot Dosim**. 2017; 175(3): 313-320.

7. Anam C, Haryanto F, Widita R, Arif I, Dougherty G, McLean D. *The impact of patient's table on size-specific dose estimates (SSDE)*. **Australas Phys Eng Sci Med**. 2017; 40(1): 153-158.
8. Anam C, Arif I, Haryanto F, Widita R, Lestari FP, Adi K, Dougherty G. *A simplified method for the water-equivalent diameter calculation to estimate patient dose in CT examinations*. **Radiat Prot Dosim**. 2019; 185(1): 42–49.
9. Anam C, Haryanto F, Widita R, Arif I, Dougherty G, McLean D. *Volume computed tomography dose index (CTDIvol) and size-specific dose estimate (SSDE) in tube current modulation CT*. **Int J Rad Res**. 2018; 16(3): 289-297.
10. Anam C, Fujibuchi T, Toyoda T, Sato N, Haryanto F, Widita R, Arif I, Dougherty G. *A simple method for calibrating pixel values of the CT localizer radiograph for calculating water-equivalent diameter and size-specific dose estimate*. **Radiat Prot Dosim**. 2018; 179(2): 158–168.
11. Anam C, Haryanto F, Widita R, Arif I, Dougherty G. *Profile of CT scan output dose in axial and helical modes using convolution*. **J Phys Conf Ser.** 2016; 694: 012034.
12. Anam C, Haryanto F, Widita R, Arif I, Dougherty G. *The profile of patient dose along the longitudinal axis in CT using tube current modulation (TCM)*. **Information (Japan).** 2017; 20(1B): 377-382.
13. Anam C, Haryanto F, Widita R, Arif I, Dougherty G. *Estimation of eye radiation dose during nasopharyngeal CT examination for an individual patient*. **Information (Japan).** 2016; 19(9B): 3951-3962.
14. Anam C, Haryanto F, Widita R, Arif I, Dougherty G. *A size-specific effective dose for patients undergoing CT examinations*. **J Phys Conf Ser**. 2019; 1204: 012002.
15. Anam C, Adhianto D, Sutanto H, Adi K, Ali MH, Rae WID, Fujibuchi T, Dougherty G. *Comparison of central, peripheral, and weighted size-specific dose in CT*. **J X-ray Sci Technol**. 2020; 28: 695–708.
16. Anam C, Dewi WK, Masdi M, Haryanto F, Fujibuchi T, Dougherty G. *Investigation of eye lens dose estimate based on AAPM report 293 in head computed tomography*. **J Biomed Phys Eng**. 2021: 1-10.
17. Anam C, Fujibuchi T, Haryanto F, Widita R, Arif I, Dougherty G. *An evaluation of computed tomography dose index measurements using a pencil ionisation chamber and small detectors*. **J Radiol Prot**. 2019; 39: 112–124.
18. Adhianto D, Anam C, Sutanto H, Ali MH. *Effect of phantom size and tube voltage on the size-conversion factor for patient dose estimation in computed tomography Examinations*. **Iran J Med Phys**. 2020; 17: 282-288.

The following is a list of several publications on studies conducted using **IndoseCT**:

1. Anam C, Budi WS, Adi K, Sutanto H, Haryanto F, Ali MH, Fujibuchi T, Dougherty G. *Assessment of patient dose and noise level of clinical CT images: automated measurements*. **J Radiol Prot**. 2019; 39: 783–793.
2. Fahmi A, Anam C, Suryono, Ali MH. *The size-specific dose estimate of paediatric head CT examinations for various protocols*. **Radiat Prot Dosim**. 2020; 188(4): 522–528.
3. Fahmi A, Anam C, Suryono, Ali MH, Jauhari A. *Correlation between age and head diameters in the paediatric patients during CT examination of the head*. **Pol J Med Phys Eng**. 2019; 25(4): 229-235.

4. Utami MSN, Sutanto H, Anam C. *Effect of contrast agent administration on size-specific dose estimates (SSDE) calculations based on water equivalent diameter in CT head examinations*. **International Journal of Scientific Research in Science and Technology**. 2021; 8(3): 563-571.
5. Dewi WK, Anam C, Hidayanto E, Nitasari A, Dougherty G. *The effective and water-equivalent diameters as geometrical size functions for estimating CT dose in the thoracic, abdominal, and pelvic regions*. **Pol J Med Phys Eng**. 2021.
6. Dewi WK, Anam C, Hidayanto E, Wati AL, Dougherty G. *Correlation between anterior-posterior and lateral dimensions and the effective and water-equivalent diameters in axial images from head computed tomography examinations*. **Radiat Prot Dosim**. 2021.
7. Nitasari A, Anam C, Budi WS, Wati AL, Syarifudin S, Dougherty G. *Comparisons of water-equivalent diameter measured on images of abdominal routine computed tomography with and without a contrast agent*. **Atom Indonesia**. 2021: 1-5.
8. Ali MH, Anam C, Haryanto F, Dougherty G. *The comparison of size-specific dose estimate in CT examination based on head and body PMMA phantom*. **Journal of Physics and Its Applications**. 2018; 1(1): 1-6.
9. Wati AL, Anam C, Budi WS, Nitasari A, Syarifudin, Satoto B, Jannah M, Sepsatya F. *Patient doses based on the acceptable quality dose on thoracic CT examination*. **International Journal of Latest Engineering Research and Applications**. 2021; 6(6): 17-22.

1.5. Information

For further information about **IndoseCT 20.b** software, please contact email: anam@fisika.fsm.undip.ac.id or anamfisika@gmail.com

II. INSTALLATION of IndoseCT

2.1 Installation process of IndoseCT

Before installing IndoseCT, first make sure that the **IndoseCT** installation file has been obtained and downloaded to your computer. To get the **IndoseCT** installation file and password, you can contact the email given in the Information section (Chapter I). The **IndoseCT** installation file size is relatively small, only around 130 MB. There are two choices of **IndoseCT** installation files, namely for **32-bit** and **64-bit** systems. The **IndoseCT** installation file for a **64 bit** system is shown in **Figure 1**.

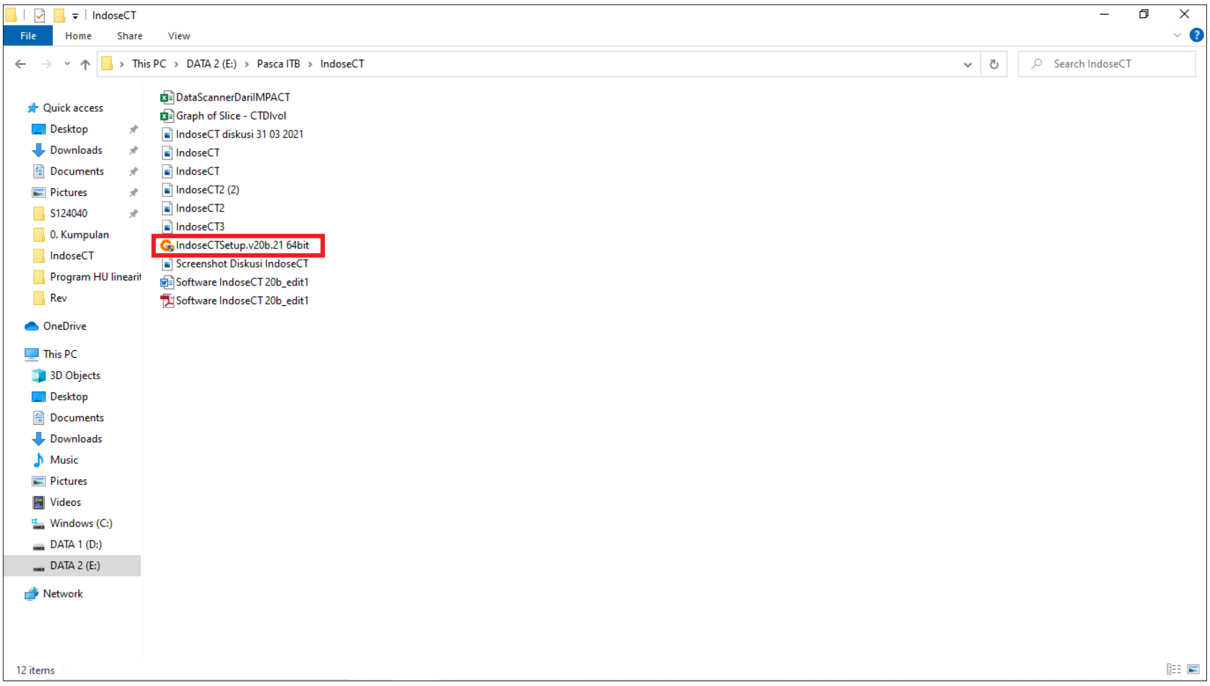

Figure 1. IndoseCT installation file. In this case the file name is **IndoseCTSetup.v20b.21 64 bit**.

To install **IndoseCT**, double click on the file. Next, information will appear that **Microsoft Defender** has detected that this file is an unrecognized application that has the potential to harm your computer (as shown in **Figure 2**). This is not a problem. Click **More info** to get a box as shown in **Figure 3**, and click **Run anyway** to continue the installation process.

If you want to continue to install, select **Yes** (from **Figure 4**), and enter the **password**. Next, click **OK** to continue

After that, **IndoseCT Setup** will appear. To continue click **Next** (**Figure 5**). The **Destination Folder** option will appear as shown in **Figure 6**.

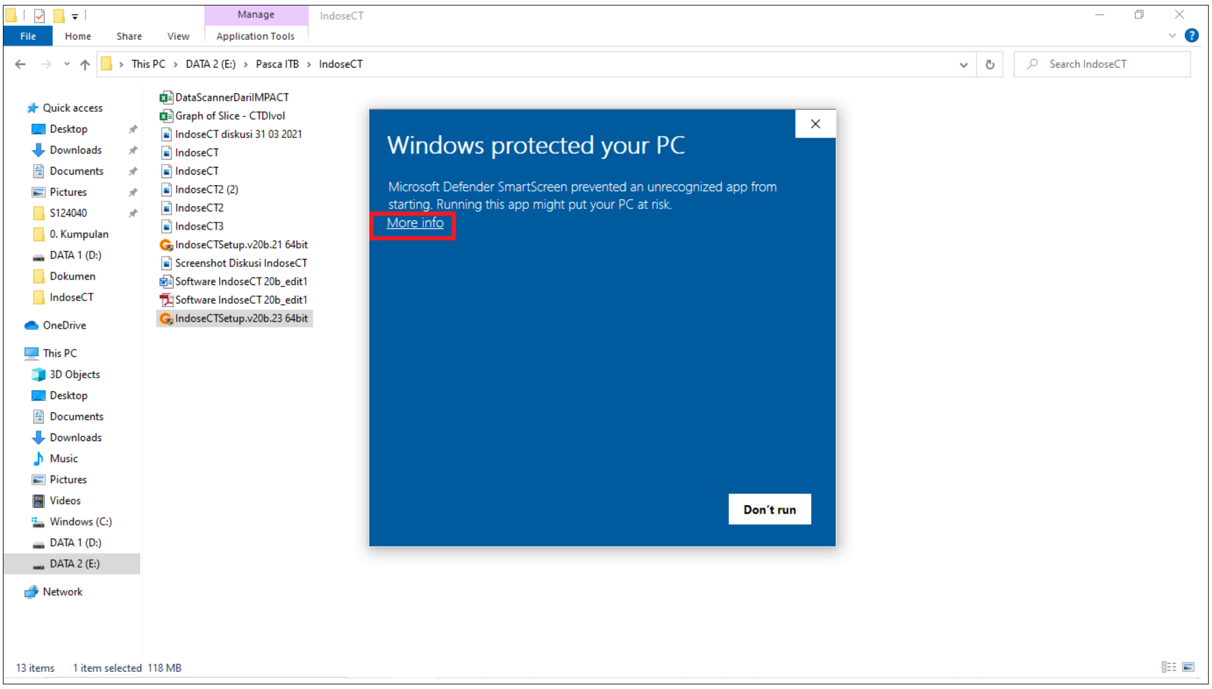

Figure 2. Information shows **Microsoft Defender** detects that this file is an unrecognized application that has the potential to harm your computer. This is not a problem. Continue by clicking **More info**.

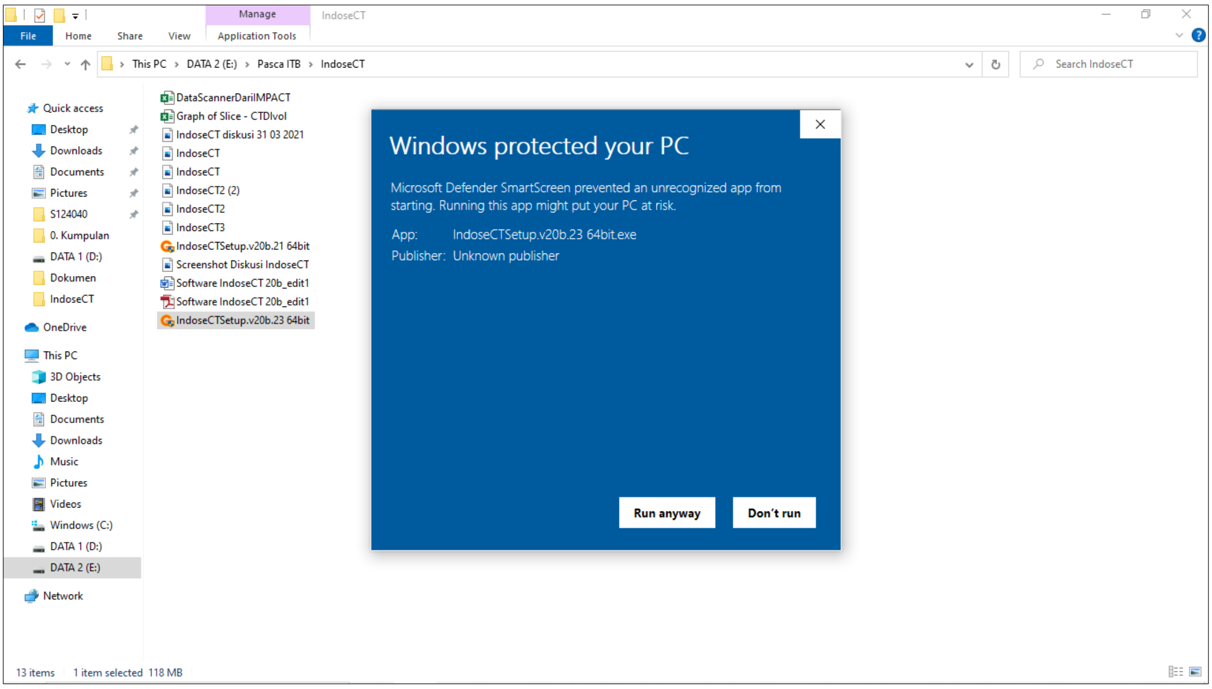

Figure 3. Information shows that this application is **IndoseCTSetup.v20b.23 64 bit**. Click **Run anyway** to continue.

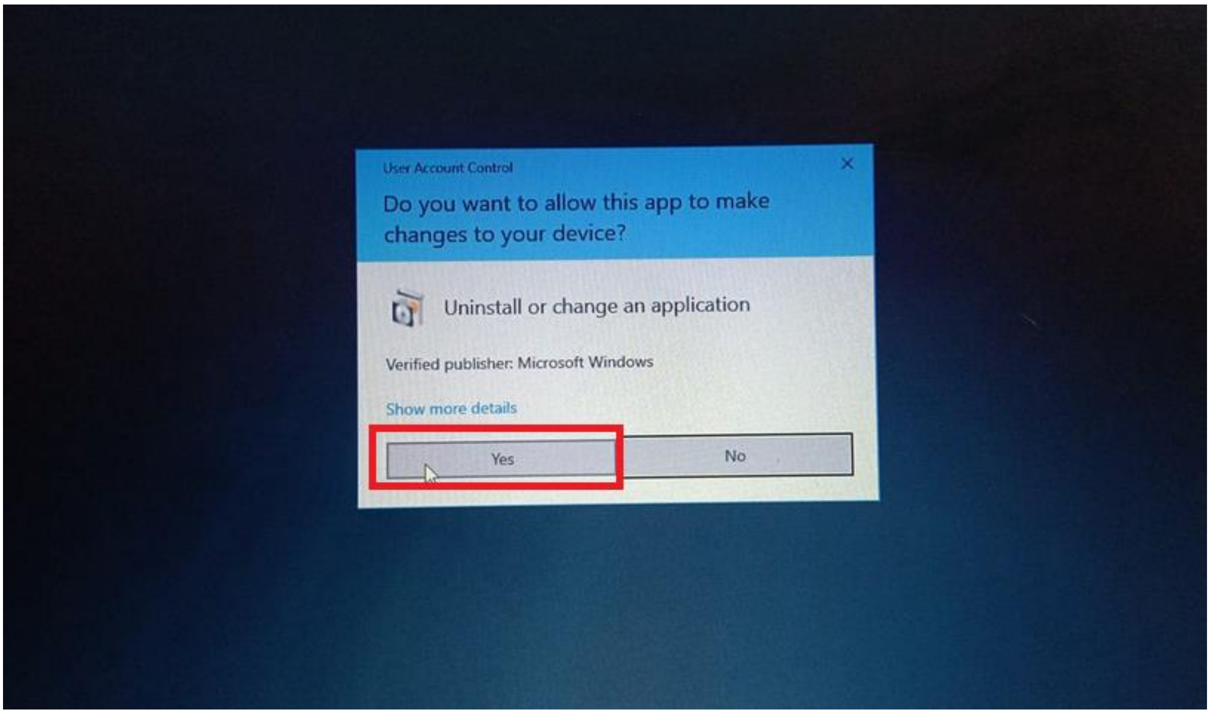

Figure 4. The dialog contains options whether you want to allow this software to be installed on your computer or not.

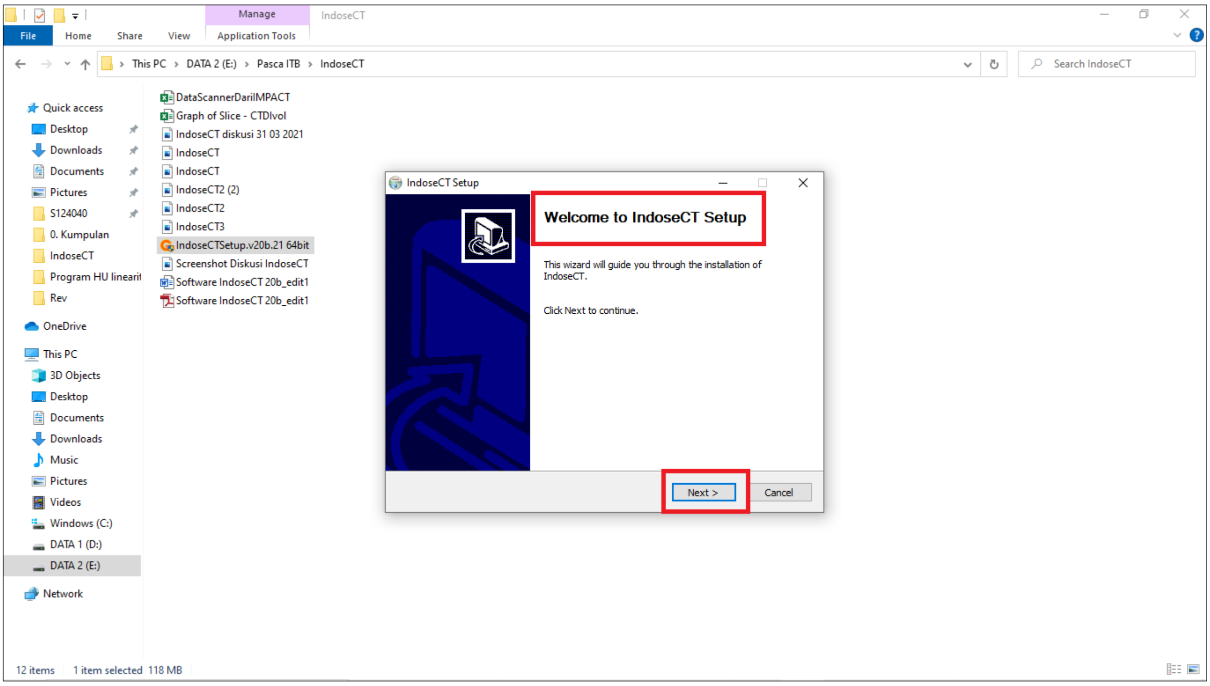

Figure 5. IndoseCT Setup dialog. Select **Next** button to continue the installation process.

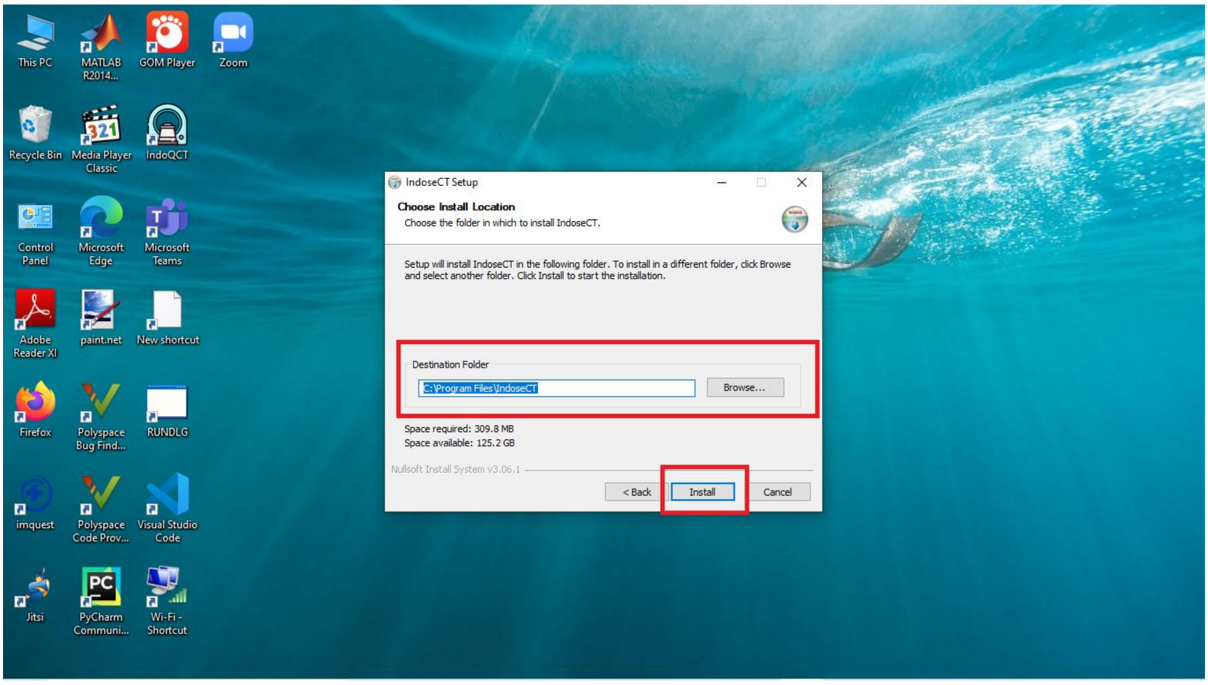

Figure 6. Selection of the destination folder to place the **IndoseCT** file to be installed on the computer**.**

The **Destination Folder** by default is located in **C:\Program Files\IndoseCT**. If you agree to this **Destination Folder**, the installation process will continue. (Or if you want to place it in a specific folder, select **Browse**, enter the desired **Destination Folder**. Click **Install**, and the installation progress dialog will appear as shown in **Figure 7**. Wait a few moments for the installation process to complete. The time of the installation is dependent on the speed of the computer. For computers with i5 processors, the installation process takes no more than 5 minutes. When finished, a **Completed** notification will appear. Then click **Next**, and the **Completing IndoseCT Setup** dialog appears. Before choosing **Finish**, you can choose the **Run IndoseCT** option to open **IndoseCT** opened immediately, after clicking the **Finish** button.

At this point, the **IndoseCT** installation is completed. IndoseCT is ready to be used to calculate patient doses. The first screen of **IndoseCT** is shown in **Figure 8**.

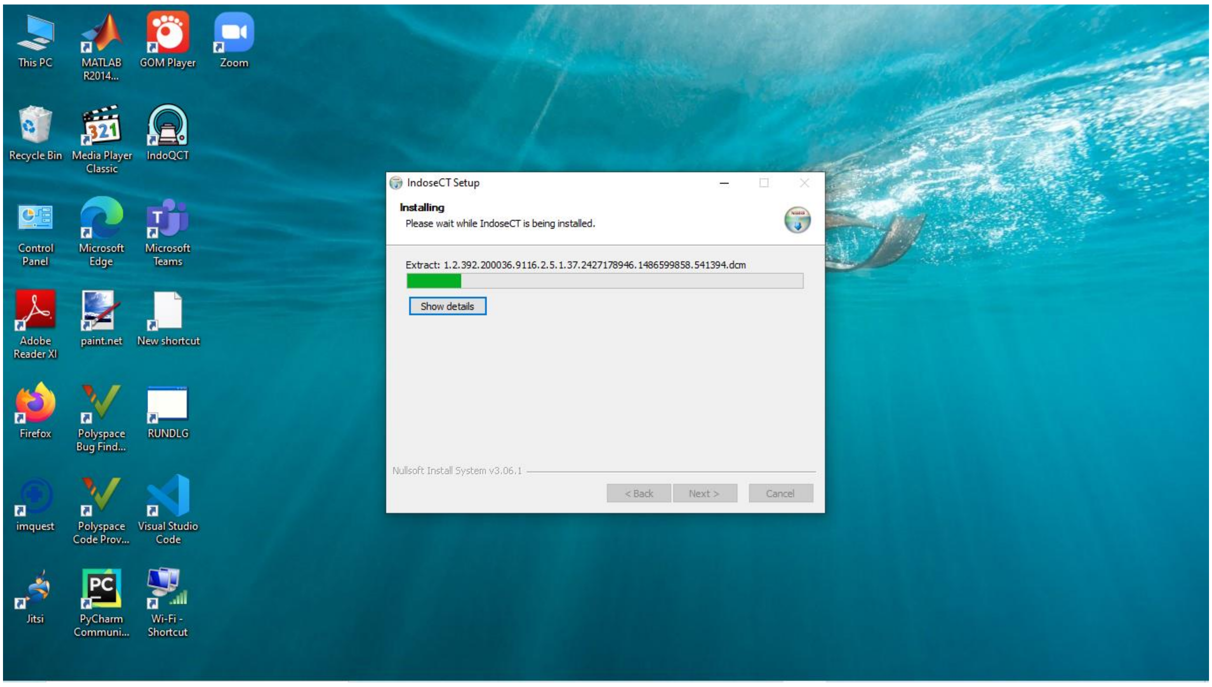

Figure 7. IndoseCT installation progress dialog.

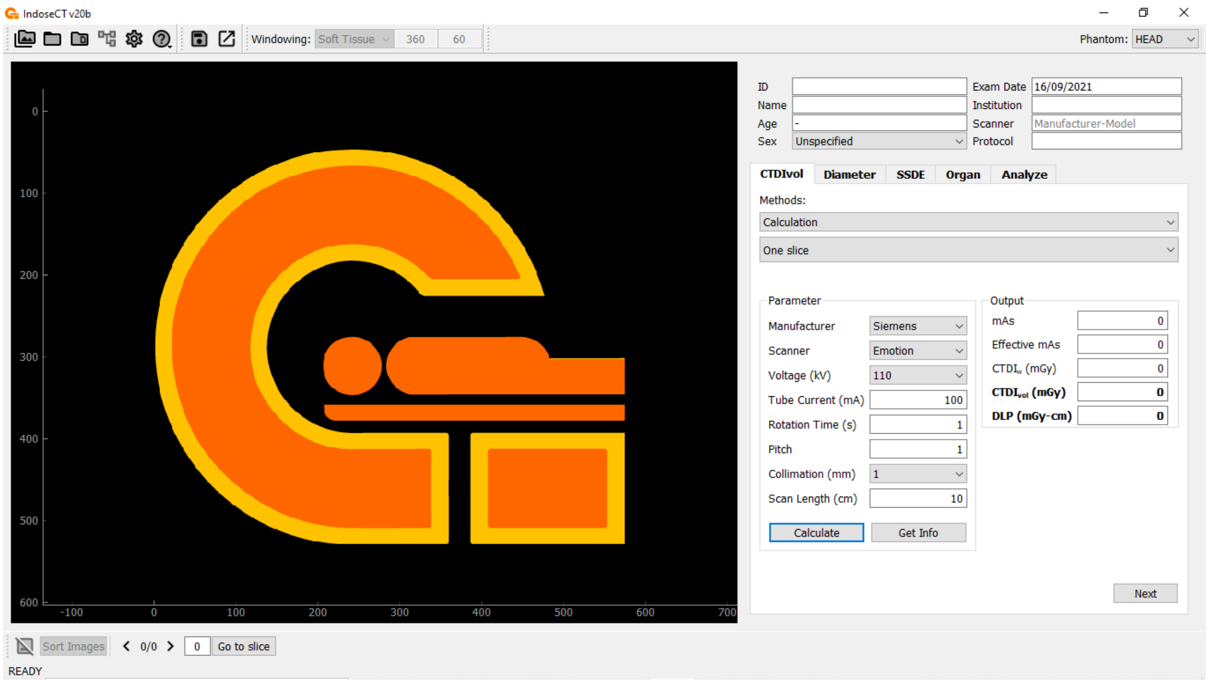

Figure 8. Main view of **IndoseCT 20.b**.

2.2. Starting / Running the IndoseCT

After installation, **IndoseCT** is ready to be used anytime. Left-click the **Start** button at the lower left corner, and click **IndoseCT**.

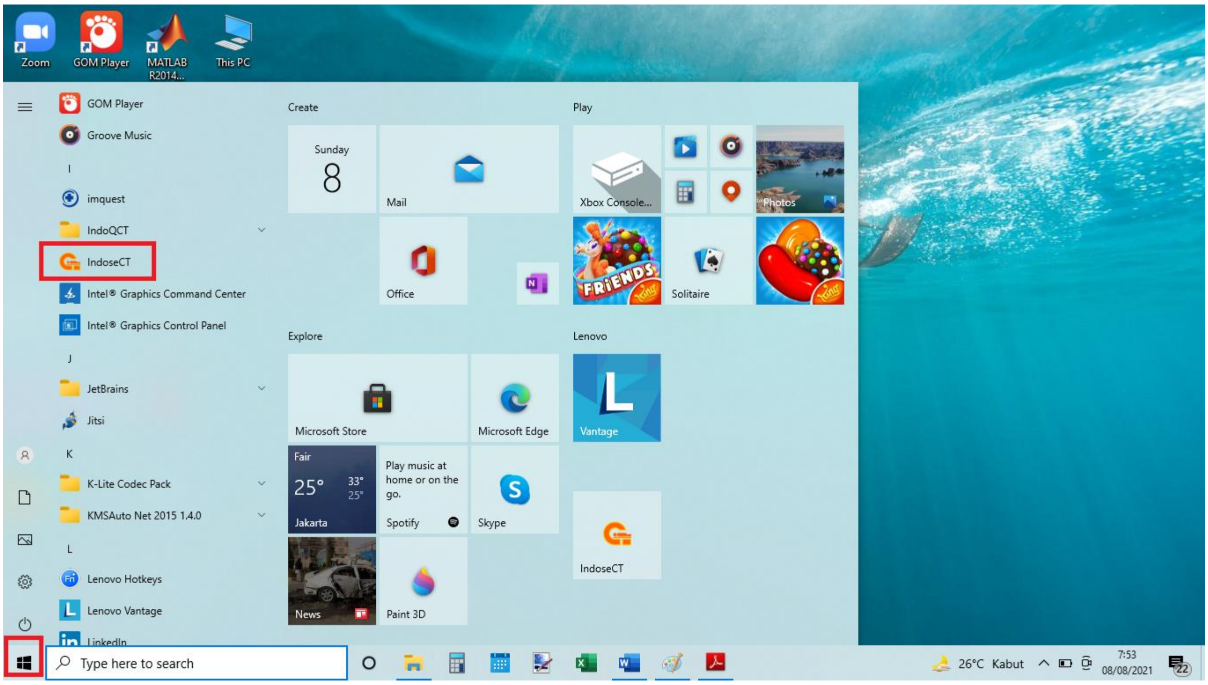

Figure 9. Opening **IndoseCT** via the **Start** menu button.

2.3. Creating a shortcut for IndoseCT

To be able to open **IndoseCT** quickly, an **IndoseCT** shortcut can be created and displayed on the desktop. To create an **IndoseCT** shortcut, right-click on the desktop, select **New**, then select **Shortcut** as shown in **Figure 10**.

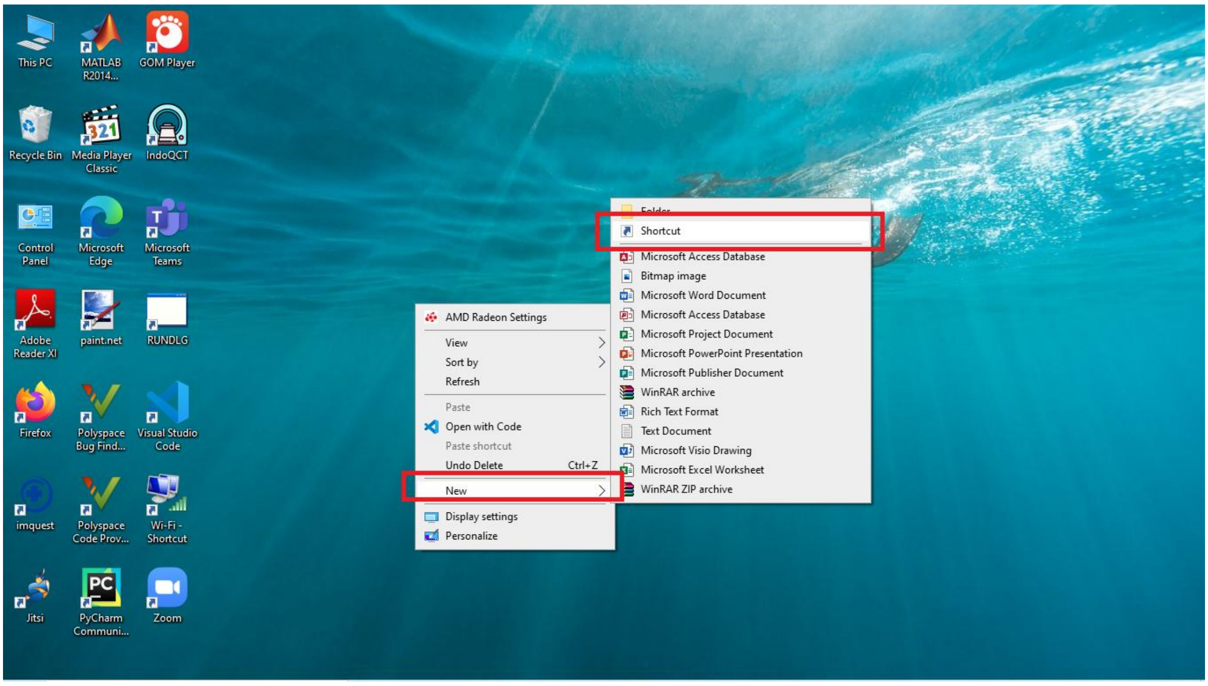

Figure 10. The display showing how to create a shortcut forf **IndoseCT**.

Next, select **Browse** for the folder where **IndoseCT** was placed during installation. If during installation you left the default option (**C:\Program Files\IndoseCT**), then **IndoseCT** is in **C** and then in **Program Files** (**Figure 11**).

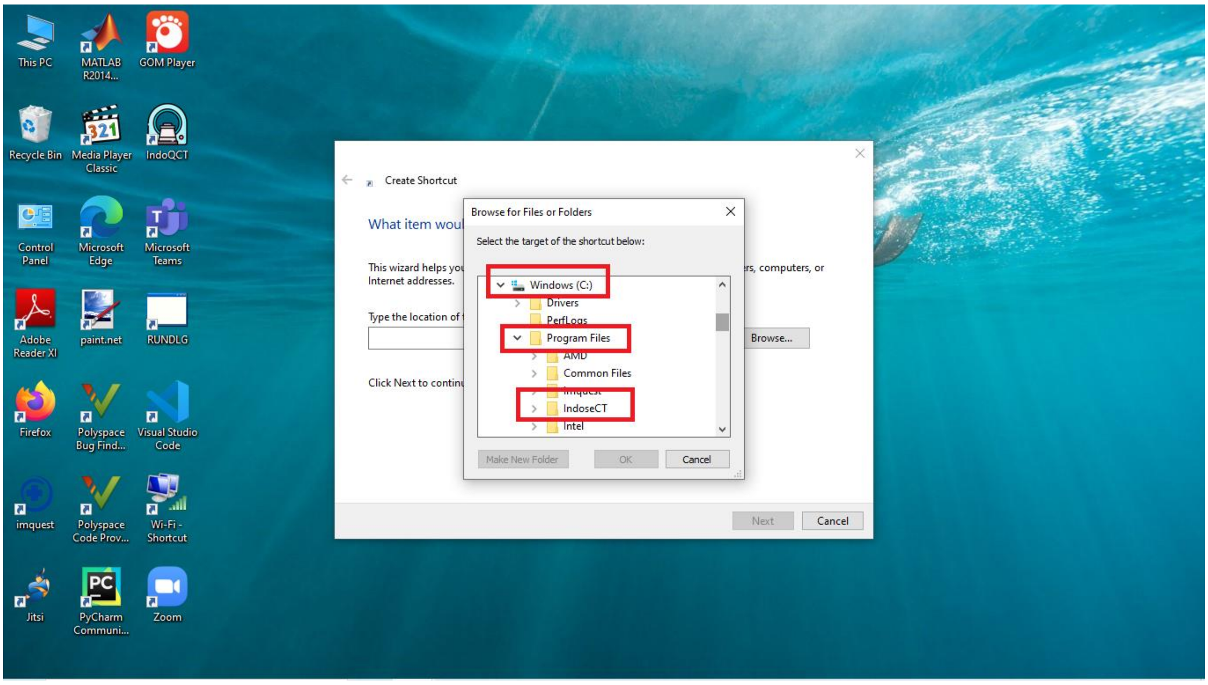

Figure 11. **IndoseCT** folder is located in **C:\Program Files**

Look for the **IndoseCT.exe** file (as shown in **Figure 12**), select it and click **OK**. Then the exe-file is ready to be the **IndoseCT** shortcut. Select **Next** to continue, and then click **Finish** as shown in **Figure 13**.

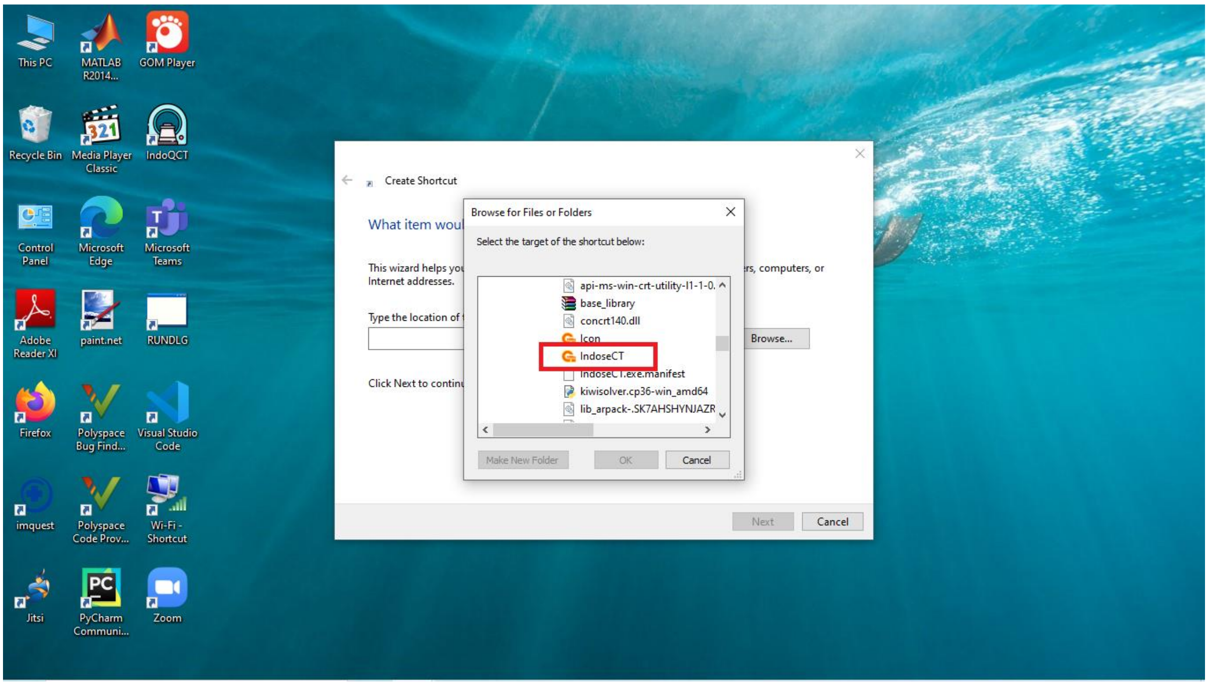

Figure 12. **IndoseCT.exe** file.

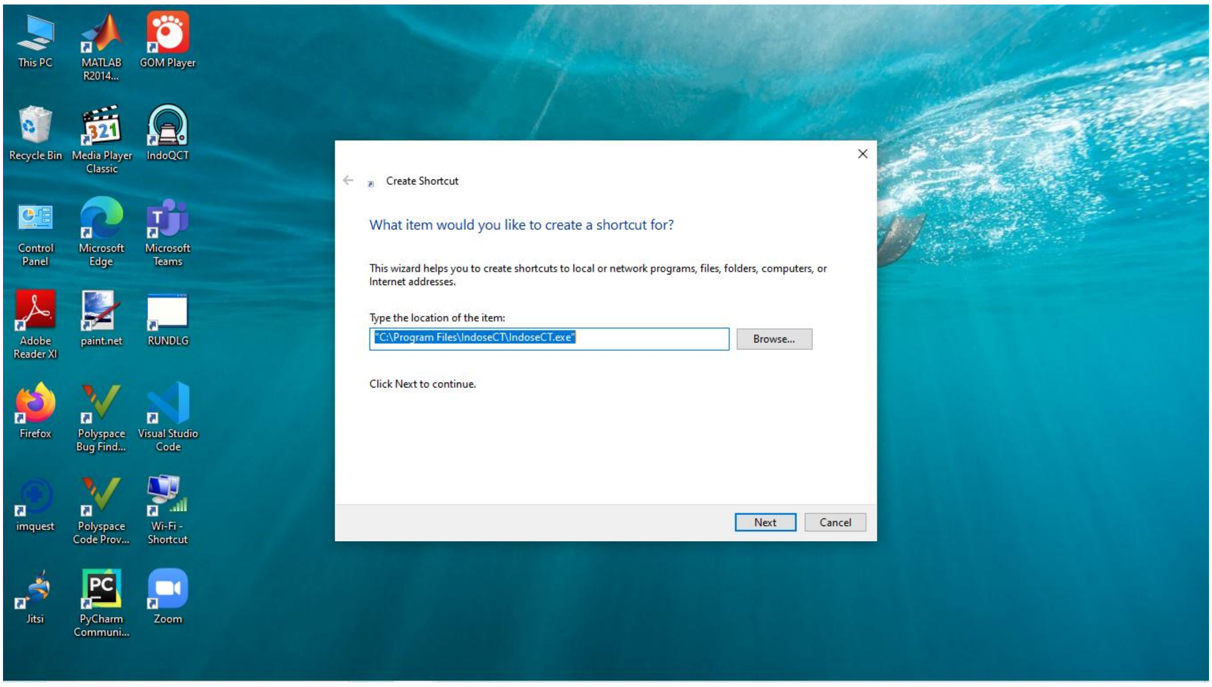

Figure 13. The location of the **IndoseCT.exe** file has been selected and is ready to be displayed as a shortcut on the desktop.

You can sort the shortcuts on the desktop, for example by name, by right-clicking on the desktop, then **Sort by**, then selecting **Name**. At that time, all the shortcuts on our desktop have been sorted by name. An example of the **IndoseCT** shortcut on the desktop, is shown in **Figure 14**.

Figure 14. IndoseCT shortcut on computer desktop. To enter **IndoseCT**, all you have to do is to double click on the shortcut.

2.4. Uninstall the IndoseCT

The process of uninstalling **IndoseCT** is also very easy. First, left-click the **Start** button and search for **IndoseCT**. If it is visible, then right-click **IndoseCT** (**Figure 15**). Then select **Uninstall**. You can also go directly to **Control Panel Home** by clicking the **Control Panel** shortcut (**Figure 16**). After that, click **Programs and Features** (**Figure 17**).

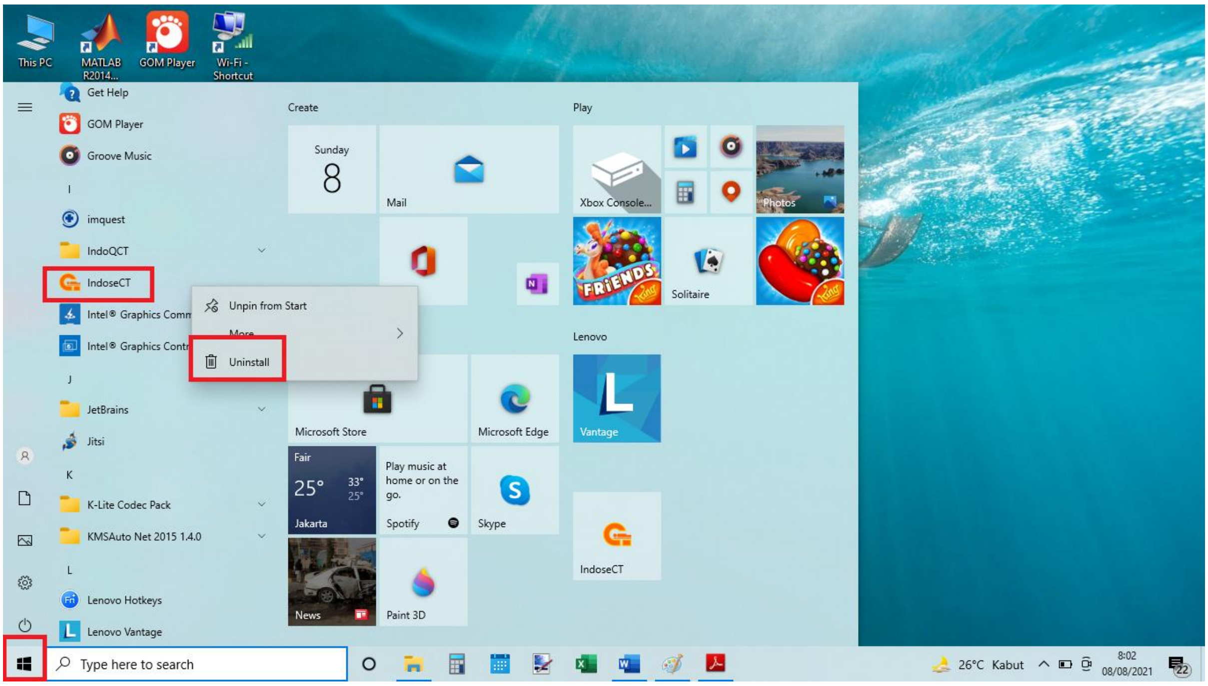

Figure 15. The process of uninstalling **IndoseCT**. Click the **Start button** (in this example at the lower left corner of the desktop), then search for **IndoseCT**. If you have found it, **right-click** it, and the **Uninstall** option will appear.

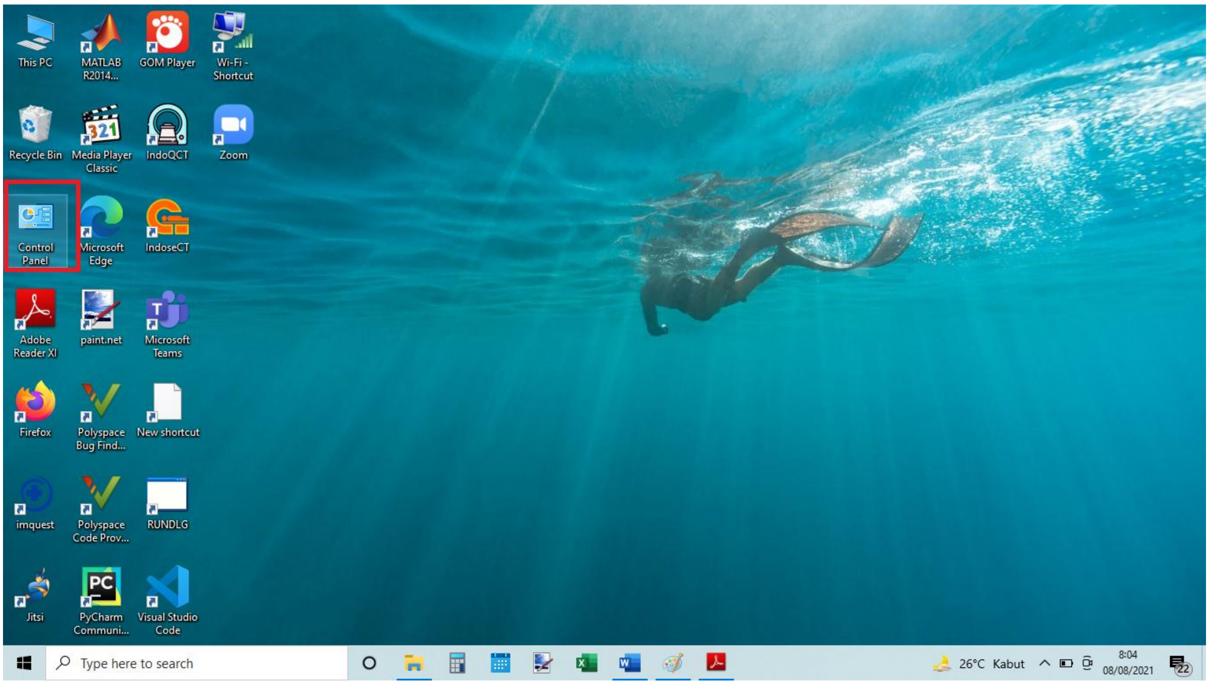

Figure 16. Shortcut Control Panel.

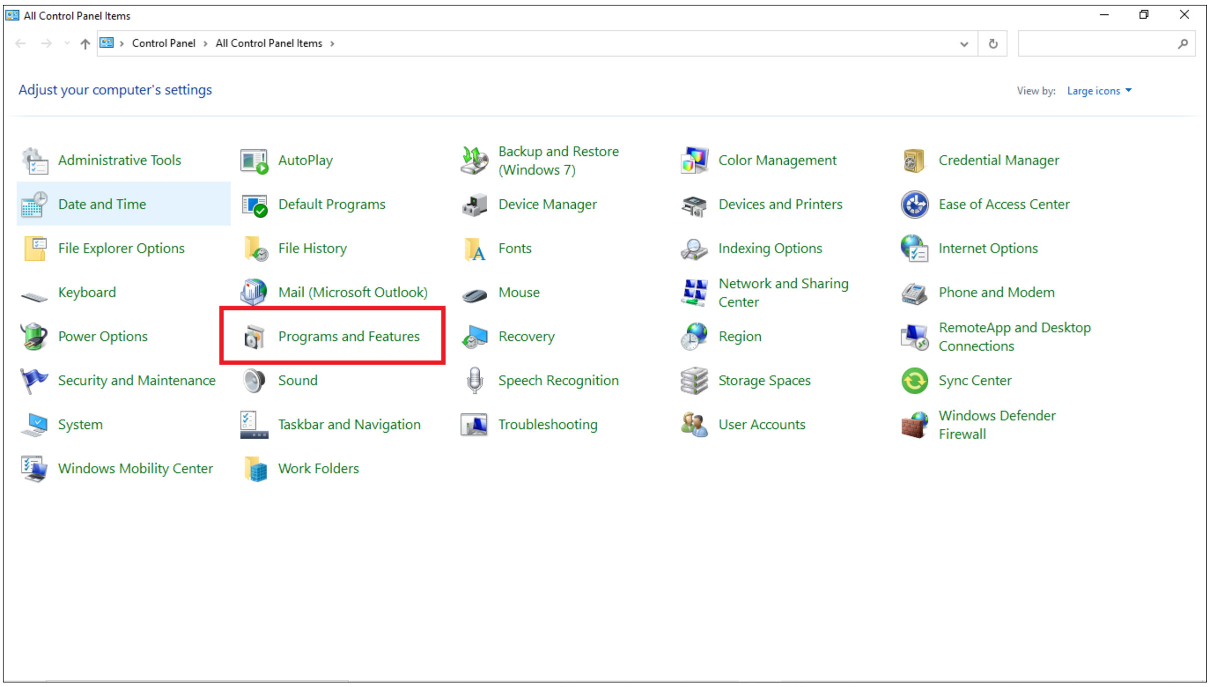

Figure 17. To uninstall **IndoseCT**, double-click on **Programs and Features**.

