Lesion Synthesis Toolbox
User Manual

Version 1.0

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1   Introduction

Lesion Synthesis Toolbox (LST) is a research tool developed by Ran Klein and his trainees at The Ottawa Hospital Research Institute in MATLAB®. LST is intended to generate well controlled fake lesions in raw positron emission tomography (PET) and reconstructed CT data and reconstruct the PET images in a realistic fashion.

Thus far, LST has only been implemented and tested for GE Healthcare PET/CT scanners, using their DUETTO image reconstruction toolbox, which requires a research collaboration agreement with GE Healthcare. For more information on DUETTO and research collaboration contracts, contact your GE Healthcare research representative and/or Elizbeth Philps (Elizabeth.Philps@med.ge.com). Nevertheless, LST was designed to be extendable to work with other vendors and products and we are looking forward to collaborating to achieve this.

LST can be used to reconstruct raw PET data. Lesions can be added with varying contrast, size, and shape, to both PET and CT data sets and can be previewed on the reconstructed images. In the case of PET, this is achieved by introducing the lesion signal into the projection data, prior to image reconstruction. In the case of CT, the lesions are painted into the reconstructed image. PET images can be reconstructed using any vendor supported algorithm (e.g., OSEM and Q.Clear™) and parameters.

LST can be used to create ground truth lesion reference images to train, validate and characterise human and AI observers. Furthermore, by changing reconstruction parameters, researchers can analyze how reconstruction changes the detectability of lesions and accurately models the noise and texture in a PET image.

Raw PET data and corresponding CTs can be imported from the PET scanner console using LST. Images with and without lesions can be displayed with various options for fusion, colormaps, and intensity levels directly within LST. Resulting image data (with and without lesions) can then be exported by DICOM transfer or DICOM files. Corresponding ground truth data on the lesions can also be exported.

LST is based of the Master's work of Hanif Gabrani-Juma[1, 2] and Quinn de Bourbon, under the supervision of Ran Klein at The Ottawa Hospital.

Figure 1: The Lesion Synthesis Toolbox icon

2   *Starting LST*

LST can be run directly in MATLAB © by:

1) Copying the LST program files to a local directory.
2) Adding the local directory to the MATLAB path.
3) Adding the DUETTO to the path. Recommended to make the path in the *Recon Engines.*
4) Executing LesionSynthesisToolbox.mlapp in MATLAB

Alternatively, LST can be compiled to run as a standalone executable or webapp as per MATLAB documentations.

When LST runs for a first time, it will ask for a location to create the default data directories. The user can select either 'initialize new' or 'locate existing' to initialize the application data directory. As well, there is as an option to abort. If one of the first two options are selected, a file explorer window will open. From here the user can select a file folder in which a new folder is created, or an existing folder is selected, depending on if the user chose to initialize a new folder or locate an existing one.

- If these data are to be shared between multiple computer users, it is recommended to a shared directory such as "C:\Lesion Synthesis Toolbox".
- These folders will store the archive of raw data and reconstructed images, which can be very large files. It is recommended to select a drive with >1TB capacity.

The LST data subdirectories by default include:

- Application Data – where LST configuration settings are saved including general settings, project settings and reconstruction profiles.
- Raw Data – where raw PET associated CT data are archived when retrieved from the scanner console.
- Recon Queue – where reconstructions are queued for processing.
- Reconstructed Archive – where reconstructed image data are archived along with their CT and intermediate reconstruction files. Reconstructed PET are saved as DICOM directories and in a _fir3D.mat file format, both of which are named for the reconstruction type. The CTs are saved as DICOM in a CTAC_DICOM directory and as a CTAC.mat file. Each patient data is saved in a unique identifier directory.
- Simulation Archive – where simulations are queued for processing.
- Simulation Queue – where simulated studies are archived. Subdirectories identify the patient and sub-subdirectories identify the simulation name. In each simulation CT images are saved in a DICOM directory and _fir3D.mat file (same as for Reconstructed Archive). Likewise simulated PET named according to the reconstruction profile. The simulation parameters are also saved in a _LesionParams.mat file.

When initializing a new installation, before the users can access the toolbox, the administrator must set up accounts for each user. The administrator is directed to the *Configure* tab to add users and make other general configurations such as setup/change the directories for the specific project. More details are available in the section 7 - Configure Tab.