The **Control Panel Home** dialog will open as shown in **Figure 18**. Left-click **IndoseCT**, then **Uninstall/Change** will appear at the top. If you want to continue the uninstall process, then click **Uninstall/Change**. Next, there will be a notification whether you want to continue this process or not (**Figure 19**). If so, select **Uninstall**.

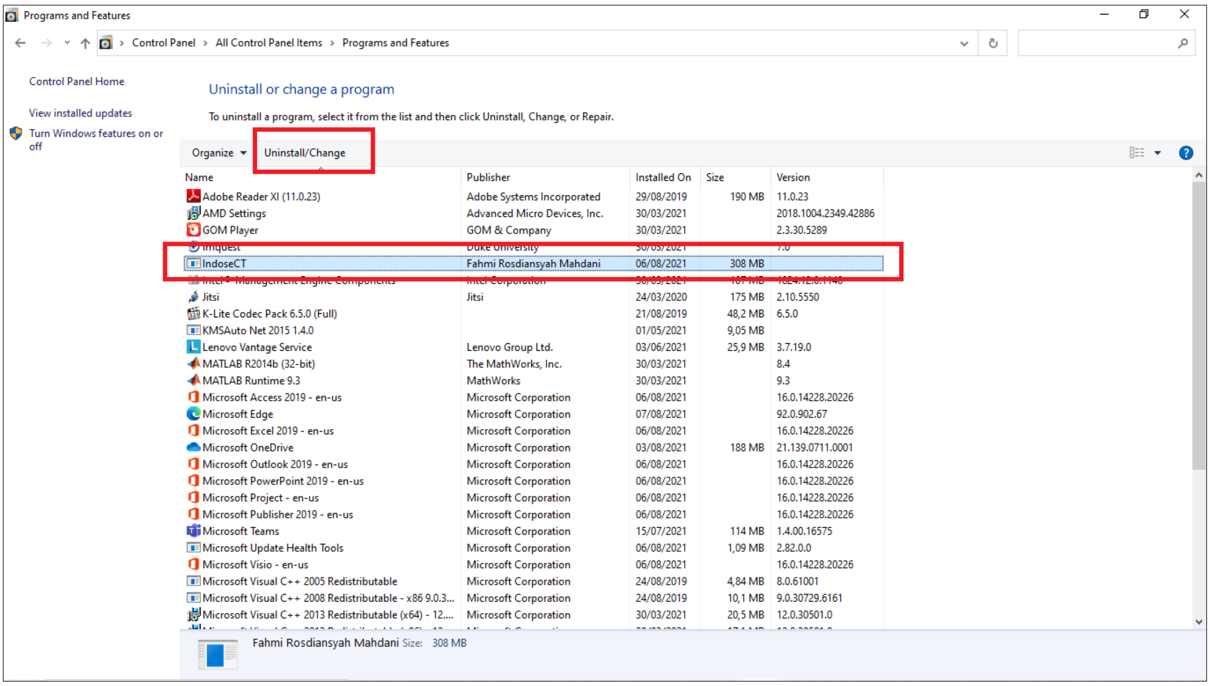

Figure 18. Control Panel Home dialog for uninstalling **IndoseCT**.

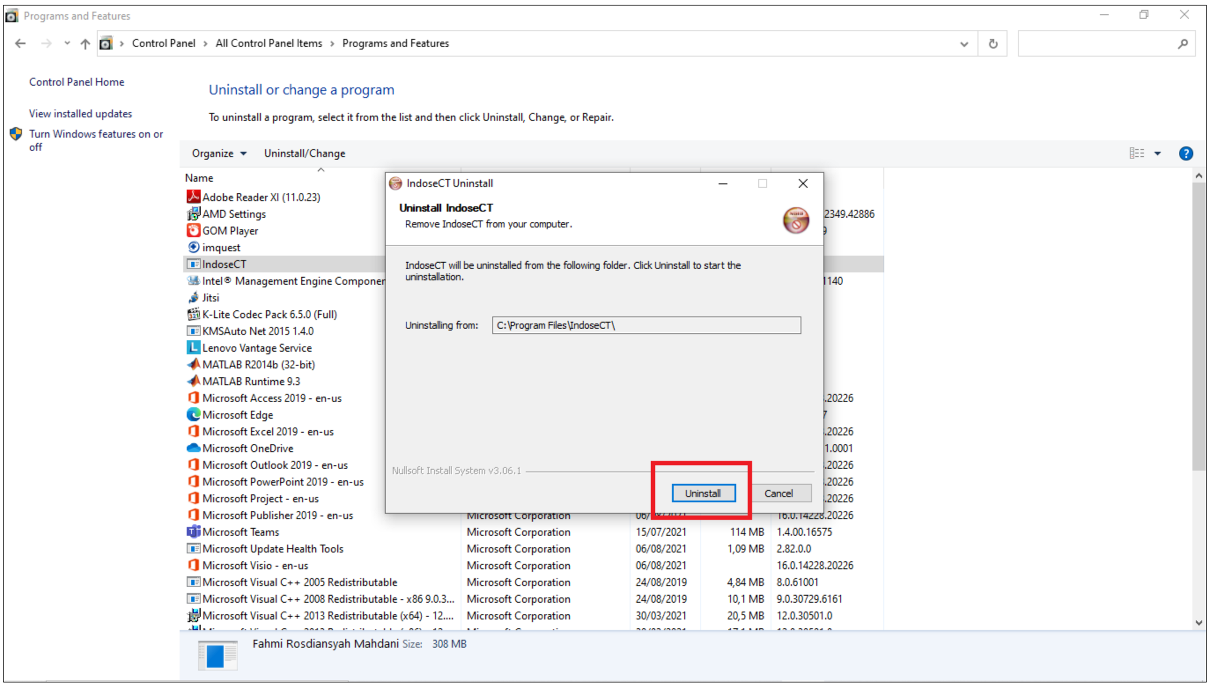

Figure 19. Dialog for notification whether you continue the uninstall process or not.

A dialog on the progress of the uninstall process appears, and when it is finished, a **Completed notification** will appear as shown in **Figure 20**. Then select **Close**. At this point, the process of uninstalling **IndoseCT** is complete.

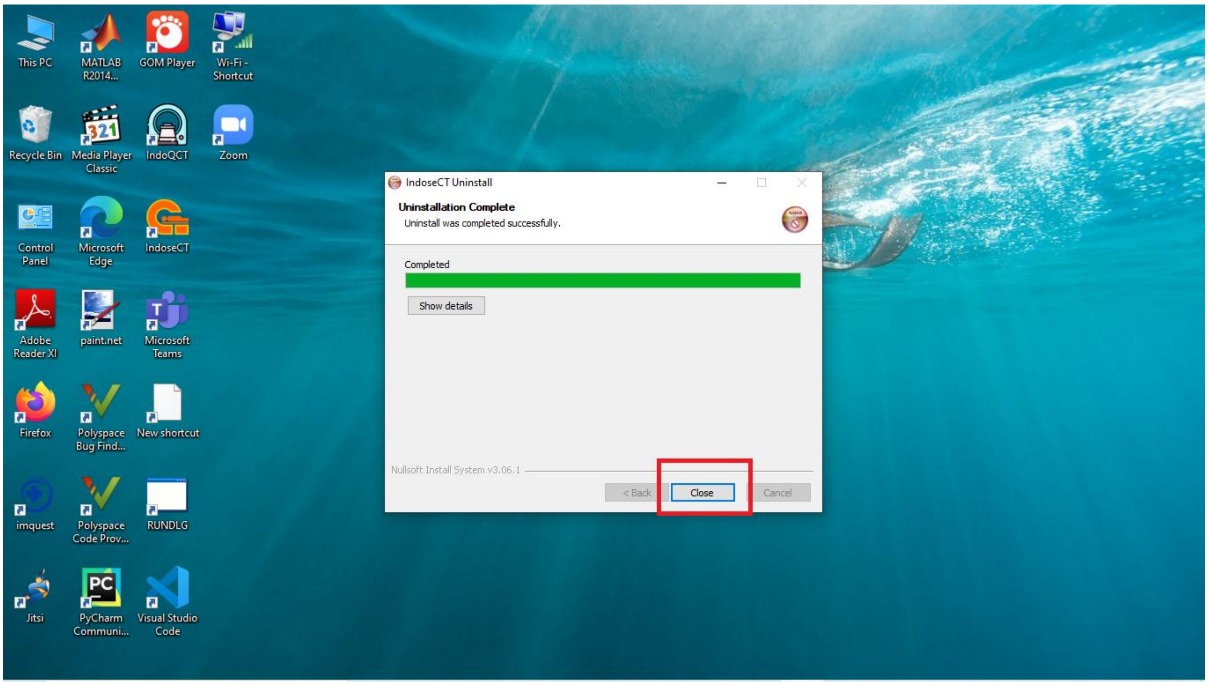

Figure 20. Notification that the uninstall process is complete.

III. MAIN PART of IndoseCT

In the previous chapter, we discussed how to install and run **IndoseCT**. The main view of **IndoseCT 20.b** after opening was shown in **Figure 8**. This chapter will discuss the parts of **IndoseCT** in general.

The **first part** of **IndoseCT** is the main part to calculate patient size, radiation dose and analyze the data that has been obtained. This section consists of 5 tabs, namely **CTDIvol**, **Diameter**, **SSDE**, **Organ**, and **Analyze** (**Figure 21**).

The **$CTDI_{vol}$ tab** is a section for calculating , obtaining or entering the $CTDI_{vol}$ value. $CTDI_{vol}$ itself is a quantity that describes the output dose of the CT machine.

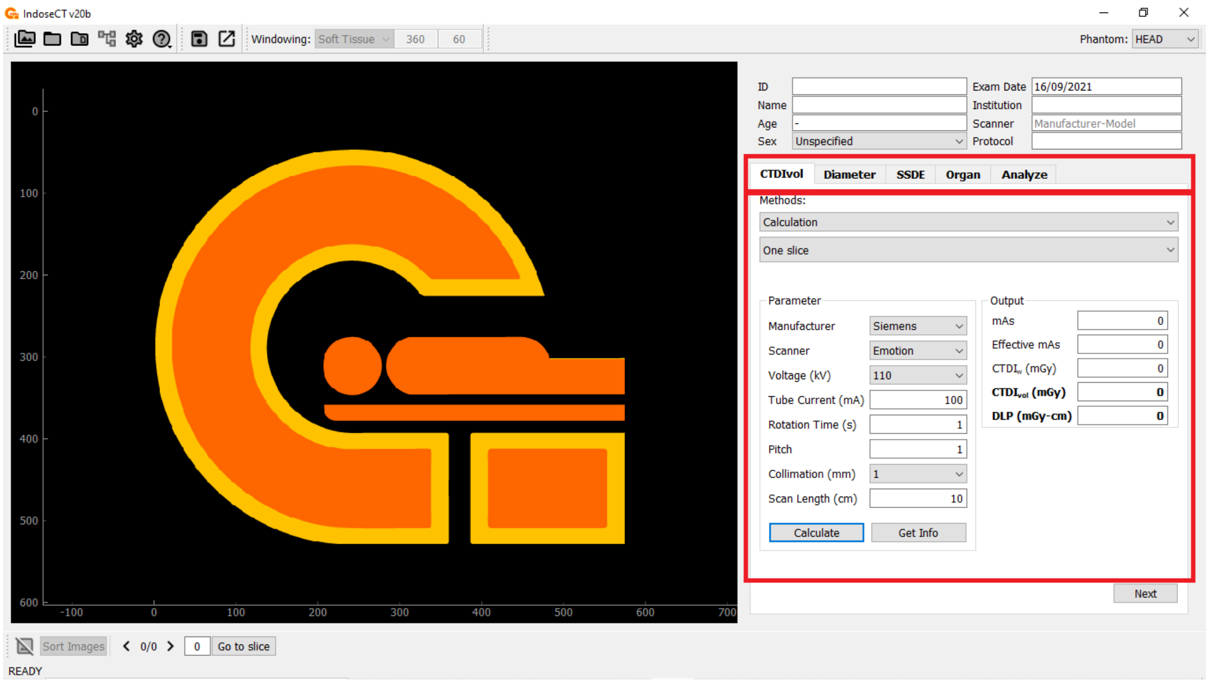

Figure 21. The main view of **IndoseCT**, which consists of several tabs to calculate patient size, radiation dose and analyze data.

The **Diameter tab** is a section for calculating, obtaining or simply entering a patient's diameter value. In general, two diameters are used, namely the effective diameter (D_{eff}) and the water-equivalent diameter (D_w).

The **SSDE tab** is a section for calculating size-specific dose estimate (SSDE) values. SSDE is a quantity that describes the dose received by the patient. SSDE is measured from the device output dose ($CTDI_{vol}$) and patient size characteristics (diameter). Therefore, to calculate the SSDE value, the previous two tabs must be completed (**$CTDI_{vol}$ and Diameter tabs**)

The **Organ tab** is a section for calculating radiation doses to an organ. Calculation of the dose of organs is based on the SSDEs. In order to obtain an organ dose value, the previous three tabs have to be completed (**$CTDI_{vol}$**, **Diameter**, and **SSDE tabs**). However, in **IndoseCT** organ doses are not stored in the database, only $CTDI_{vol}$, diameter and SSDE values are stored.

The Analyze tab is a section for analyzing the results that have been stored in the database. Various parameters can be connected and displayed in graphical form, for example the relationship between D_W and SSDE, and so on.

Detailed discussion of each tab will be discussed in later chapters.

The **second part** of **IndoseCT** is a screen for displaying patient images (**Figure 22**), including segmentation results and various attempts to get the diameter displayed on this screen. This screen can be enlarged or minimized by dragging the right border of the image to the right or to the left.

Figure 22. IndoseCT screen display for patient images and image processing results.

The **third part** is a group of buttons at the top of the image and at the bottom of the image (**Figure 23**). The upper group of buttons is for opening the image, displaying DICOM info, and specifying the image windowing to use. **Figure 24** shows a button to download the **IndoseCT** manual book. The bottom group of buttons is for deleting images, sorting images, and shifting images from one slice to another.

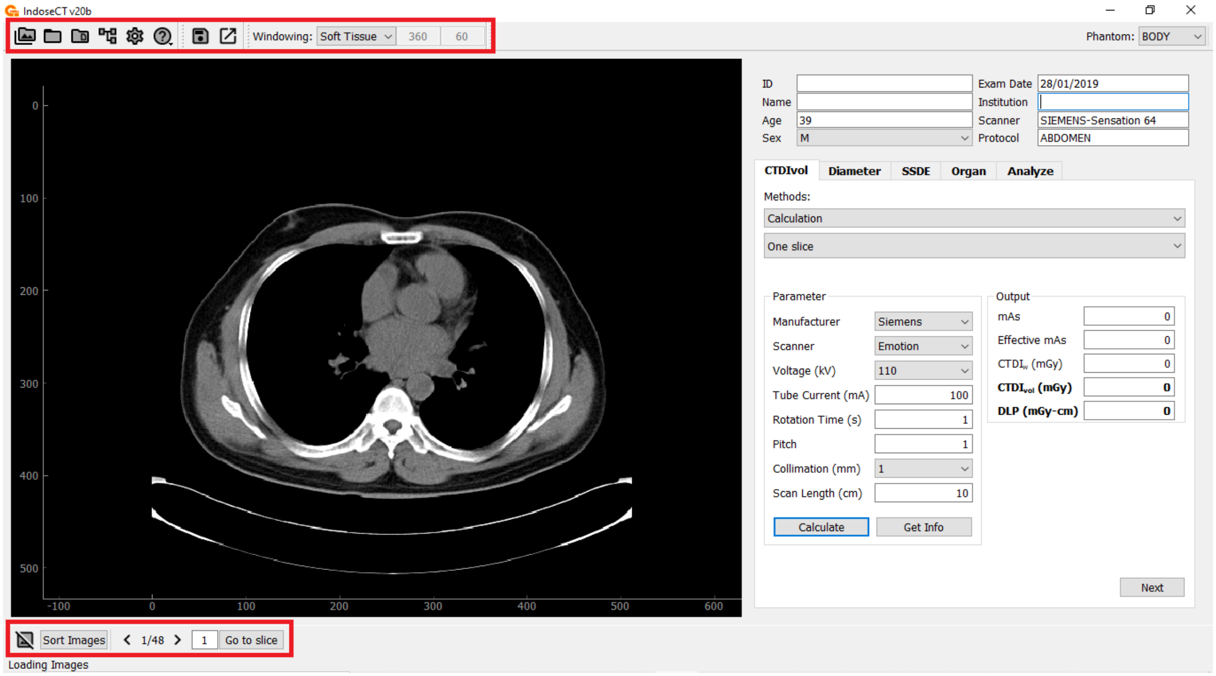

Figure 23. The third part displays a group of buttons at the top of the image and at the bottom of the image for various purposes, such as opening an image, displaying DICOM info, and so on.

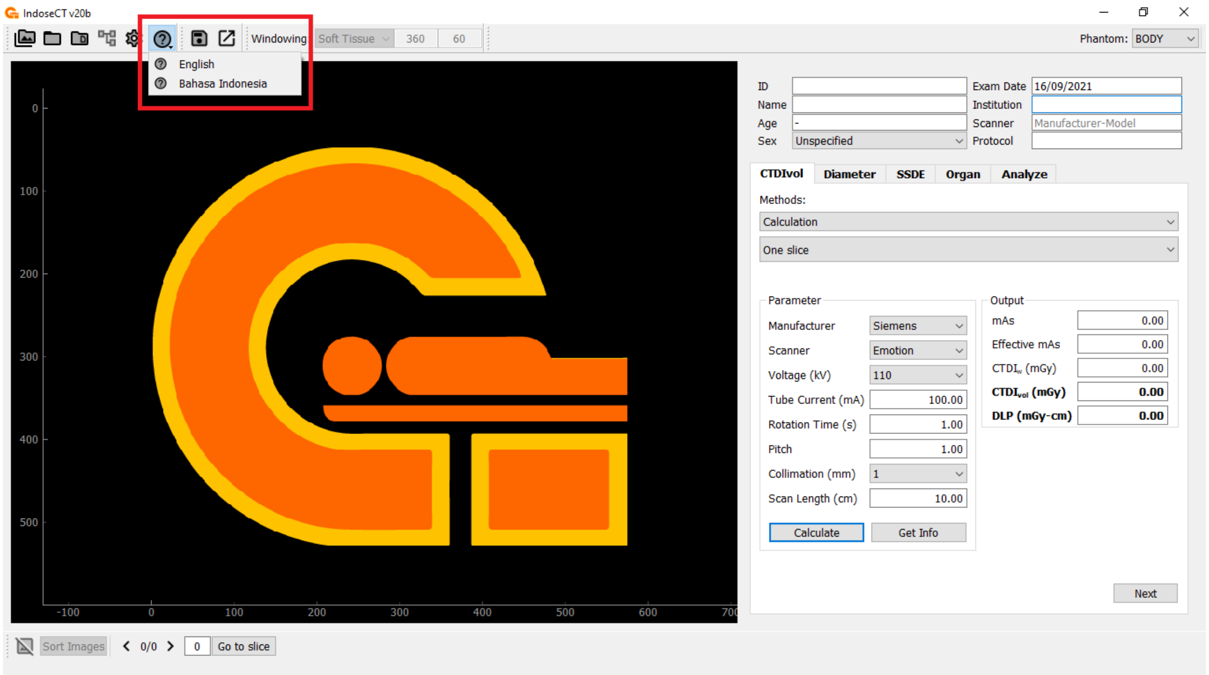

Figure 24. Button to download the **IndoseCT** manual book.

The <u>**fourth part**</u> for displaying patient information, such as ID, name, age, gender, examination time, hospital, type of scanner, and the protocol used (**Figure 25**). This information will be filled in automatically when the image is opened. If we calculate the dose without using the image and this information is to be stored in the database, then this information must be filled in manually.

Figure 25. Part to display patient information, such as ID, name, age, gender, examination time, hospital, type of scanner, and protocol used.

The **fifth part** is the graphical part. For every calculation, especially those involving profile data or data sets that have been stored in the database, the results can be displayed in a graph (**Figure 26**). These charts can be saved and the data can be exported to Microsoft Excel.

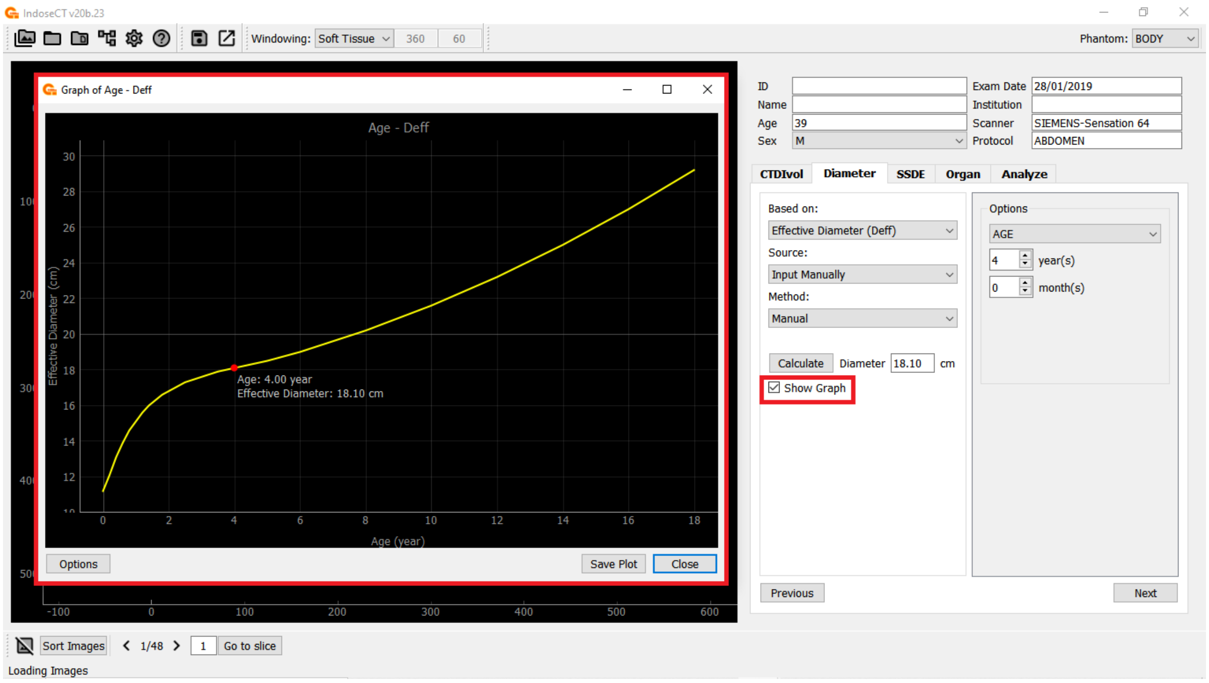

Figure 26. The Graphical display to view profile data of a parameter or data set that has been stored in the database. These charts can be opened and closed without interrupting calculations.

IV. PATIENT IMAGE

4.1. Open image

The advantage of **IndoseCT** is that $CTDI_{vol}$, D_{eff}, D_W, SSDE, and DLP can be taken and calculated from patient images. However, all these parameters can also be obtained without patient images. **IndoseCT** provides the option that all of these parameters can be obtained independently of the patient image. If we want to get the values of all these parameters from the patient image, then the patient image must be opened first.

IndoseCT has two options for opening images, namely by **file** and by **folder**. For educational purposes, **IndoseCT** has provided one sample, namely an anthropomorphic phantom from the lower end of the pelvis to the top of the head. The sample images can be opened by left-clicking the **Open Sample** button **(Figure 27**). In this sample there are 88 slices (images).

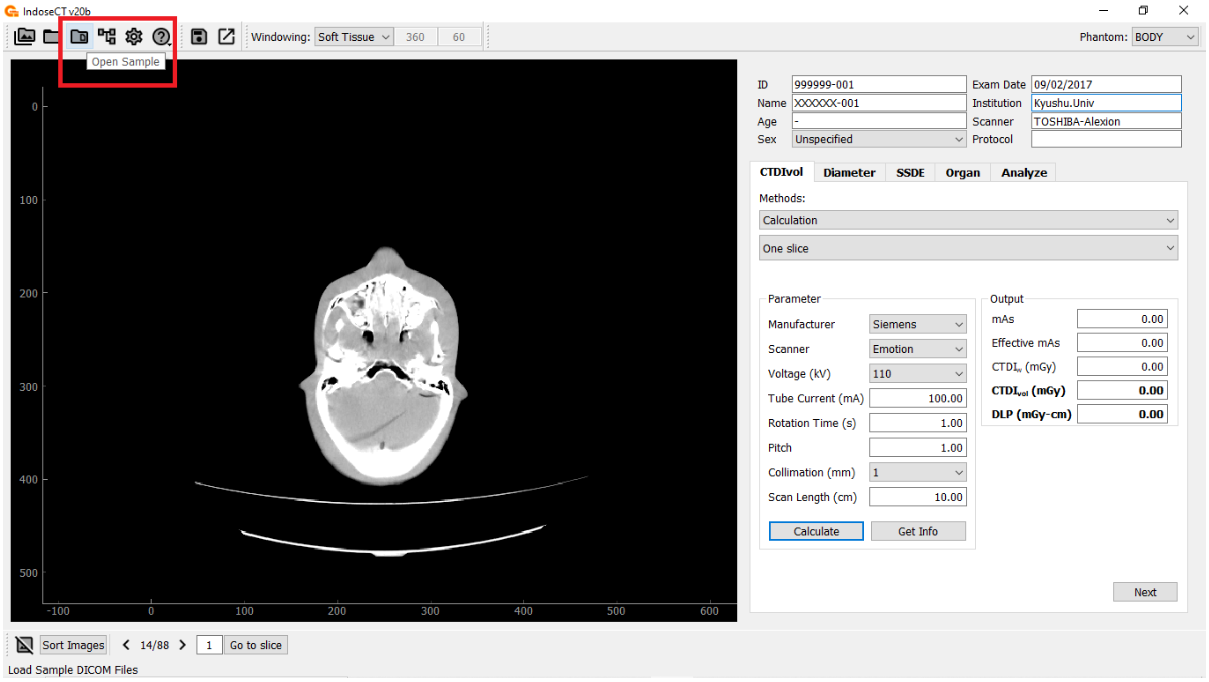

Figure 27. Open Sample button to open sample images.

To open an image by file, press the **Open File(s)** button at the upper left corner (**Figure 28**), and the **Open File** dialog will appear. Select the folder where the patient image files are stored. At that time, the file names will be empty. Then select **All Files**, under **Type Files**, which is located at the very bottom (see **Figure 29**). After that, the file name of the patient image will be displayed.

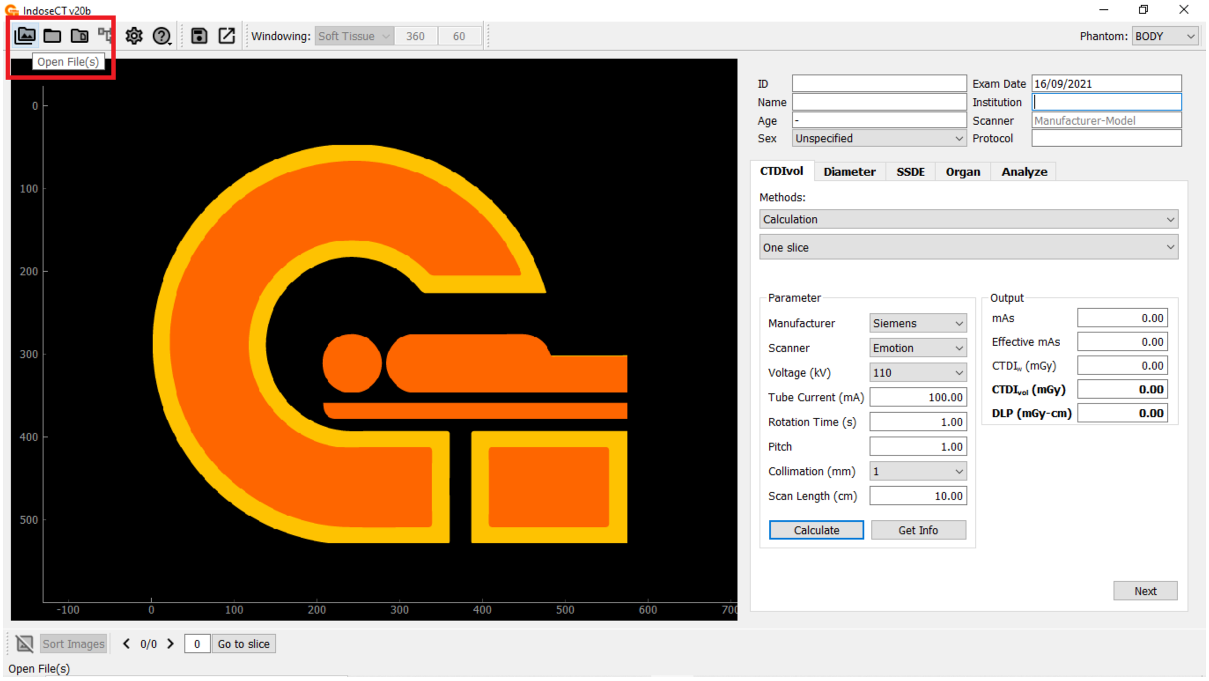

Figure 28. Open File(s) button to open an image by file.

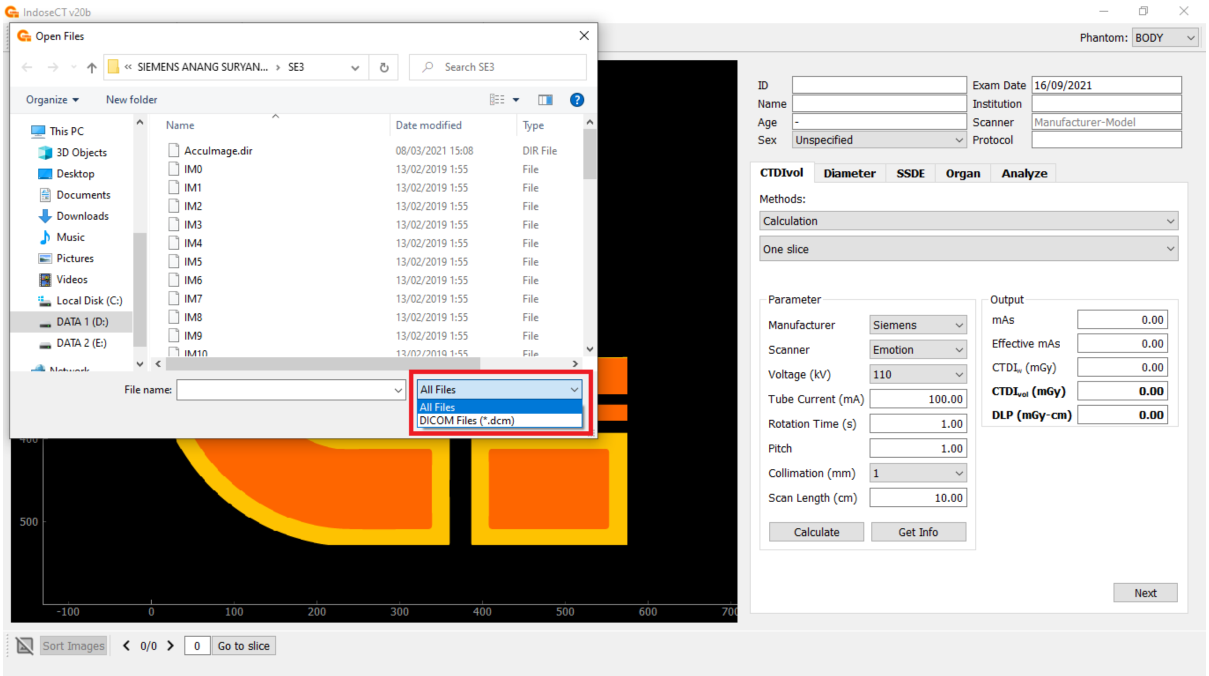

Figure 29. Display of the **Open Files** dialog.

Note that in general, patient images consist of more than one slice (file) (in some cases more than 1000 slices). If you choose only one file, then just select one file, click **Open** or directly double-click on the file. To select multiple patient image files, click the first file, then press the **Shift key** on the keyboard and hold it, then press the key to move the cursor down. Or the user can also press **Ctrl + A**. However, it must be remembered, that at the bottom of the file there is usually an **AccuImage.dir** file, this file should not be selected (**Figure 30**). When several files have been selected, the next step to open the image is to press the **Open** button. As noted the selected image is the patient's axial image file. Check that the axial image files have the same file size, about 516 KB, and do not select files of a different size (These are not patient axial image files).

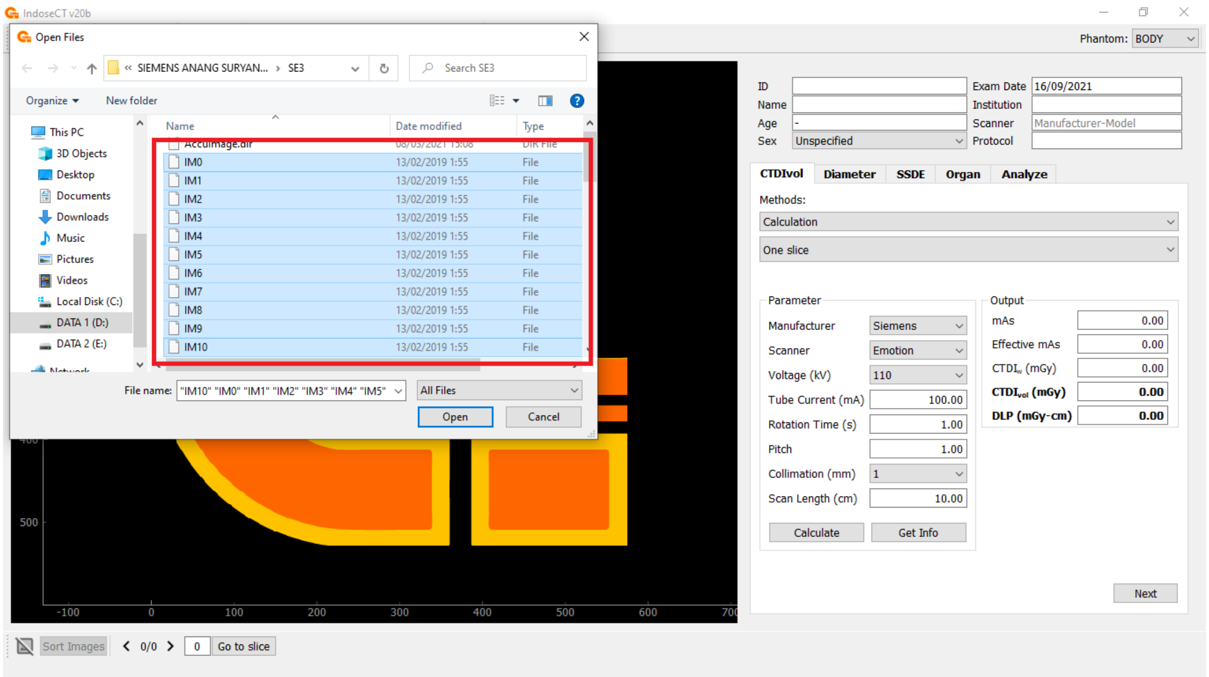

Figure 30. Display of selected patient image files (blue blocks).

Pressing the **Open** button will open all files. To open multiple images (of hundreds or thousands) usually takes a few seconds. On the computer screen, there is a notification of the progress of the file opening (**Figure 31**). Wait a moment for the axial images of the patient to be displayed on the computer screen.

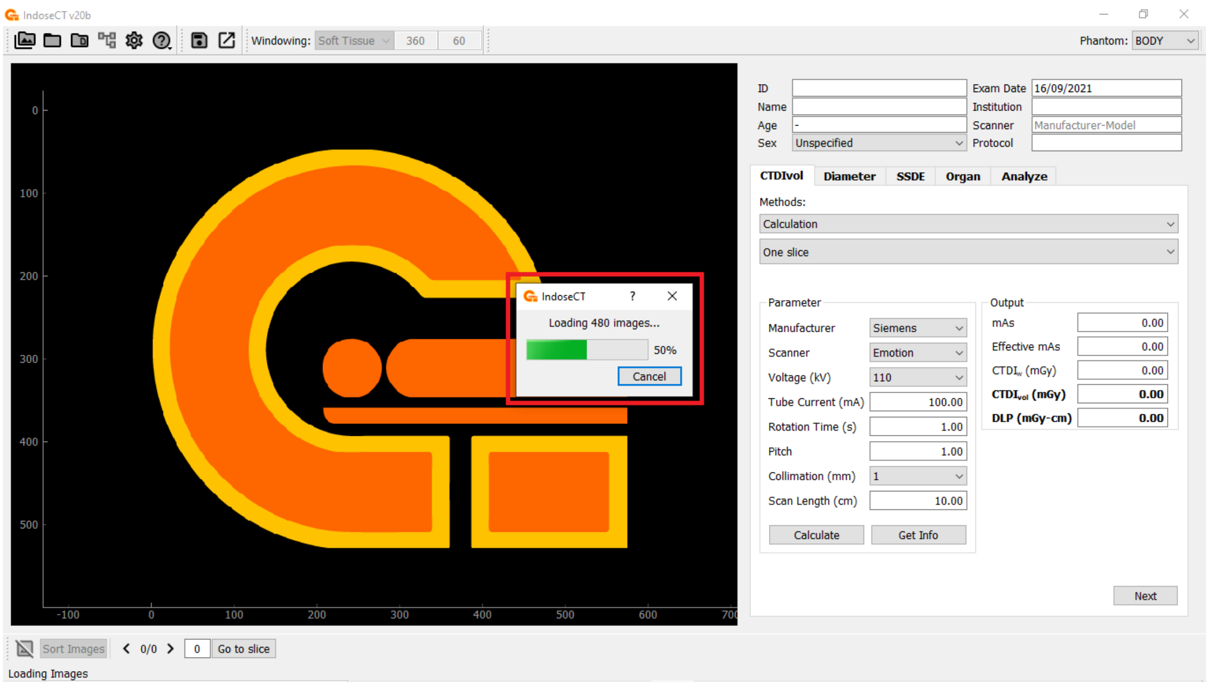

Figure 31. Notification of patient axial images opening as a percentage of the total.

To open images by folder, select the **Open Folder** button which is to the right of the **Open Folder** button (**Figure 32**). When the button is pressed, the **Open Folder** dialog will appear. Select the folder where the patient image files are stored.

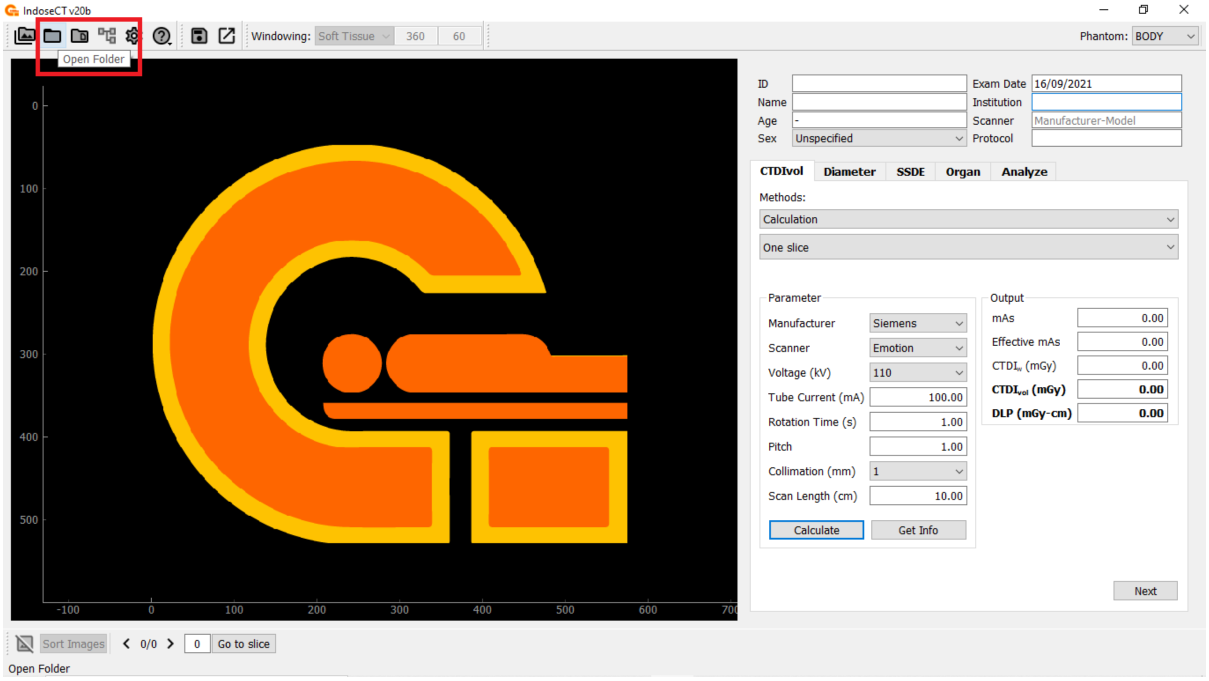

Figure 32. Open File(s) button to open an image by file.

Note that opening multiple images on a folder basis is more practical than on a file basis. However, it must be ensured that in the folder there are no other files except the patient's axial image file. If there are other files, then DICOM info from the axial image will not be able to be displayed later. This causes the next process (such as calculating patient diameter) to fail since calculating this parameter requires information from the DICOM info. An explanation of DICOM info is discussed in the next sub-chapter. An example of an opened patient image is shown in **Figure 33**.

Figure 33. Example of patient image display that has been successfully accessed. The ID and name of patient and name of institution are erased for patient privacy.

4.2. Show image

Access to the next file (slice) is achieved by clicking the **>** and **<** buttons (below the image). The **>** button is for viewing the next slice, and the **<** button is for viewing the previous slice. In the middle is the number of slices visible on the screen and the total number of slices. In the example (**Figure 34**), the opened slice is number 30, and the total number of slices is 88.

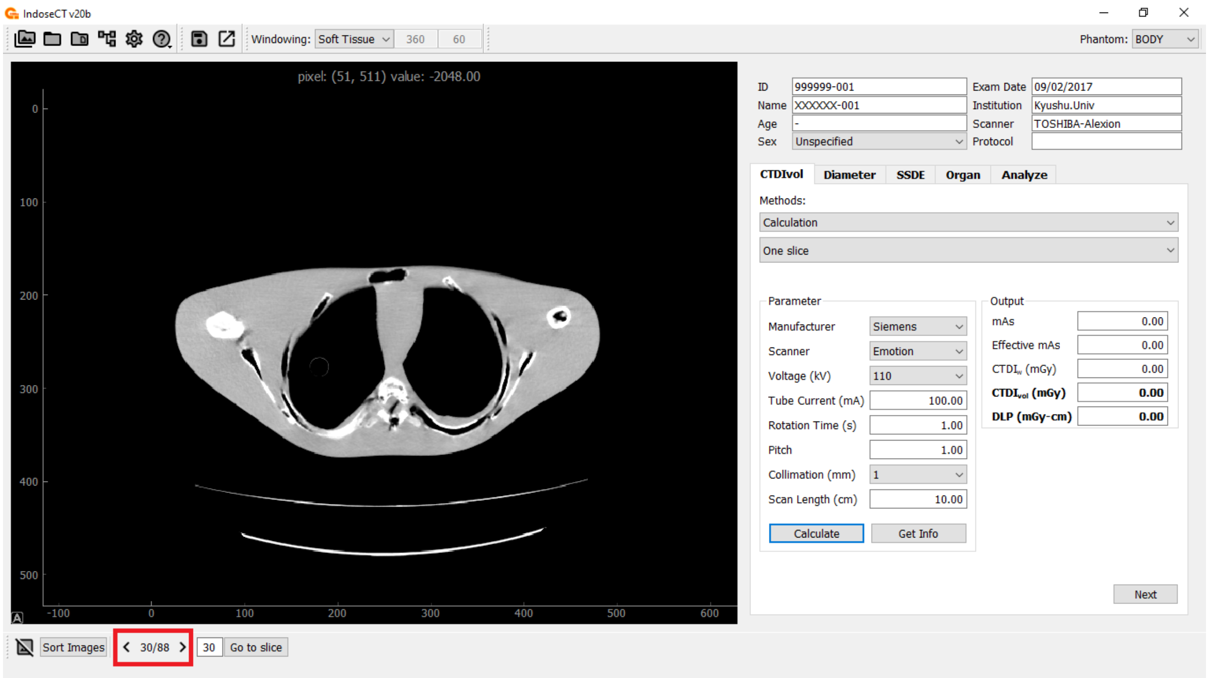

Figure 34. The **>** button to move to the next slice, and the **<** button to move to the previous slice.

If the slice number is the same as the total number of slices, by clicking the **>** button will return the visible slice to slice number one. Conversely, if the slice number is equal to 1, then clicking the **<** button will display the last slice.

To quickly access a particular slice, you can fill in the number of the desired slice, and click **Go to slice**. This will greatly help speed up thedisplay, if we are working with hundreds or even thousands of images (slices), as is common with modern CT machines.

More practically, the user can use the arrow keys on the **keyboard**. The **up arrow key** is to view the next slice, the **down arrow key** is to view the previous slice, the **left arrow key** is to view the previous 5th slice, and the **right arrow key** is to view the next 5th slice.

In fact, often the images we get are not sequential, for example the first slice shows the head image, the second slice shows the chest image, the third slice shows the head image again, and so on. This will be very difficult. To **sort images**, you can do this by pressing the **Sort Images** button (at the bottom corner). Images can be deleted by pressing the **Close Images** button, which is to the left of the **Sort Images** button.

The CT number within images has a very wide range from about -1000 HU to over +3000 HU. With this wide range, if the image is displayed as it is, the contrast between objects will appear very low. To improve the contrast appearance of objects in image, the windowing technique is used (more information about windowing in books on CT). **IndoseCT** is equipped with **Windowing** selection, namely: **Soft Tissue**, **Bone**, **Lung**, **Liver**, **Brain**, **Fat**, **Spline**, **PF (Posterior Fossa)**, **IAC (Internal Acoustic Canal)**, **Vascular**, **Custom,** and **None**. The default is **Soft Tissue.** **Custom window** means that the user can define their own window-width (WW) and window-level (WL) values. **None** means that the image is displayed without using windowing. This means that the image is displayed from the minimum to the maximum value. The sample image when displayed using the **Bone** window looks like in **Figure 35** and using the **Lung** window looks like in **Figure 36**.

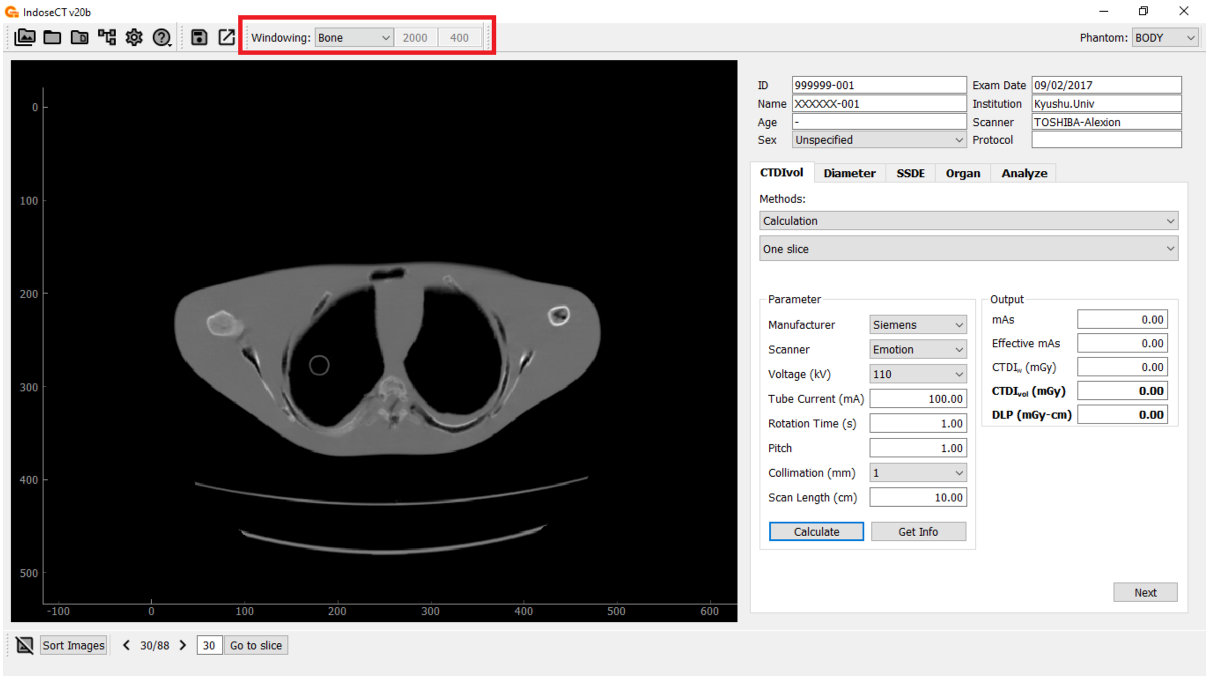

Figure 35. Sample image of the chest area displayed with the **Bone** window.

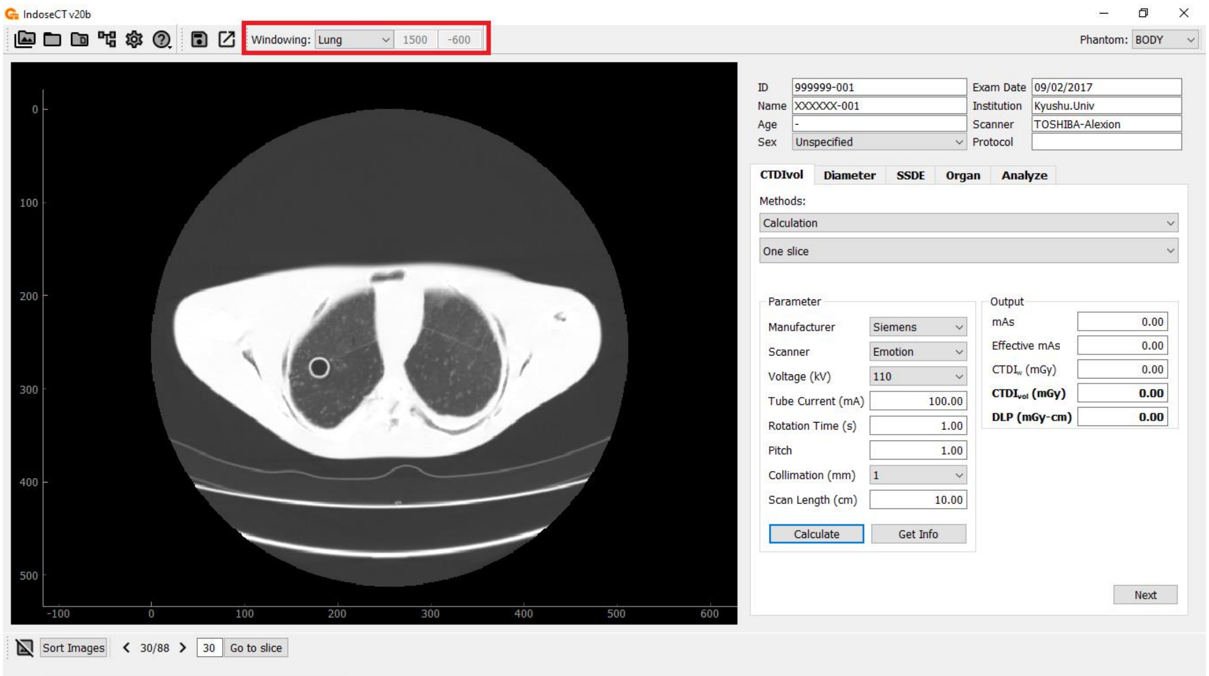

Figure 36. Sample image of the chest area displayed with the **Lung** window.

4.3. Zoom-in, zoom-out and move image

The opened patient image can be enlarged (zoom-in) or minimized (zoom-out) or shifted as needed. To enlarge or minimize an image, place the cursor over the image, then use three fingers to enlarge the image. An enlarged anthropomorphic phantom image is shown in **Figure 37** and a minimized image is shown in **Figure 38**.

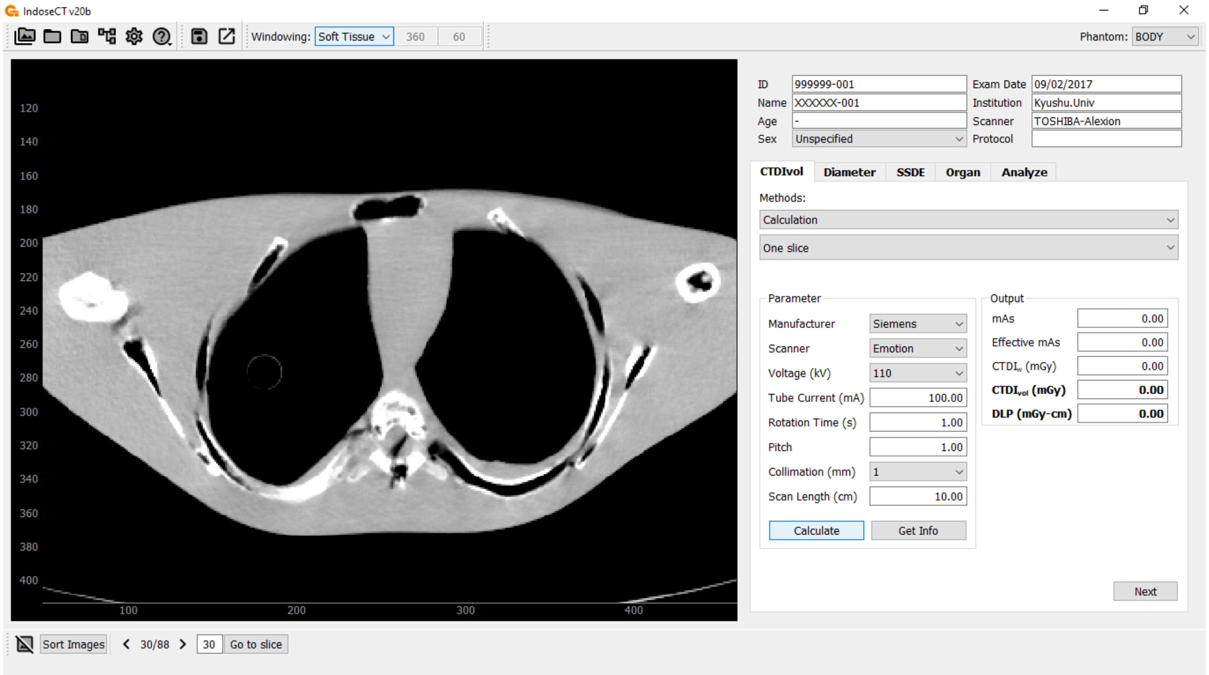

Figure 37. An enlarged sample image of the chest area.

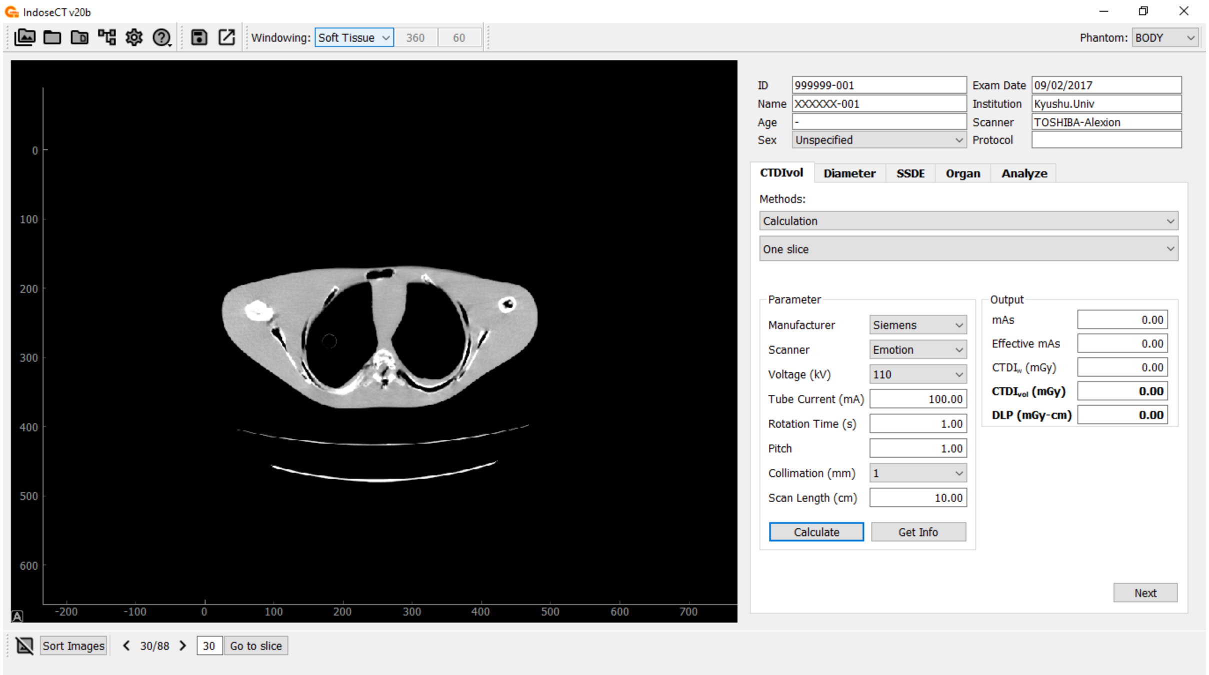

Figure 38. Image of a minimized sample of the chest area.

To move an image, place the cursor over the image, hold down the left-click and shift the image to the desired position. An example of a shifted image is shown in **Figure 39**.

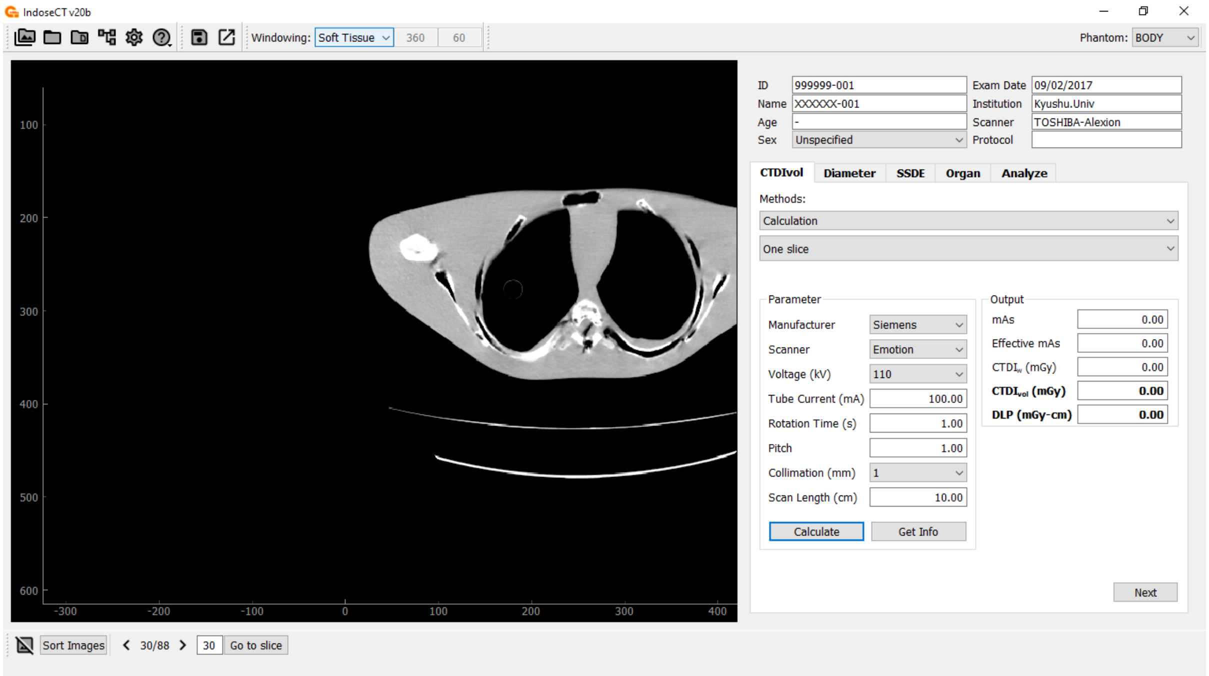

Figure 39. Sample image of the displaced chest area.

4.4. Image pixel value

When taking D_{eff} or D_W measurements, sometimes we want to know the pixel value at a certain point in the patient's image. In **IndoseCT**, to find out the pixel value and its position (at the x- and y-coordinates), simply place the cursor on the pixel in question. The pixel value and its position will be displayed dynamically at the top of the image, as shown in **Figure 40**.

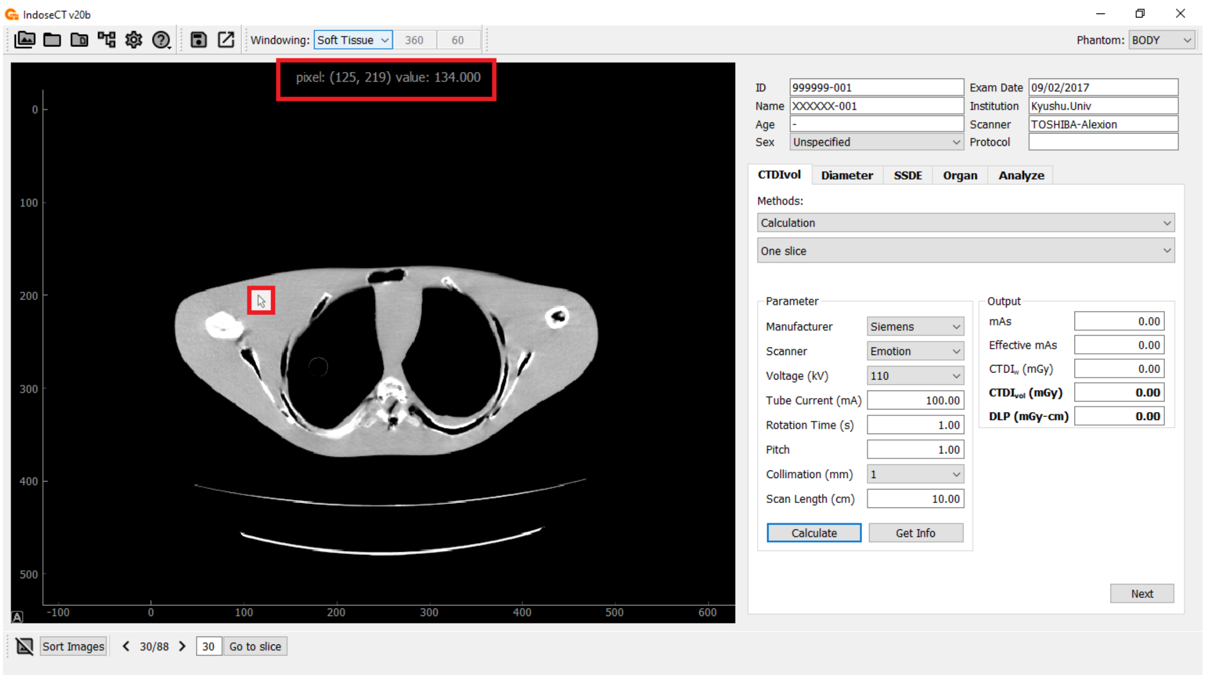

Figure 40. When the cursor position is placed at a certain position in the image, the pixel value will be obtained and displayed automatically at the top of the image.

4.5. DICOM info

Unlike non-medical images, medical images are saved in the DICOM format. In the DICOM format, the image also contains detailed information about the image, for example image size, number of pixels, date of data acquisition, patient name, patient age, and so on. This information is often referred to as DICOM info or DICOM header. The DICOM details may vary from one scanner to another. To display DICOM info, press the **DICOM Info** button. An example of DICOM info can be seen in **Figure 41**. To find out the meaning of DICOM info, refer to books or journals that discuss DICOM info. The user may need to retrieve some of this information for certain purposes, for example if the user wants to know the height of the patient table to calculate mis-centering or the user wants to know the field of view (FOV) of the image obtained.

Note that the DICOM info that appears is for the currently active image on the screen. If we want to see DICOM info for the next slice, then the image must be moved to the next slice first. In general, the DICOM info for each slice is similar except for some parameters such as slice location, tube current value (for TCM applications), and image acquisition time.

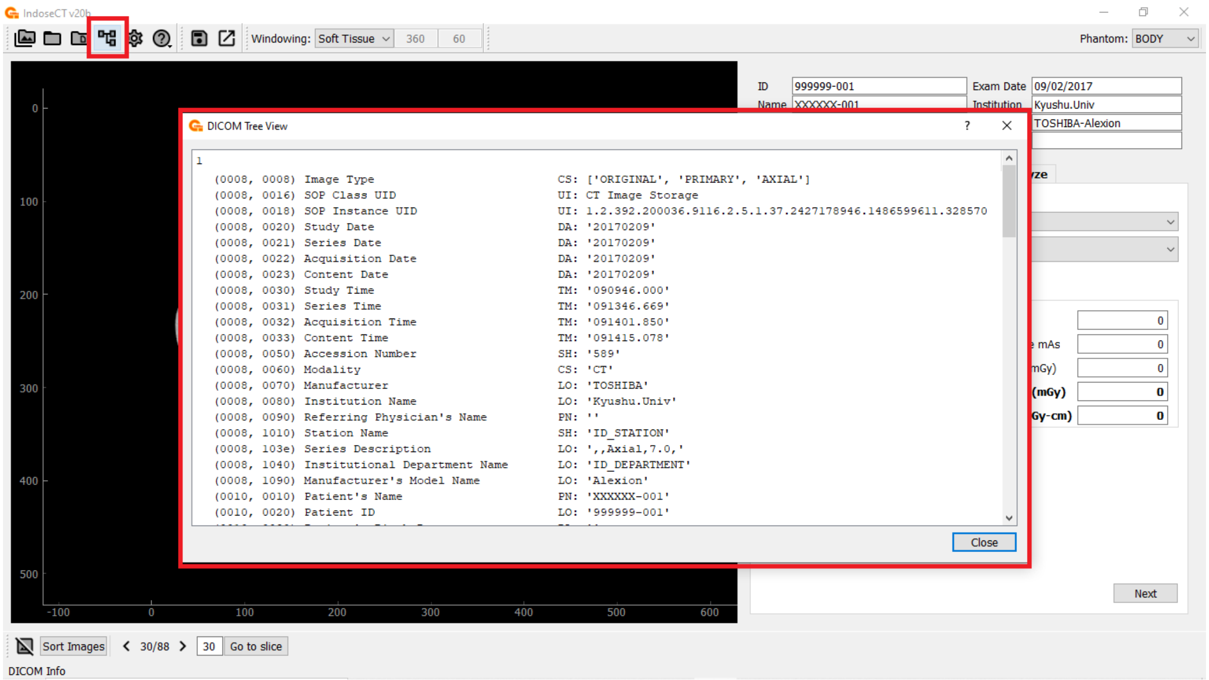

Figure 41. Button to display DICOM info and an example of DICOM info.

4.6 Patient data

Before calculating patient's dose, patient data be filled in first. This data is useful for analysis at the final stage. The data that needs to be filled in includes (see **Figure 42**):

- Patient ID (**ID**)
- Patient name (**Name**)
- Patient age (**Age**)
- Patient's gender (**Sex**)
- Date of examination (**Exam Date**)
- Institution where examination is performed (name of hospital) (**Institution**)
- Scanner type, both manufacturer and scanner model (**Scanner**).

- Examination protocol (**Protocol**)

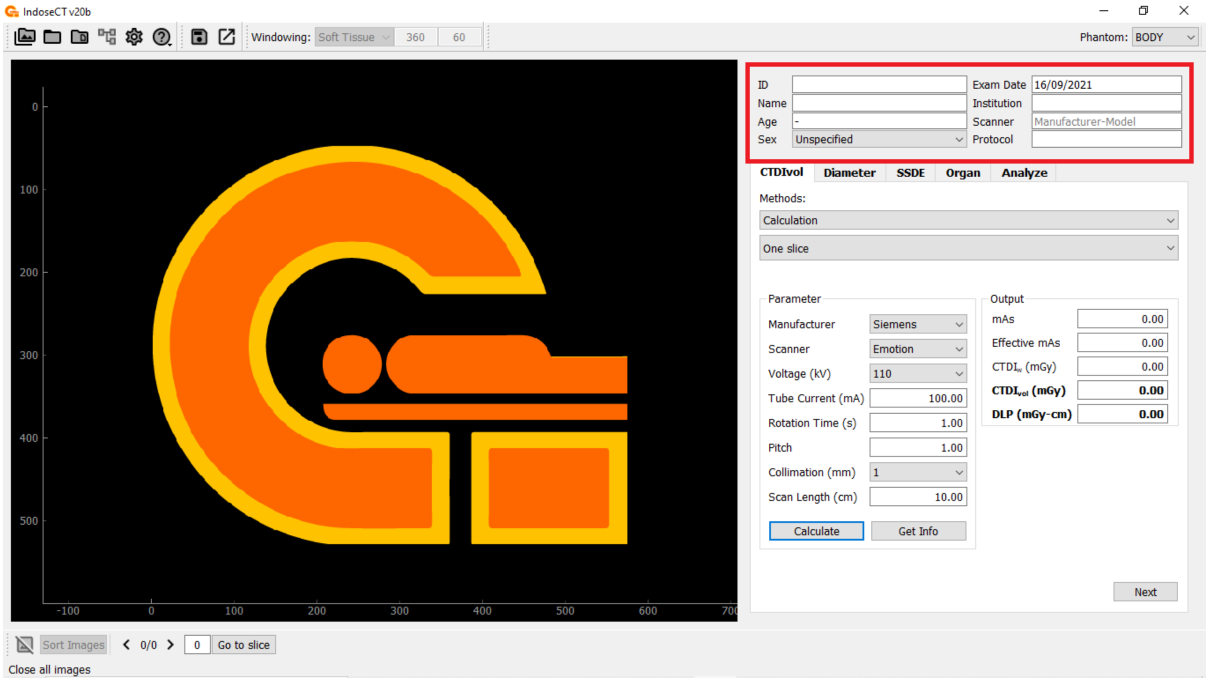

Figure 42. Patient data entry form. This patient data should be filled in for further analysis.

Note: When the patient image is opened, the data input parameters above are directly extracted from the DICOM info of the image. An example of patient information that has been filled in when opening a sample image can be seen in **Figure 43**.

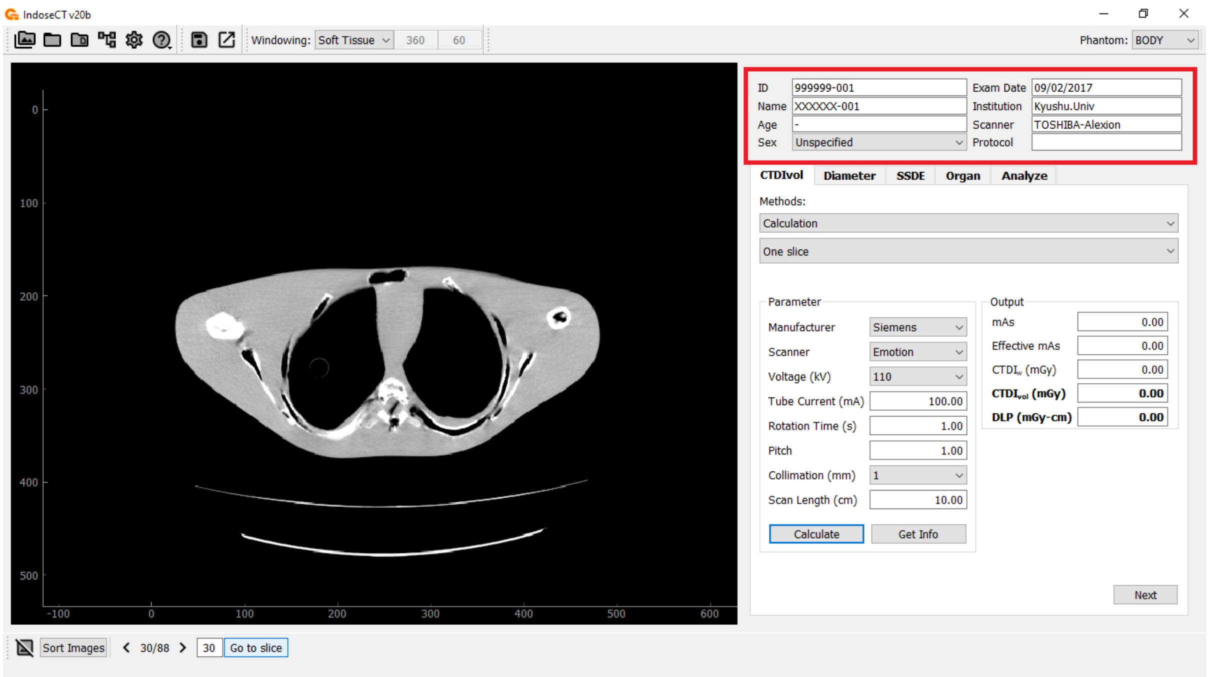

Figure 43. Filled form from DICOM info of the sample image. **Age**, **Sex** and **Protocol** content fields are not filled because the information was not available in the DICOM info of the sample image.

V. DETERMINATION OF THE CTDI$_{vol}$

The magnitude of the CT dose is generally expressed using the metric CTDI$_{vol}$. CTDI$_{vol}$ is a quantity that determines the magnitude of the output dose of the CT machine. The CTDI$_{vol}$ value is strongly influenced by exposure factors such as tube voltage (kVp), tube current (mA), rotation time (s), pitch, and collimation width. The CTDI$_{vol}$ is specific for each scanner. The patient dose is calculated based on the magnitude of the CTDI$_{vol}$ combined with the specific characteristics of the patient.

The second quantity that describes the total energy transferred to the patient is the dose-length product (DLP). This DLP is calculated based on the product of CTDI$_{vol}$ and scan length (L). Calculation of the patient's effective dose is usually calculated from this DLP and conversion factor (f).

On modern CT machines, these CTDI$_{vol}$ and DLP values are usually displayed on the CT console screen. For the newest product CT machines, these two values are also stored in DICOM info. In addition, the CTDI$_{vol}$ and DLP values are also quantities that must be checked periodically in the quality control (QC) program.

To calculate CTDI$_{vol}$, first select the **CTDI$_{vol}$** tab in the row of tabs. If the **CTDI$_{vol}$** tab is clicked, the color will change from gray to white. By default, when **IndoseCT** is activated, this **CTDI$_{vol}$** calculation appears on the first screen.

In **IndoseCT 20.b**, there are three options for determining it: calculation (**Calculation**), manual (**Input Manually**), and taken from DICOM info (**Get From DICOM**) (**Figure 44**). The default option is **Calculation**.

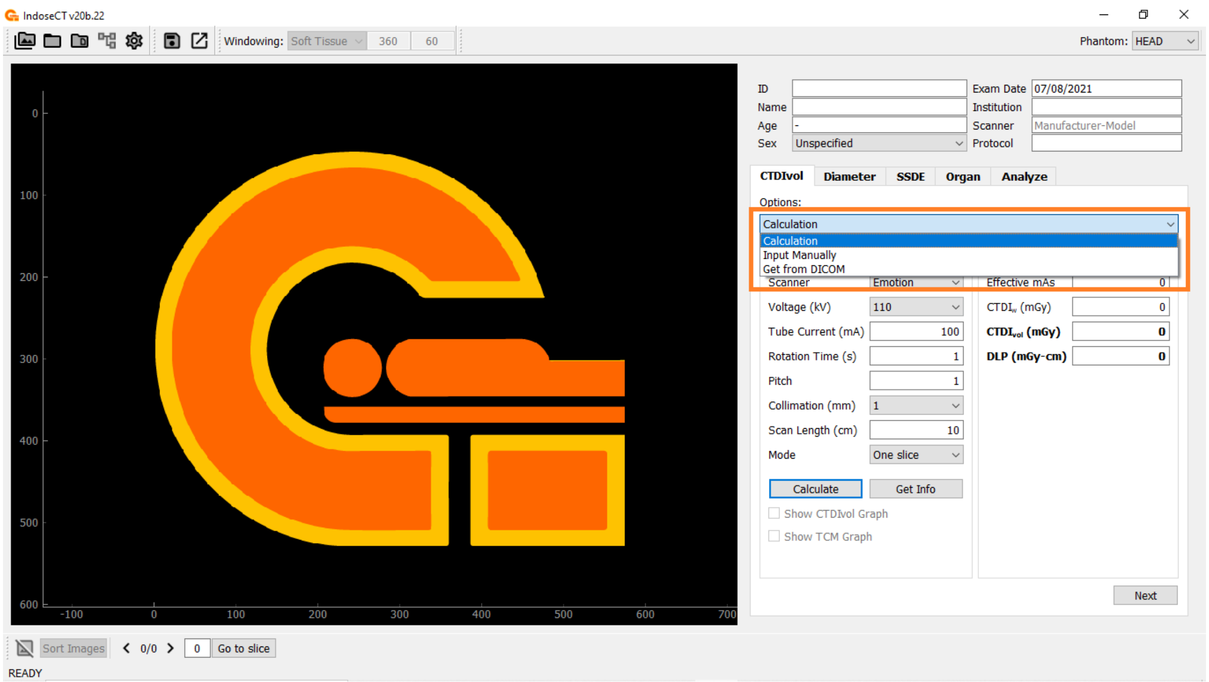

Figure 44. There are three options to obtain the CTDI$_{vol}$ value in **IndoseCT**, namely **Calculation**, **Input Manually,** and **Get from DICOM**.

5.1 Input manually

When the user already has the $CTDI_{vol}$ and DLP values, either from the CT console screen or from measurements (e.g. when conducting a quality control (QC) program or compliance test) or from other software, the user enters these values into this **IndoseCT**. The steps are as follows (see **Figure 45**):

- Select **Enter Manually** option**.**
- Fill in the **$CTDI_{vol}$ (mGy)** box with the $CTDI_{vol}$ value.
- Fill in the **DLP (mGy-cm)** box with the DLP value.

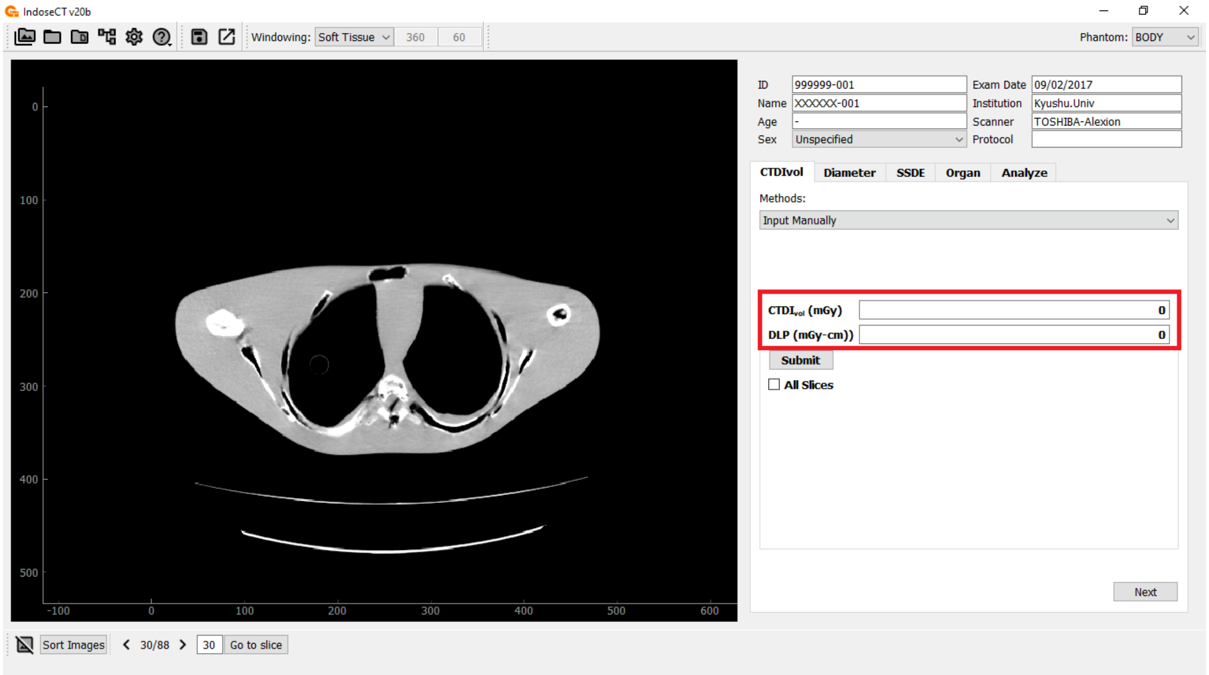

Figure 45. Display for entering $CTDI_{vol}$ and DLP values manually.

5.2 Calculation

a. One slice

The default $CTDI_{vol}$ and DLP calculations on **IndoseCT** is **One slice** option (**Figure 46**). In addition to the **One slice** option, another option is **Z-axis**.

If the user does not yet have the $CTDI_{vol}$ and DLP values, then the user can calculate these two quantities by entering the type of CT used for the exposure factors. In **IndoseCT**, the only available options are for CT manufacturers **Siemens**, **Toshiba**, **General Electric** (GE) and **Philips** (See **Figure 46**). For other manufacturers, values are still in process.

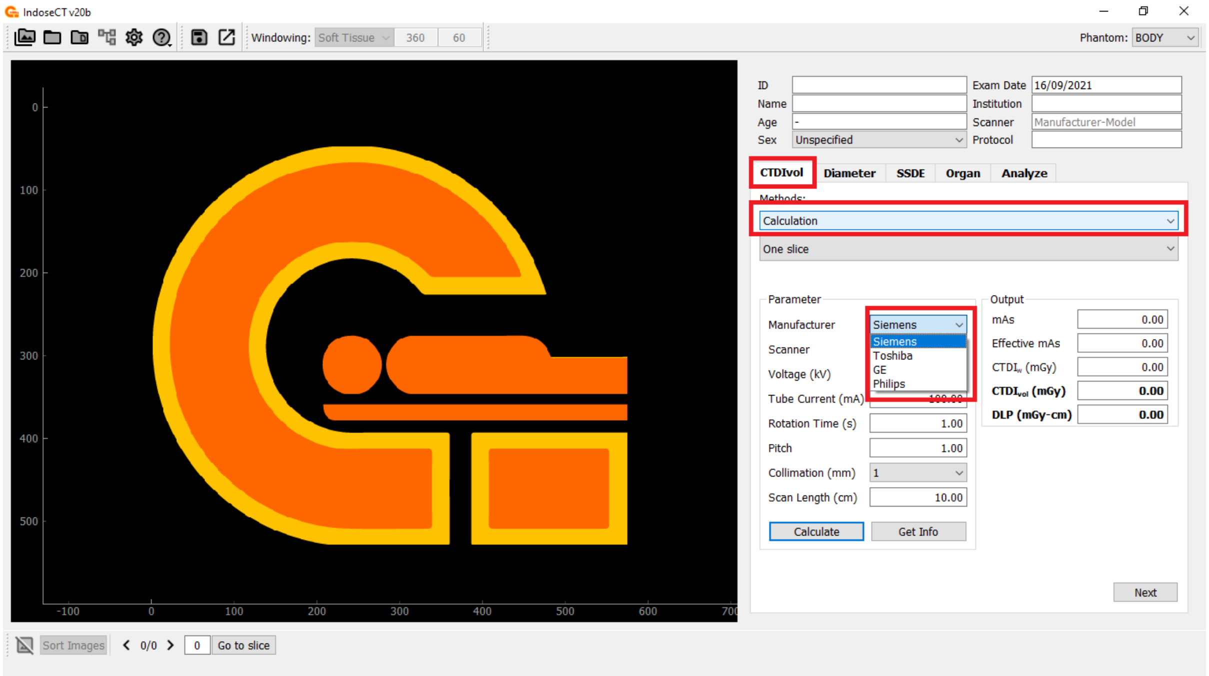

Figure 46. There are four manufacturer options in **IndoseCT**.

The steps to calculate $CTDI_{vol}$ are as follows:

- Select the **$CTDI_{vol}$** tab (Actually, when **IndoseCT** is opened, the first tab is **$CTDI_{vol}$**).
- Select the **Calculation** option (Actually, when IndoseCT is opened, the first option is to specify this $CTDI_{vol}$).
- Select the **Manufacturers** name.
  There are four options including **Siemens**, **Toshiba**, **General Electric** (GE) and **Philips**. The default is **Siemens.**
- Select the type of **Scanner**.
  - There are 11 types of scanners for Siemens: **Emotion, Emotion Duo, Emotion 6, Sensation 4, Sensation 10, Sensation 16, Sensation 16 Straton, Sensation 64, Sensation Open, Somatom Definition AS, and Somatom Perspective**. A selection of Siemens scanner types is shown in **Figure 47**.
  - There are 8 scanners for Toshiba: **Asteion, Asteion Dual, Asteion Multi, Aquilion Multi/4, Aquilon 16, Aquilion 64, Alexion, and Alexion Access**.
  - There are 7 scanners for GE: **HiSpeed, HiSpeed ZX/i, LightSpeed, LightSpeed Plus, LightSpeed Ultra, LightSpeed 16** and **LightSpeed VCT**.
  - There are 9 types of scanners for Philips: **AV, LX, M/EG, Mx8000, SR700, CT Secura, Brilliance 16, Brilliance 64,** and **Ingenuity**.

  The default scanner is **Emotion Duo**.
- Select **Voltage (kV)**. The voltage value depends on the type of scanner used.
- Fill in the **Tube Current (mA)** value. The default tube current value is **100 mA**.
- Fill in the **Rotation Time(s)**. The default rotation time is **1 s**.

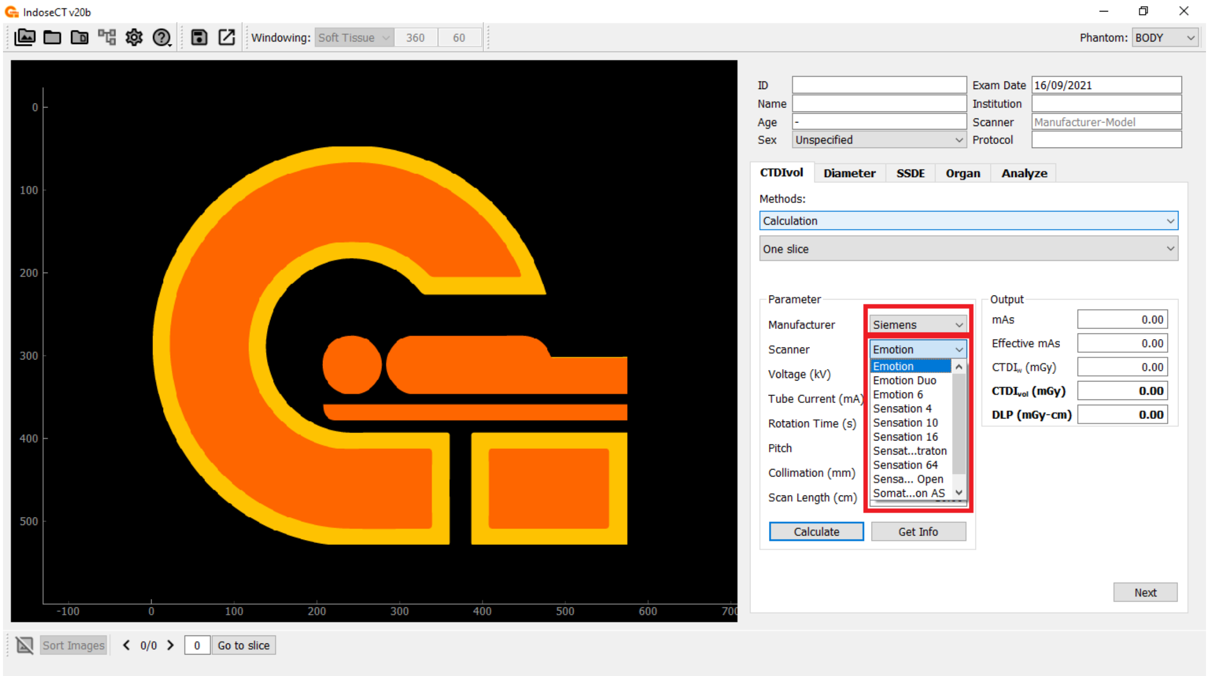

Figure 47. A list of scanner options available for Siemens on **IndoseCT**.

- Fill in the **Pitch**. The default pitch is **1**.
- Select **Collimation Width (mm)**. The choice of collimation width is determined by the manufacturer's name and the type of scanner.
- Fill in the **Scan length (cm)**. The default scan length is **10 cm**.
- When everything is filled in, then press the **Calculate** button.

The $CTDI_{vol}$ and DLP values will then be calculated. In addition, the mAs value, effective mAs (mAs divided by pitch), and CTDIw values will also be obtained. The $CTDI_{vol}$ value is $CTDI_w$ divided by pitch, and DLP. An example of $CTDI_{vol}$ and DLP calculation results for Siemens Emotion is shown in **Figure 48**.

For practical purposes, input parameters for calculating $CTDI_{vol}$, such as tube current, tube voltage and so on, can also be taken from the DICOM info. However, this only applies if the CT manufacturer and scanner type are already in the existing scanner database. To retrieve DICOM info, press the **Get Info** button. For example, the input parameters taken from the DICOM info for the Siemens Sensation 64 are shown in **Figure 49**.

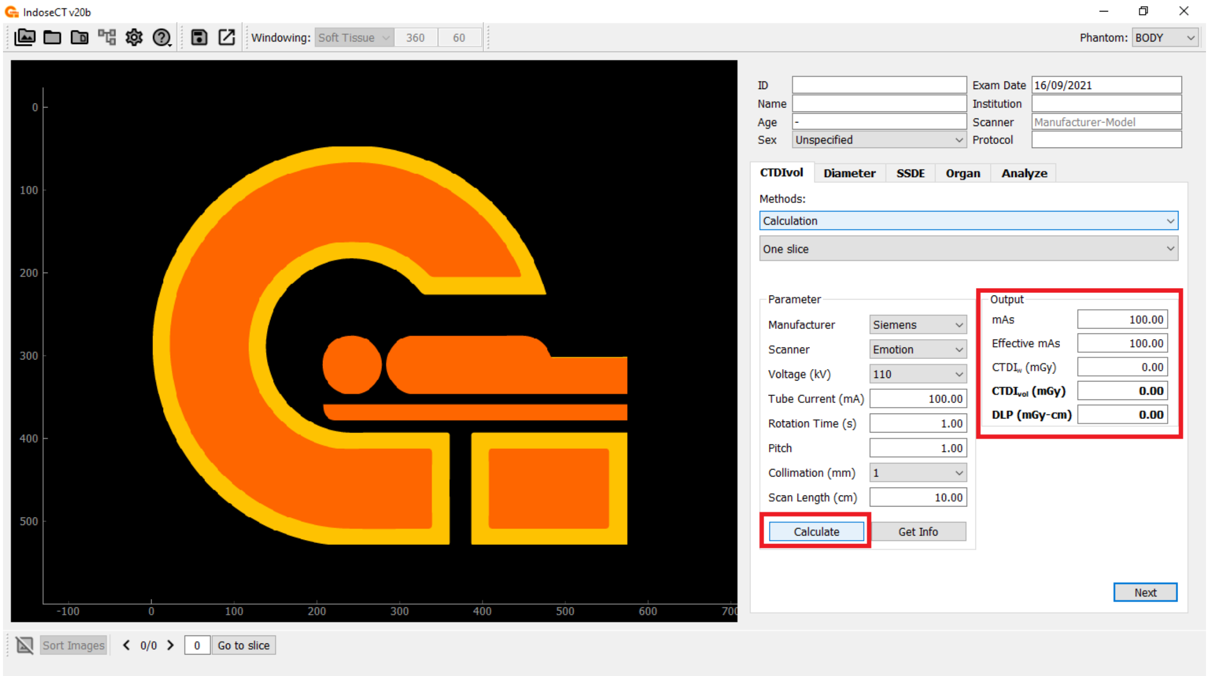

Figure 48. CTDI$_{vol}$ and DLP calculation results for Siemens Emotion.

Figure 49. Input parameter values are retrieved from DICOM Info with the **Get Info** button to calculate CTDI$_{vol}$.

For CT applications using the tube current modulation (TCM) technique, the **Tube Current (mA)** is not known at the beginning of scanning. The value of tube current (mA) varies greatly along the z-axis and is determined during scanning based on the patient's scout image (scanogram or localizer). If a patient image is available, the **Tube Current (mA)** value can be extracted from the DICOM info for the patient image. This **IndoseCT** software has also been equipped with a feature to extract these varied mA values, namely by pressing the **Get Info** button.

b. Z-axis option

In order to display the tube current rating (mA) info and calculate the $CTDI_{vol}$ value along the longitudinal-axis, the **Z-axis mode** option must be selected **(Figure 50**).

When **Z-axis mode** is selected there are three options, namely **Slice Step**, **Slice Number**, and **Regional** (**Figure 50**). If **Slice Step** is selected and the field is filled with 1, it means that the $CTDI_{vol}$ value is calculated from all slices. If the field is filled with 2, it means that the $CTDI_{vol}$ value is calculated from the 1st slice, then the 3rd slice, then the 5th slice, and so on.

If **Slice Number** is selected and the field is filled with 1, it means that the $CTDI_{vol}$ value is calculated from the (single) middle slice. If the field is filled with 3, it means that the $CTDI_{vol}$ value is calculated from one slice in the middle, one slice at position 1/3 from the beginning, and one slice at position 1/3 from the end.

Meanwhile, if **Regional** is selected, then we can specify a slice to start (e.g. the 15th slice) and a slice to end (e.g. the 25th slice). **Regional** selection is very useful for estimating the dose of organs located at certain positions. It has been reported from several studies that organ dose estimation using $CTDI_{vol}$ calculated from the regional mean is more accurate than that calculated from the average of all existing slices (Anam et al. J Biomed Phys Eng. 2021; Khatonabadi et al. Med Phys. 2013; 40(5): 051905; Bostani et al. Med Phys. 2015; 42(2): 958-968).

Figure 50. Z-axis mode for calculating tube current values (mA) and $CTDI_{vol}$ along the longitudinal axis for the TCM technique. Tube current rating (mA) is taken from the DICOM info.

The tube current profile graph and $CTDI_{vol}$ can be displayed by selecting **Show $CTDI_{vol}$ Graph** and **Show mA Graph** (**Figure 50**). The two graphs can be displayed simultaneously or separately. After all the options are determined, the **Calculate** button is pressed, and the tube current (mA) (**Figure 51**) and $CTDI_{vol}$ values will automatically be displayed along the longitudinal-axis (**Figure 52**). The average value is filled in the **Tube Current (mA)** and **CTDI$_{vol}$ (mGy)** fields.

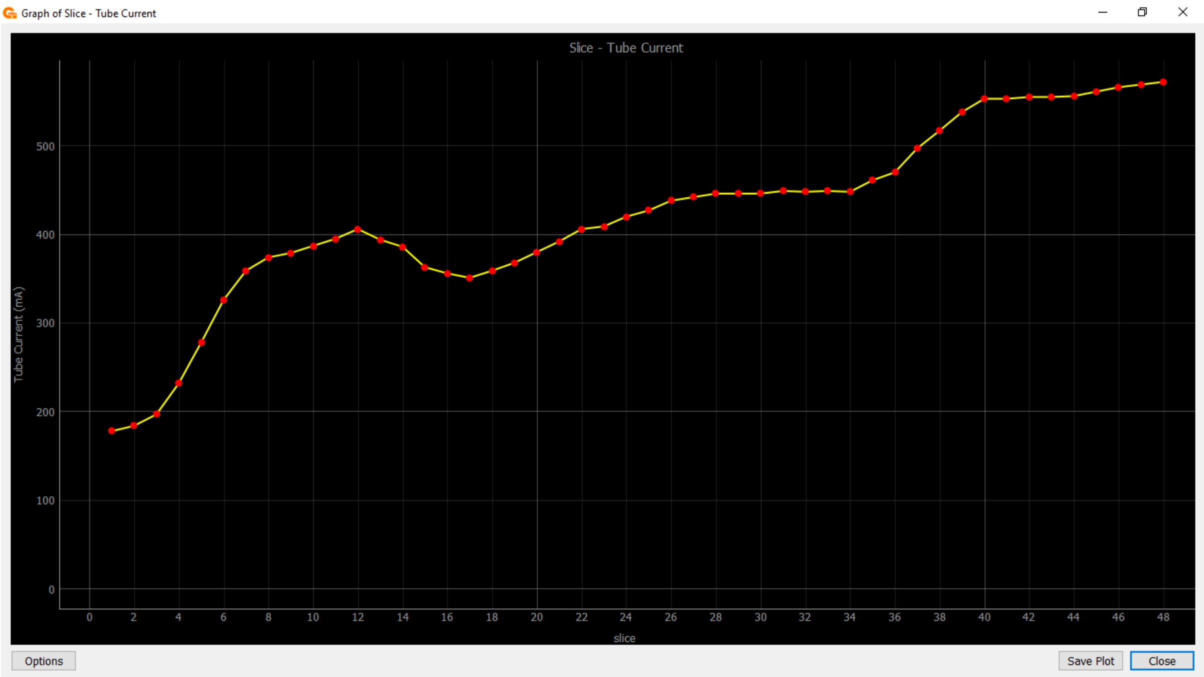

Figure 51. Graph of tube current profile (mA) along the longitudinal axis for the TCM technique. This tube current (mA) is extracted from the DICOM info of patient image.

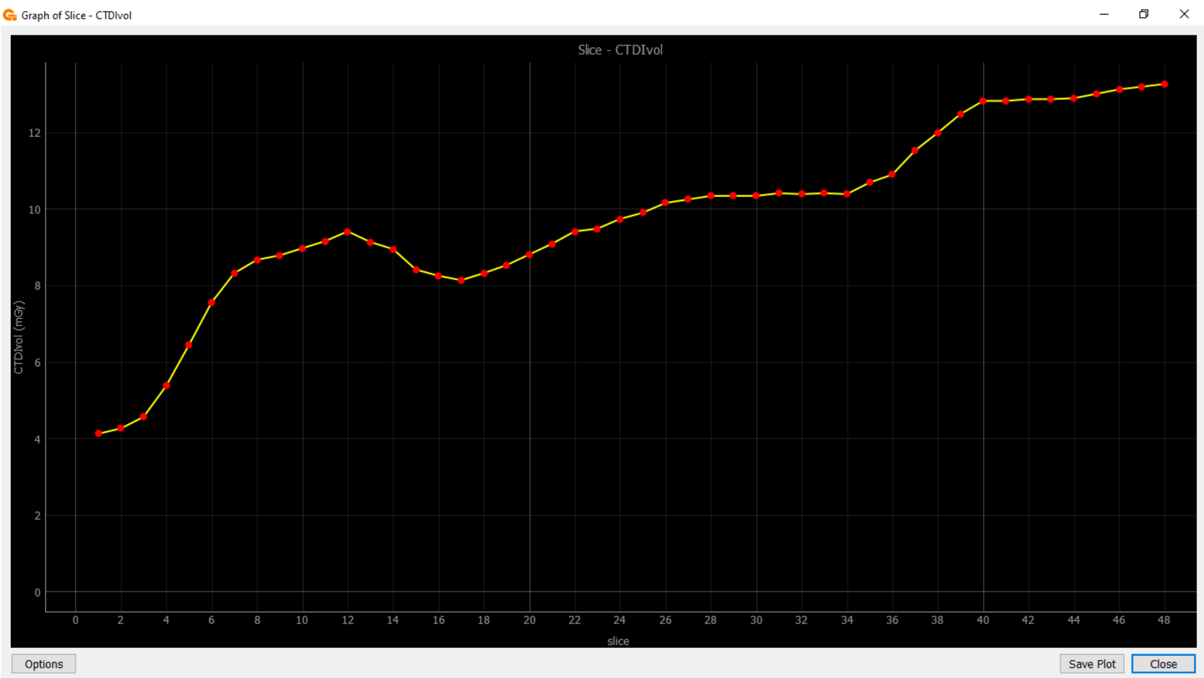

Figure 52. Graph of the CTDI$_{vol}$ (mGy) profile along the longitudinal axis for the TCM technique.

The average tube current (mA) value and its standard deviation can be displayed on the graph by pressing the **Option** button. Then proceed by selecting the **Mean** and **Standard Deviation** of the y-data value. The $CTDI_{vol}$ (mGy) profile graph with the mean and standard deviation is shown in **Figure 53**.

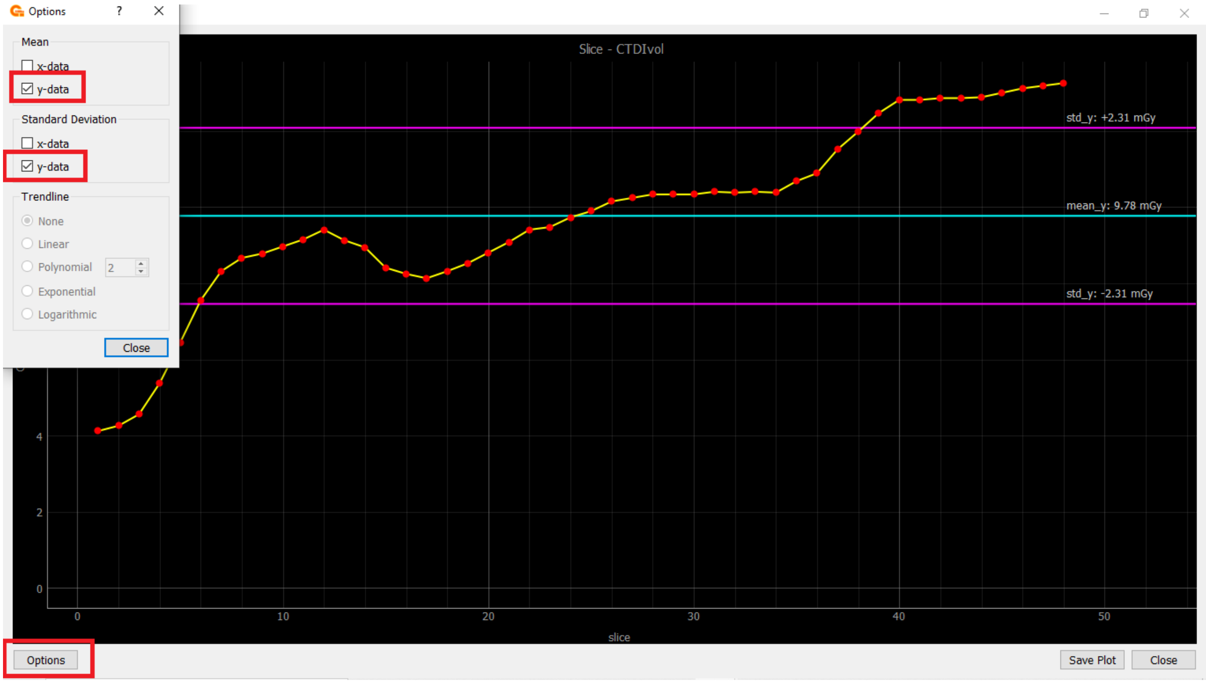

Figure 53. Graph of the CTDIvol (mGy) profile along the longitudinal axis for the TCM technique with the mean and standard deviation lines.

The x-axis and y-axis of the profile graph can be set by the user to the minimum and maximum values. Right-click on the graph, then highlight the x-axis or y-axis, then the minimum and maximum values can be determined manually to make the graph look optimal. The tube current graph (mA) for which the minimum value of the y-axis has been set to **100 mA** is shown in **Figure 54**.