3 The Login Tab

In this window (see Figure 2), the user can enter their credentials to unlock the workspace. Users are configured in the Configuration tab as described in section 27.1 - General settings. Each user may have their own list of projects and their associated settings.
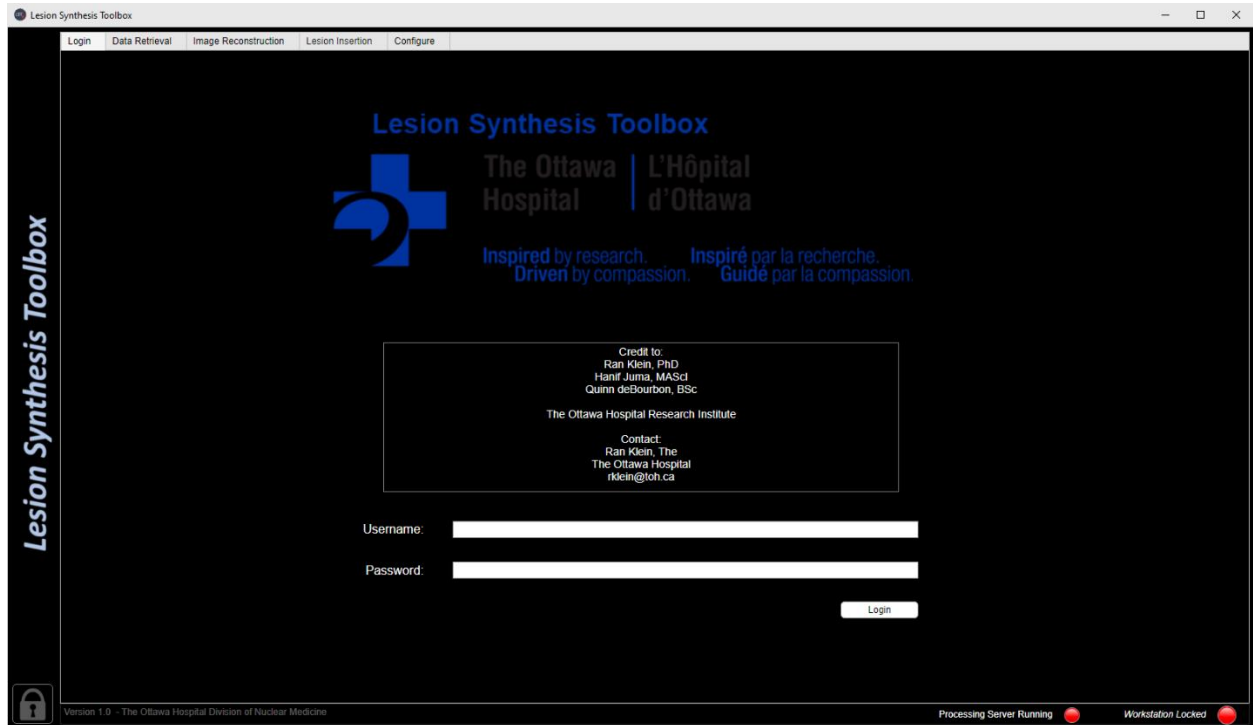

Figure 2: The login tab

Table 1: Elements from Figure 2

Element	Name	Description
Field	Username	The user enters their username.
Field	Password	The user enters their password.
Button	Login	If the username and password are correct, the workstation will be unlocked.
Lamp	Processing Server Running 🔴	Indicates whether the processing server is running in the background to process any reconstructions or simulations in the queues. A red circle 🔴 indicates that the server is not running, while a green circle 🟢 indicates that the server is running.
Lamp	Workstation Locked 🔴	If the username entered is incorrect, the "Workstation Locked" text will change to "username does not exist". If the username is correct, but the password is incorrect, the text will display "password does not match". If the workstation is unlocked, the red circle changes to a green circle 🟢 and the "Workstation Locked" text will change to the User's name.

Button	Logout 🔒	When clicked, the user is logged out and the workspace is locked.