The resulting graph can be saved (**Save Plot**) in several formats. Write file name, and select **Save as type** to choose **PNG**, **TIFF**, **JPEG**, **Bitmap**, **Scalable**, **Comma-Separated Value**, or **Microsoft Excel Workbook** (**Figure 55**).

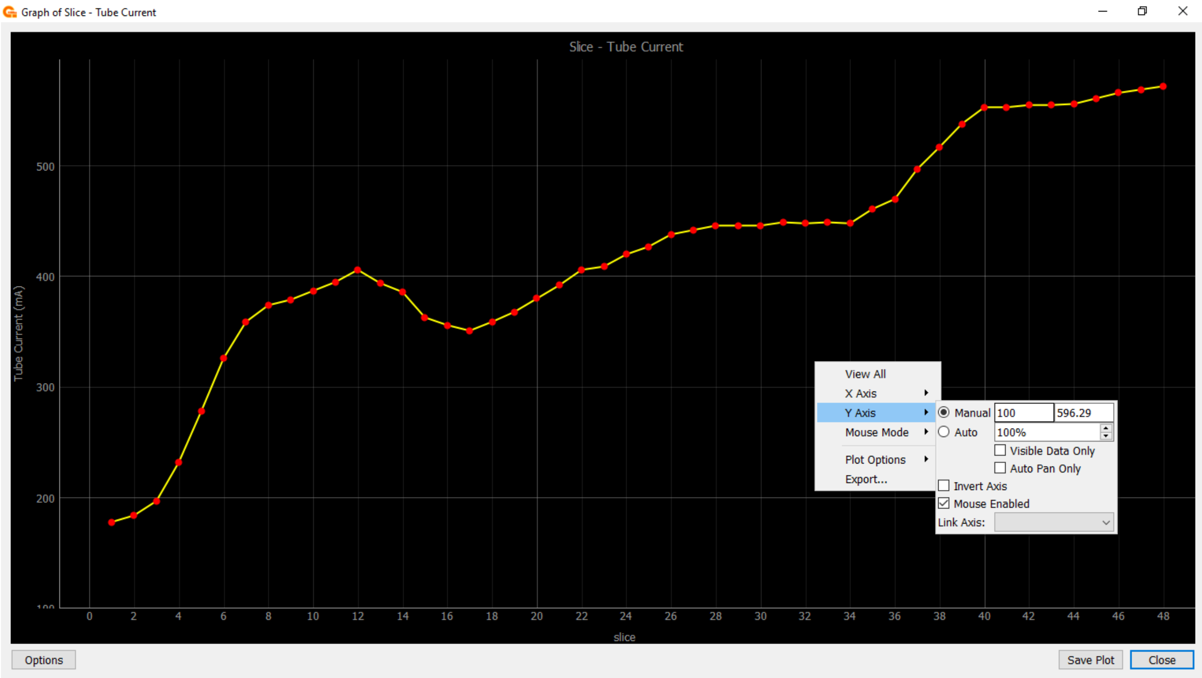

Figure 54. Graph of tube current (mA) where the minimum value of the y-axis has been changed to **100 mA**.

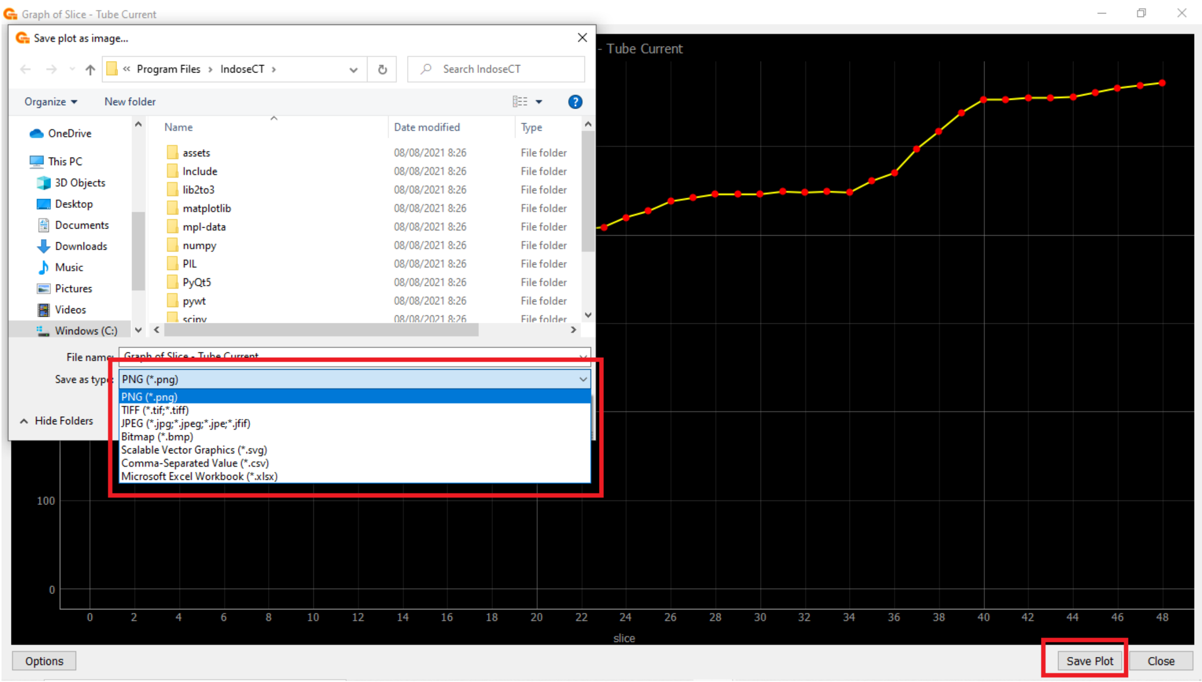

Figure 55. Options for saving tube current profiles and $CTDI_{vol}$ along the longitudinal, by selecting Save as type.

An example of a Microsoft Excel data/file from a $CTDI_{vol}$ profile along the longitudinal-axis is shown in **Figure 56**. We can then manipulate the data in Microsoft Excel as needed.

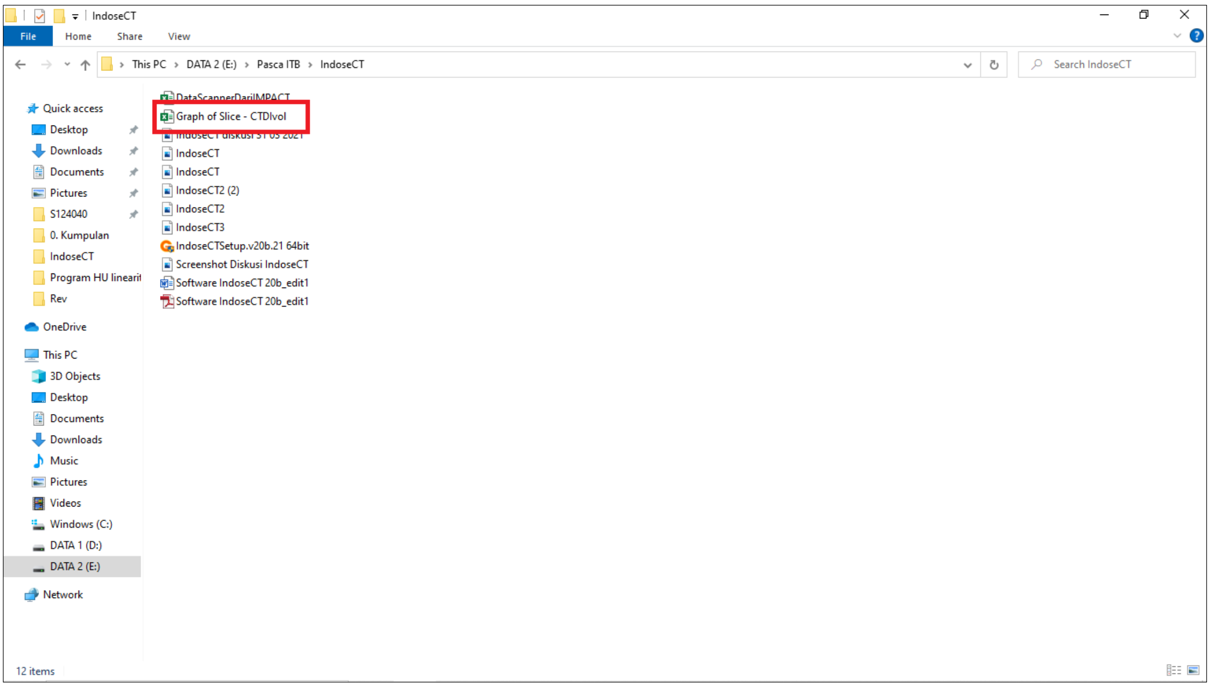

Figure 56. Example Microsoft Excel file of a $CTDI_{vol}$ profile along the longitudinal axis.

5.3 From DICOM info

For the latest CT devices, usually $CTDI_{vol}$ is already stored in DICOM info. In this case, the $CTDI_{vol}$ value can be directly taken from the DICOM info, and the DLP value is calculated as the product of the $CTDI_{vol}$ value and the scan length (L). The scan length itself is calculated as the distance between the slice location for the last slice minus the slice location for the first slice, then add the beam width.

a. One slice

To extract $CTDI_{vol}$ from the DICOM info select **Get from DICOM** from the options. Choose whether only one slice (**One slice**) or **Z-axis**.

For **One slice**, press the **Calculate** button (**Figure 57**), and the $CTDI_{vol}$ value will be obtained for that slice **(Figure 58**).

If the $CTDI_{vol}$ value is already available in the DICOM info, **Get from DICOM** option is very straightforward. However, in reality, not all DICOM info stores $CTDI_{vol}$ values. If the DICOM info does not store the $CTDI_{vol}$ value, then **IndoseCT** will assign a value of 0 to $CTDI_{vol}$ (**Figure 58**). Thus, we must use one of the other two options to obtain the $CTDI_{vol}$ value.

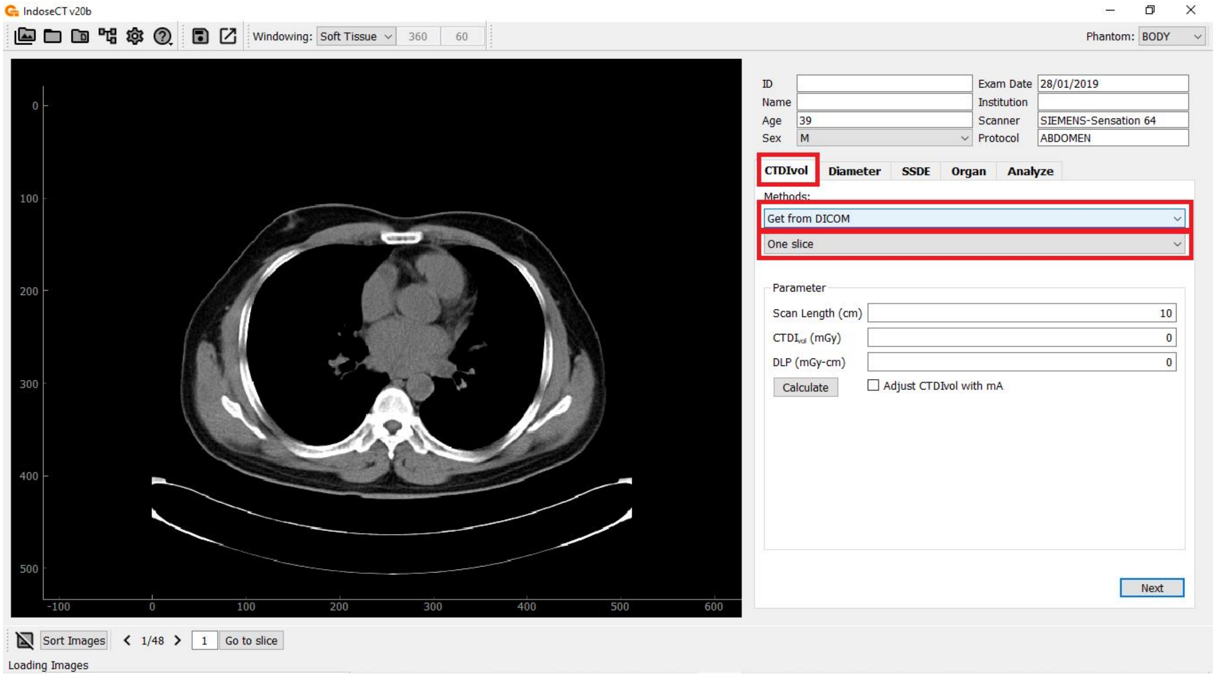

Figure 57. The option selected for calculation on the visible slice is **One slice**. After that proceed by pressing the **Calculate** button.

Figure 58. For **One slice** mode, the $CTDI_{vol}$ value in the slice is obtained.

Figure 59. If DICOM info does not store the CTDI_{vol} value, then **IndoseCT** will assign a value of 0 to CTDI_{vol} and DLP.

In the TCM technique, the tube current (mA) varies for each slice, causing the CTDI_{vol} value to vary also. In reality, not all CTDI_{vol} values when using the TCM technique will vary according to the tube current value. For this situation, the CTDI_{vol} value can be adjusted by selecting **Adjust CTDI_{vol} with mA** (**Figure 60**).

Figure 60. Not every CT machine that uses the TCM technique produces a CTDI_{vol} value that follows the tube current value. For this situation, the CTDI_{vol} value can be adjusted by selecting **Adjust CTDI_{vol} with mA.**

b. Z-axis option

To find out whether the CTDI$_{vol}$ that applies to TCM has been adapted or not, select the **Z-axis** option. There are then three further options, namely **Slice Step**, **Slice Number**, and **Regional** (**Figure 61**). **Figure 61** shows that the CTDI$_{vol}$ value on the **Siemens Somatom 64** already follows the current value (mA).

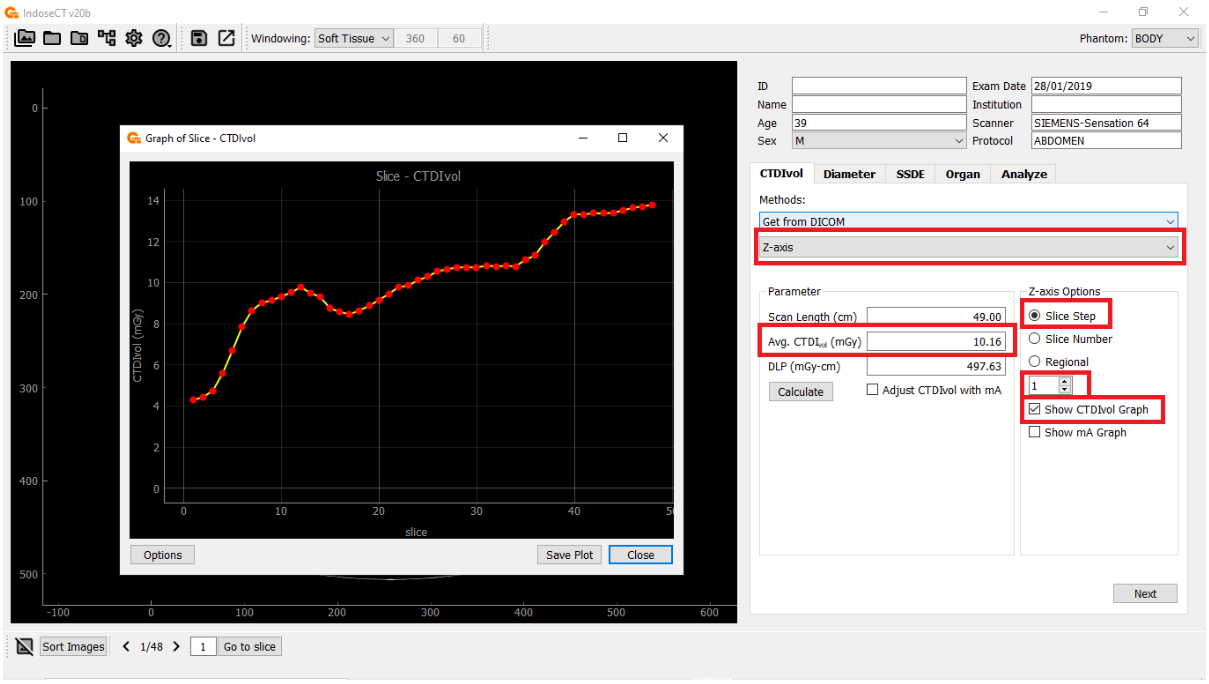

Figure 61. The CTDI$_{vol}$ value on the **Siemens Somatom 64** has been adjusted to the current value (mA).

Figure 62 shows that the CTDI$_{vol}$ value on the Toshiba Aquilio 128 does not follow the tube current value (mA), even though this CT machine uses the TCM technique. In **Figure 62**, the CTDI$_{vol}$ must be adjusted to the tube current value, namely by selecting **Adjust CTDI$_{vol}$ with mA**. When this is done, the CTDI$_{vol}$ value automatically fluctuates according to the tube current value (mA) (**Figure 63**).

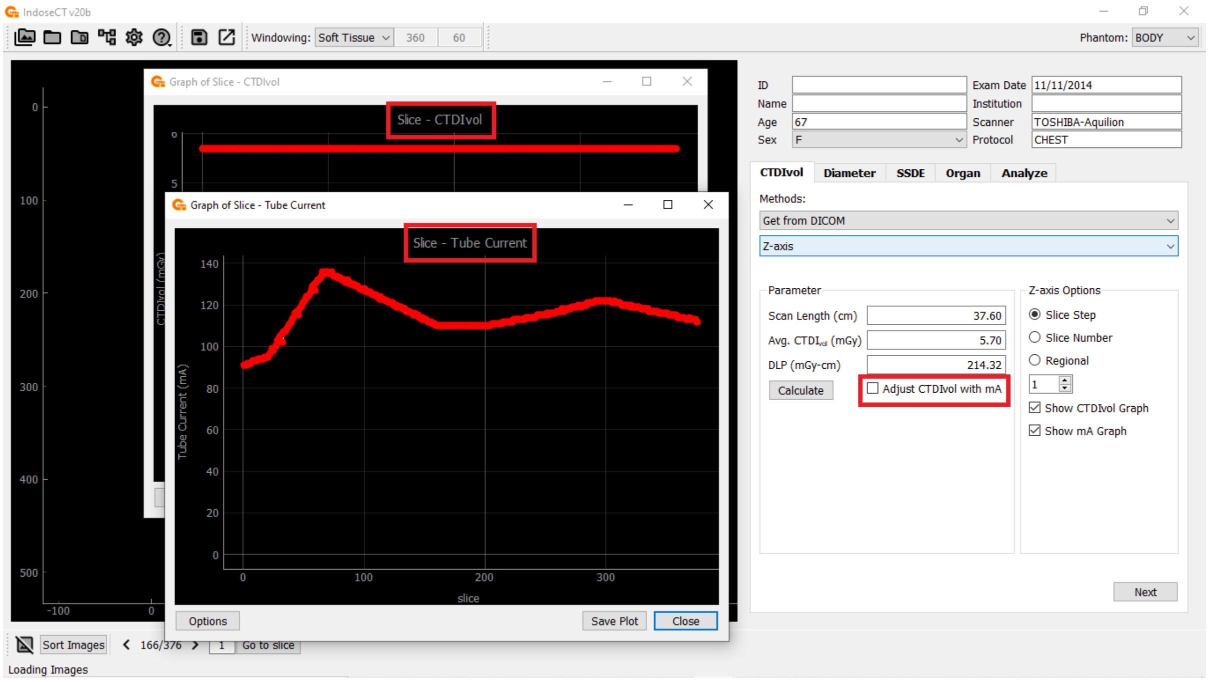

Figure 62. The CTDI$_{vol}$ value on the Toshiba Aquilio 128 has not been pre-adjusted to the tube current (mA) value.

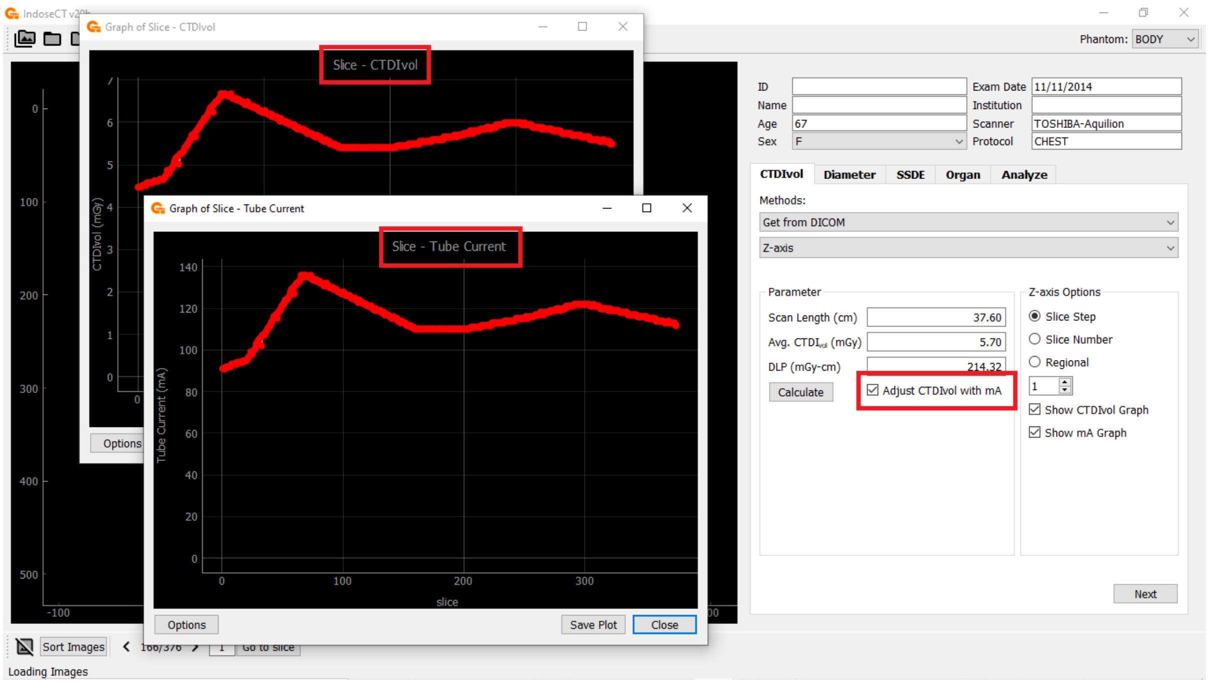

Figure 63. By selecting **Adjust CTDI$_{vol}$ with mA**, the CTDI$_{vol}$ value in the use of TCM which initially did not follow the tube current (mA) now fluctuates according to the tube current value (mA).

If the CTDI$_{vol}$ and DLP values have been filled in (using one of the three methods described, namely: **Calculation**, **Get from DICOM**, and **Input Manually**), then the user can proceed to the second stage, which is calculation of the effective diameter (D$_{eff)}$ or water-equivalent diameter (D$_{w)}$.

Note: The $CTDI_{vol}$ values obtained are based on two phantom sizes, i.e. either a phantom body (with a diameter of 32 cm) or a head (with a diameter of 16 cm). When determining the $CTDI_{vol}$ and DLP values, we must also carefully select the phantom type (phantom size) by selecting the **Phantom** option in the upper right corner. For $CTDI_{vol}$ values obtained automatically on the image, the phantom type has also been filled in automatically. However, the user needs to do double-check to ensure this selection. Incorrect selection of this type of phantom can result in a very large error in the estimated dose value.

VI. CALCULATION OF EFFECTIVE DIAMETER (D_{eff})

In principle, there are two types of diameter used to calculate the radiation dose received by the patient, namely the effective diameter (D_{eff}) and the water-equivalent diameter (D_w). The earlier D_{eff} is used for patient dose estimation, while D_w was introduced later and is more accurate. D_{eff} only takes into account the patient's geometry, while D_w takes into account the geometry and attenuation of the organ (organ composition) simultaneously.

IndoseCT can be used to calculate both D_{eff} and D_w. Select the **Diameter** tab, and choose either D_{eff} or D_w, as shown in **Figure 64**. (In this chapter, we will focus on discussing how to determine D_{eff}, then in the next chapter we will discuss on how to determine D_w).

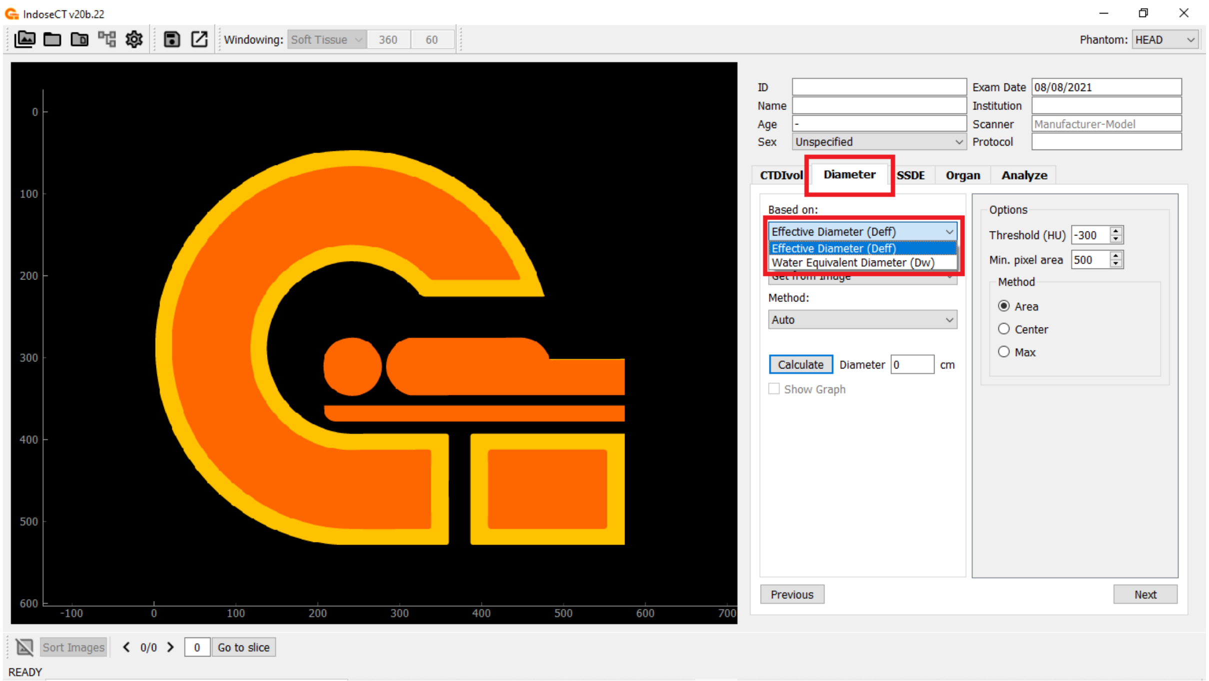

Figure 64. To calculate the diameter, select the **Diameter** tab. There are two types of diameter that can be used, namely the **effective diameter (D_{eff})** and the **water equivalent diameter (D_w)**.

To calculate the D_{eff}, there are two main options, namely the value is entered manually (**Input Manually**) or calculated from the image (**Get from Image**) as shown in **Figure 65**.

If the D_{eff} value is entered manually, the user should already have some patient data, such as AP diameter, LAT, AP+LAT, or patient age. Otherwise, if the D_{eff} value is taken from the image, the patient image in DICOM format must have been opened (how to open it has been discussed in the previous chapter).

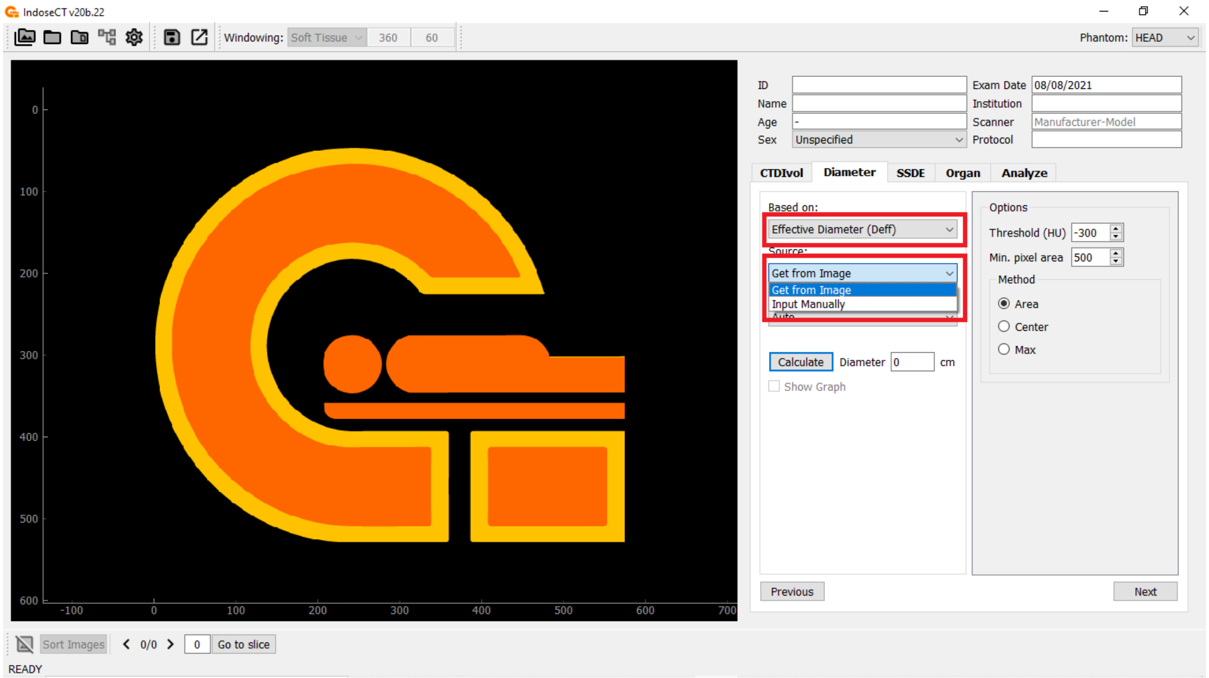

Figure 65. There are two main options for calculating D_{eff}, namely the value is entered manually (**Input Manually**) or calculated from the image (**Get from Image**).

6.1 Manual calculation

D_{eff} value can be calculated manually by selecting the menu option of **Input Manually**. There are five options for **Input Manually** (**Figure 66**).

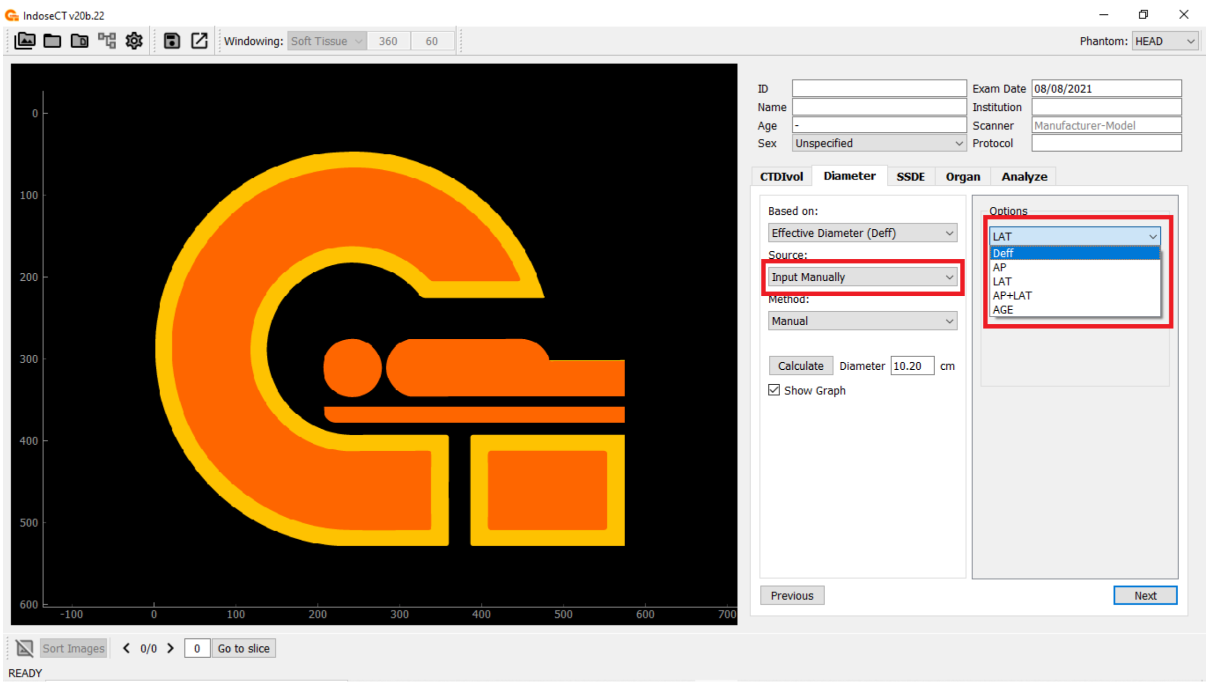

Figure 65. There are five options for calculating D_{eff} manually, using the diameter of **D_{eff}**, **AP**, **LAT**, **LAT+AP**, and **AGE**.

a. Input D_{eff} manually

If the user already has a D_{eff} value, then the D_{eff} value can be directly inputted to **IndoseCT**. In this method, no calculation is actually carried out. The steps are as follows (see **Figure 67**)

- Select **Input Manually** option**.**
- Select **D_{eff}** option.
- Fill in the value for the patient
- Press the **Calculate** button.

The D_{eff} value will be displayed in the **D_{eff} (cm)** box and visualized in a graph.

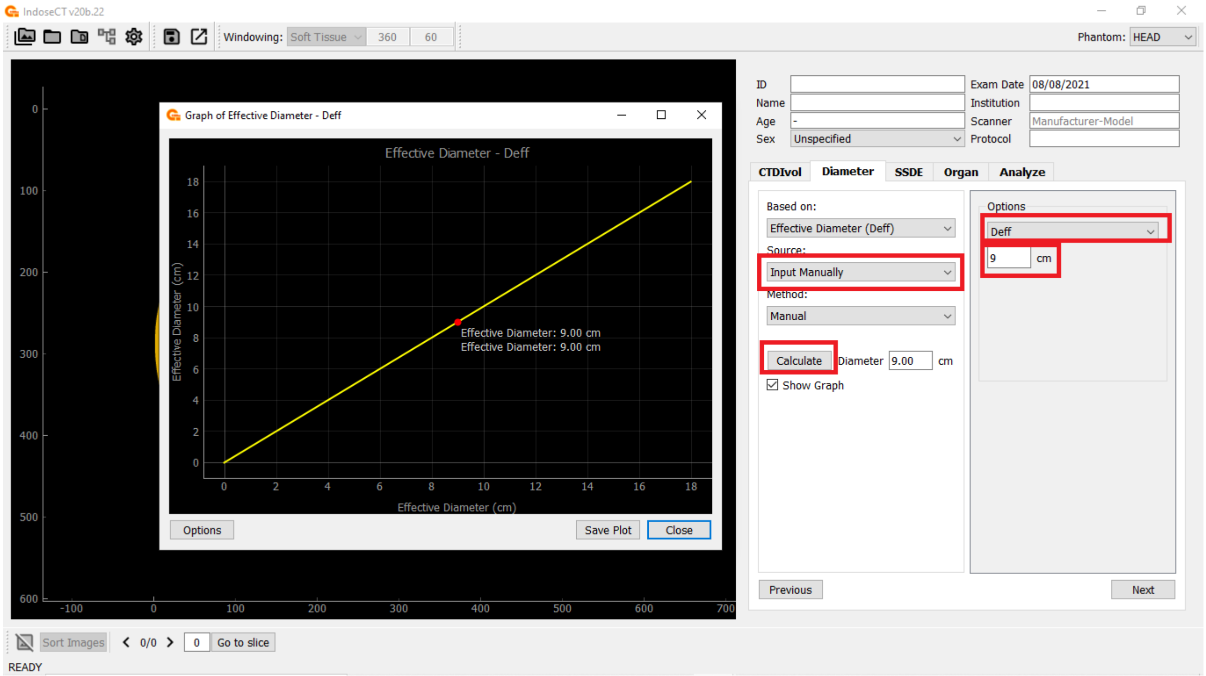

Figure 67. The display for inputting the D_{eff} value and the result. D_{eff} graph is shown with red dot.

b. D_{eff} calculation from AP diameter

To calculate the effective diameter (D_{eff}) from the AP diameter (see **Figure 68**):

- Select **Input Manually** option**.**
- Select **AP** option.
- Fill in the patient's AP diameter. (In this case, set the diameter value is set at 10 cm).
- Click **Calculate** button

The D_{eff} value will be calculated and the result will be displayed in the **D_{eff} (cm)** box, which is 11.60 cm. In this case, it is also displayed visually with graphics. The x-axis shows AP with a size of 10 cm, and the y-axis shows a D_{eff} with a size of 11.60 cm.

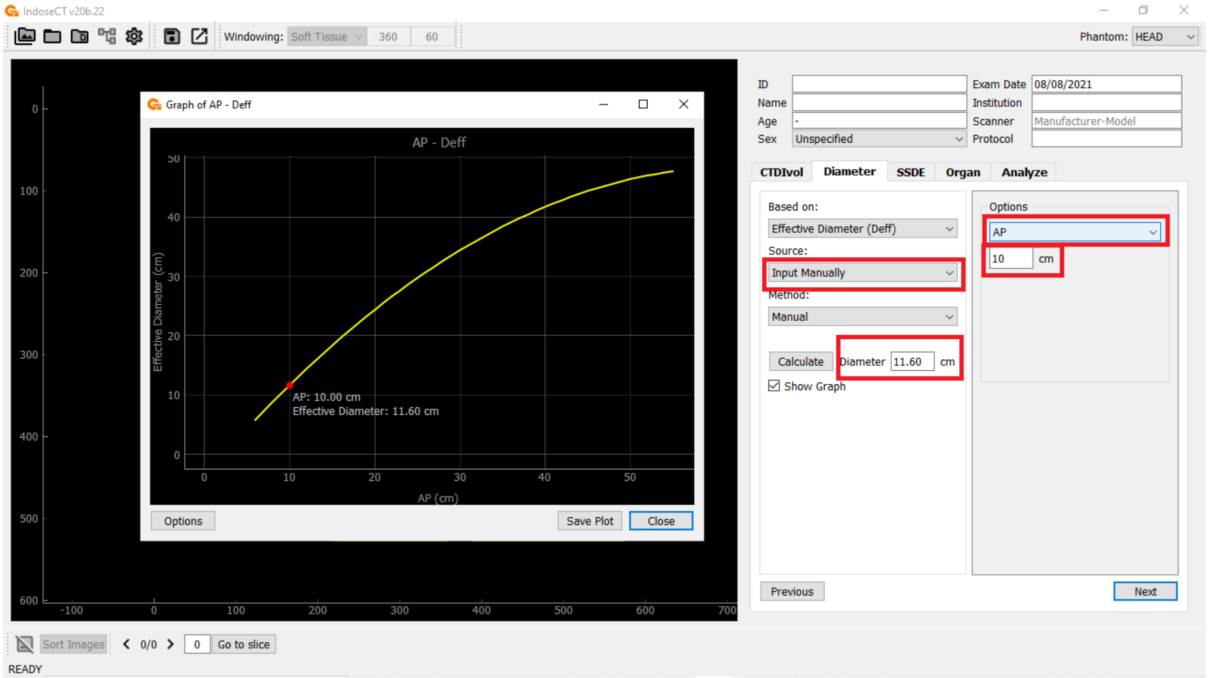

Figure 68. The display of the D$_{eff}$ calculation from the AP diameter. The D$_{eff}$ value in graph is shown by a red dot.

c. D$_{eff}$ calculation from LAT diameter

Calculate the D$_{eff}$ of the LAT diameter as follows (see **Figure 69**):

- Select **Input Manually** option**.**
- Select **LAT** option.
- Fill in the patient's LAT diameter. In this example, it is filled with 10 cm.
- Press the **Calculate** button**.**

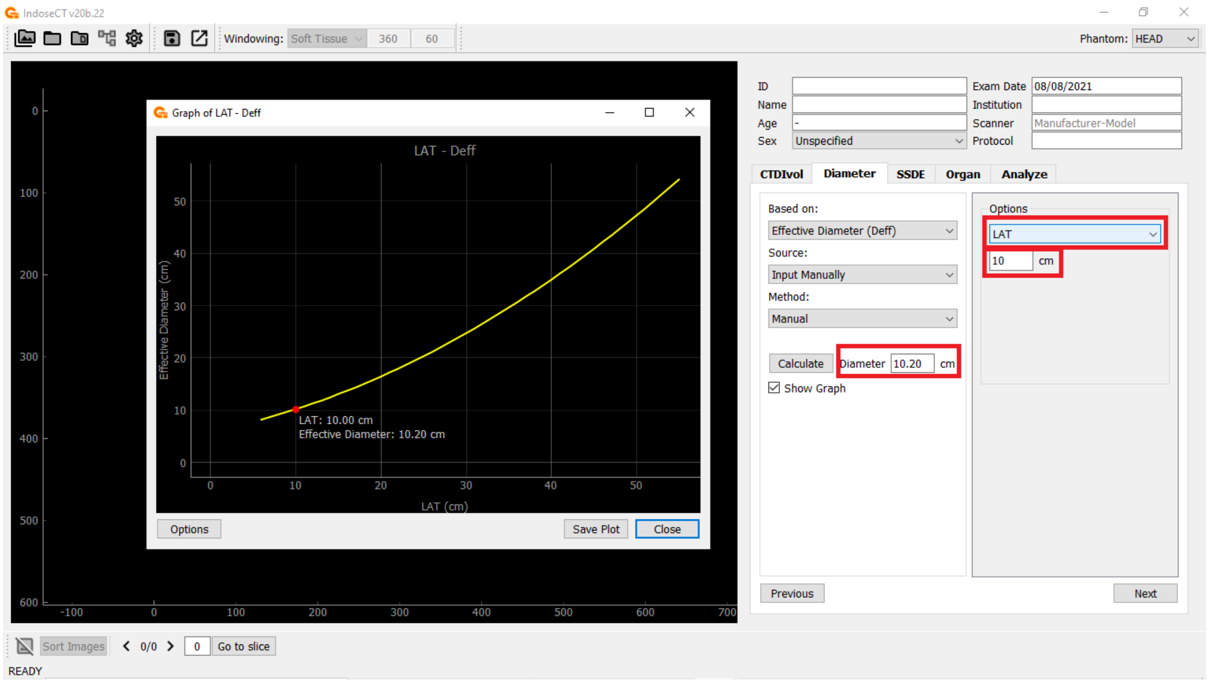

Figure 69. The display for the D$_{eff}$ calculation from the LAT diameter. The red dot in a graph shows the D$_{eff}$ value**.**

After that, the D_{eff} value is calculated, and the results are displayed in the **D_{eff} (cm)** box, which is 10.20 cm. In this case, it is also displayed visually with graphics. The x-axis shows LAT with a magnitude of 10 cm, and the y-axis shows a D_{eff} with a size of 10.20 cm.

d. D_{eff} calculation from AP+LAT diameter

Calculate the D_{eff} from the AP+LAT diameter as follows (see **Figure 70**):

- Select **Input Manually** option**.**
- Select **AP+LAT** option.
- Fill in the patient's AP diameter. In this example, it is filled with 10 cm.
- Fill in the patient's LAT diameter. In this example, it is filled with 15 cm.
- Press the **Calculate** button**.**

After that, the D_{eff} value is calculated, and the results are displayed in the **D_{eff} (cm)** box, which is 12.20 cm. In this case it is also displayed visually with graphics. The x-axis shows AP+LAT with a magnitude of 25 cm, and the y-axis shows a D_{eff} with a size of 12.20 cm.

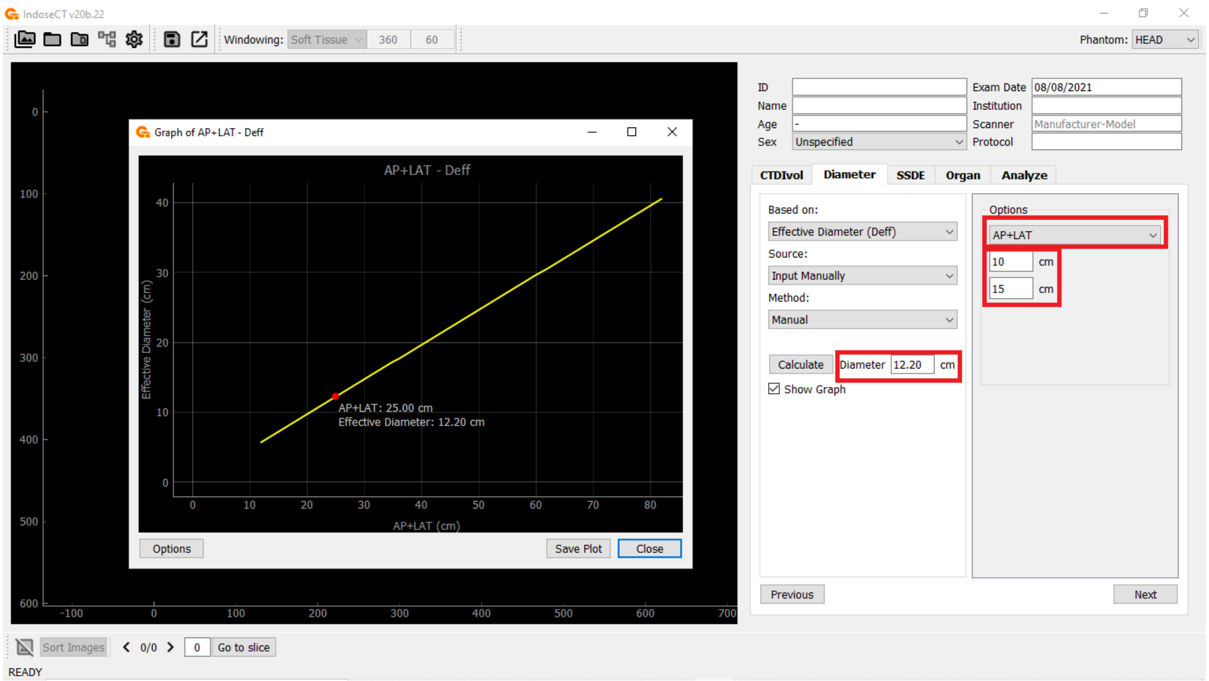

Figure 70. Display for D_{eff} calculation from AP+LAT diameter. The red dot in a graph indicates the D_{eff} value.

e. D_{eff} calculation from age

If the diameter of the patient is unknown, then the D_{eff} value can be estimated from the patient's age. However, it should be noted that the D_{eff} value based on age has a large variability. D_{eff} calculations with patient age should be avoided if possible, because its accuracy is low. Obtaining D_{eff} values from other methods is preferable.

Steps to estimate D_{eff} from the patient's age are as follows (see **Figure 71**):

- Select **Input Manually** option**.**
- Select **AGE (max 18)** option**.** In this example, it will be 5 years and 2 months.

- Fill in the patient's age in the **Year** box. Note: Maximum age is 18 years, and minimum is 0 years.
- Press the **Calculate** button.

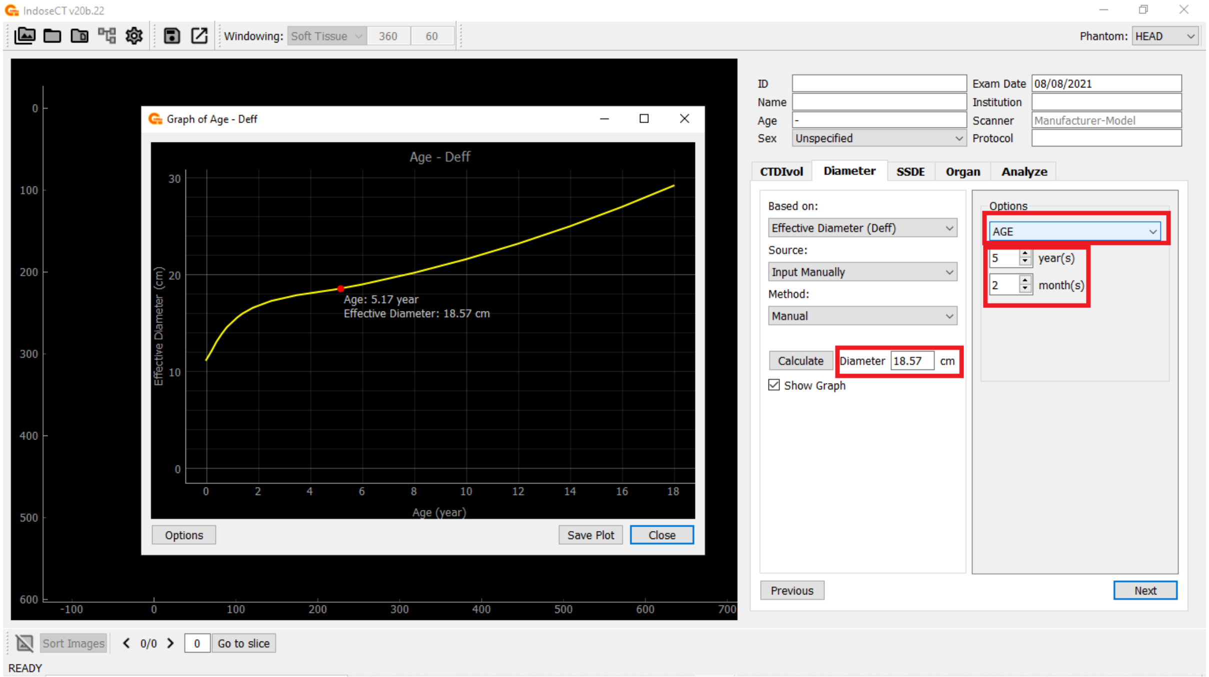

Figure 71. Display for the D_{eff} calculation of the patient's age. The red dot in a graph indicates the D_{eff} value.

After that, the D_{eff} value is calculated, and the results are displayed in the **D_{eff} (cm)** box, which is 18.57 cm. In this case, it is also displayed visually with graphics. The x-axis shows the patient's age 5.17 years (5 years 2 months), and the y-axis shows D_{eff} with a size of 18.57 cm.

Note: When calculating the D_{eff} value using age, the **Phantom** must be **the Body Phantom** (not the **Head Phantom)**

6.2 D_{eff} calculation from image

In this case, the D_{eff} value is carried out directly from the patient's axial image. The user must select **Get from Image** from the available options, after ensuring that the patient's CT image has been opened. There are three choices of methods, namely: **Manual**, **Auto**, and **Auto (Z-axis) (Figure 72)**. We will start with the **Manual** method.

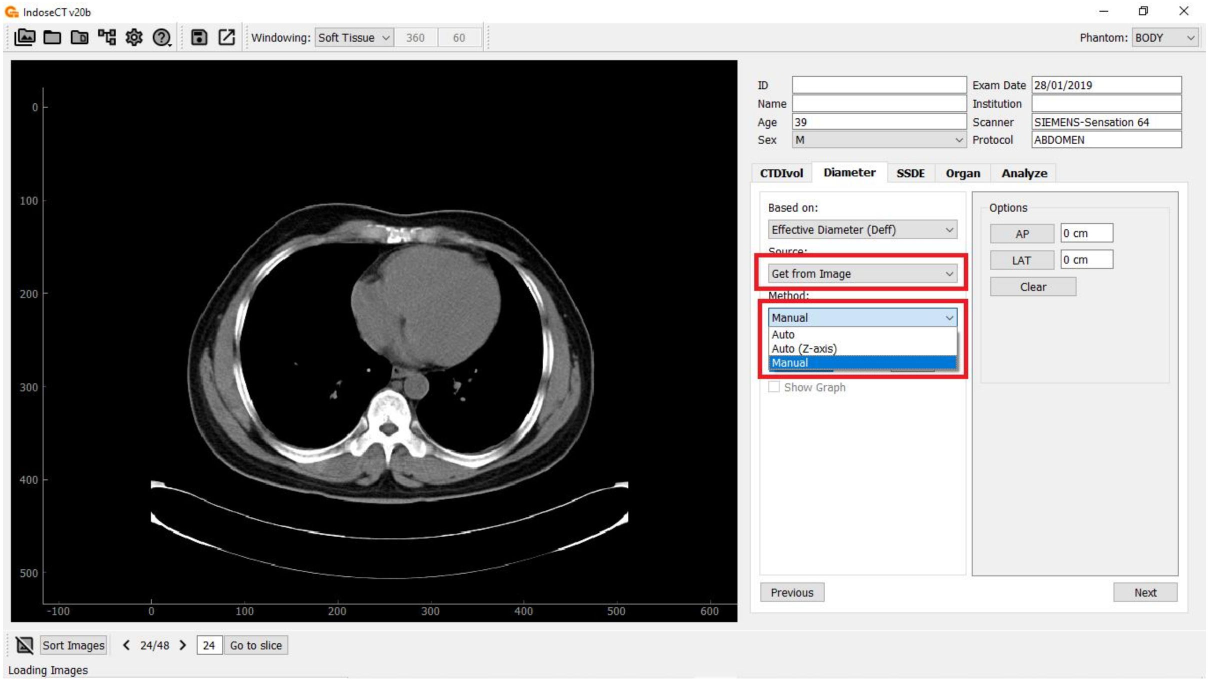

Figure 72. D_{eff} calculation from the image. There are three choices of methods, namely: **Manual**, **Auto**, and **Auto (Z-axis)**. When the user uses the **Get From Image** option menu, the patient's CT image in DICOM format must have already been opened.

a. Manual calculation

To perform a manual D_{eff} calculation from an image, steps are as follows (see **Figure 73**):

- First select **Manual** from the available options.
- Next, two buttons and two fields/in box will appear.
- Press the **LAT** button, a line will appear on the patient image in the lateral direction. We have to shift the line and make sure the left edge is on the left border of the patient image and the right end is on the right border of the patient image. If the line is in the correct position, then we will get the LAT diameter value in the **LAT** box. In this example, we get the LAT diameter as 31.31 cm.
- Press the **AP** button, a line will appear on the patient image in the AP direction. We have to shift the line and make sure the top edge is on the top border of the patient image and the bottom edge is on the bottom edge of the patient image. If the line is in the correct position, then we will get the AP diameter value in the **AP** box. In this example, we get the diameter of the AP as 22.23 cm.
- Press the **Calculate** button.

We will get the D_{eff} value in the **Diameter (cm)** box. In this example we get the D_{eff} value of 26.38 cm.

Both lines can be removed by pressing the **Clear** button. If desired, the process can be repeated again.

The weakness of this method is that it is very subjective because it depends on the user subjectivity to determine the patient limit. In this case, the appropriate window selection can be used. In certain cases, the **Fat window** may be better, and in other certain cases the **Bone window** may be better.

Figure 73. Display for calculating D_{eff} manually from a patient image.

b. Automated calculation

For automatic calculation, the user just presses one button (**Auto**), and **IndoseCT** will calculate the D_{eff} value automatically. There are 3 options for automatic, namely: **Area**, **Center**, and **Max** (**Figure 74**). **Area** is the D_{eff} value calculated from the area of the patient image that has been segmented automatically. **Center** is the D_{eff} value will be calculated based on the AP and LAT values when passing the patient's midpoint. **Max** means that the D_{eff} value is calculated based on the maximum AP and maximum LAT values (Anam et al. Atom Indonesia. 2017; 43(1): 55-60).

Calculation the value of D_{eff} with the **Area** method is as follows.

- Select **Auto**.
- Select **Area**.
- Press the **Calculate** Button.
- Wait a few moments, then the image segmentation results will be visible and the calculation results for the D_{eff} value will be displayed in the **Diameter (cm)** box (**Figure 75**). In this case, we get an effective diameter value of 28.05 cm.
- This process wills likely take less than a second.

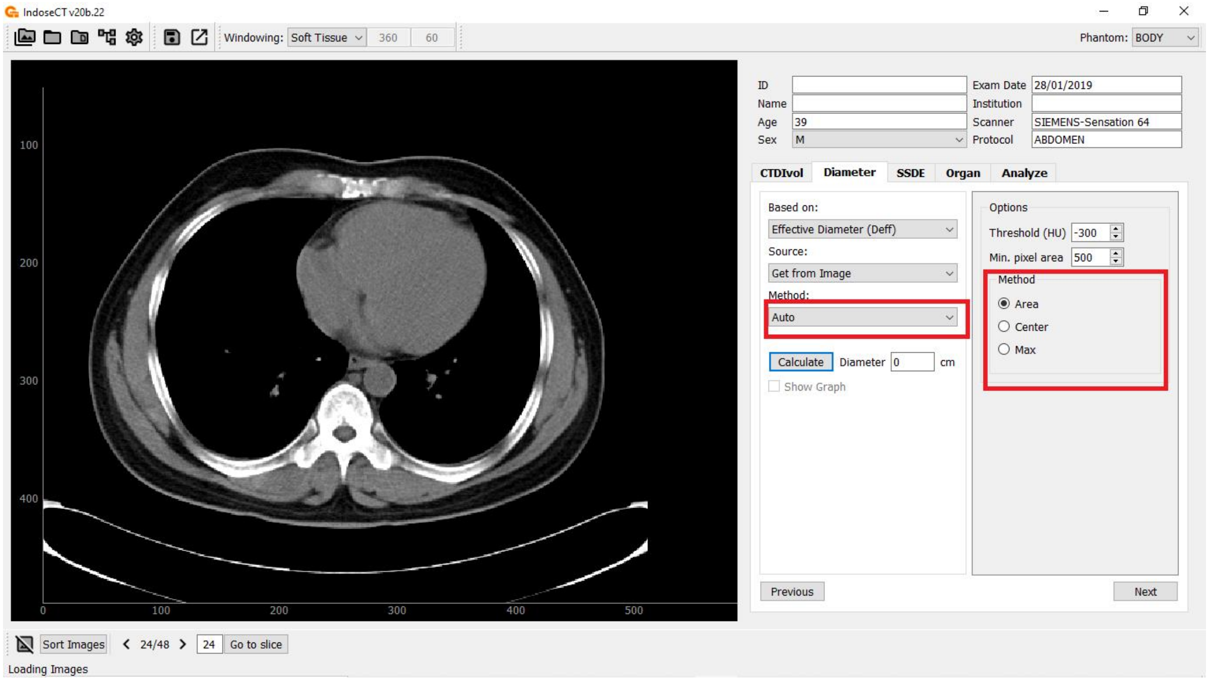

Figure 74. D_{eff} calculation with automatic calculation. There are three choices of methods, namely **Area**, **Center**, and **Max**.

In certain cases, this segmentation may not be accurate. In this case, the user can change the threshold value in HU. By default, **IndoseCT** uses a value of -300 HU. In some cases, this threshold results in a fairly good patient segmentation. However, some materials with HU around -200 HU may be included in the segmentation. To overcome this, the threshold value can be increased to -200 HU or other. Under certain conditions, the HU value may need to be lowered, for example to -500 HU.

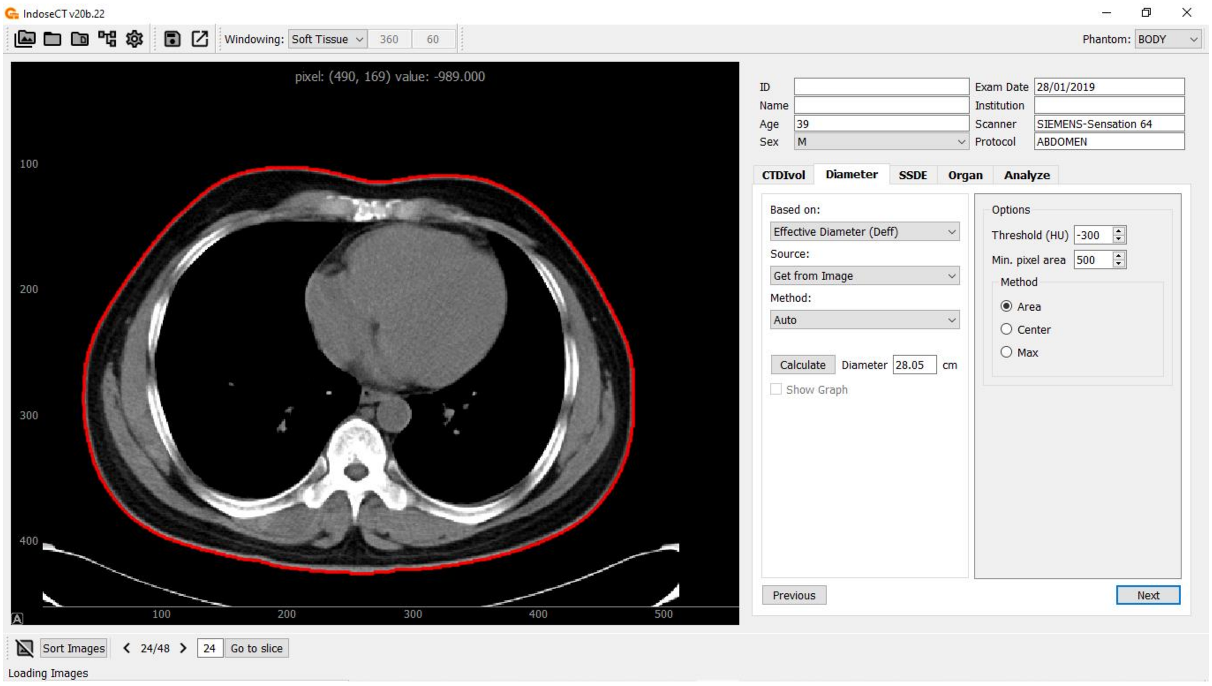

Figure 75. The display for calculating the D_{eff} automatically from a patient image using the **Area** option. The D_{eff} value obtained is 28.05 cm.

Calculating D_{eff} with the **Center** method is as follows (see **Figure 76)**.

- Select **Auto**.
- Select **Center**.
- Press the **Calculate** Button.

Wait a few moments, then the image segmentation results will be visible and the calculation results for the D_{eff} value will be displayed in the **Diameter (cm)** box (**Figure 76**). In addition to the **effective diameter** value, we will get values of **LAT** and **AP** diameters. In this example, we get a D_{eff} value of 27.10 cm. This value is generally a little smaller than using the **Area** method.

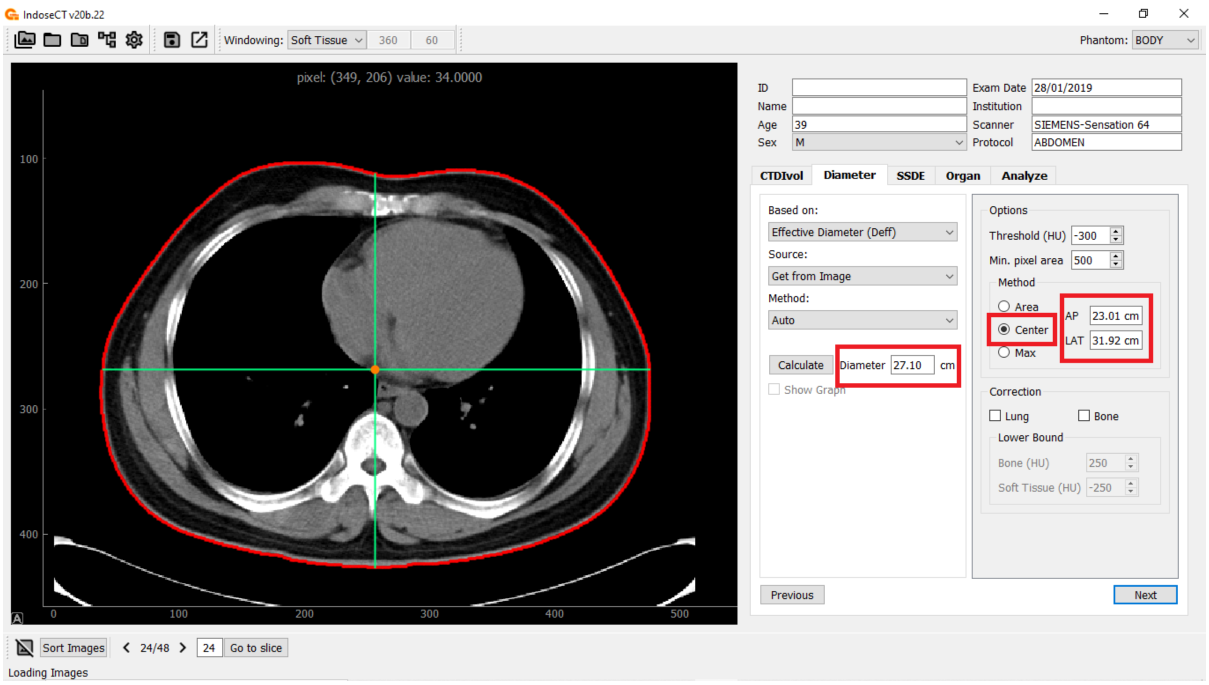

Figure 76. The display for calculating the D_{eff} automatically from a patient image using the **Center** option. The D_{eff} value obtained is 27.10 cm.

Calculating the D_{eff} value with the **Max** method is as follows (**Figure 76**):

- Select **Auto**.
- Select **Max**.
- Press the **Calculate** button.

Figure 77. The display for calculating the D_{eff} automatically from a patient image using the **Max** option. The D_{eff} value obtained is 27.42 cm.

Wait a few moments, then the image segmentation results will be visible and the calculated D_{eff} value will be displayed in the **Diameter (cm)** box (**Figure 77**). In addition to the D_{eff} value, we also get the **LAT** and **AP** values. In this example, we get a D_{eff} value of 27.42 cm. This value is closer to the **Area** method, compared to using the **Center** method.

The use of effective diameter, reported in several journals, is less accurate for patient dose estimation especially in the chest area. This is because in the chest, there are lungs whose composition is mainly air. The HU value of the lungs is about -600 HU. Thus, the water-equivalent chest diameter should be smaller than the effective diameter. This causes the dose received by the patient to be high.

In order to obtain a more accurate patient diameter and dose estimate, this effective diameter needs to be corrected. The easiest way is to correct the pixels that represent the **Lung**, with a correction factor of 0.3. However, apart from the lungs, there are also bones in the chest with HU values above +1000. **IndoseCT** also provides bone correction options. The **bone** correction factor uses a value of 1.8.

To detect lung, by default **IndoseCT** uses a threshold value of -250 HU, and to detect bone it uses a threshold value of +250 HU. These values need to be tested for accuracy with continuing research. The user can change these threshold values freely.

This lung and bone correction will only be active when we use the **Center** or **Max** options. An example of the **Center** method which uses **Lung** correction only, is shown in **Figure 78**, and one which uses **Lung** and **Bone** corrections is shown in **Figure 79**.

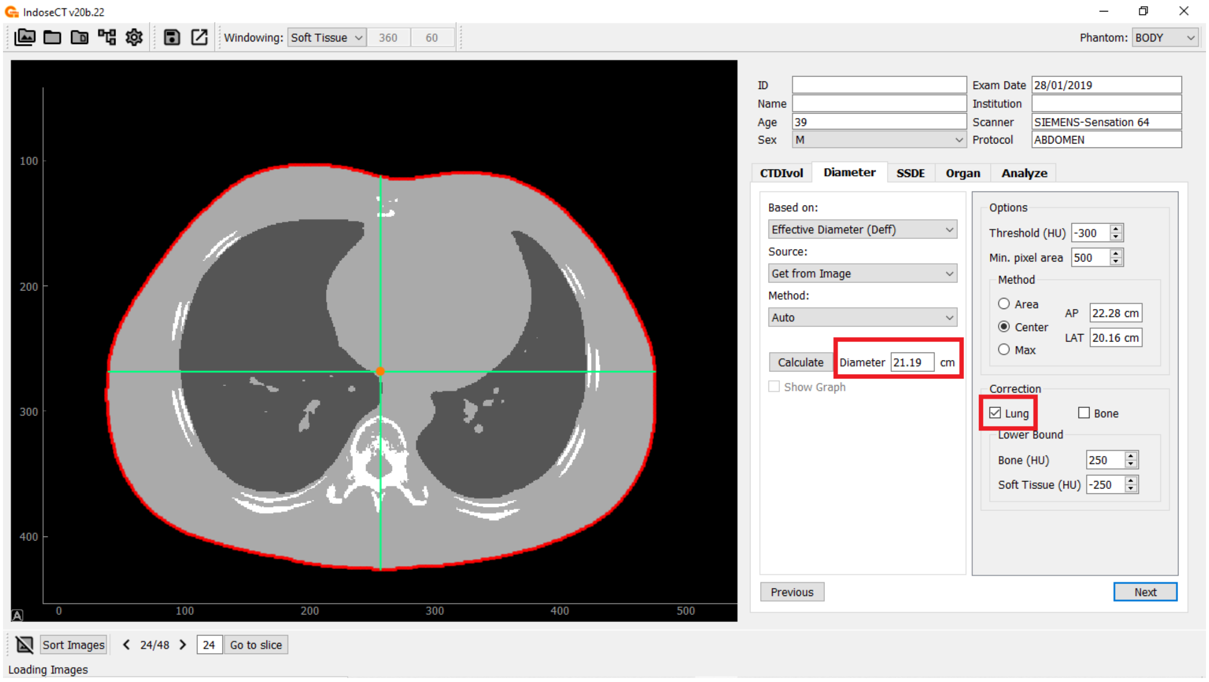

Figure 78. An example of the **Center** method using **Lung** correction. In the image there are 4 color gradations. Outside the patient has a pixel value of 0, lungs have a pixel value of 1, soft tissue has a pixel value of 2, and bones have a pixel value of 3. The D_{eff} value is 21.19 cm.

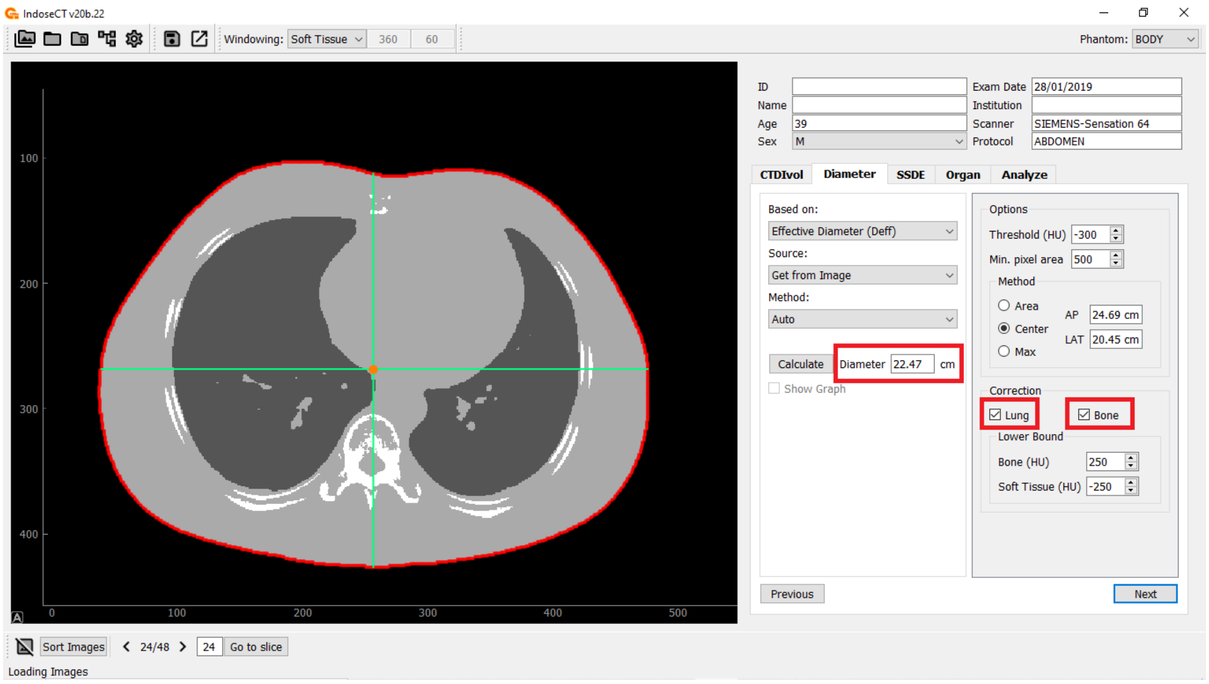

Figure 79. Example of the **Center** method using **Lung** and **Bone** corrections. The D_{eff} value is 22.47 cm.

The effective diameter value obtained is 21.19 cm, which is much smaller than without the **Lung** correction, which is 27.10 cm. The use of **Lung** and **Bone** corrections resulted in an effective diameter value of 22.47 cm, which is slightly larger than using the **Lung** correction alone. The use of **Lung** and **Bone** corrections result in a more accurate patient dose estimate.

c. Z-axis auto calculation

The D_{eff} value is different for each slice. **IndoseCT** gives the user the option to calculate D_{eff} in Z-axis (for all slices). However, the calculation may take a considerable time.

To calculate the D_{eff} of multiple slices, the steps are as follows:

- Select **Diameter** tab.
- Select **Effective Diameter (cm)** option.
- Select **Get from Image** option. For this, the image must have been opened.
- Select the **Auto (Z-axis)** option (See **Figure 80**).
- In this case there are three options: **Slice Step**, **Slice Number**, and **Regional**. The explanation of each will be discussed in the following discussion.

As with the previous **Auto** method, the **Auto (Z-axis)**, the **Area**, **Center**, and **Max** options are still applicable. In addition, if the user uses the **Center** or **Max** options, the **Lung** and/or **Bone** corrections are also still valid.

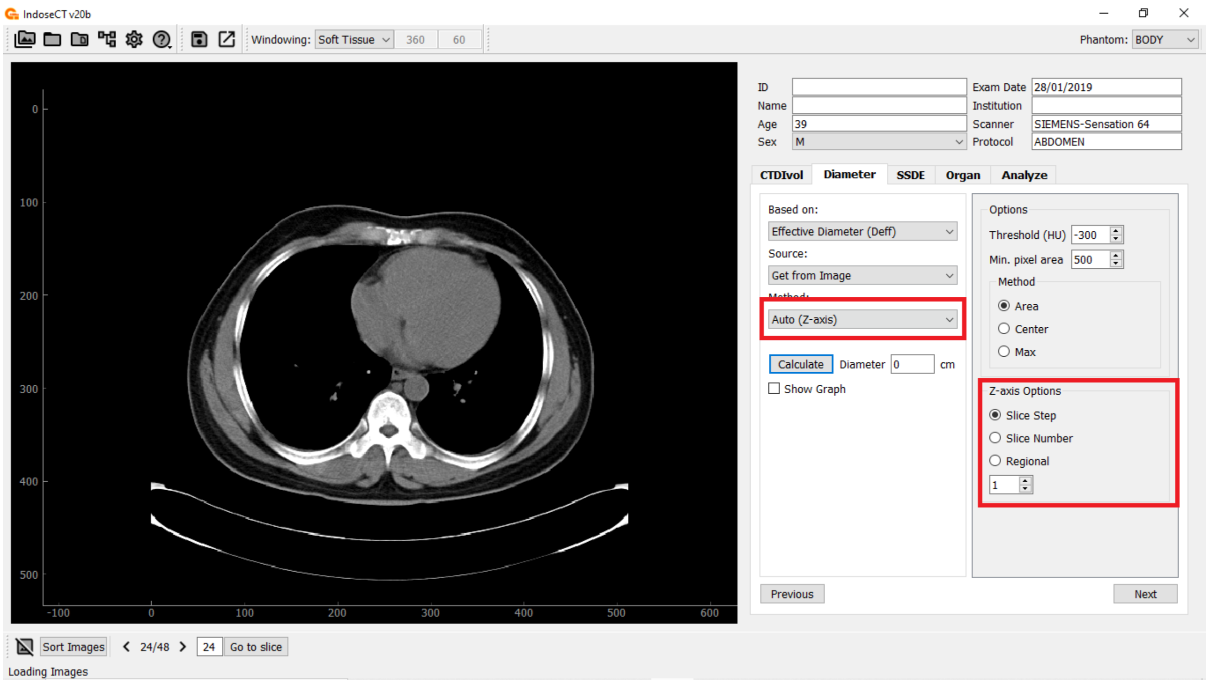

Figure 80. Auto (Z-axis) calculation preview for $D_{eff.}$ In this case, there are three choices, namely **Slice Step**, **Slice Number**, and **Regional**.

The purpose of **Slice Step** is to provide a choice of steps to use. If we select **Slice Step** and fill it with a value of 1, the D_{eff} calculation is done on the first slice, the next slice is the 2nd slice, and the next slice again is the 3rd slice and so on. Because the **Slice Step** we are using is 1, the D_{eff} will be calculated from all slices (**Figure 81**). After we fill the **Slice Step**, we can immediately click **Calculate**.

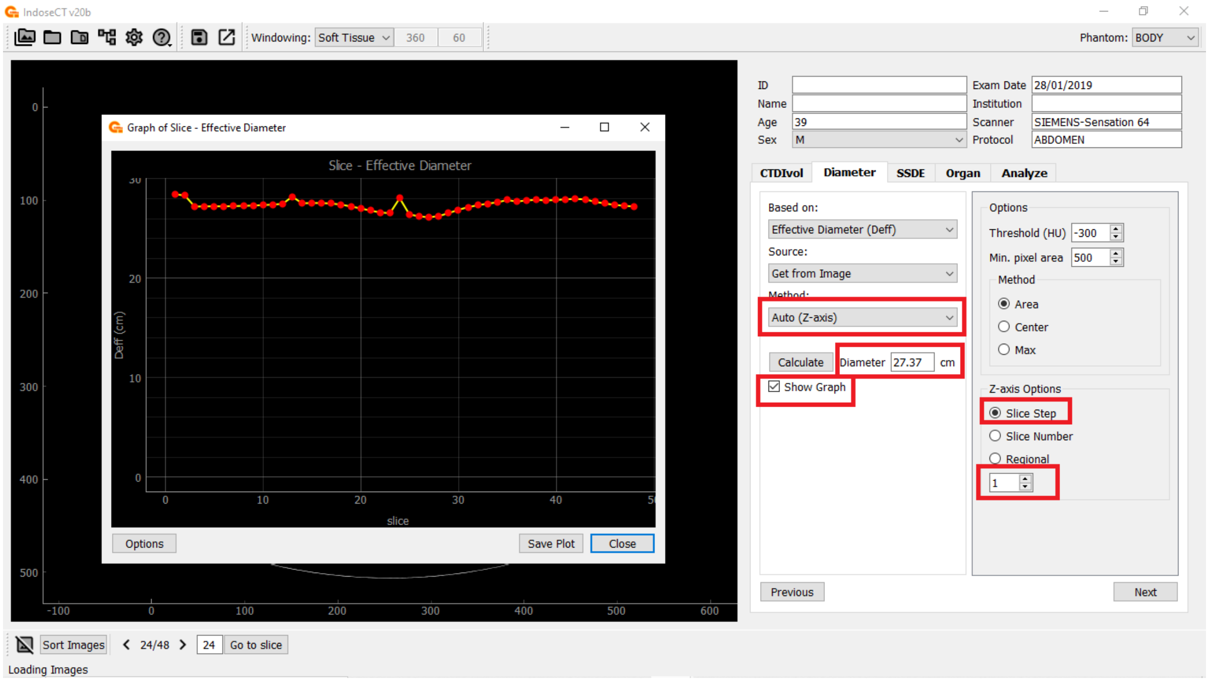

Figure 81. The D_{eff} calculation display for the **Slice Step** option equal to 1. The **Diameter (cm)** box will be filled with the average D_{eff}.

To speed up the calculation of D_{eff}, users can also use **Slice Step** 2 or other values according to the number of slices of patients. The user is advised to use a number of iterations of around 10. For example, if the number of slices is 500, the first to be counted is slice 1, then slice 11, then slice 21, and so on. By filling the **Slice Step** equal to 10, the computation time becomes around 10 times faster than using a **Slice Step** of 1.

In addition to the **Slice Step** option, there is another option to speed up computing, namely using the **Slice Number** option. If we fill the **Slice Number** with 1, then from all existing slices, only 1 slice will be counted in the middle. If we use **Slice Number** 3, D_{eff} will be calculated from 3 slices, namely the middle slice, the third slice from the left and the third slice from the right. **Figure 82** shows the choice of **Slice Number 9**, where the D_{eff} calculation is performed on 9 slices that are evenly distributed along the longitudinal axis. The slice number used to calculate the D_{eff} is shown on the graph.

Another **Auto (Z-axis)** option for calculating D_{eff} is **Regional**. In this case, user can specify a certain slice number to start (e.g. slice number 15) and specify a slice number to end (e.g. slice number 30). This **Regional** option is very useful for calculating the average D_{eff} and SSDE averages for certain organs only.

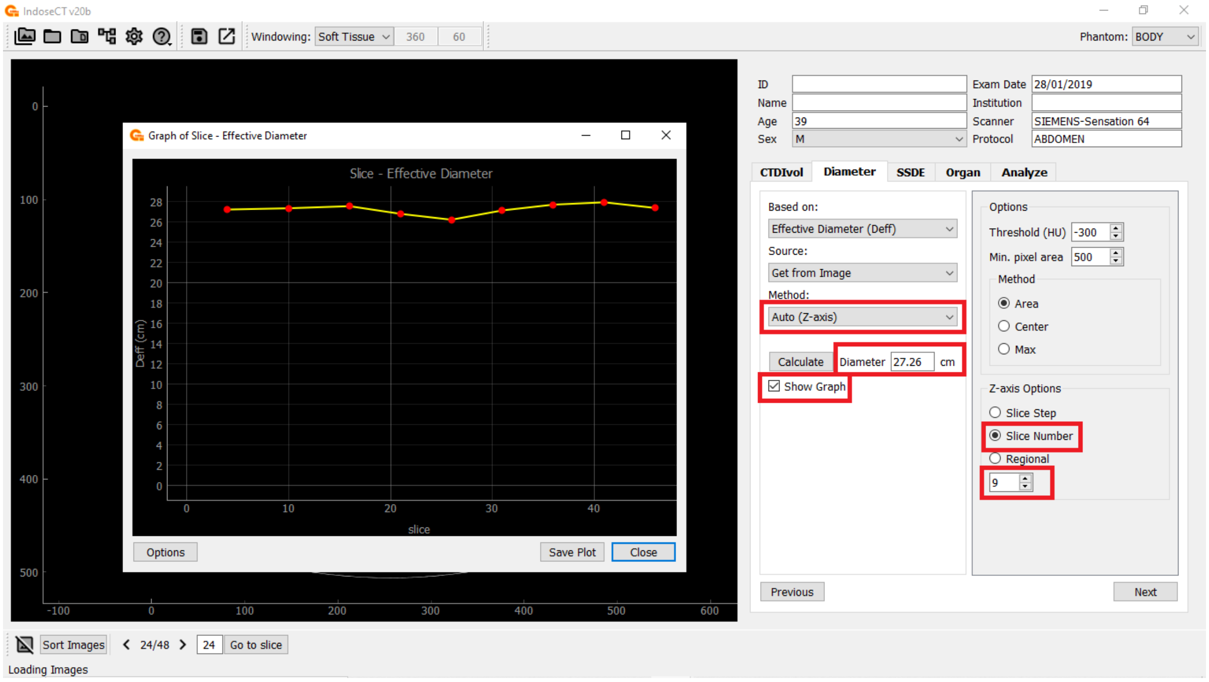

Figure 82. D_{eff} calculation for the **Slice Number** option. In this case, the **Slice Number** is filled with the number 9. The graph shows 9 points of D_{eff} value. The **Diameter (cm)** box will be filled with the average D_{eff} of these 9 values.

It has been reported by several studies that the organ dose is less accurate if estimated from the whole slice, but it is more accurate if it is estimated only on certain slices where the organ is located (Anam et al. J Biomed Phys Eng. 2021). An example of a Regional option for calculating D_{eff} is shown in **Figure 83**.

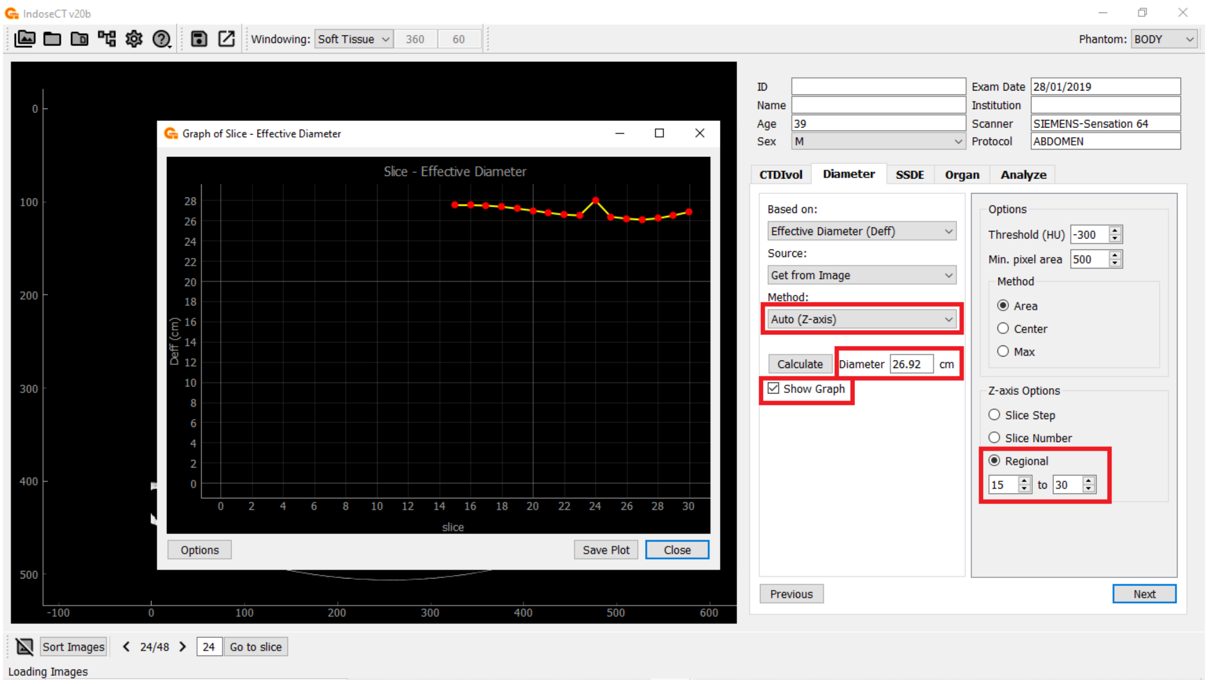

Figure 83. D_{eff} calculation display for **Regional** options. In this case, user can specify a specific slice number to start with and a slice number to end. The **Diameter (cm)** box will be filled with the average D_{eff} of the several slices used.

Note: There is currently no protocol for the number of slices to be used for SSDE calculation. The AAPM stated that the calculation of the slice in the middle (along the longitudinal axis) is acceptable. Using **Auto (Z-axis)** option will give a more accurate result, but it will take a longer time.

In the **Auto (Z-axis)** option, if we want the graph to be displayed, **Show Graph** must be selected. As before, this graph can be processed, saved, or exported to Microsoft Excel (**Figure 84**).

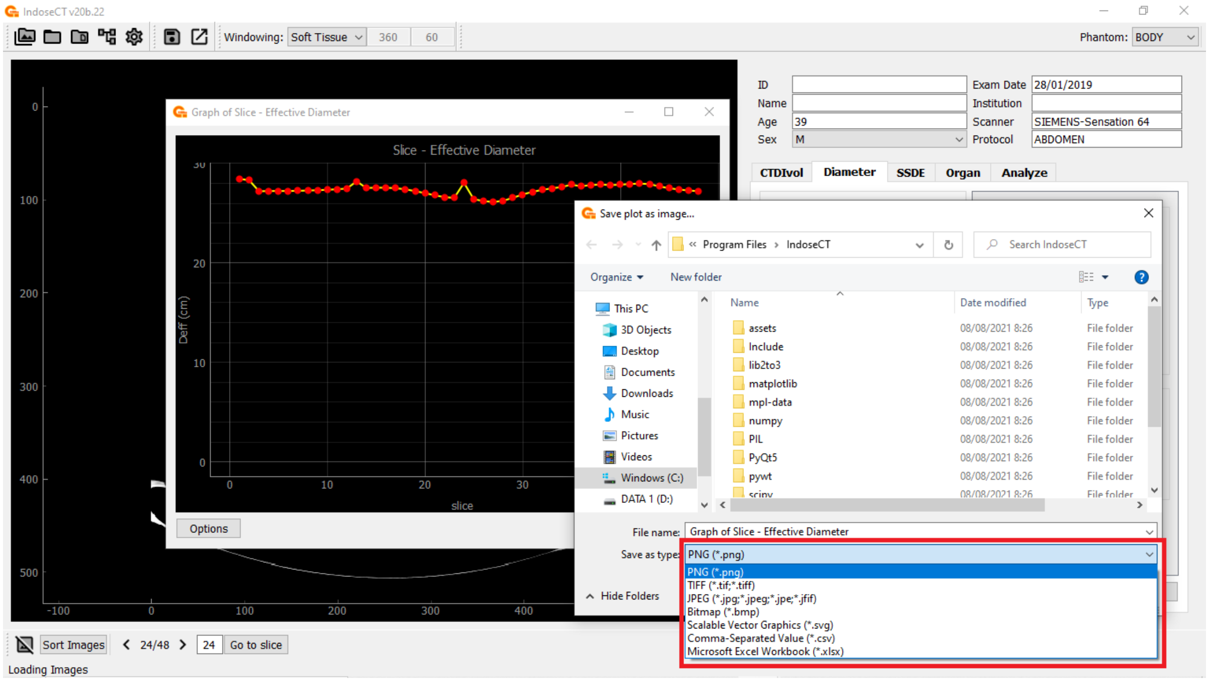

Figure 84. The graph of the result of the D_{eff} calculation using **Auto (Z-axis)** can be saved in a certain format.

VII. CALCULATION OF THE WATER EQUIVALENT DIAMETER (D_w)

The water-equivalent diameter (D_w) is a metric that takes into account the size and composition of the patient. Therefore, for patient dose estimation, D_w is more accurate than D_{eff}. **IndoseCT** can be used to calculate D_w. In **IndoseCT**, the user can either directly enter the D_w value because it is already known(**Input manually**), or the D_w value is calculated from the patient image (**Get from Image**) (**Figure 85**).

Steps for D_w calculation are as follows:

- Select the **Diameter** tab.
- Select the **Water Equivalent Diameter (D_w)** option.
- Choose whether to enter the D_w value manually **(Input Manually**) or calculate it from the image (**Get from Image**).

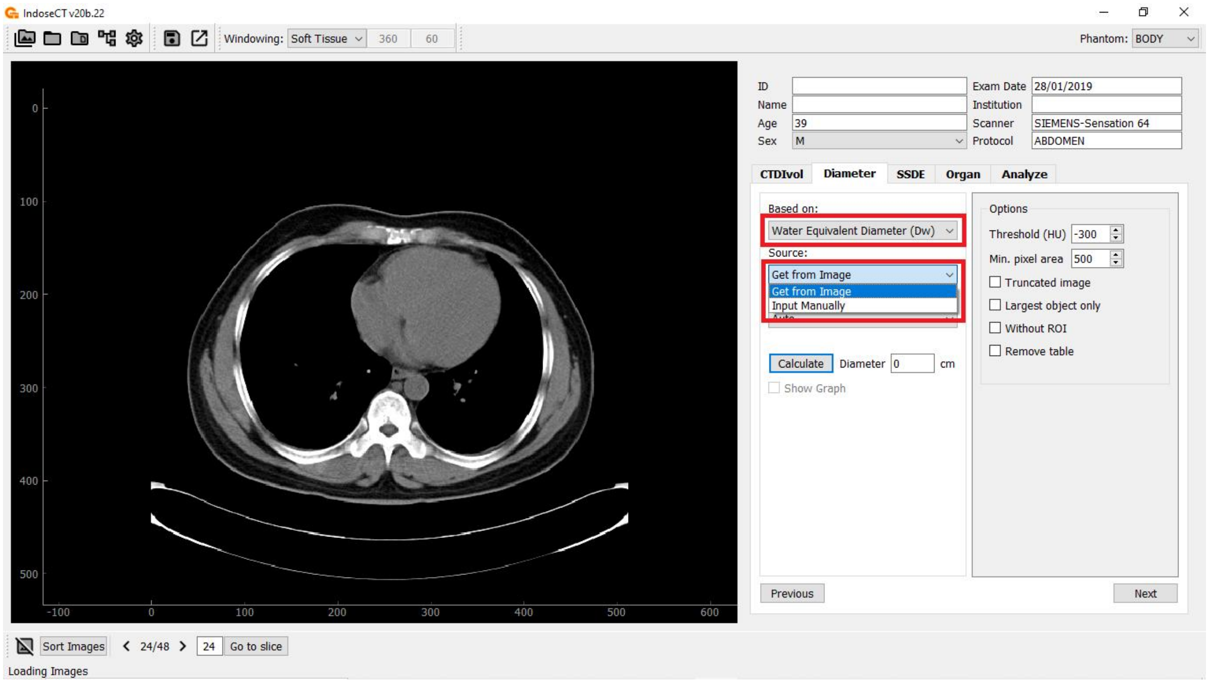

Figure 85. Calculation of D_w there are two choices of methods, namely: **Manually** and **Get From Image.** To use the **Get From Image** option, the user must have opened the patient's CT image in DICOM format.

7.1 Input D_w value manually

The D_w value can be entered manually, by performing the following steps (see **Figure 86**):

- Select the **Input Manually** option.
- Enter the value of D_w in the **Diameter** field.

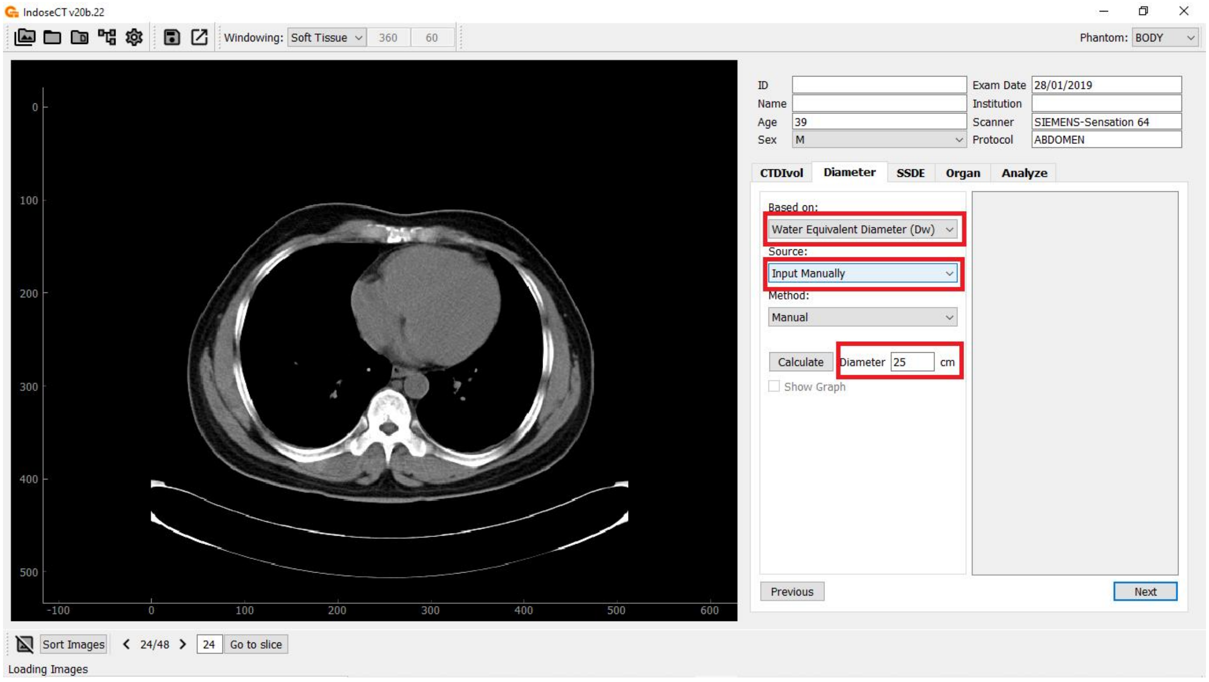

Figure 86. Display to input the D_W values manually.

7.2 D_W calculation from image

If the user does not have a D_W value, then the D_W value must be calculated from the patient image. In this case there are three options, namely **Manual**, **Auto**, and **Auto (Z-axis)** (See **Figure 87**).

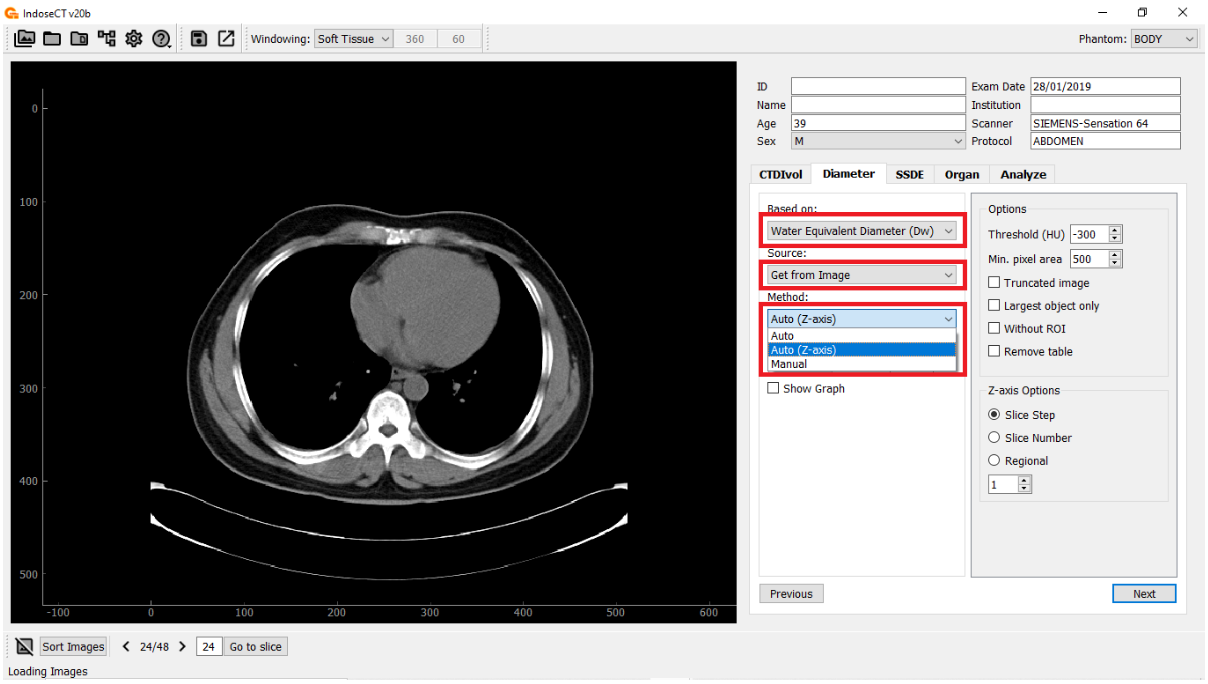

Figure 87. Calculation of D_W from the image. There are three choices of methods, namely: **Manual**, **Auto**, and **Auto (Z-axis)**. To use the **Get From Image** option, the user must have opened a CT image in DICOM format.

a. D_w calculation manually

To perform manual D_w calculations from images, there are two tools, namely **Ellipse** and **Polygon** (**Figure 88**). The first D_w calculation, used in AAPM 220, is by using an **Ellipse** tool.

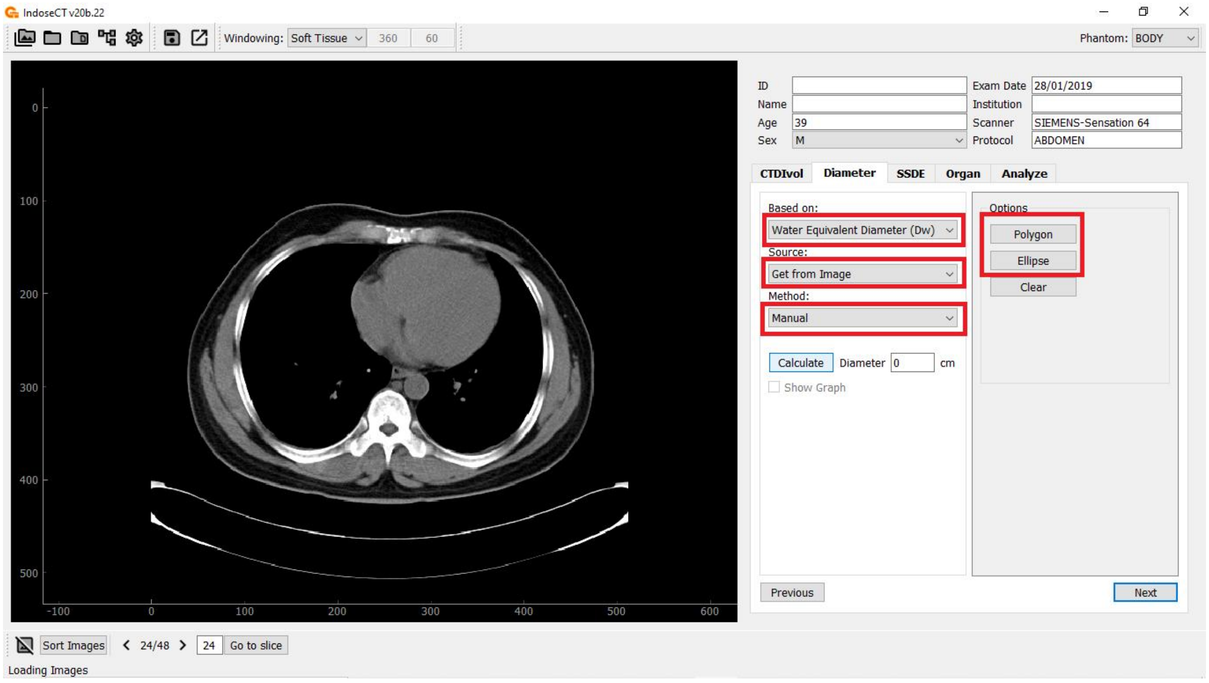

Figure 88. Calculation of D_w from the image manually can use two tools, namely: **Ellipse** and **Polygon**.

➢ D_w calculation with Ellipse tool

To perform D_w calculations from patient images using the **Ellipse** tool, the following steps are taken:

- Select the **Diameter** tab.
- Select the **Water Equivalent Diameter (D_w)** option.
- Select the **Get from Image** option.
- Select the **Manual** option.
- Then press the **Ellipse** button.
- After that, an ellipse will appear (**Figure 89**). The user must enlarge, shrink, rotate or move the ellipse so that the ellipse covers the entire patient image and only a few objects outside the patient enter the ellipse.
- In **Figure 89**, the ellipse contains a small circle and a small diamond. The small circle is for rotating the ellipse and the small diamond is for enlarging and shrinking the ellipse, including changing the scale to a circle or an ellipse. To move the ellipse place the cursor inside the ellipse and drag the ellipse to the proper position. If the cursor is outside the ellipse, the shifted object is not the ellipse, but the patient image.
- Even before pressing the **Calculate** button, the D_w value will already be seen in the **Diameter (cm)** box (**Figure 90**).

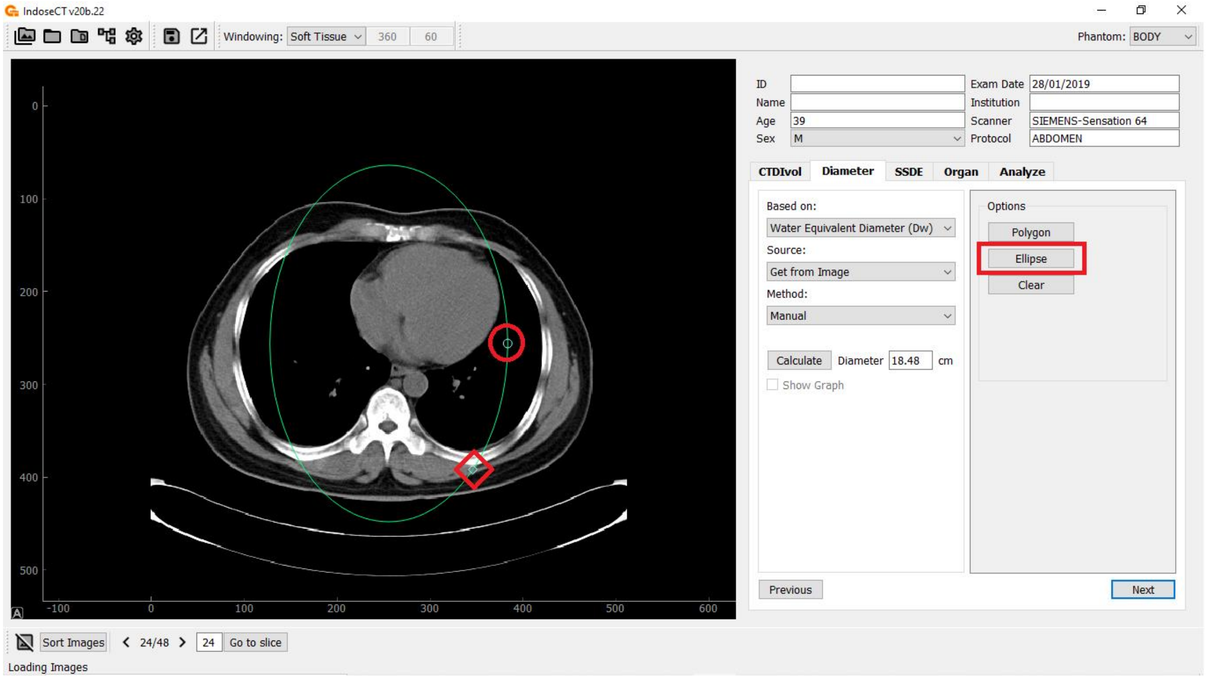

Figure 89. Calculating D_W values from patient images using the **Ellipse** tool. The small circle on the ellipse is used for rotating the ellipse and the small diamond is used for zooming-in, zooming-out, and changing the scale of the ellipse.