4   *Data Retrieval Tab*

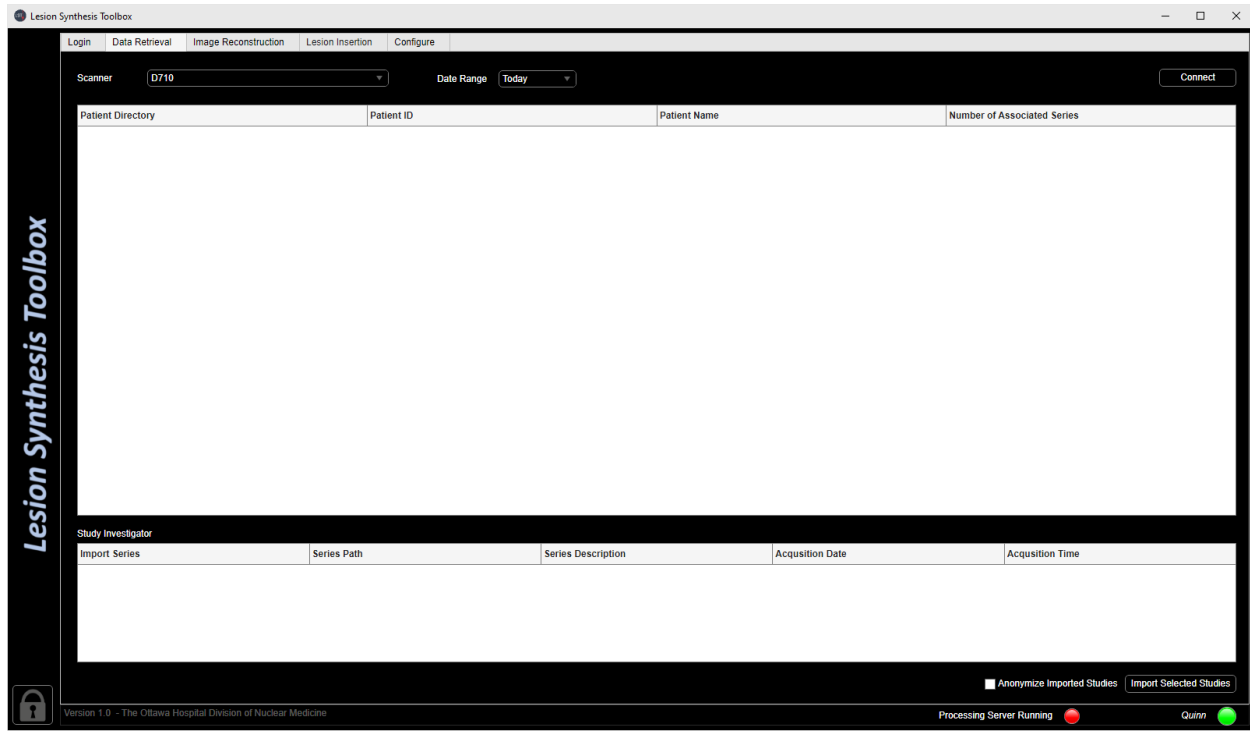The data retrieval window connects to the scanner to retrieve recent data files.

Figure 3: Data Retrieval tab

Table 2: Elements from Figure 3

Element	Name	Description
Drop Down List	Scanner	The user selects a scanner from a drop-down list. The scanner list can be changed in the 'Configure' tab.
Drop Down List	Date Range	The user selects the date range for the data from the scanner. The date options are 'today', 'past week', 'past 2 weeks', 'past 3 weeks', 'past month', and 'all'.
Button	Connect	If the connection to the selected scanner is unsuccessful, the button will turn red. If the connection is successful, the button will turn green and the data from the selected date range will load onto the patient data table.
Table	Patient Data	The patient data files are listed with the patient directory, patient ID, patient name, and number of associated series. The patient data files can be sorted in ascending or descending order based on the directory, ID, and name. The user can select a patient to get more information.
Table	Study Investigator	The selected patient information appears, including the series path, series description, acquisition date, and acquisition time. A check box in the import series column can be selected to be imported.