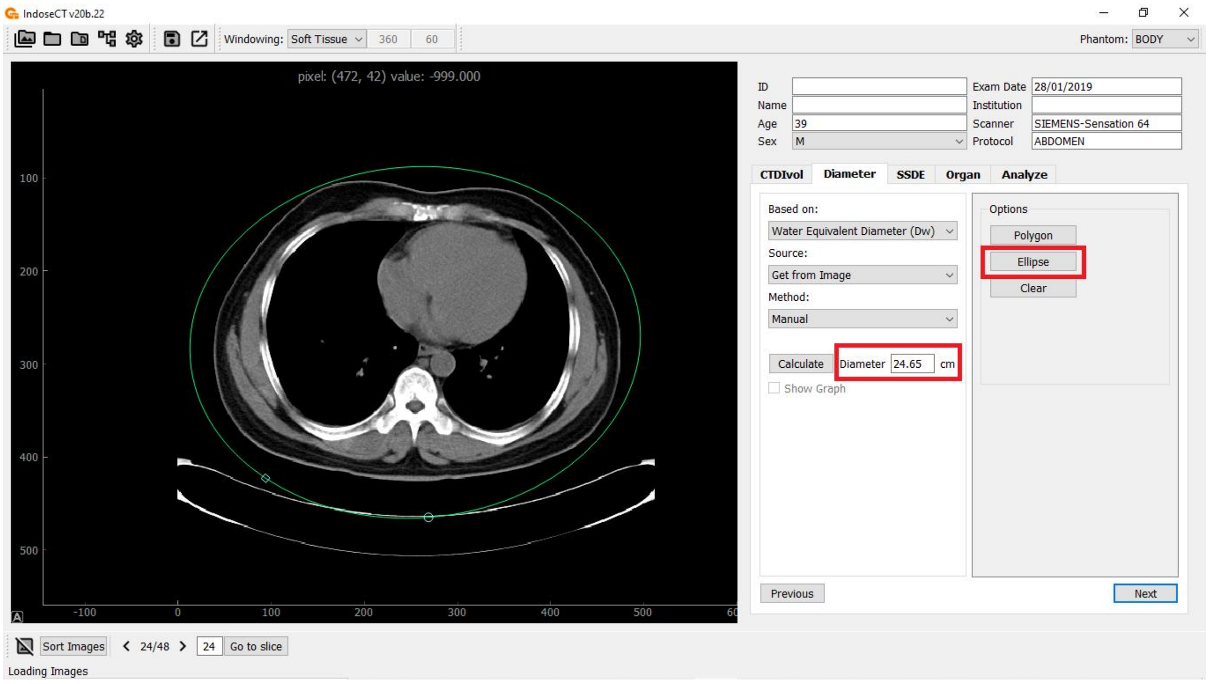

Figure 90. The ellipse has covered the entire image and only a few objects outside the ellipse are included within it. The D_W value can be seen in the **Diameter (cm)** box.

➢ D_W calculation with Polygon tool

To perform D_W calculations from patient images using the **Polygon** tool, several steps are taken as follows:

- Select the **Diameter** tab.

- Select the **Water Equivalent Diameter (D_w)** option.
- Select the **Get from Image** option.
- Select the **Manual** option.
- Then press the **Polygon** button (**Figure 91**).
- Move the cursor to the patient's image, after which the cursor will change to a cross shape.
- Click on the edge of the patient image, then move to another point (see **Figure 91**) and so on, until all the patient boundaries have been covered with the red plus signs.
- To finish, double-click near the first plus sign. The points we created will then be connected as shown in **Figure 92**.
- Even before pressing the **Calculate** button, the value of D_w will already be seen in the **Diameter (cm)** box (**Figure 92**).
- If there are some points that are not right on the edge of the patient image, these points can be shifted (See **Figure 93**). Points can also be added, by clicking between two existing points.

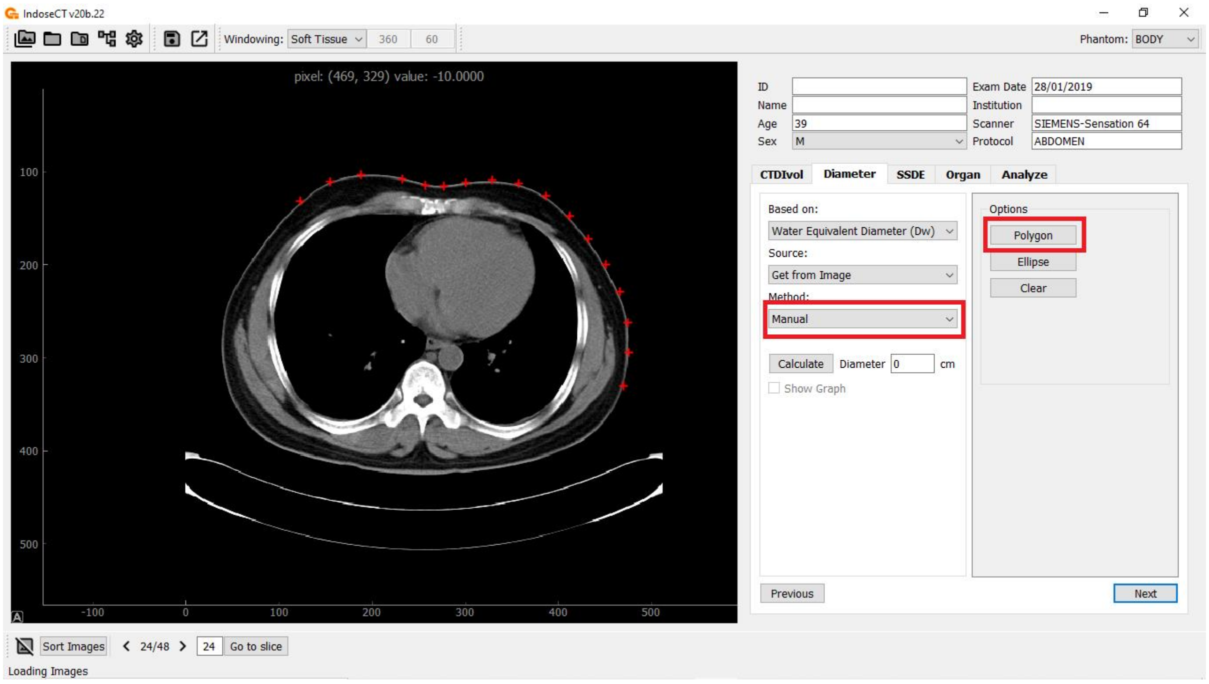

Figure 91. Display of the segmentation process for calculating D_w values from patient images using the **Polygon** tool.

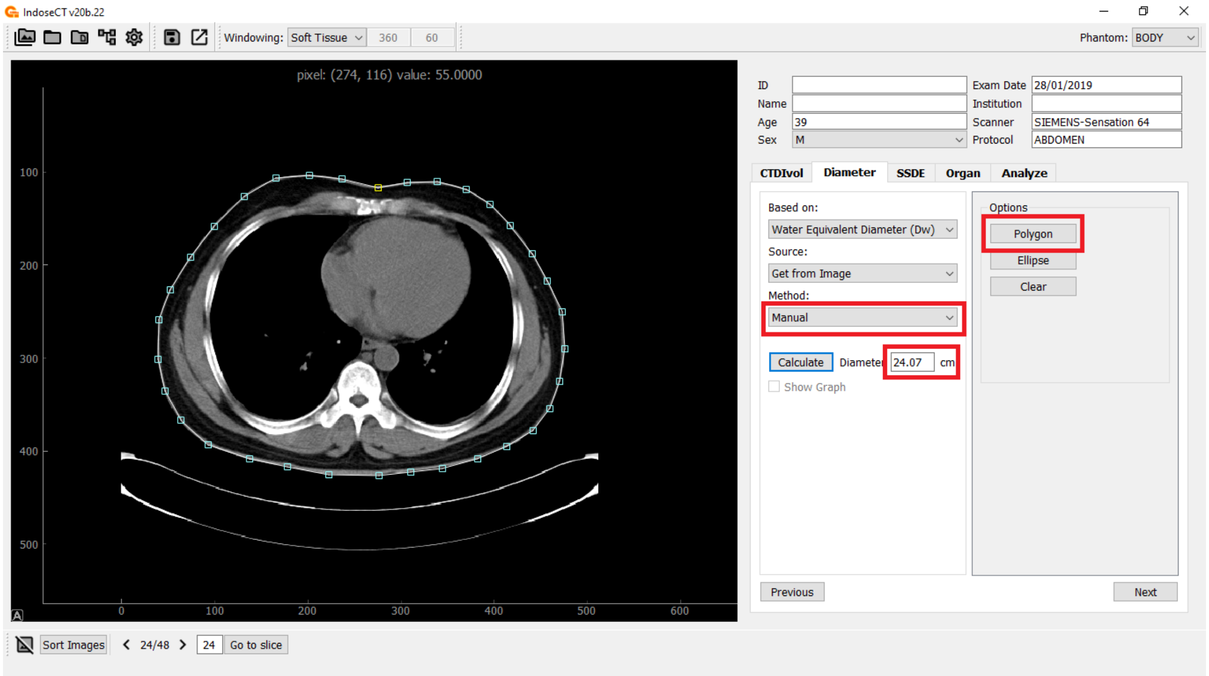

Figure 92. Display of the final result of the segmentation process using the **Polygon** tool to calculate the D_W value of the patient image.

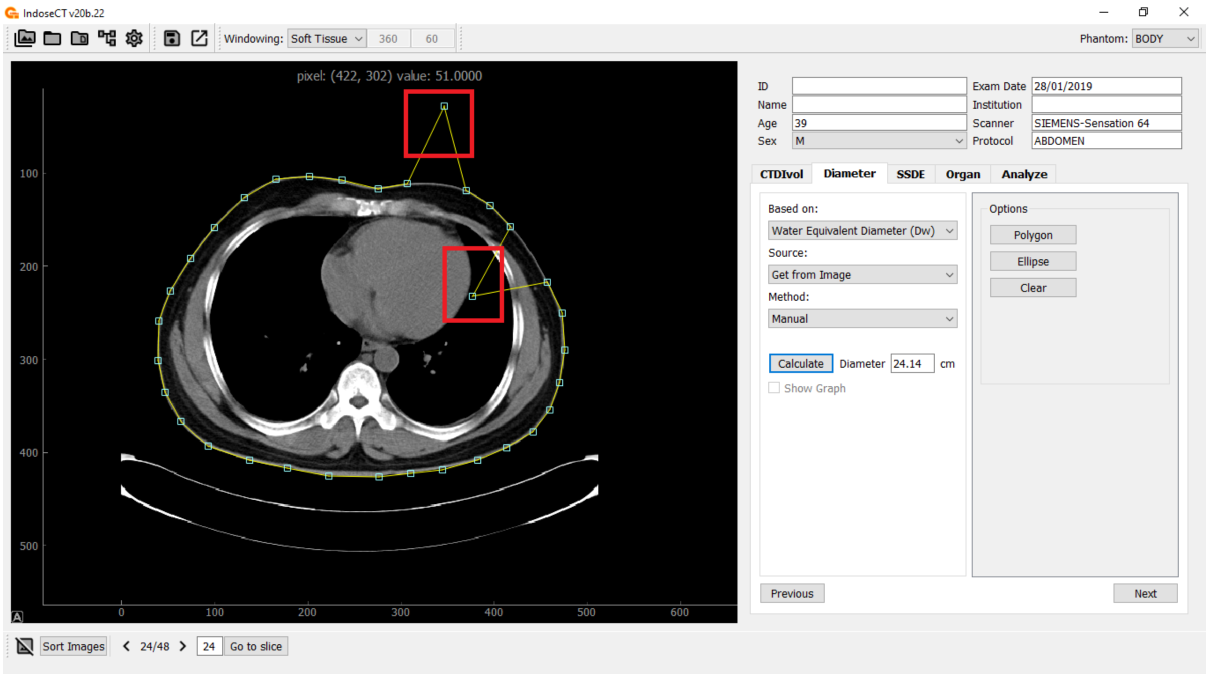

Figure 93. Example of two points that are shifted outward from the patient boundary and shifted inward from the patient boundary. For an accurate calculation of D_W, the points should be kept within the patient boundary.

b. D_W calculation automatically (Auto)

To perform D_W calculations automatically from patient images, the following steps are taken (see **Figure 94**):

- Select the **Diameter** tab.
- Select the **Water Equivalent Diameter (D_W)** option.

- Select the **Get from Image** option.
- Select the **Auto** option.
- Next, there are four fields in **IndoseCT**: **Truncated images**, **Largest object only**, **Without ROI**, and **Remove table** (**Figure 94**). These four fields can be left blank (default), or one or two can be filled in.
- Press the **Calculate** button.
- If the calculation is completed, it is indicated by the appearance of the D_W value in the **Diameter (cm)** box and the patient image will be contoured with a red line.

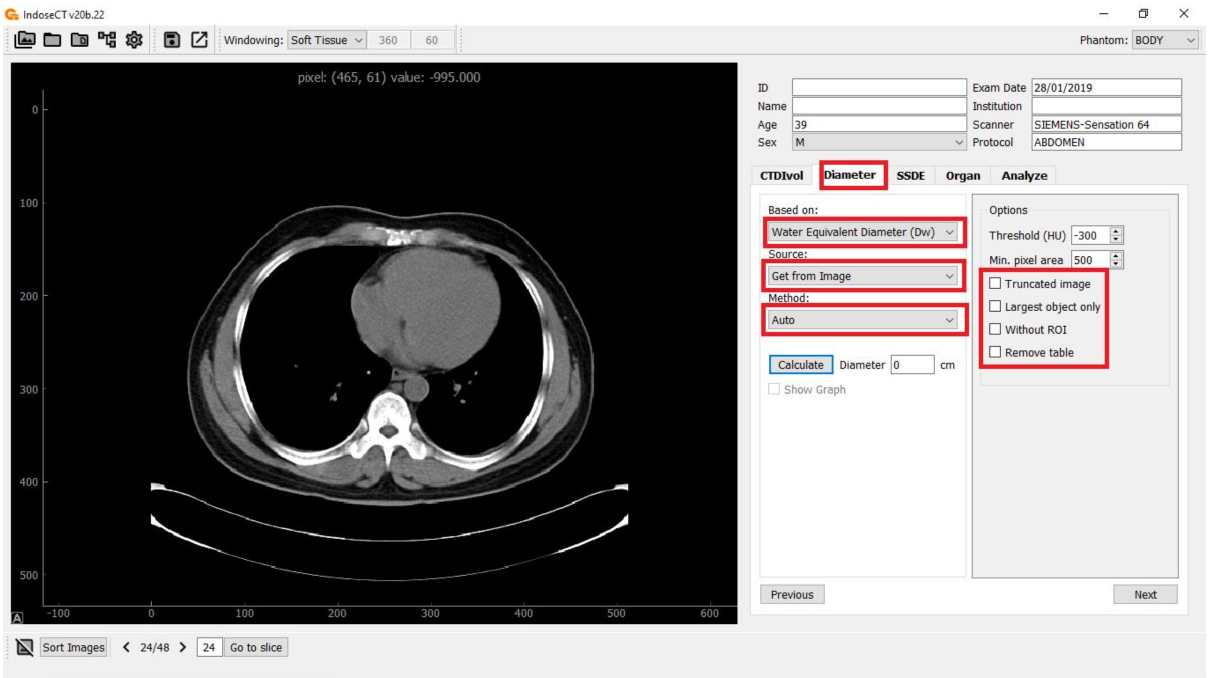

Figure 94. D_W calculation is carried out automatically. There are four fields: **Truncated images**, **Largest object only**, **Without ROI**, and **Remove table**.

For the default condition, the user does not need to select the four options available. **IndoseCT** will segment the patient objects, even though there may be several objects (such as chest, one hand or both hands), and the patient table is removed automatically (Anam et al. J Appl Clin Med Phys. 2021;1-11). In this default condition, a new image segmentation method is used. The segmentation process and the D_W calculation is performed by pressing the **Calculate** button. The results are shown in **Figure 95**, which shows that the patient image is well segmented, and the D_W value is displayed in the **Diameter (cm)** box.

Figure 95. Display of automatic calculation of D_W values from patient images by default (without selecting any of the four options: **Truncated image**, **Largest object only**, **Without ROI**, and **Remove table**).

Selecting the default condition and selecting the **Largest object only** will give the same result if the patient object in the image consists of only one part (as in **Figure 95**). But for more than one object, for example the stomach and hands, the result will be different as in **Figures 96** and **97**.

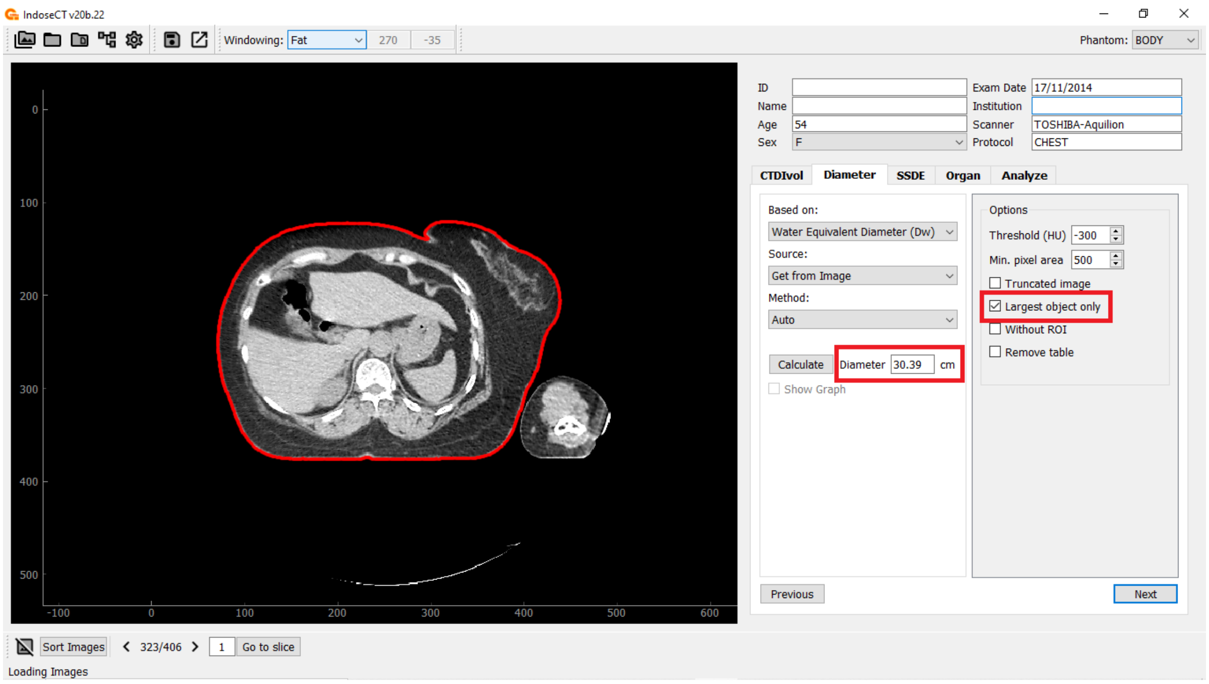

Figure 96. Segmentation using the **Largest object only** option causes only the largest object to be segmented (the patient's stomach), while the patient's hand (which is separated from the abdomen) is not segmented.

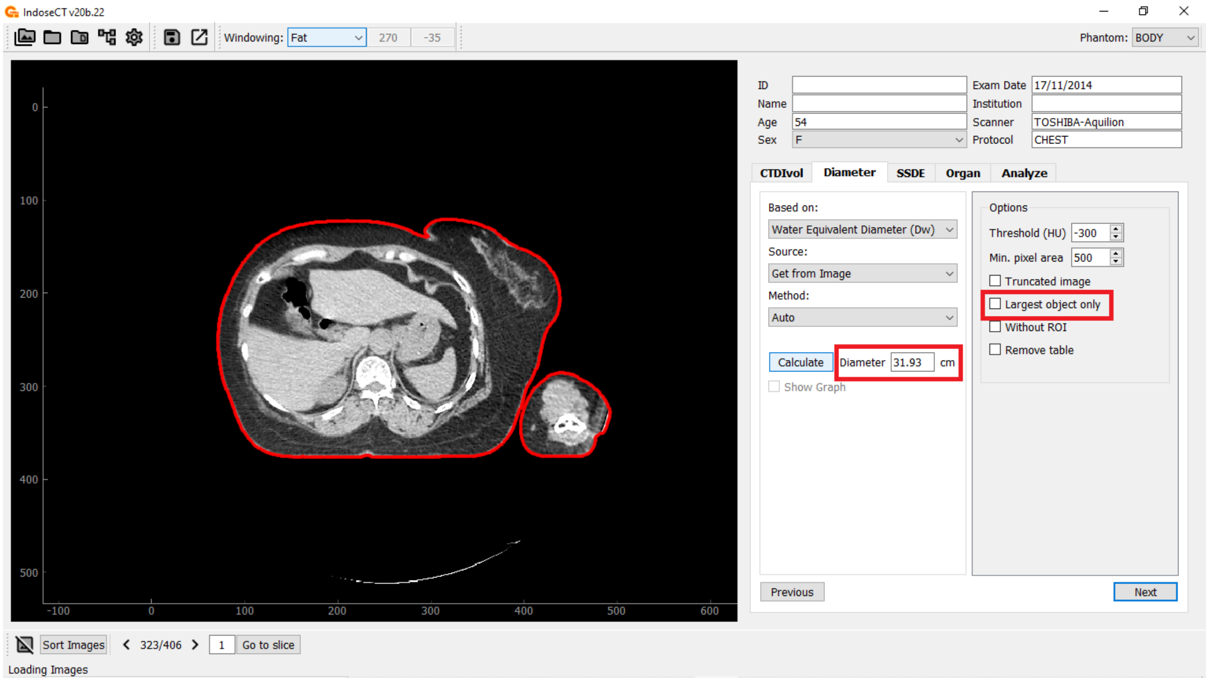

Figure 96. Segmentation without **the Largest object only** option (default) results in segmentation of body parts, even though in the image there is more than one part (such as the patient's abdomen and hands).

In **Figure 96**, segmentation using the **Largest object only** option results in only the largest object being segmented (the patient's abdomen), while the patient's hand (which is separated from the abdomen) is not segmented (Anam et al. J Appl Clin Med Phys. 2016 ;17(4):320-333). In **Figure 97**, the segmentation does not use the **Largest object only** option (default) and all sections are well segmented (both the patient's abdomen and hands). Thus, by not selecting the **Largest object only**, a higher D_W value will be obtained(In the old version of **IndoseCT**, the default condition is to use the **Largest object only**. But in this new version, the default condition is not to use the **Largest object only)**.

The **Truncated image** option is used to compensate for a cropped image. For an uncropped image as shown in **Figure 95**, the **Truncated image** option will have no effect. However, for a cropped image as shown in **Figure 98**, using the **Truncated image** option results in a more accurate D_W value. In this case, **IndoseCT** will calculate the truncation percentage (TP), then apply a truncation correction factor based on the TP value. Detailed information can be found in Anam et al. Radiat Prot Dosim. 2017; 175(3): 313-320.

Figure 98 shows the calculation of D_W on a cropped image but does not use the **Truncated image** option. In this case, the D_W value is 19.92 cm. **Figure 99** shows the same image calculated using the **Truncated image** optionwhich gives a value of D_W is 20.32 cm. For a truncated image, using a **Truncated Image** produces a slightly larger D_W value.

Figure 98. Calculation of D_w on a cropped image, but not using the **Truncated image** option. The value of D_w is 19.92 cm.

Figure 99. Calculation of D_w on a cropped image and using the **Truncated image** option. The value of D_w is 20.32 cm.

Alternatively, the D_w value can be calculated from the entire image although it is less accurate. With this method, the image area exceeds the patient area. However, the linear attenuation of the air is close to 0 and the HU value is around -1000, so it does not have much effect on the final value of D_w (Anam C, et al. Radiat Prot Dosim. 2019; 185(1): 42–49). If we want to use this option, then in the options section we select **Without ROI** (**Figure 100**). In our example the D_W value is 25.55 cm, which is slightly larger than using automatic segmentation, 24.21 cm (**Figure 95**).

Figure 100. Calculation of D_W **Without ROI**. The value of D_W is 25.55 cm.

The calculation of D_W **Without ROI** is accurate if there is nothing other than air outside the patient. In reality, however, there are sometimes objects with large linear attenuation, for example the patient table. Therefore, the **Without ROI** option can be combined with the **Remove table** as shown in **Figure 101**.

Figure 101. Calculation of D_W using **Without ROI** and **Remove table**. The value of D_W is 24.81 cm.

It can be seen that the patient table was successfully removed and as a consequence the D_W obtained decreased to 24.81 cm. However, this value is still slightly larger than using the two previous options.

Note: By default, image segmentation uses a threshold value of -300 HU (**Figure 102**). This threshold value is not always appropriate. If this threshold value cannot segment the patient properly, the user can change this threshold value to be higher, for example -200 HU, or smaller to -400 HU. In this segmentation, we used a **Min. pixel area** of 500 pixels. If there are objects with an area of less than 500 pixels, then those object will be ignored in the segmentation process. This value can be changed as needed.

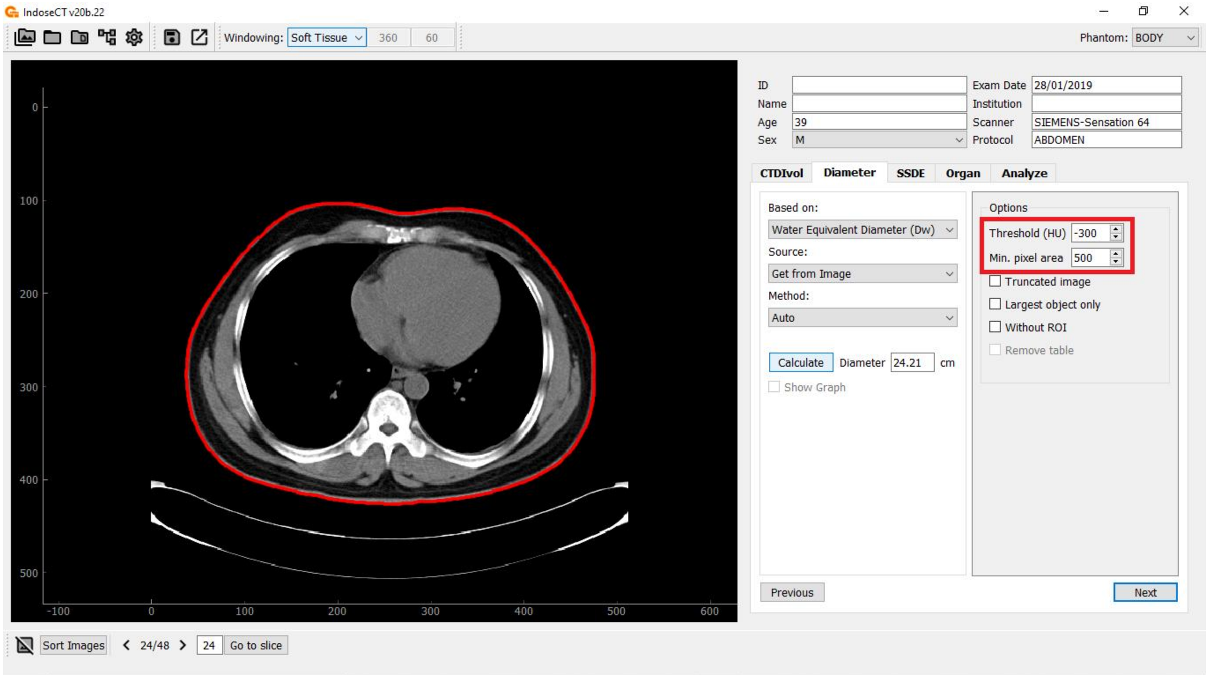

Figure 102. For image segmentation automatically using a **Threshold** of -300 HU and **Min. pixel area** of 500 pixels. These values are not always appropriate for segmenting various cases. If these values cannot segment the patient properly, they can be changed.

The special algorithm in **IndoseCT** for segmenting patients has worked well in hundreds of patients with several CT scanners. However, **IndoseCT** also still has limitations, namely in some cases sometimes it cannot segments images properly. If the user judges that the segmentation area is too large or too small, the user can calculate D_W by using manual calculation, i.e. by using the **Polygon** or **Ellipse** tool options.

c. D_W calculation with auto (Z-axis)

The value of D_W is different for each slice. **IndoseCT** gives user the option to calculate D_W along the Z-axis (for all slices) (Anam et al. J Biomed Phys Eng. 2021). However, this calculation may be time-consuming.

These are the steps to calculate D_W from multiple image slices

- Select the **Diameter** tab.

- Select the **Water Equivalent Diameter (cm)** option.
- Select the **Get from Image** option. For this, the image must be already open.
- Select the **Auto (Z-axis)** option (See **Figure 103**).
- Just as with **Auto (Z-axis)** in D_{eff} calculation, for D_w calculation there are also three options: **Slice Step**, **Slice Number,** and **Regional**.

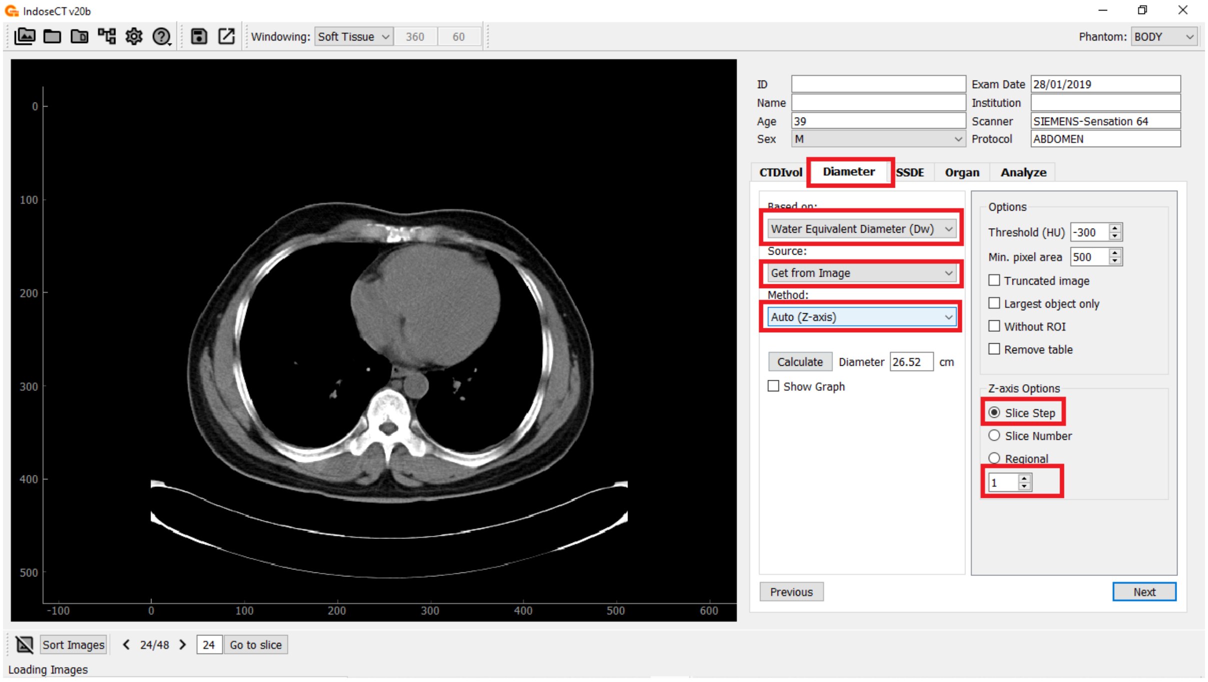

Figure 103. Auto (Z-axis) calculation display for D_W. There are threeoptions, namely **Slice Step**, **Slice Number**, and **Regional**.

An example of the results of the **Auto (Z-axis)** calculation graph with **Slice Step** 1 is shown in **Figure 104**. The average D_w value is entered in the **Diameter (cm)** box.

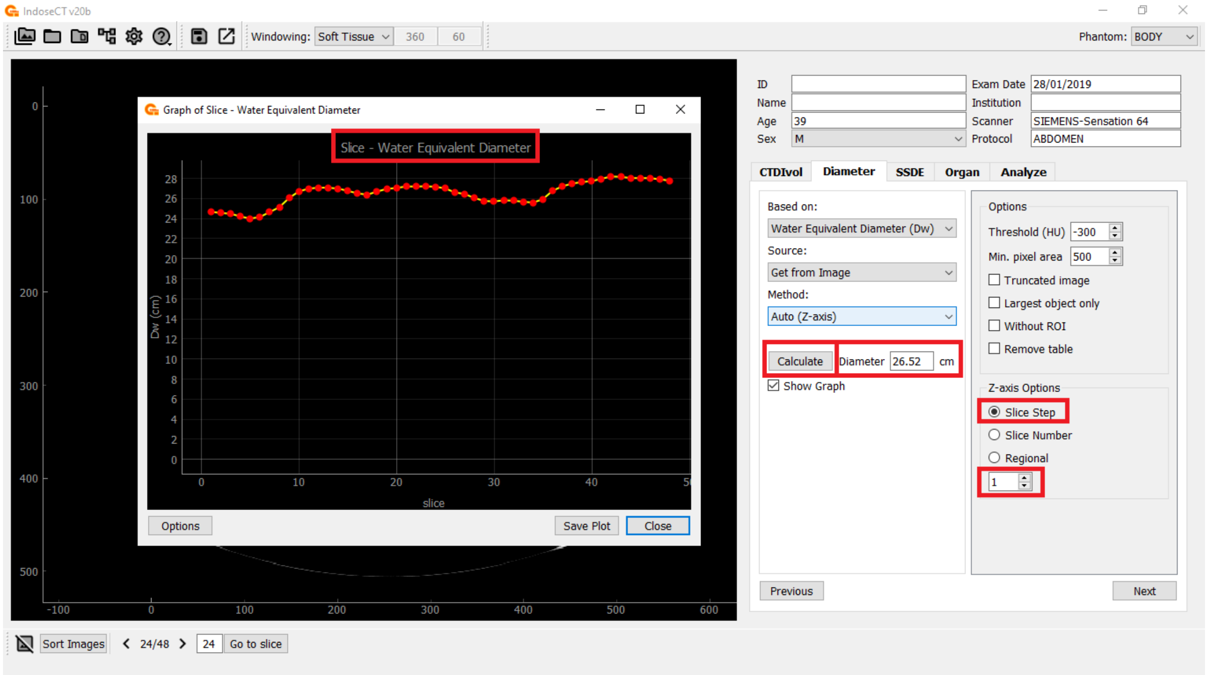

Figure 104. Example of the results of the **Auto (Z-axis)** calculation graph with **Slice Step 1**.

Note that D_W calculation with **Auto (Z-axis)** option, and with **Slice Step, 1** option, is the most accurate method of calculating the patient diameter for calculating patient dose, compared to all the previously described methods. This method is recommended for use in the calculation of patient diameter. However, the calculation this may take a longer depending on the number of slices. However, for the number of slices of about 500, the time required is generally not more than 1 minute.

VIII. CALCULATION OF SIZE-SPECIFIC DOSE ESTIMATE (SSDE)

The SSDE value can be calculated after the $CTDI_{vol}$, D_{eff} or D_w values are filled in completely. The SSDE value represents the dose estimate in the individual patient.

To calculate the SSDE value, there are two options, namely calculating the SSDE at one particular slice (**One slice** option) or several slices along the Z-axis (**Z-axis** option).

a. One slice

The steps to calculate SSDE value are as follows (see **Figure 105**):

- To calculate $CTDI_{vol}$, first select the **SSDE** tab in the tab rows. If the **SSDE** tab is clicked, the color will change to white.
- Make sure the type of **Phantom** used is **Body** or **Head**.

Note: When calculating the SSDE value, the phantom option must be correctly chosen as **Body** or **Head** phantom, otherwise the SSDE calculation will be wrong. When opening an image, this **Phantom** option will be filled in automatically. However, the user should double-check this.

- Next choose the conversion factor to use. For the **Body Phantom** option, only AAPM 204 is used, while for the **Head Phantom**, there are two choices, namely **AAPM 204** and **AAPM 293** (**Figure 105**). The new and more accurate conversion factor for head is the **AAPM 293**.

Figure 105. For **Body Phantom** only conversion factors from **AAPM 204** are used, while for **Head Phantom** there are two choices of conversion factors, namely **AAPM 204** and **AAPM 293**.

- Next, choose the **Protocol** used. For the **Body Phantom** there are 10 choices (**Figure 106**), while for the **Head Phantom** there are three options (**Figure 107**). Actually, the choice of protocol has no effect on the SSDE value, but it does affect the value of the effective dose. Since the effective dose is calculated in conjunction with the SSDE calculation, the choice of this protocol needs to be done.

- Choose **One slice** option.
- Press the **Calculate** button.

Figure 106. There are 10 options for selecting the **Protocol** for the **Body Phantom**.

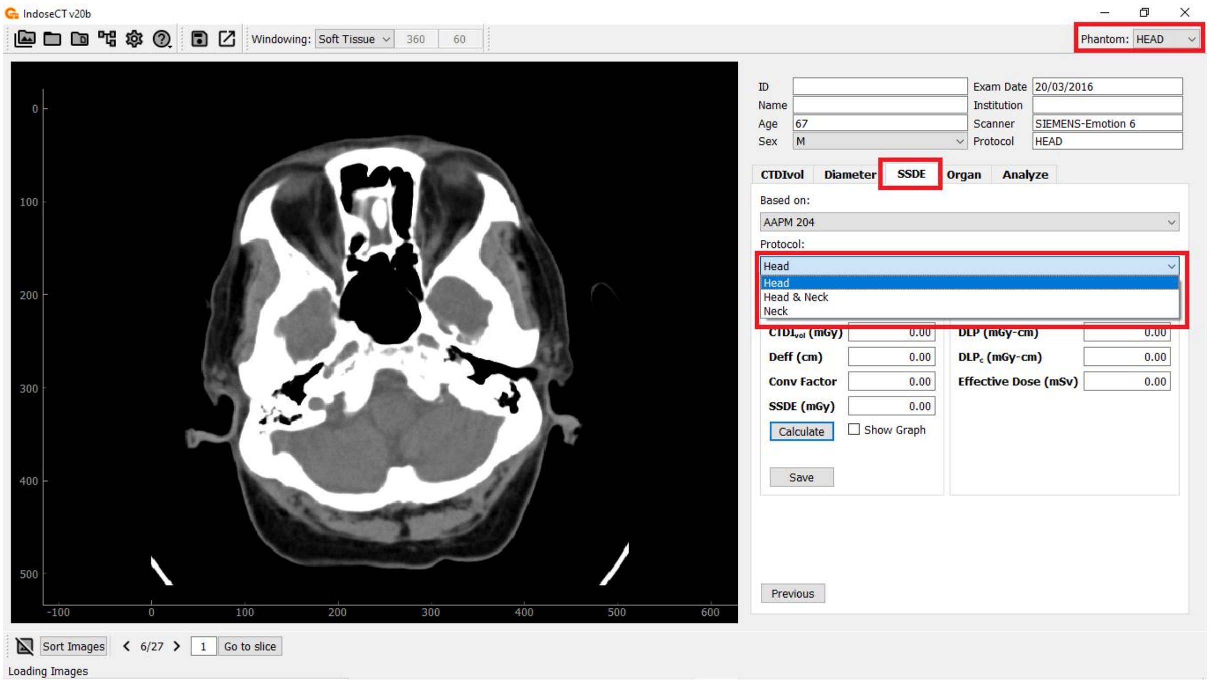

Figure 107. There are three options for selecting the **Protocol** for the **Head Phantom**.

After a moment, the values of **$CTDI_{vol}$**, **D_{eff} (cm)** or **D_w (cm)**, **Conv Factor**, **SSDE**, **DLP**, **DLPc** (corrected DLP) will be displayed. The **Conv Factor** value is also displayed visually with a graph.

The head phantom conversion factor based on **AAPM 204** is shown in **Figure 108**, and based on **AAPM 293** is shown in **Figure 109**. The conversion factor based on **AAPM 293** is slightly smaller than **AAPM 204**.

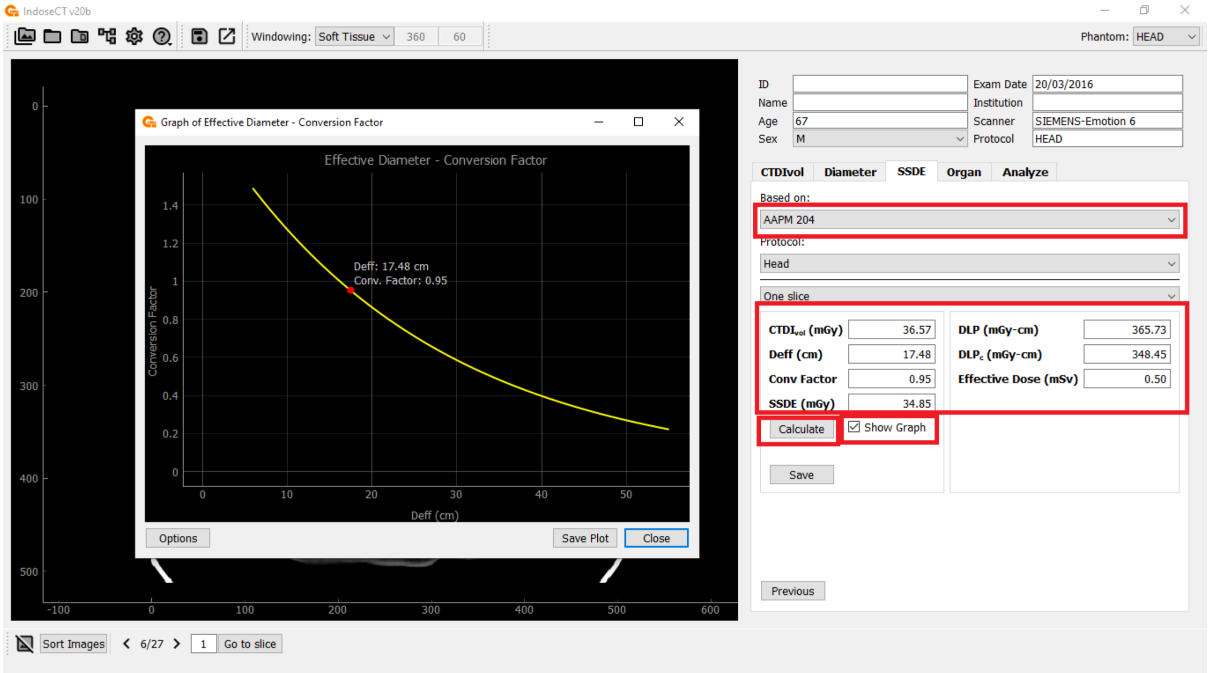

Figure 108. Display of **CTDIvol**, **Deff (cm)** or **D_W (cm)** values, **Conv Factor**, **SSDE**, **DLP**, and **DLPc** (corrected DLP). **Conv Factor** values can also be displayed graphically. In this case, the **AAPM 204** conversion factor is used.

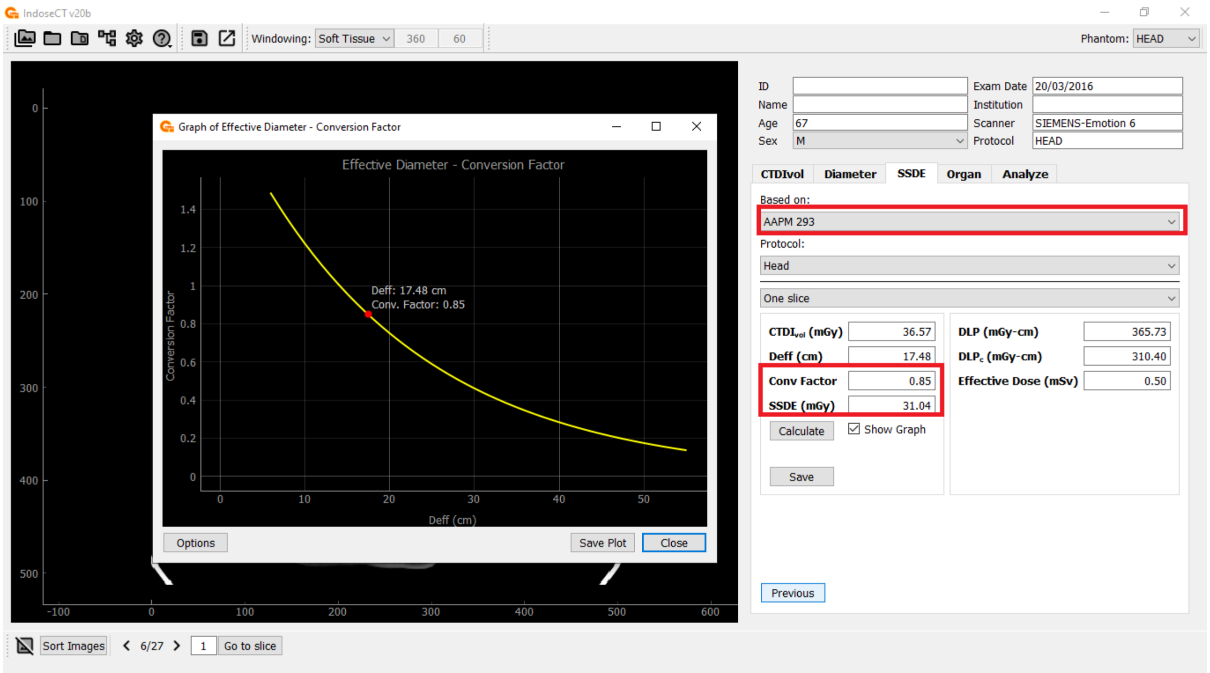

Figure 109. Display of **$CTDI_{vol}$**, **D_{eff} (cm)** or **D_W (cm)** values, **Conv Factor**, **SSDE**, **DLP**, and **DLPc** (corrected DLP). In this case, the **AAPM 293** conversion factor is used.

b. Z-axis

As with $CTDI_{vol}$ and Diameter (D_{eff} or D_w) values, SSDE values can be calculated directly along the Z-axis. To obtain the SSDE value along the Z-axis, it must be ensured that the $CTDI_{vol}$ and Diameter (Deff or Dw) values have also been calculated along the Z-axis. To calculate the SSDE value along the Z-axis, it is done by selecting the **Z-axis** (**Figure 110**). Next, three options appear as before, namely **Slice Step**, **Slice Number**, and **Regional**. The explanation of these three options has been discussed in the section on calculating $CTDI_{vol}$ and Diameter (D_{eff} or D_w). A graph of SSDE values along the Z-axis can be displayed by selecting **Show SSDE Graph** (**Figure 111**).

Figure 110. **Z-axis** mode for calculating SSDE along the Z-axis. There are three further choices, namely **Slice Step**, **Slice Number**, and **Regional**.

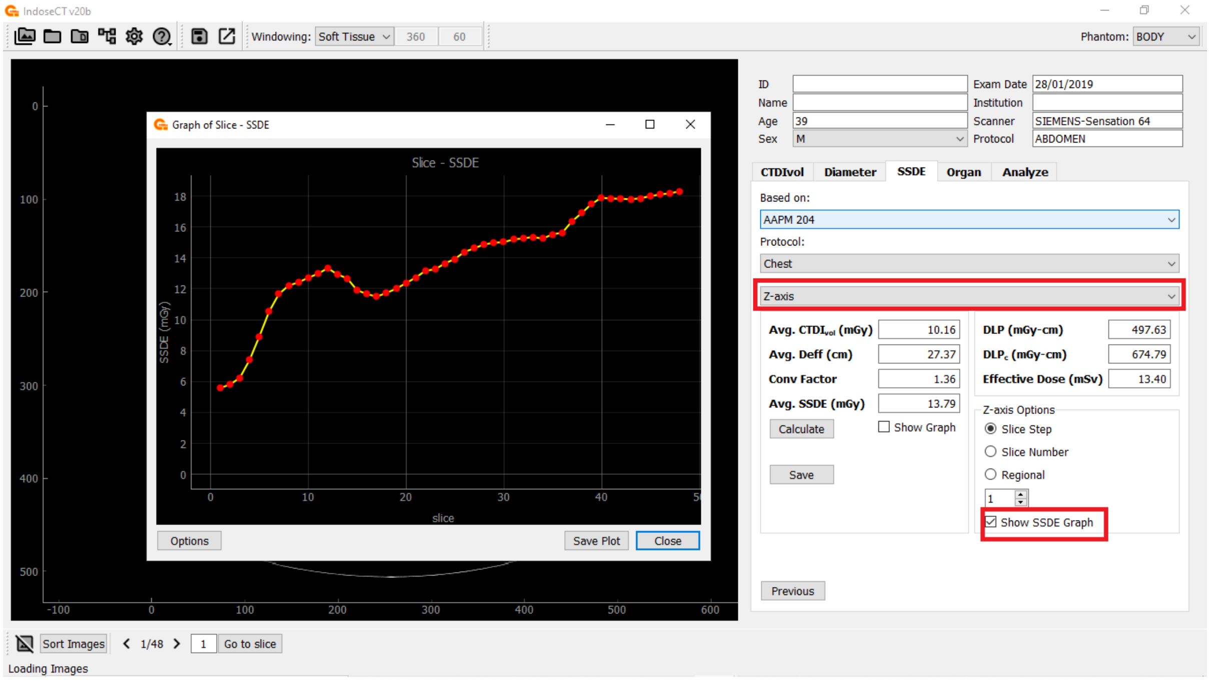

Figure 111. A graph of SSDE along Z-axis for **Slice Step** 1.

IX. CALCULATION OF EFFECTIVE DOSE

Once the DLP value is obtained it is possible to calculate the patient's effective dose (mSv units). This effective dose reflects the patient's risk and the probability of developing cancer in the future. In the **IndoseCT** software, the effective dose is calculated on an individual patient basis, namely by **DLPc** (corrected DLP), not just DLP-based. To calculate the effective dose, the user must determine the type of protocol used. For **Head Phantom** there are 3 protocol options, namely: **Head**, **Head & Neck**, and **Neck**. For the **Body Phantom**, there are 10 protocol options, namely: **Chest**, **Liver**, **Liver to Kidney**, **Abdomen**, **Adrenal**, **Kidney**, **Chest-Abdomen-Pelvis**, **Abdomen-Pelvis**, **Kidney to Bladder** and **Pelvis**.

The calculation of the effective dose here is coupled with the calculation of the SSDE. Thus, the choices for calculating the SSDE are also used to calculate the patient's effective dose.

The display of the effective dose is shown in **Figure 112**. With the **IndoseCT**, the value of the effective dose is strongly influenced by the size of the patient.