| Checkbox	Anonymize Imported Studies	The selected patient data will be anonymized once the 'Import Selected Studies' button is pushed.
Button	Import Selected Studies	The selected patient data will be copied to the Image Reconstruction Tab. This process may take several minutes.
Pop-Up Window	Anonymization	The selected patient data is anonymized by replacing the patient family name, given name, ID, and the date of birth, however the year of birth is kept. The window is shown in Figure 4.
Pop-Up Window	Confirm in place anonymization	The user can choose to copy over only the anonymized version of the data using the 'In place' button, or can create a copy and transfer both versions using the 'Duplicate' button to the Image Reconstruction Tab. This window is shown in Figure 5.
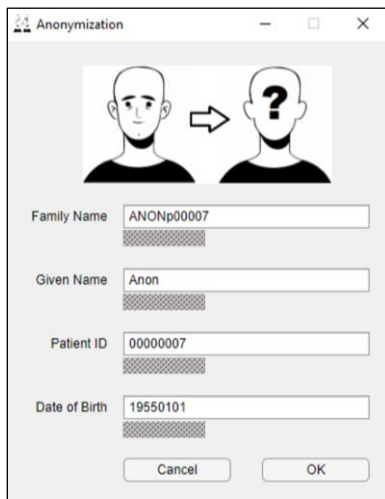
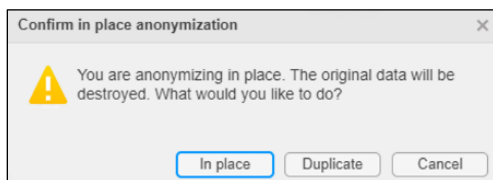*Figure 4: Anonymization window*

Figure 5: In place anonymization

5   Image Reconstruction Tab

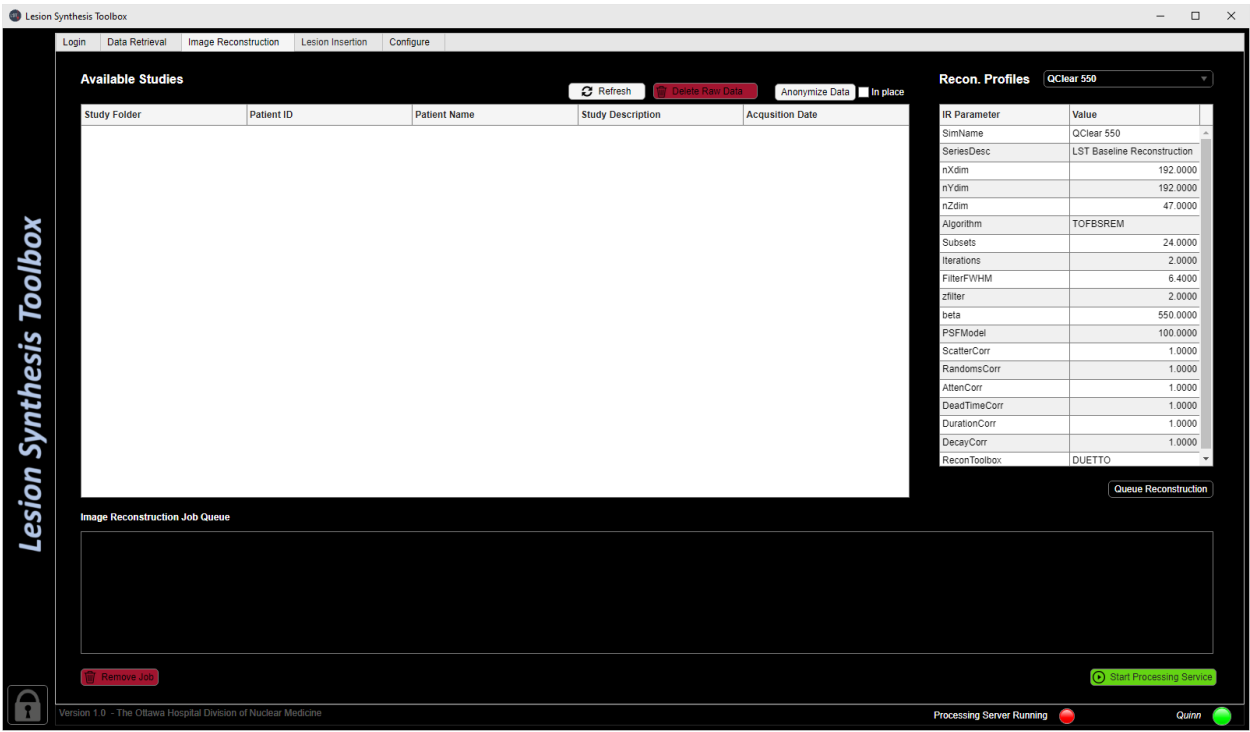In the image reconstruction window, the patient data is set up to be reconstructed.

Figure 6: Image Reconstruction tab

Table 3: Elements from Figure 6

Element	Name	Description
Table	Available studies	The studies available for reconstruction are listed by study folder, patient ID, patient name, study description, and acquisition date. The user can select a study to be reconstructed or deleted.
Button	Refresh	The list of available studies is refreshed.
Button	Delete Raw Data	The study selected by the user is deleted.
Button	Anonymize Data	The selected patient data is duplicated and is anonymized. The pop-up window 'Anonymization' from Figure 4 appears.
Checkbox	In Place	When the checkbox is selected and the button 'Anonymize Data' is clicked, the raw data is deleted after anonymization. The pop-up window 'Confirm in place anonymization' from Figure 5 appears.
Drop Down List	Recon. Profiles	The user selects the type of reconstruction method from a drop-down list. These are defined in the *Recon settings* as described in section 7.3.

Table	IR Parameter	The reconstruction profile parameters are shown with their respective values. These values can be adjusted by the user.
Button	Queue Reconstruction	The patient file is added to the job queue.
List	Image Reconstruction Job Queue	Lists the patient file in the queue, listed as {patient name}\{profile method}_reconParams.mat. The user can select jobs from the queue to be removed.
Button	Remove Job	The selected patient file from the queue is removed.
Button	Start Processing Service	Starts the background image reconstruction and lesion simulation service.

6   *Lesion Insertion Tab*

The Lesion Insertion tab is used to simulate define, simulate and validate lesions (e.g., emulated disease) within the patient data. It consists of a 4-step workflow, defined in sub-tabs:

6.1   Select Patient Sub-Tab
The patient selection tab provides previews of reconstructed patient data.
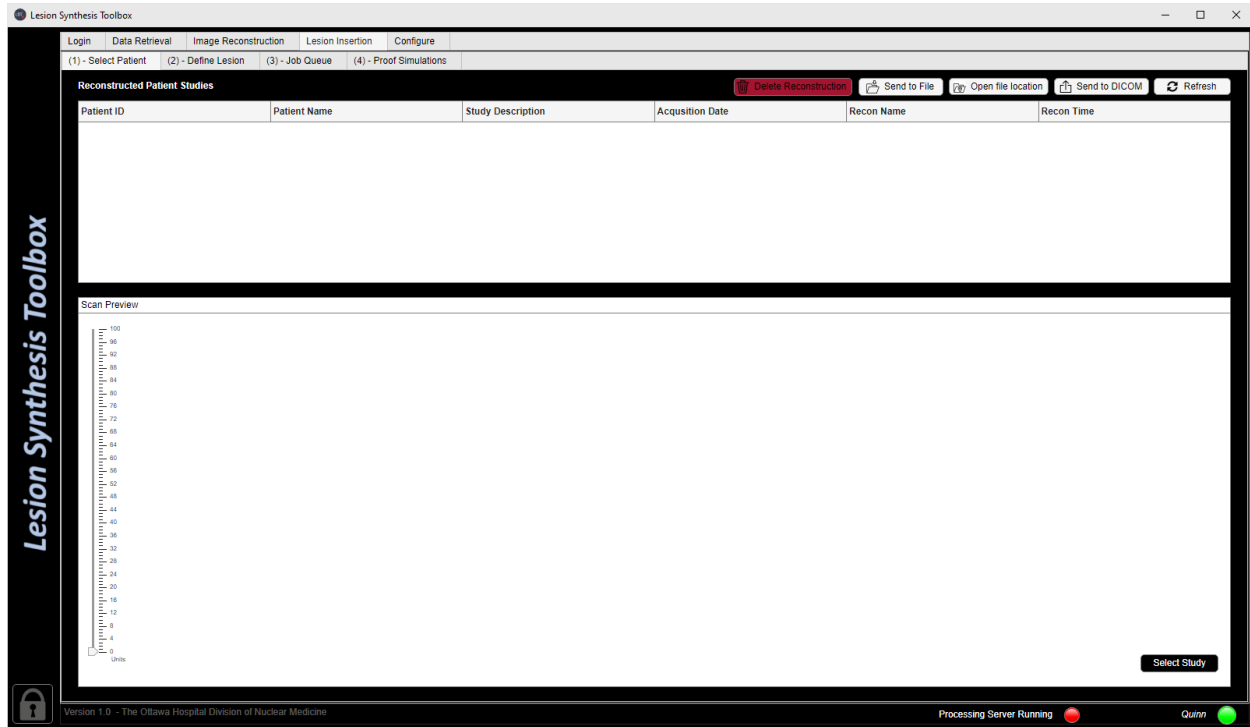

Figure 7: Lesion Insertion tab for Select Patient sub-tab.