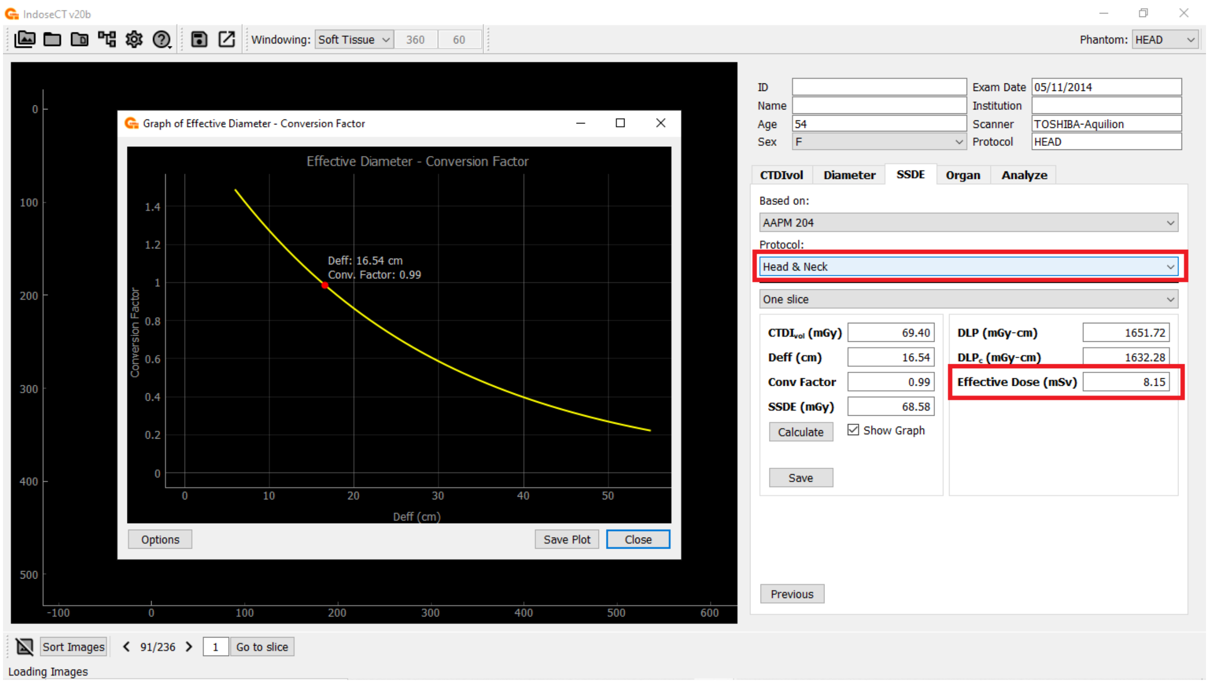

Figure 112. Display of the calculation of the effective dose on the **Head & Neck** protocol.

X. SAVE PATIENT DATA

If **CTDIvol**, **Deff (cm)** or **D_w (cm)** values, **Conv Factor**, **SSDE**, **DLP**, **DLPc** (corrected DLP) and **Effective Dose** have been calculated, then these values can be saved by pressing the **Save** button (see **Figure 113**). The data is stored in a database, which can be viewed by clicking the **Database** button above the head image (**Figure 113**).

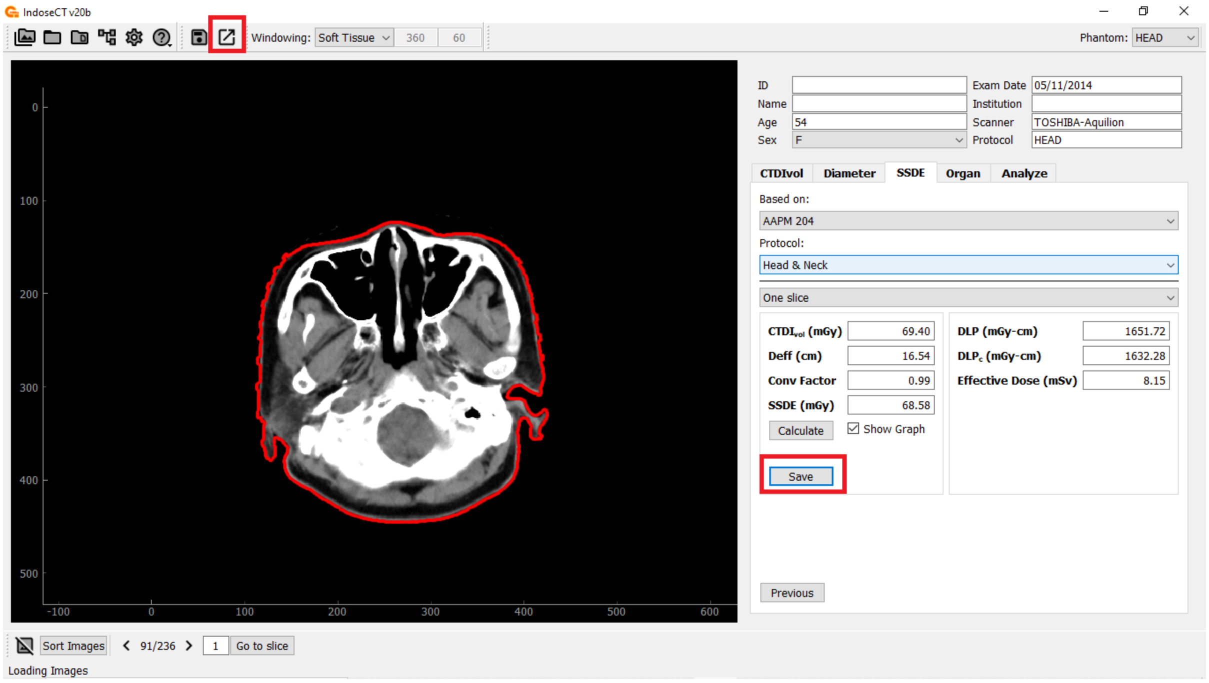

Figure 113. CTDI$_{vol}$, D$_{eff}$ (cm) or **Dw (cm)** values, **Conv Factor**, **SSDE**, **DLP**, **DLPc** (corrected DLP) and **Effective Dose** can be saved by clicking the **Save** button. The data stored in the database is viewed by clicking the button above the image which is given a red box.

The database consists of **Patient_ID**, **Name**, **Age**, **Sex**, **Exam_date**, **Institution**, **Manufacturer**, **Scanner model**, **Protocol**, **CTDIvol**, **Diameter**, **Diameter type**, **SSDE**, **DLP**, **DLPc**, and **Effective dose** (**Figure 114**). Patient and institutional names are closed to maintain the confidentiality of patient and hospital data.

Note that **Diameter type** is an explanation of whether the diameter is the effective diameter (D_{eff}) or the water equivalent diameter (D_w). In the example of **Figure 114**, the **Diameter type** is **Dw**. Also note that the user cannot save both D_{eff} and D_w at the same time. The user can only calculate and save one **Diameter type**. If the user is conducting research and wants to determine the relationship between D_{eff} and D_w, for example, then the data retrieval must be done twice. For example, the D_{eff} data is calculated first, then saved. Then it is repeated again by retrieving D_w data and saving it. The D_{eff} and D_w data are then exported to Microsoft Excel for further analysis.

If the stored data is not visible in the database, the user can press the **Refresh** button. To exit the database, press the **Close** button.

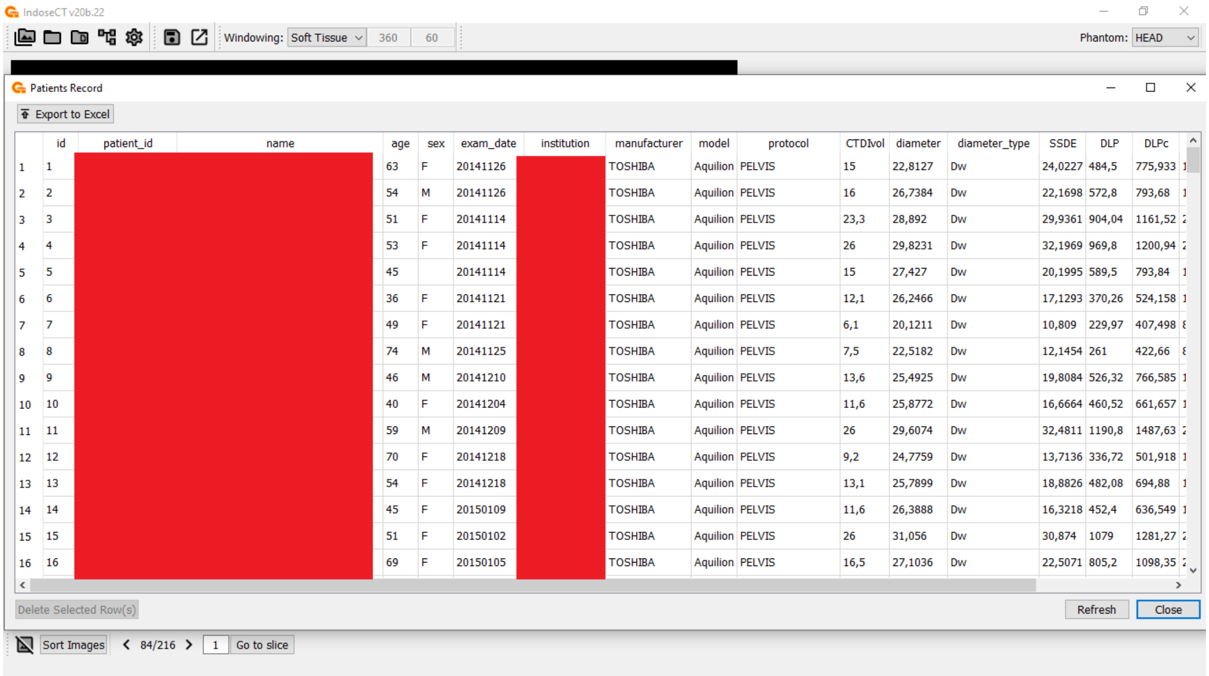

Figure 114. The database consists of **Patient_ID**, **Name**, **Age**, **Sex**, **Exam Date**, **Institution**, **Manufacturer**, **Scanner model**, **Protocol**, **CTDIvol**, **Diameter**, **Diameter type**, **SSDE**, **DLP**, **DLPc**, and **Effective dose**.

If there is erroneous or double data (because this database does not use a primary key, so that double data is possible), the user can delete the desired data by clicking on the data to be deleted, then pressing the **Delete Selected Rows** button (**Figure 115**).

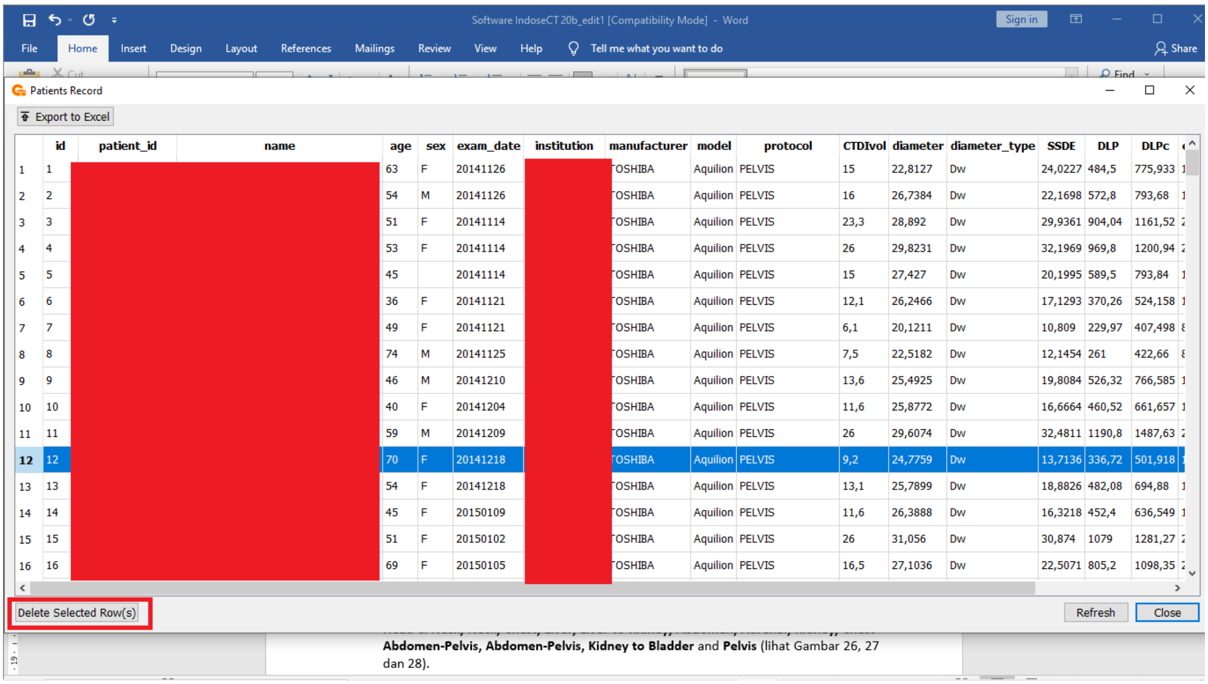

Figure115. The desired data can be deleted by clicking the data, then pressing the **Delete Selected Rows** button.

Furthermore, the data can be exported to Microsoft Excel for further analysis by pressing the **Export to Ecxel** button in the upper left corner (**Figure 116**). To save an Excel file, the user must specify a folder and also a file name. However, this database can also be processed and displayed using **IndoseCT**, without using Excel. An explanation of data analysis and how to display is shown in **Chapter XII**.

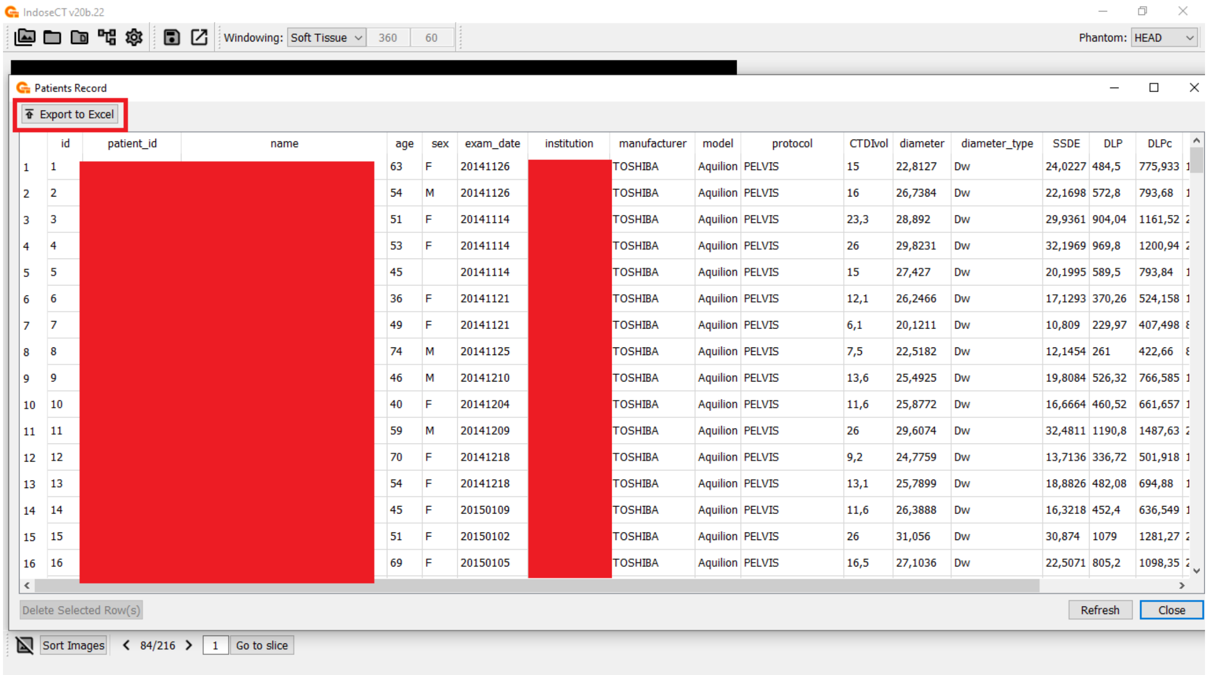

Figure 116. Data can be exported to Microsoft Excel for further analysis by pressing the **Export to Excel** button in the upper left corner.

XI. CALCULATION OF ORGAN DOSE

In addition to $CTDI_{vol}$, DLP, D_{eff} or D_w, SSDE and effective dose values, **IndoseCT** can also be used to calculate organ dose. The calculation of the organ dose using **IndoseCT** is also very much determined by the diameter of the patient, either D_{eff} or D_w. Since the dose of the organ is strongly influenced by the patient's diameter and SSDEthe CTDIvol, diameter (D_{eff} or D_w), and SSDE values must be calculated beforehand.

To perform an organ dose calculation, the **Organ** tab must be selected first. There are two choices of methods for calculating organ doses, namely **MC (Monte Carlo) Data** and **Direct Calculation**, as shown in **Figure 117**.

However, it should be understood that the calculation of the dose of this organ still has many limitations and challenges. The accuracy of the organ dose using IndoseCT needs further verification.

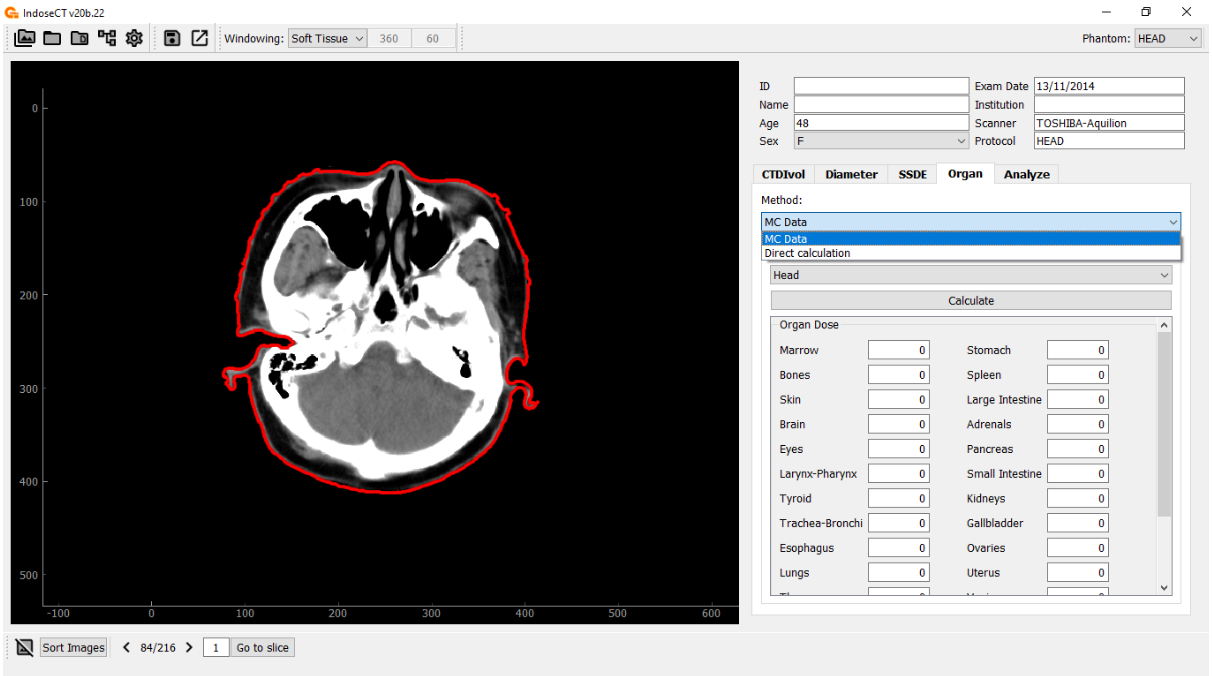

Figure 117. There are two choices of methods for calculating organ doses, namely **MC (Monte Carlo) Data** and **Direct Calculation**.

10.1 Monte Carlo data

Calculation of organ dose with Monte Carlo data (**MC Data**) refers to the results of a previous publication (Sahbaee et al. Med Phys. 2014; 41(7): 072104). This research was conducted using a Monte Carlo simulation on computational phantoms of varying sizes. From the study, the relationship between SSDE and dose in several organs was determined for several protocols. Tthis calculation method is only applicable to the available protocols. The diameter used in Sahbaee et al (2014) only uses the effective diameter. In **IndoseCT**, this approach is extended to the water equivalent diameter (D_w).

There are 28 sensitive organs estimated in this software, namely: **Marrow**, **Bones**, **Skin**, **Brain**, **Eyes**, **Larynx-Pharynx**, **Thyroid**, **Trachea-Bronchi**, **Esophagus**, **Lungs**, **Thymus**, **Breasts**, **Heart**,

Liver, **Stomach**, **Spleen**, **Large Intestine**, **Adrenals**, **Pancreas**, **Small Intestines**, **Kidneys**, **Gallbladder**, **Ovaries**, **Uterus**, **Vagina**, **Bladder**, **Prostate**, and **Testes**.

The steps for estimating organ dose values are as follows:

- Previously, the CTDIvol, diameter, and SSDE values must be obtained.
- Select the **Organ** tab. The color will change to white.
- Next select the protocol used. There are 13 protocol options. For the head there are three protocols. namely: **Head**, **Head & Neck**, and **Neck**. For the body there are ten protocols, namely: **Chest**, **Liver**, **Liver to Kidney**, **Stomach**, **Adrenal**, **Kidney**, **Chest-Stomach-Pelvis**, **Stomach-Pelvis**, **Kidney to Bladder** and **Pelvis** (see **Figure 118**).
- Press the **Calculate** button. The organ dose values will be obtained and displayed on the organ dose boxes (**Figure 118**) and are also displayed visually with a graph (**Figure 119**).

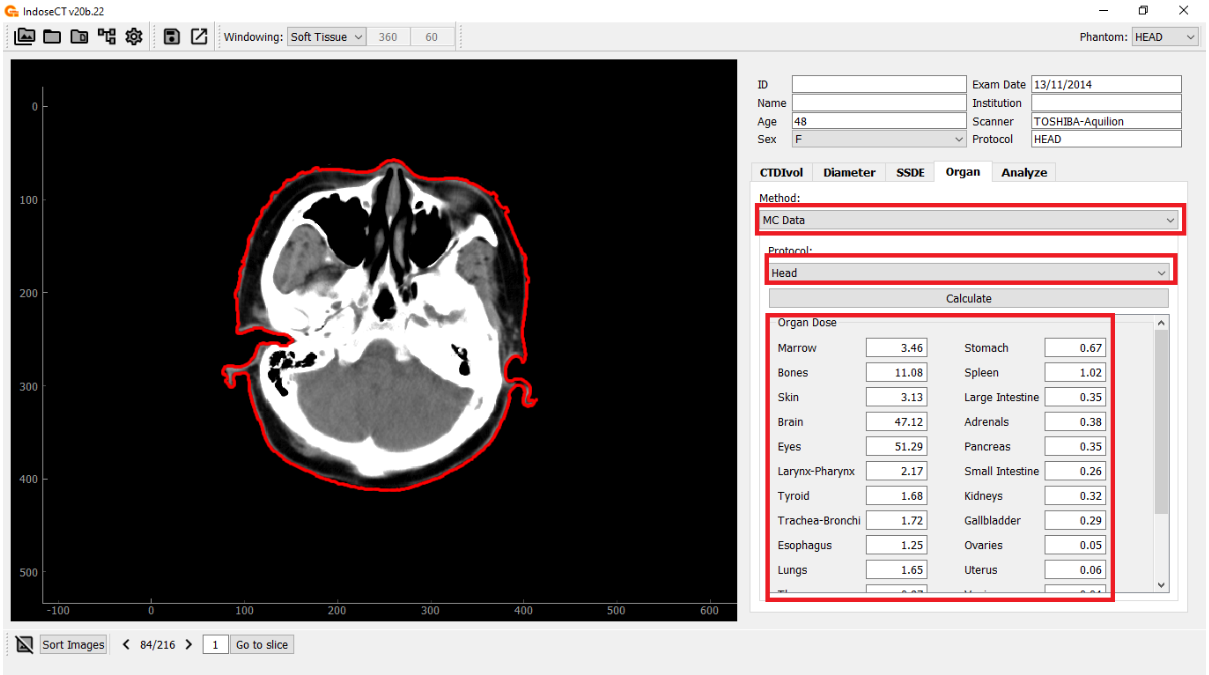

Figure 118. An example of calculating the organ dose in the **Head** protocol using the **MC Data** method.

As with previous graphs, this organ dose graph can be saved or exported to Microsoft Excel. It can be seen from **Figure 118** that the radiation dose for organs located in the head area are large (In this example, the dose in **Brain** is 47.12 mGy) because it is exposed to the primary radiation. For the organs that are outside the head (e.g. **Pancreas**, **Uterus** and so on), the radiation dose is small, because they are only exposed to scattered radiation.

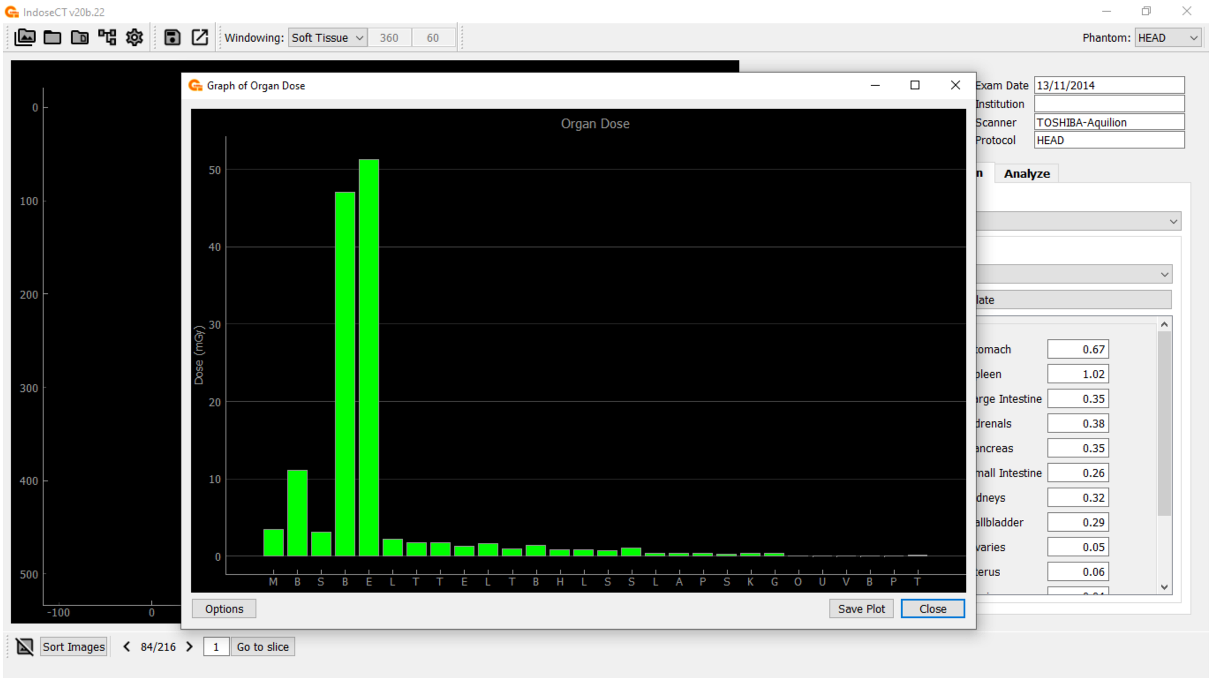

Figure 119. Display graph for organ doses. The x-axis is the initial of the organ name. Organ names can be seen on the main **IndoseCT** form as shown in **Figure 118**.

10.2 Direct calculation

The dose to the organ can also be estimated directly from the patient image (Refer to a previous study on dose distribution between the periphery and center of phantoms of varying size (Anam et al. J Xray Sci Med. 2020; 28: 695-708)). The dose at a point (organ) that is at a certain position is calculated by linear interpolation between the dose in the center (called as the SSDE central, $SSDE_c$) and the dose at the edge (called as SSDE peripheral, $SSDE_p$). $SSDE_c$ and $SSDE_c$ are calculated from $SSDE_w$ using k and h correction factors (*k*-factor and *h*-factor).

The organ dose in **IndoseCT** is not only calculated at one point (one pixel), but is calculated from all the pixels in the organ. For this purpose, the user must perform organ segmentation manually. From here, the effective distance map (DEM) will be obtained if using D_{eff}, or the water-equivalent distance map (DWM) if using D_w. Each point on the DEM or DWM is then calculated using linear interpolation to give a dose map (DM). The average DM value from all pixel values within the segmentated area is calculated and this value indicates the estimated value of the organ dose.

The steps for calculating the organ dose using the **Direct Calculation** method are shown in **Figure 120**.

- Previously, the $CTDI_{vol}$, diameter, and SSDE values must be obtained.
- Select the **Organ** tab. The color will change to white.
- Select the **Direct Calculation** option.
- Click **Add contour**. When the cursor is hovered over the image, the cursor changes from **an arrow** to **a positive sign**.
- Then make a segmentation of the selected organ. To do this, click on the edge of the organ several times so that it covers the organ (**Figure 121**). At the last point, double-click, then the points will be connected to each other (**Figure 122**).

- Click the **Calculate** button. The organ dose will be calculated. The mean dose value is shown in the **Mean (mGy)** box and the standard deviation is shown in the **Std**. **Deviation (mGy)** box.

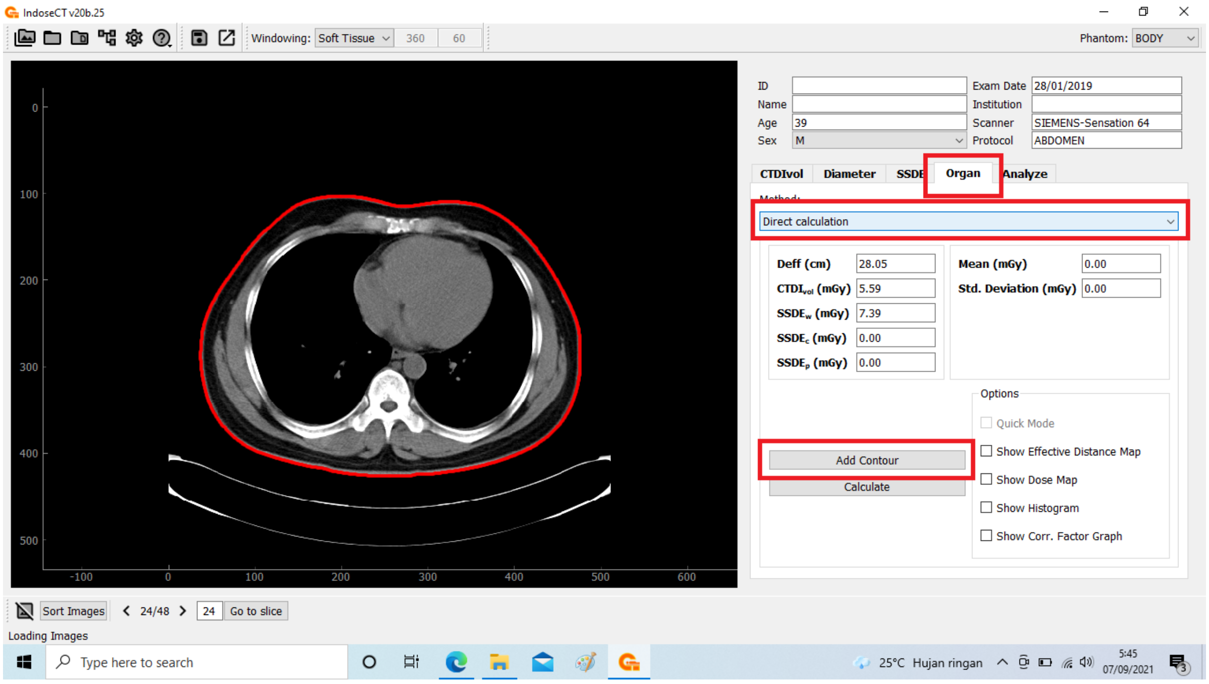

Figure 120. The dose of the organ is calculated directly by selecting the **Direct Calculation** option and followed by making a contour with **Add Contour**.

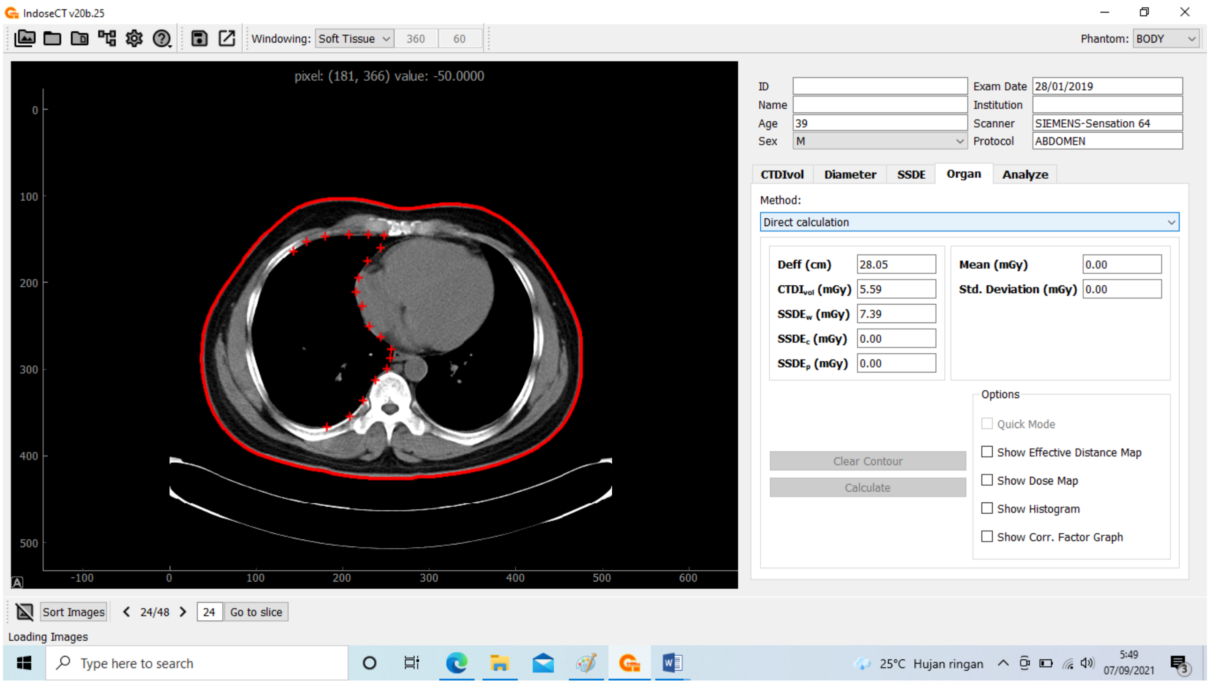

Figure 121. Segmentation of the organ for which the dose will be calculated by clicking several times on the edge of the organ so that it covers the organ.

In **Figure 122**, not only the average organ dose value is shown, but the values of **SSDEw**, **SSDEc** and **SSDEp** are also shown. The symbol **w** refers to weighted, i.e. the average SSDE (weighted) obtained from $CTDI_{vol} \times f$. The average organ dose calculated on the basis of D_{eff} in this example is 7.16 mGy.

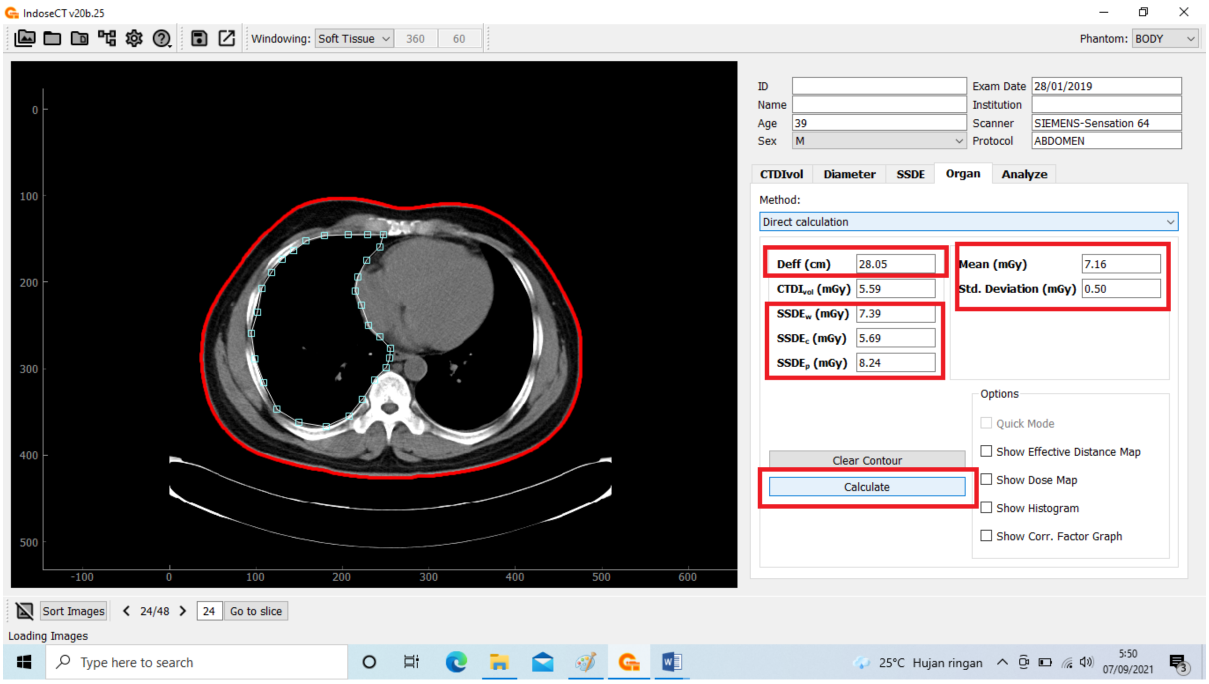

Figure 122. If the contour or segmentation is completed, the organ dose is calculated by pressing the **Calculate** button. The mean value and standard deviation of the organ dose will be calculated. This calculation is based on $D_{eff.}$ In this example, the mean value of the organ dose is 7.16 mGy.

If we want to display the *h*-factor and *k*-factor, dose map (DM), and histogram dose map (HDM), then these parameters must be selected before pressing **Calculate**, as shown in **Figure 123**. An example of *h*-factor and *k*-factor is shown in **Figure 124**. An example of a dose map (DM) and a histogram of dose map (HDM) for the D_{eff} basis is shown in **Figure 125**. The dose map is radial because it uses a D_{eff} basis.

The organ dose calculated using D_w is shown in **Figure 126**. The average organ dose is 7.77 mGy. This value is slightly larger than using D_{eff}. An example of a dose map (DM) and a histogram of dose map (HDM) based on D_w is shown in **Figure 127**. The dose map is no longer radial when using D_w.

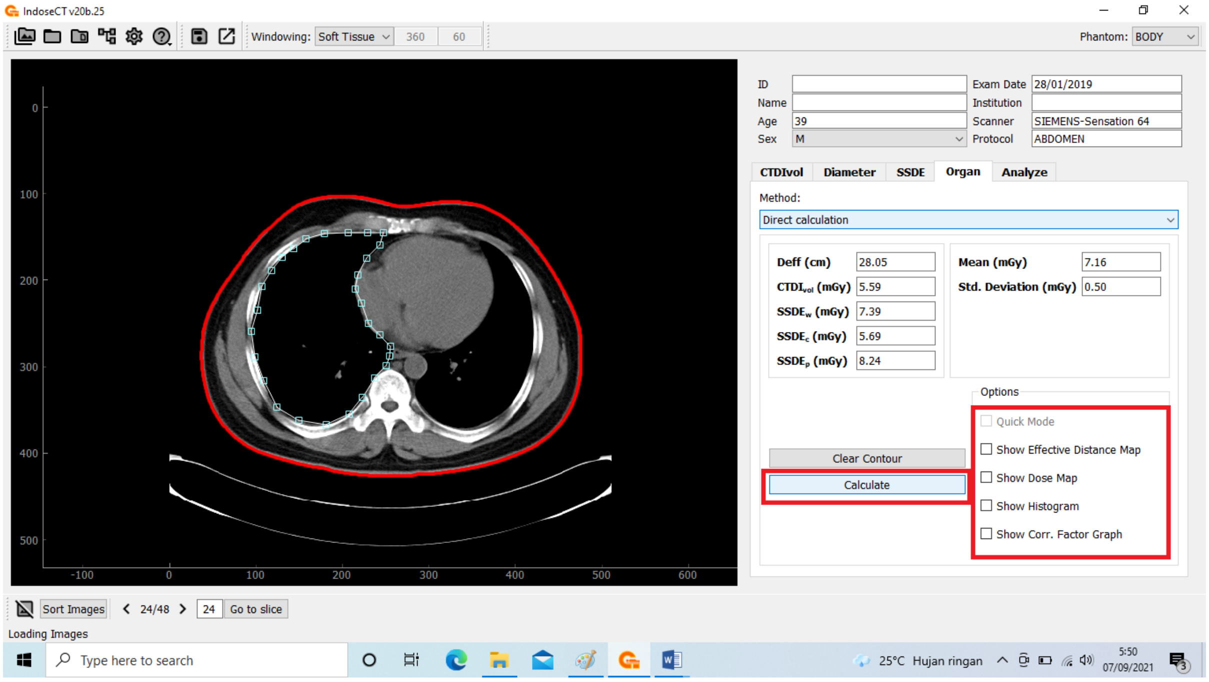

Figure 123. If the user wants to display the h-factor and k-factor, dose map, and histogram dose map, these parameters must be selected before pressing **Calculate**.

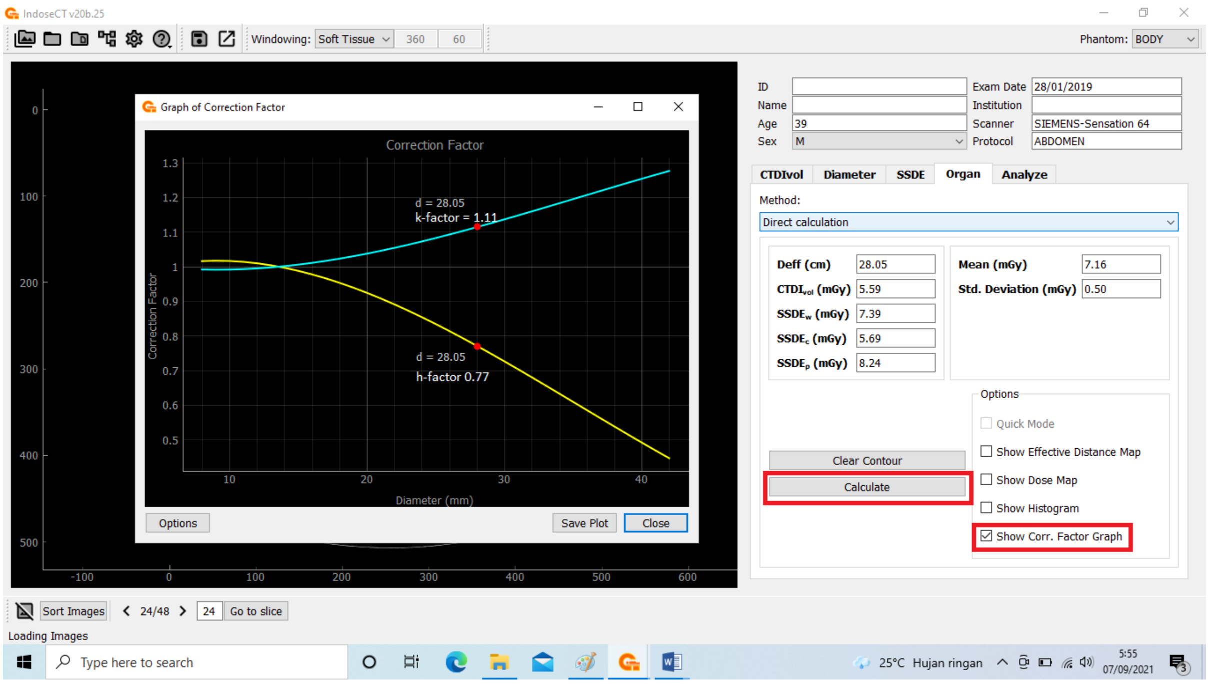

Figure 124. Example view of *h*- and *k*-factors.

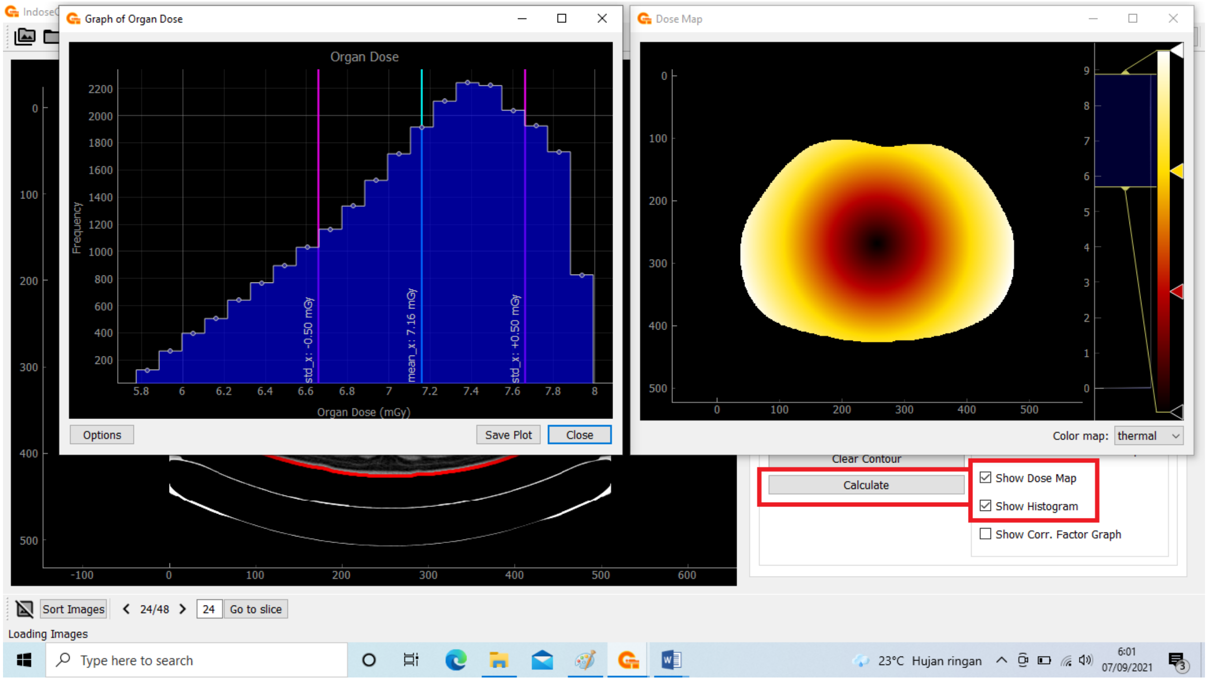

Figure 125. An example of a dose map (DM) and an organ histogram of the dose calculated using D_{eff}.

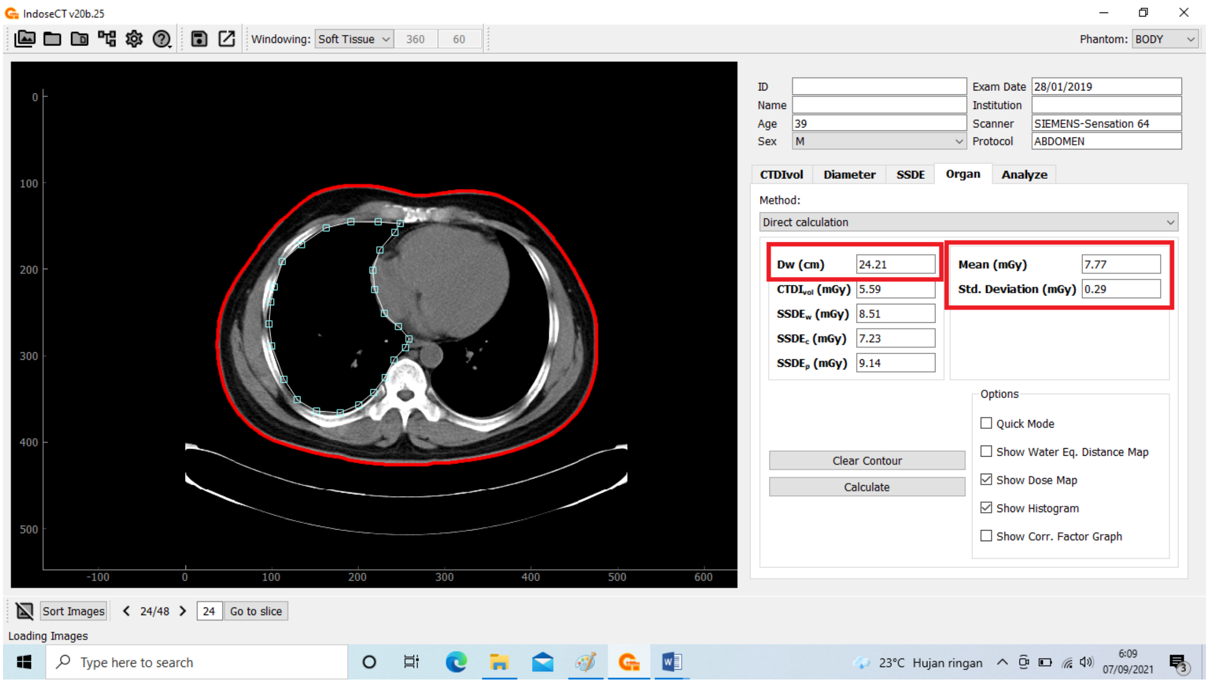

Figure 126. Mean value and standard deviation of organ dose calculated using D_w. In this example, the mean value of the organ dose is 7.77 mGy.

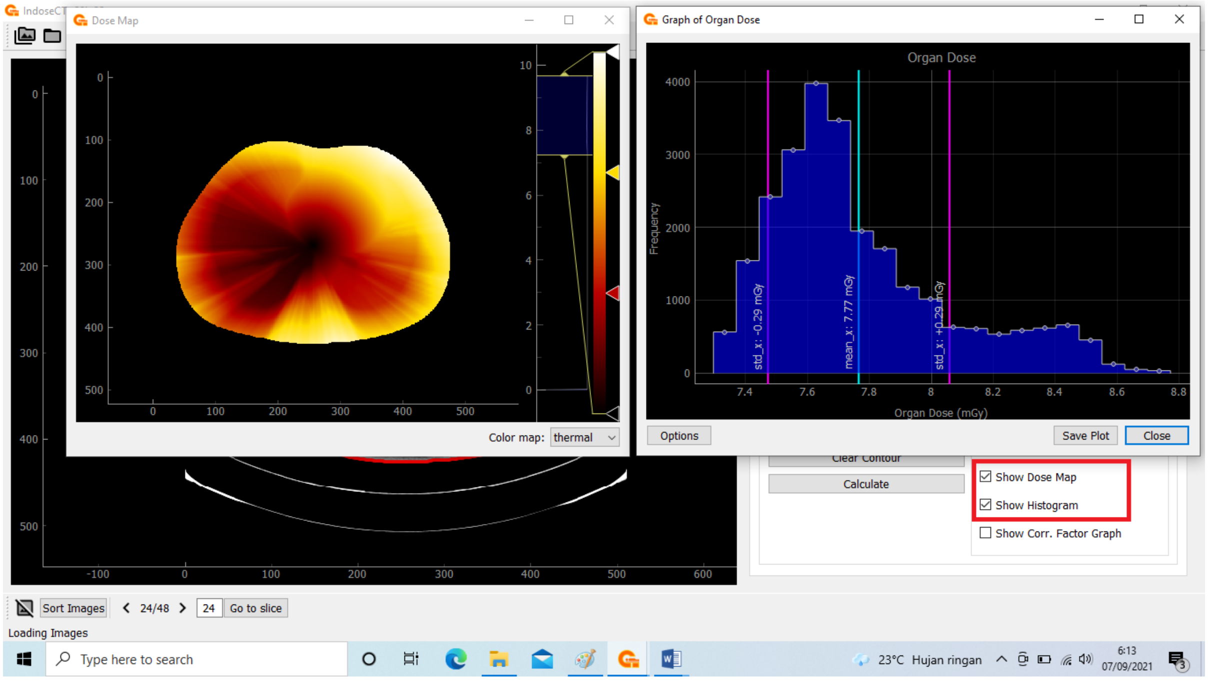

Figure 127. An example of a dose map and an organ dose histogram calculated using D_W.

XII. DATA ANALYSIS

After the patient data is stored, the data can be analyzed to provide useful information or reports to the authorities. The results of the analysis can be displayed in graphs. Reporting and documenting patient doses is very important, although sometimes it has not received much attention from the authorities.

To activate the data analysis section, click the **Analyze** button. The button will change to white, and a form like **Figure 128** will be displayed

In analyzing the data, user can filter data based on: **Institution**, **Manufacturer**, **Scanner**, **Protocol**, **Sex**, **Age**, and **Exam Date**. The data entry for each filter is based on the data that has been stored in the database. For example, **Figure 128** shows the protocols of the stored data, namely **PELVIS**, **HEAD**, **CHEST**, **ABDOMEN**, **CHEST_TO_PELVIS**, **LEG**, **Unspecified**, and **All**. **Unspecified** means that the data is not available (filled in) or information has been retrieved from DICOM info, but no information is available in the protocol section.

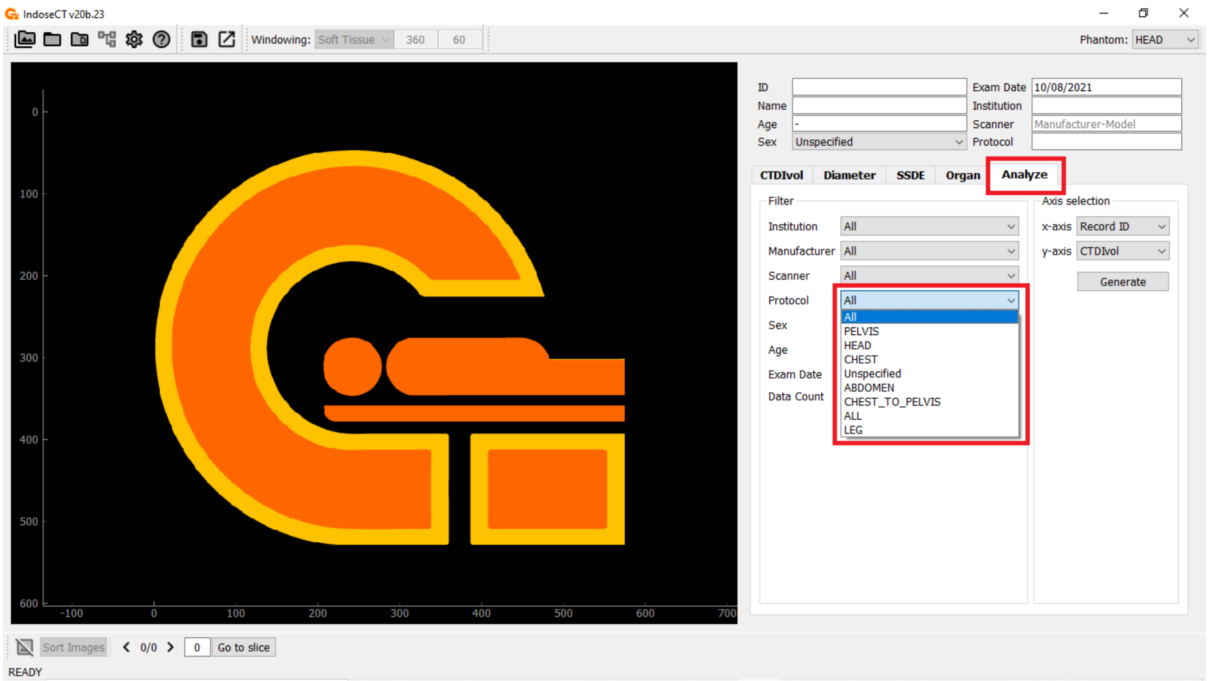

Figure 128. Display for analyzing patient dosimetry data.

Information on the number of patients appears at the bottom, namely the **Data Count**. In the example of **Figure 129**, no filtering is performed (so the filter is **All**), except for the **Protocol** which uses the **CHEST** option. It is shown that the number of patients is 137.

The user can select the x-axis and y-axis (**Figure 129**). On the x-axis there are several options, namely **Record_ID**, **CTDI$_{vol}$**, **Age**, **Deff**, **Dw**, **SSDE**, **Effective Dose**, **DLP**, **DLPc**, and **Frequency** (see **Figure 130**). On the y-axis there are also the same options (see **Figure 131**).

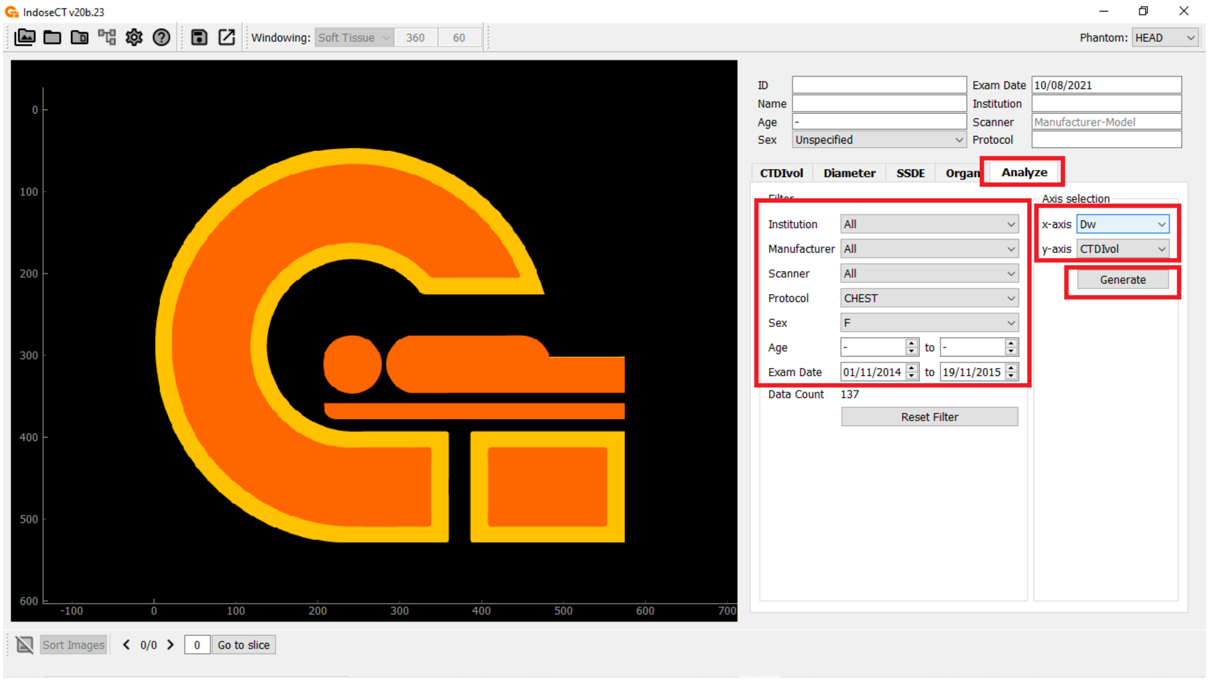

Figure 129. After filtering, the x-axis and y-axis must be determined.

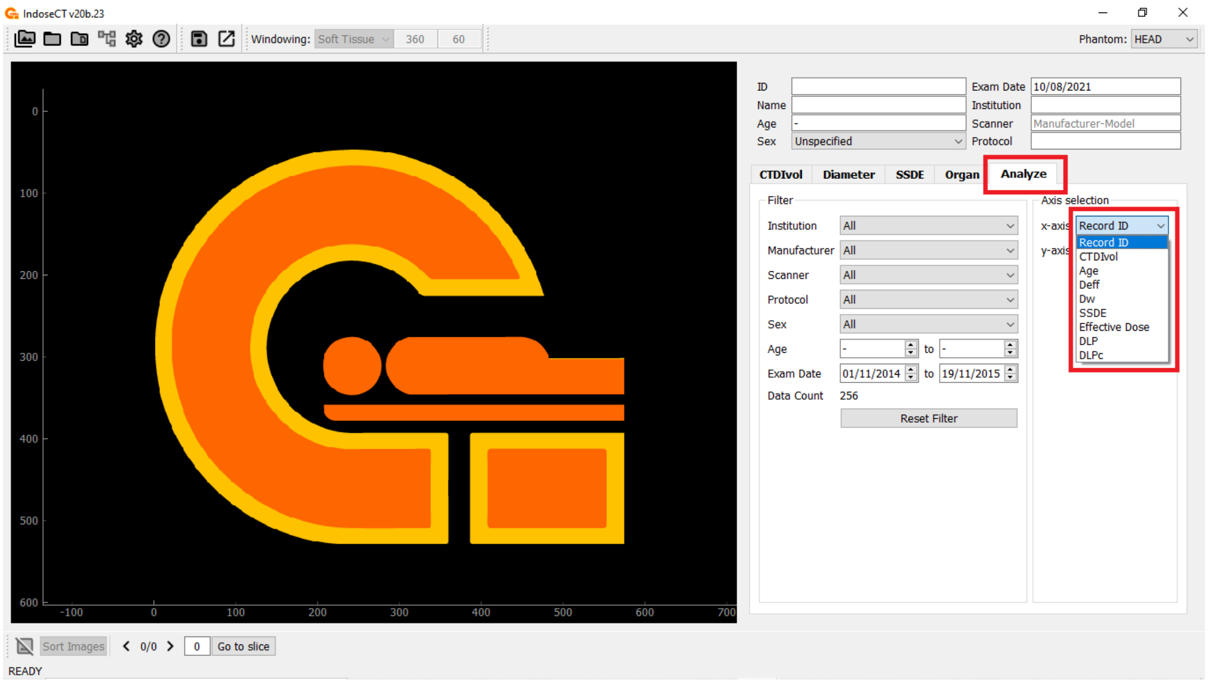

Figure 130. There are options on the x-axis, namely **Record_ID, CTDI$_{vol}$, Age, D$_{eff}$, D$_{w}$, SSDE, Effective Dose, DLP, DLPc,** and **Frequency**.

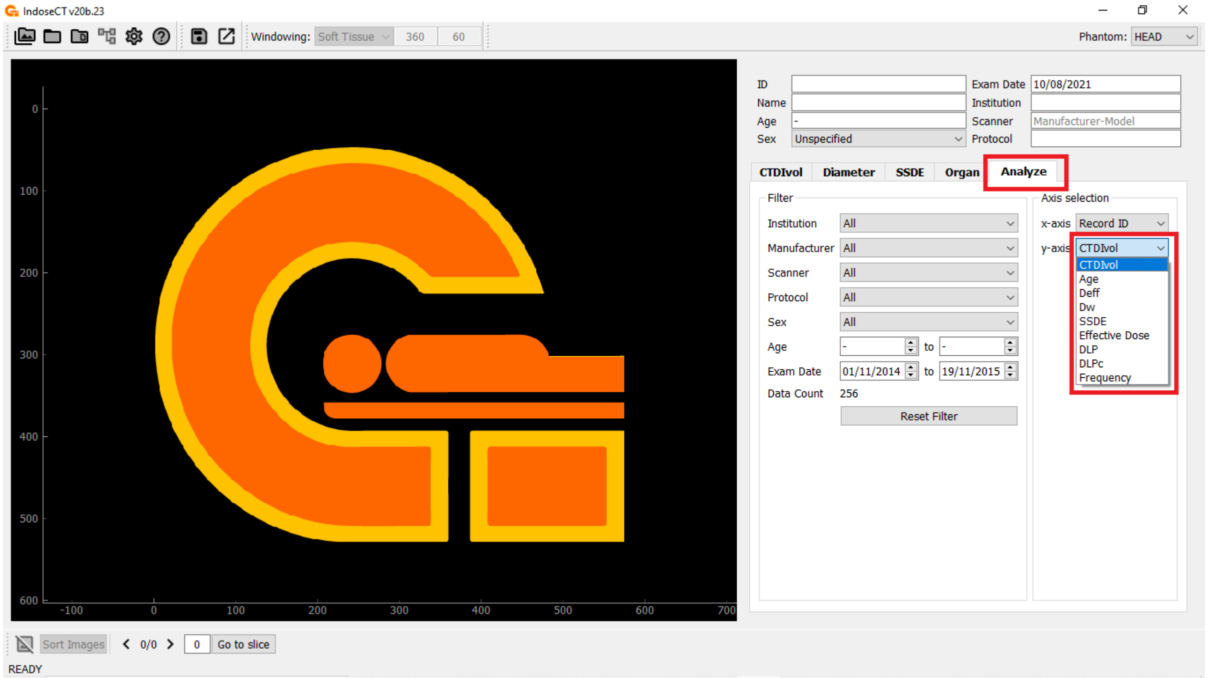

Figure 131. There are options on the y-axis, namely **Record_ID, CTDI$_{vol}$, Age, D$_{eff}$, D$_{w}$, SSDE, Effective Dose, DLP, DLPc,** and **Frequency.**

Figures 132-139 are examples of some of the graphs of patient data for analysis. **Figure 132** is a graph of **Record_ID** vs **CTDI$_{vol}$** using the **CHEST** protocol. The random data do not form a certain pattern. **Figure 133** is a graph of **D$_{w}$** vs **CTDI$_{vol}$** (using the same protocol). The value of **CTDI$_{vol}$** increases with an increase in the value of **D$_{w}$**, up to a certain **D$_{w}$** value. The increase in the **CTDI$_{vol}$** value was due to the use of the tube current modulation (TCM) method.

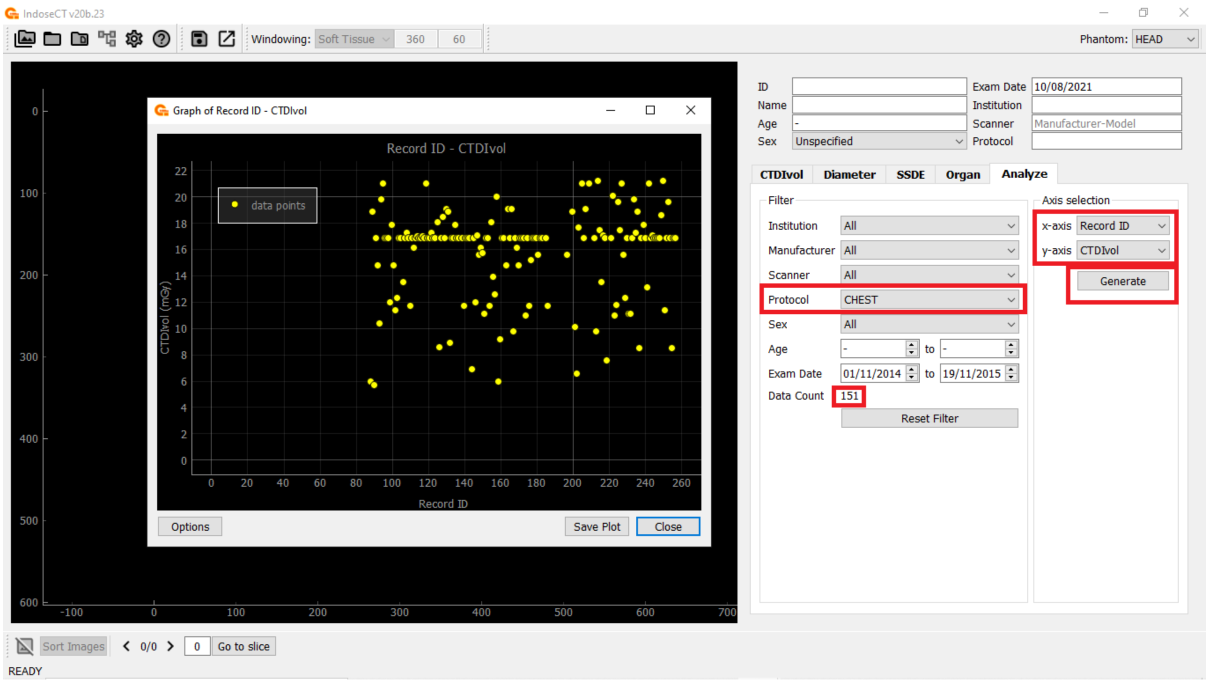

Figure 132. Example of a graph between **Record_ID** vs **CTDIvol** usingthe **CHEST** protocol.

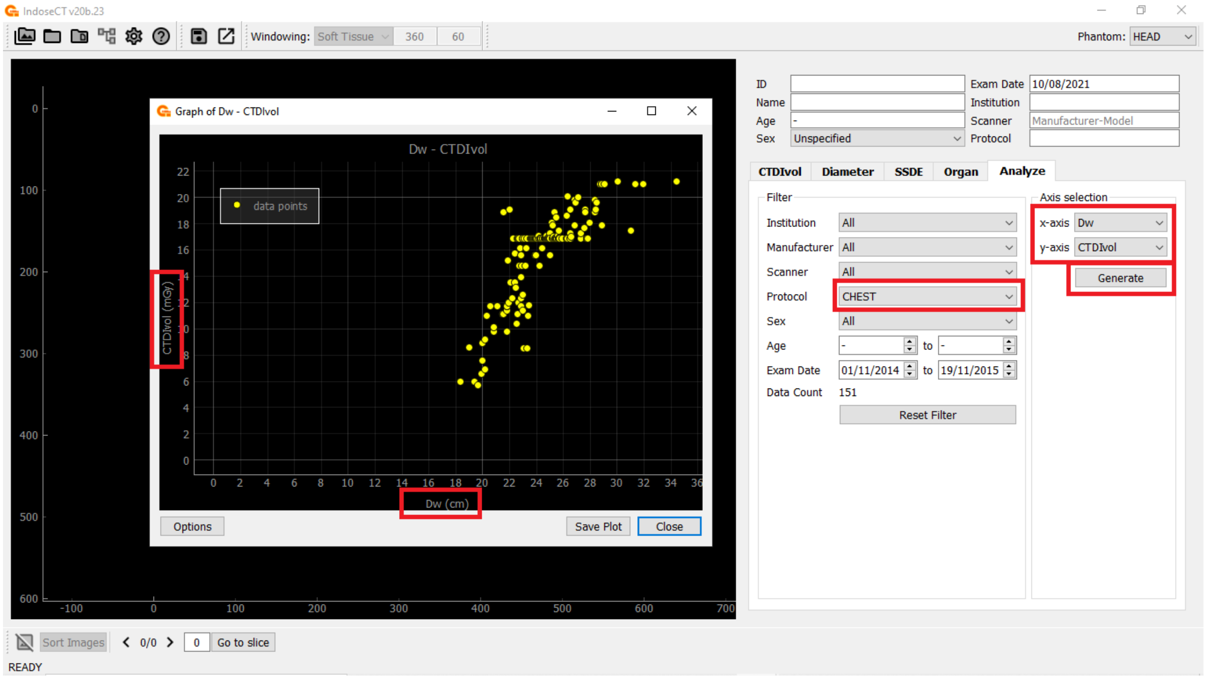

Figure 133. An example of a graph between $\mathbf{D_w}$ vs $\mathbf{CTDI_{vol}}$ using the **CHEST** protocol.

The graph in **Figure 133** can be adjusted in size. An example of an enlarged graph is shown in **Figure 134**. Trendlines can also be added to the graph. In the example of **Figure 134**, the added **Trendline** is **Linear**. A red straight line appears with the equation and R^2 value of the relationship between the two quantities $\mathbf{D_w}$ and **CTDIvol.**

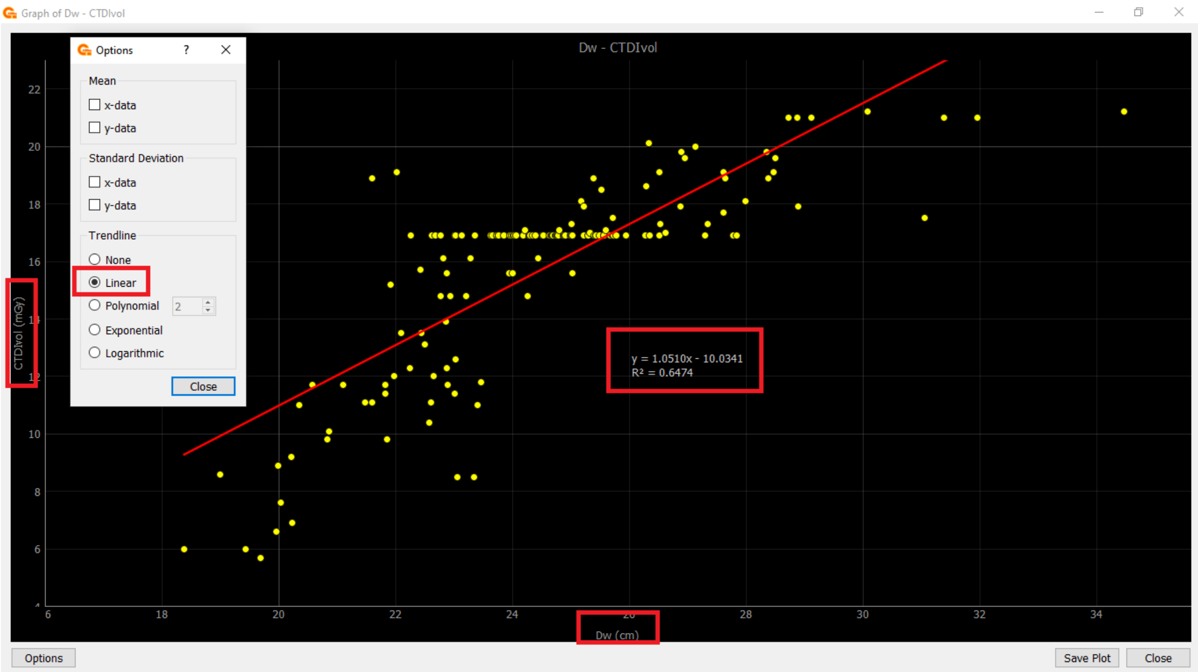

Figure 134. $\mathbf{D_w}$ vs $\mathbf{CTDI_{vol}}$ relationship graph which has been enlarged and given a **Linear Trendline.**

The **trendline** on the graph can be easily replaced and adjusted according to the data obtained. **Figure 135** is an example of a $\mathbf{D_w}$ vs **CTDIvol** relationship graph that has been enlarged and given a **Trendline** in the form of a **2nd order Polynomial**. Besides **Linear** and **Polynomial** trendlines, there are also **Exponential** and **Logarithmic**. To remove the **Trendlin**, press the **None** option. To display the x-axis and y-axis scaling adjustments by right-clicking on the graph, options will appear as shown in **Figure 135**. Highlight **X-axis**, then fill in the minimum and maximum values. Repeat for the y-axis as needed. Several options exist, for example **Plot Option** and **Export**.

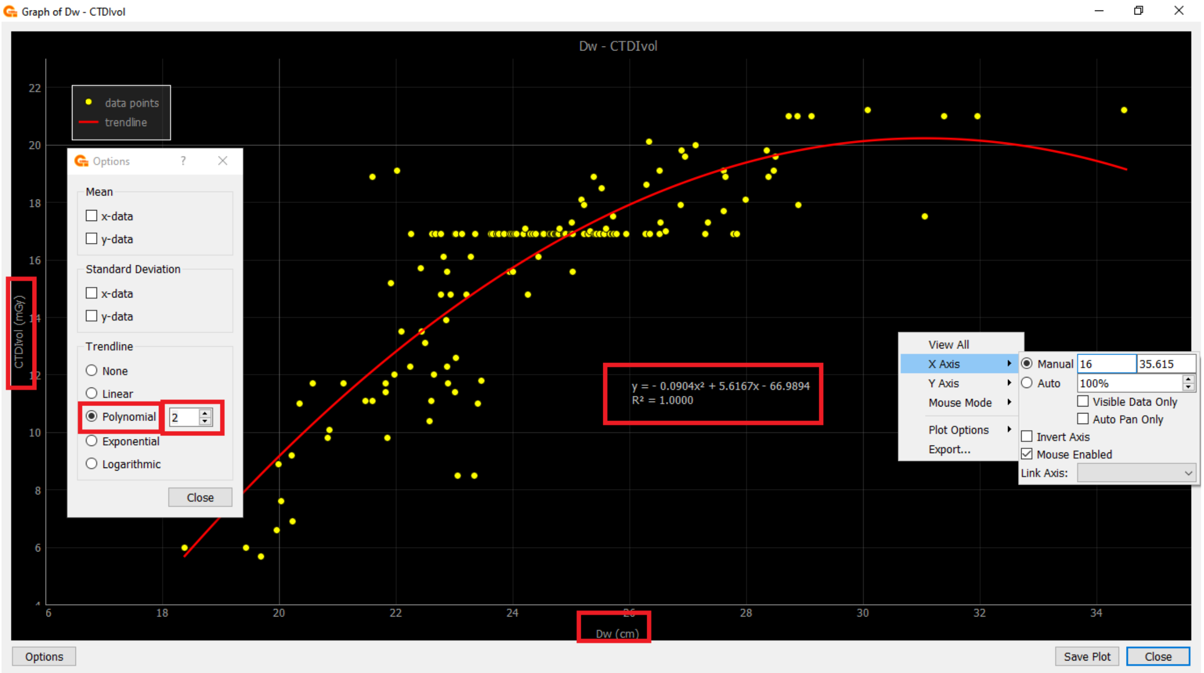

Figure 135. **Dw** vs **CTDI$_{vol}$** relationship graph that has been enlarged and given a **Trendline** in the form of a **2nd order Polynomial**. The x-axis and y-axis scales have been adjusted.

In addition to displaying the trendline of the data, **lines** can also be added to the graph showing the average value and standard deviation, either on the x-axis or on the y-axis. **Figure 136** is the same graph as **Figure 135**, but with the addition of lines of mean values and standard deviations on the x-axis and y-axis.

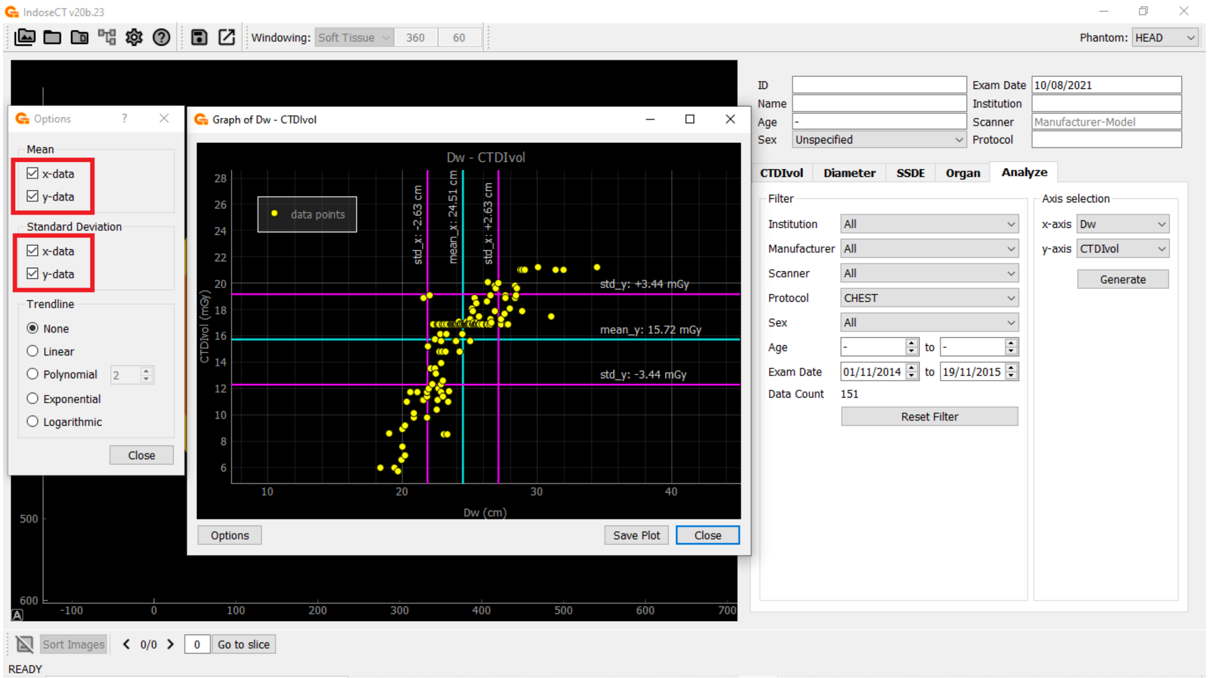

Figure 136. An enlarged graph of $\mathbf{D_w}$ vs $\mathbf{CTDI_{vol}}$ with the addition of the mean and standard deviation lines on the x-axis and y-axis.

Figure 137 shows the relationship between $\mathbf{D_w}$ vs $\mathbf{CTDI_{vol}}$ (same as **Figures 134-136** but with additional filters). In addition to the **Protocol** filter, a **Sex** filter is added, which is for women (**Female, F**). The **Data Count** only 137 patients. Thus, we can directly compare the relationship of $\mathbf{D_w}$ and $\mathbf{CTDI_{vol}}$ between male and female patients.

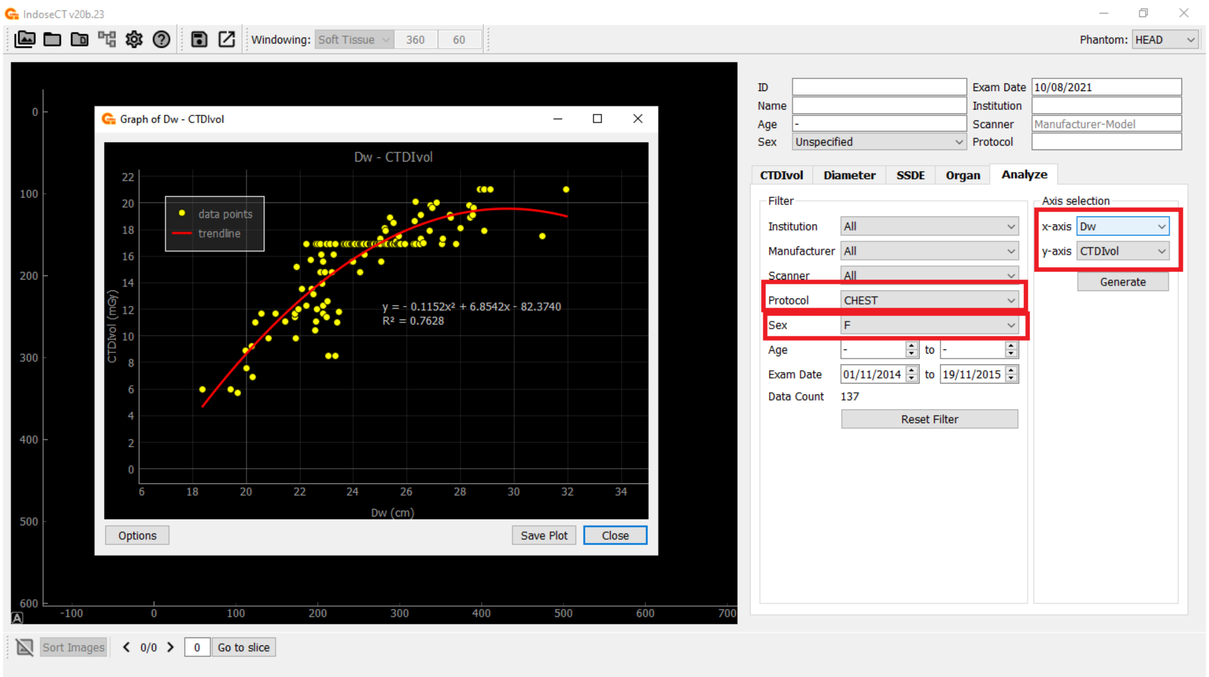

Figure 137. Graph of $\mathbf{D_w}$ vs $\mathbf{CTDI_{vol}}$ for data filtered by the **CHEST** protocol and female gender (**F**).

Figure 138 is a graph between **D_w** vs **SSDE** (using the same protocol) with a **Trendline** of **2^{nd} Order Polynomial**. The **SSDE** value increases along with the increase in the value of **D_w** to a certain point, after which it decreases.

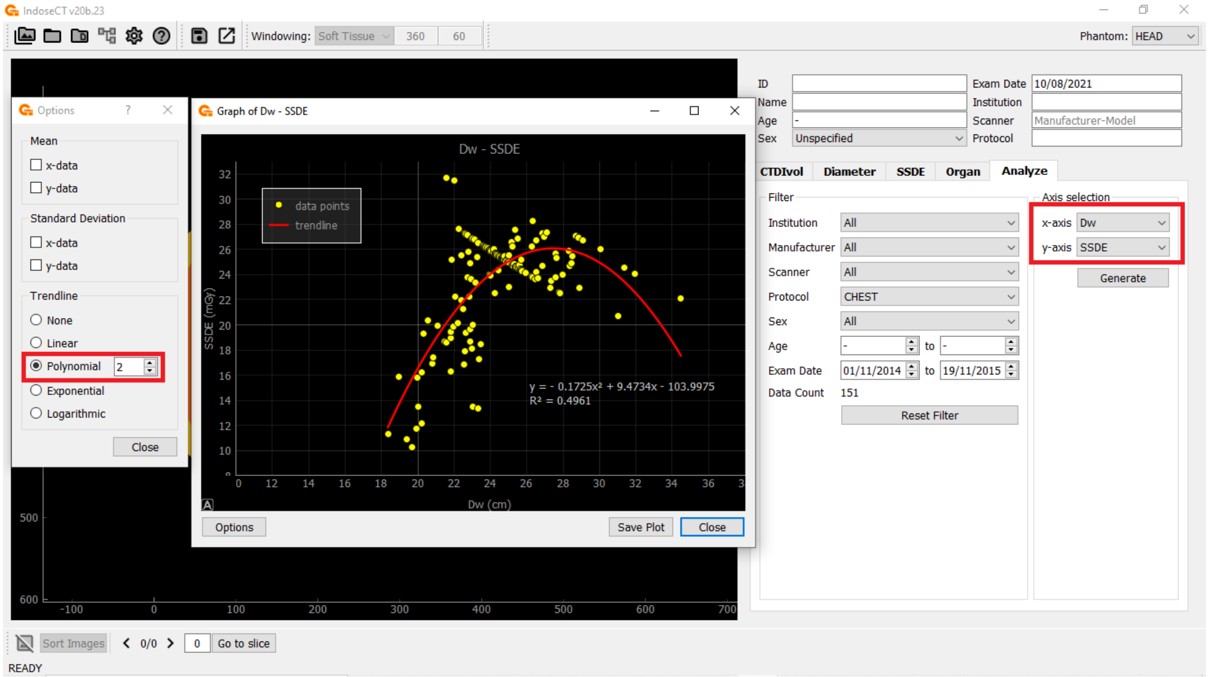

Figure 138. An example of a graph of **D_w** vs **SSDE** using the CHEST protocol.

Figure 139 is a graph of **Age** vs **D_w** (using the same protocol) using a **Linear Trendline**. The value of **D_w** tends to decrease as **Age** increases.

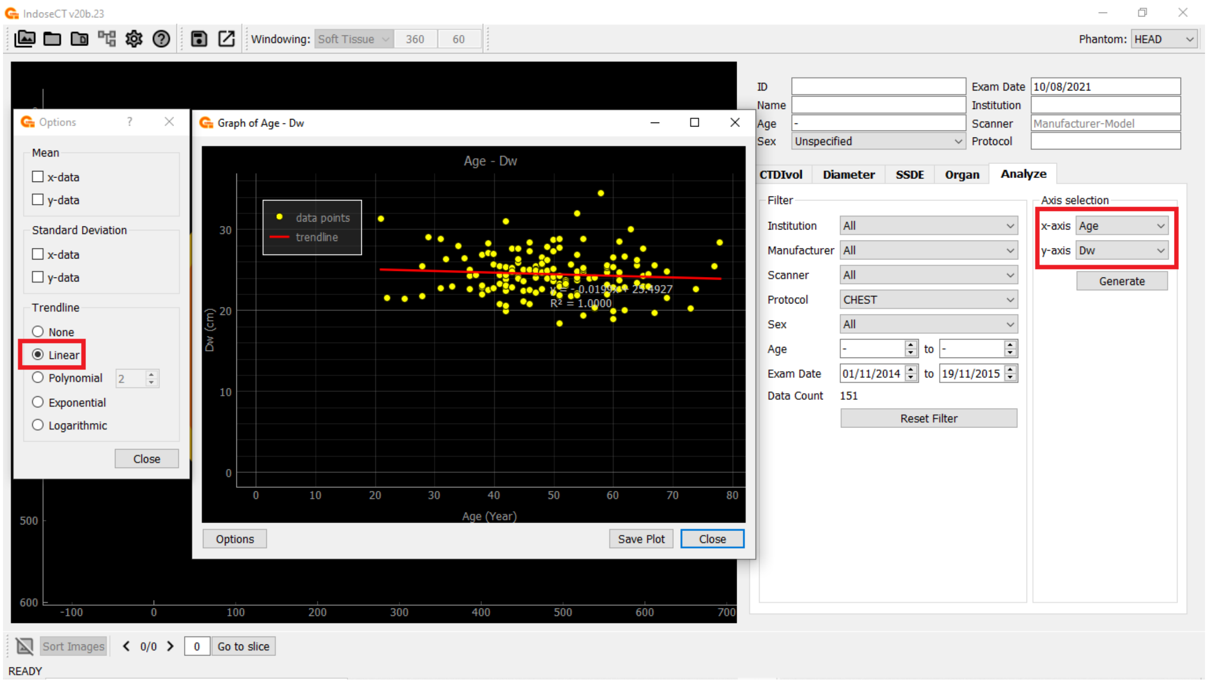

Figure 139. A graph of **Age** vs **Dw** using the **CHEST** protocol.

Figure 140 is a graph of **D$_w$** vs **Frequency** (using the same protocol). Since the y-axis is **Frequency**, this is a histogram of D$_w$. The user can specify the number of bins to form this histogram. In this example the number of bins is 15. In addition, the user can add a line showing the mean and standard deviation of the histogram.

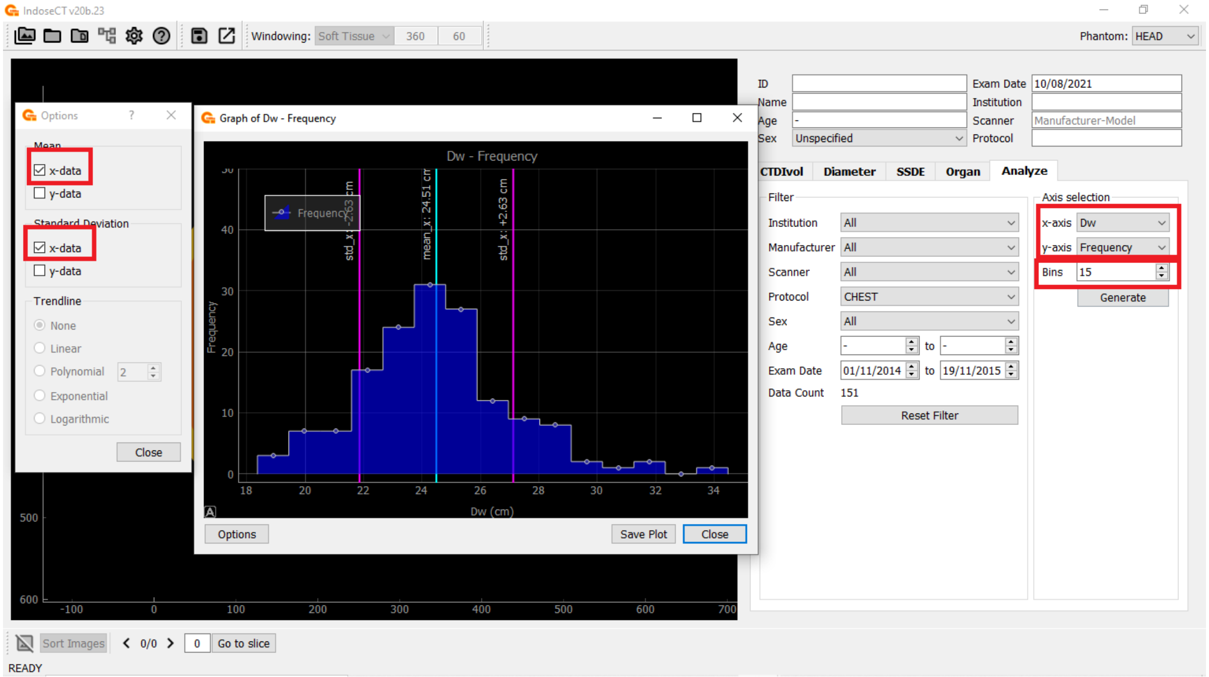

Figure 140. Example of a graph of **D$_w$** vs **Frequency.**

Figure 141 is a graph of **Age** vs **Frequency** (using the same protocol). The mean age of the patients is about 50 years.

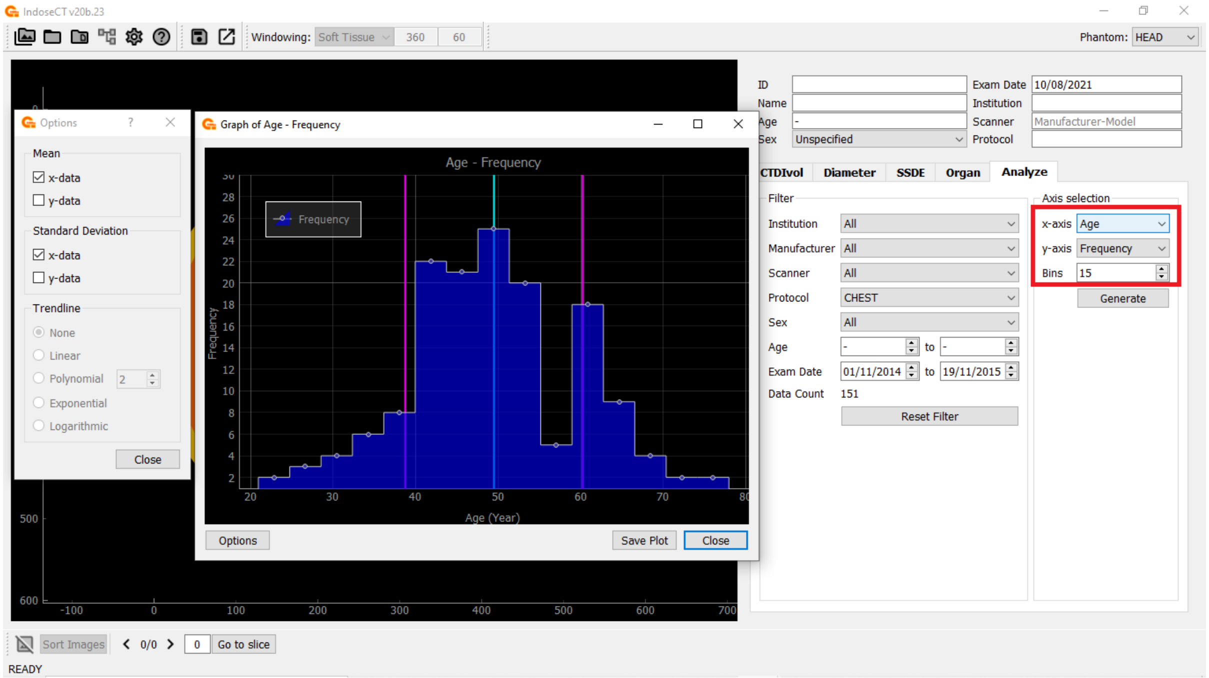

Figure 141. Example of a graph of **Age** vs **Frequency**.

The graph of **CTDI$_{vol}$** vs **Frequency** (using the same protocol) is shown in **Figure 142**. The graph of **SSDE** vs **Frequency** is shown in **Figure 143**. The graph of **Effective dose** vs **Frequency** is shown in **Figure 144**.

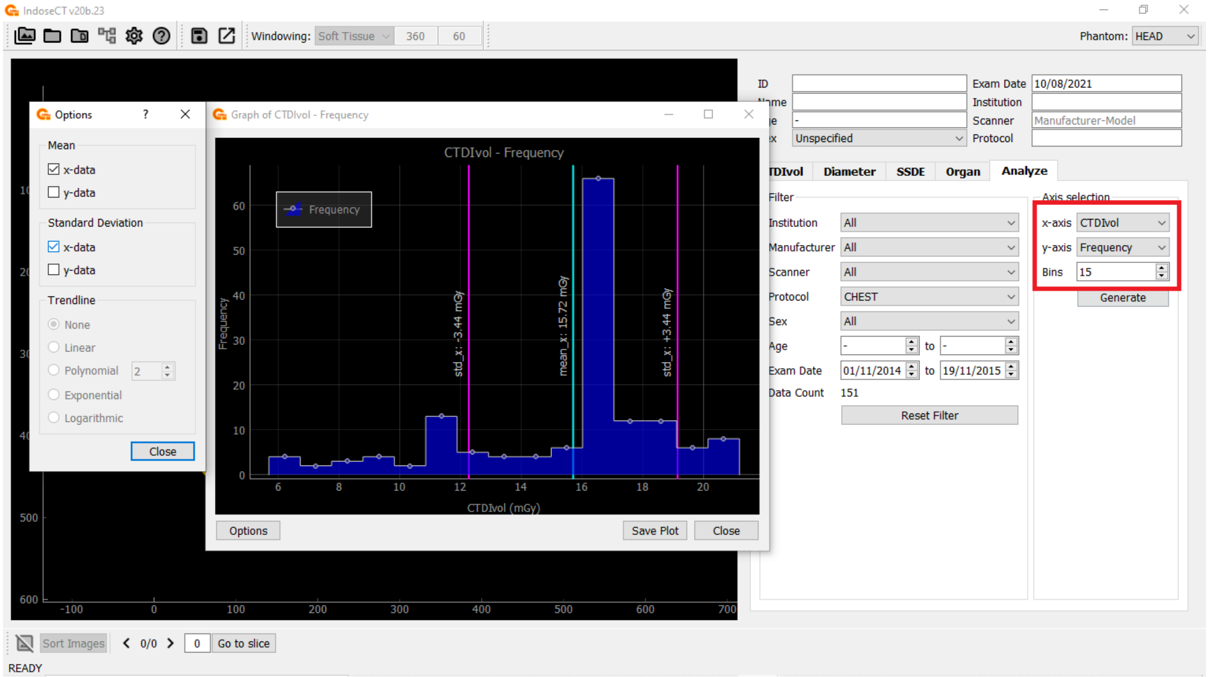

Figure 142. Example of a graph of **CTDI$_{vol}$** vs **Frequency**.

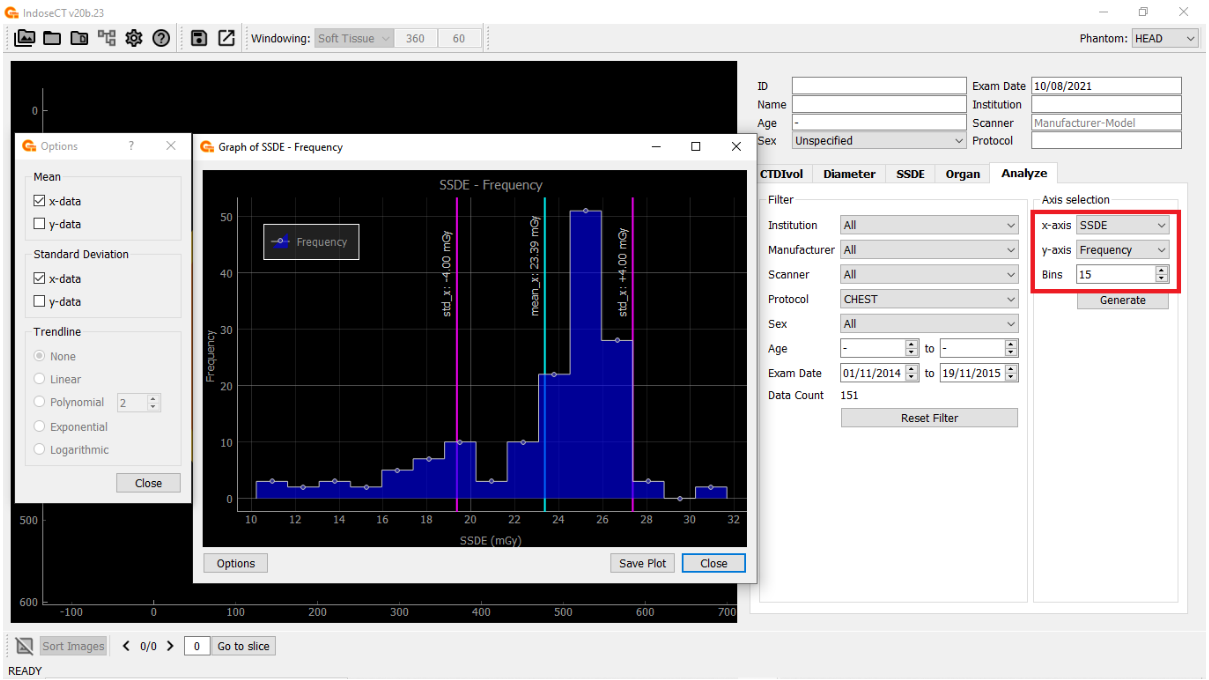

Figure 143. Example of a graph of **SSDE** vs **Frequency.**

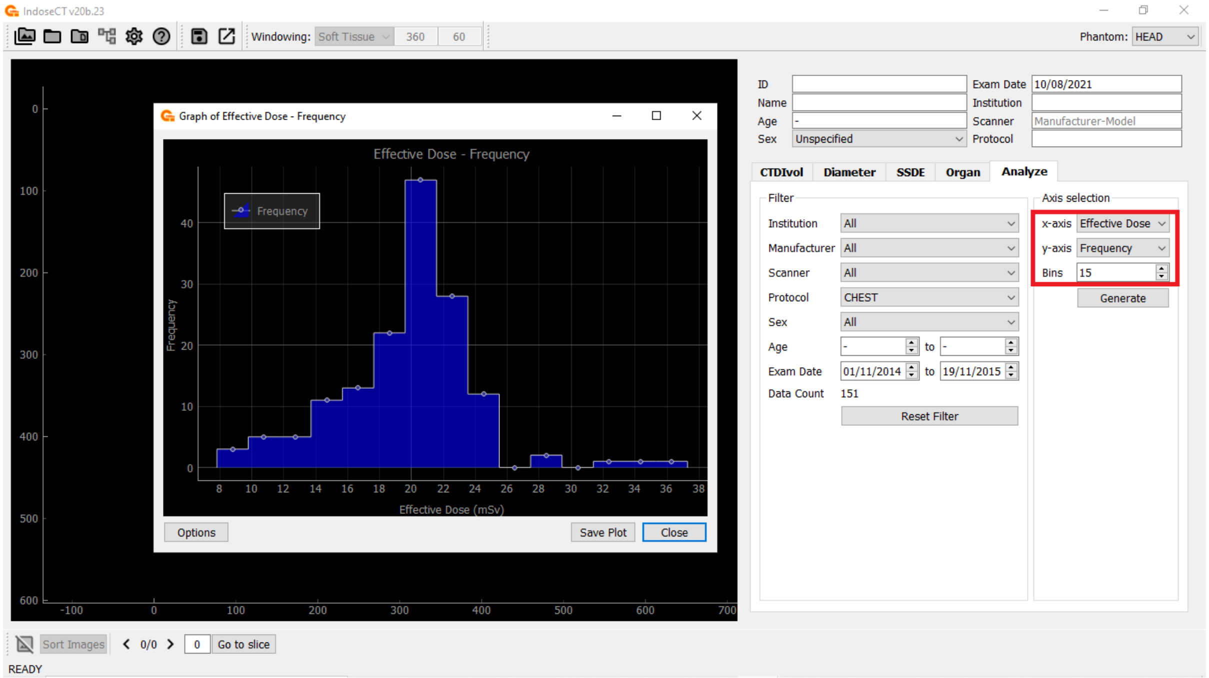

Figure 144. Example of a graph of **effective dose** vs **Frequency.**

Figures 140-144 are histograms of $CTDI_{vol}$, SSDE and effective dose values. From these histograms, we can see the distribution of patient doses. This data can be used to determine the diagnostic reference level (DRL).

XV. SUMMARY

IndoseCT 20.b is software for calculating individual patient doses, storing the data in a database, and analyzing the data. With **IndoseCT**, the patient's dose can be controlled in a simple way. With this software, individual patient doses will be known and their comparison to the population can be easily shown.

This software is a tool to monitor radiation doses of all patients undergoing CT scans. If there is a human error in the CT application, then it will be easily monitored. Special strategies can also be designed if the patient dose at the hospital is higher than it should be.

XVI. REFERENCES

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