Table 4: Elements from Figure 7

Element	Name	Description
List	Reconstructed Patient Studies	The list of patient studies that have been reconstructed will be displayed here. The user can select a study to be previewed or selected. Multiple studies can be selected to be sent to file.
Button	Delete Reconstruction	The selected studies are deleted from the list.
Button	Send to File	The selected studies CT and reconstructed PET images are sent to a folder selected by the user.
Button	Open File Location	The selected study file location is opened in the file explorer.
Button	Send to DICOM	The selected data is sent to a location specified by the DICOM send field in the 'Configure Tab.
Button	Refresh	Refreshes the list of reconstructed studies.

Image	Scan Preview	A preview of the PET image of the selected study will be displayed with the sagittal, coronal, and transverse planes. The user can select the point of view by clicking on the image or can scroll through the image along a plane using a mouse scroll.
Slider	0-maximum intensity pixel	The user can adjust the maximum intensity of the PET image, between 0 and the maximum intensity pixel in the image. The image units depend on the corresponding project configuration setting.
Button	Select Study	The selected study will be opened in the 'Define Lesion Sub-Tab for lesion insertion.

6.2   Define Lesion Sub-Tab

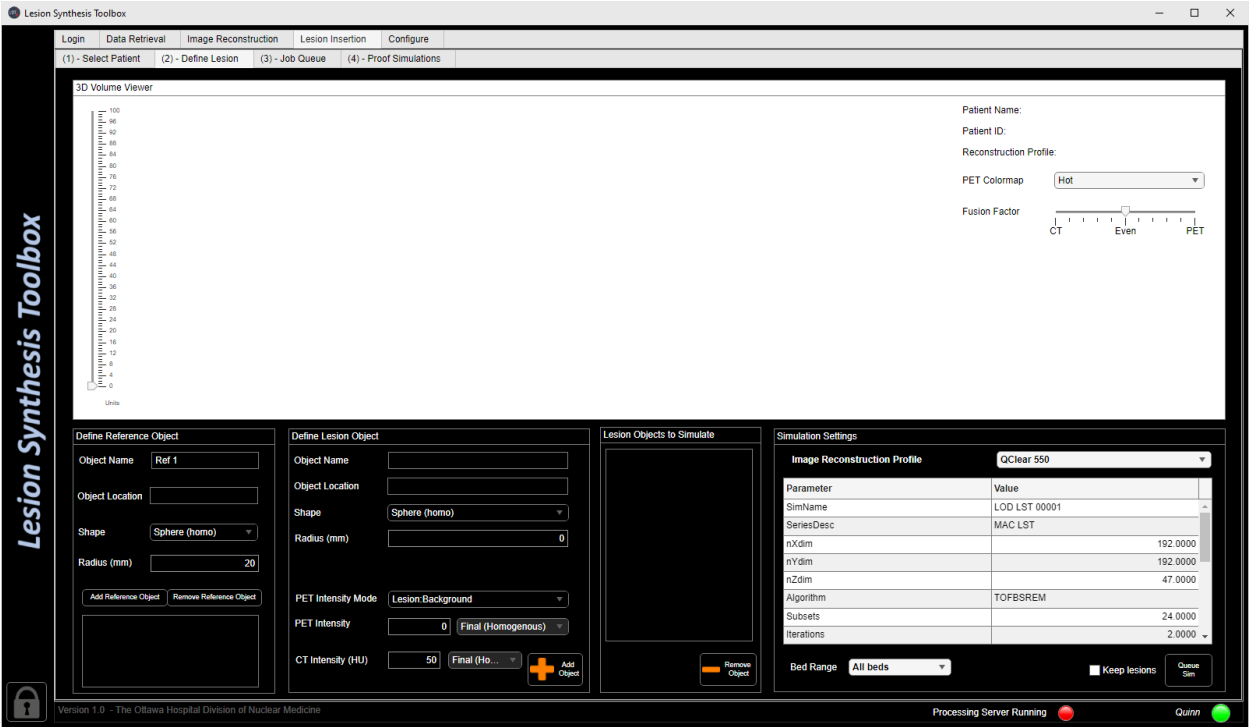In the define lesion tab, various lesion objects can be added to the patient's reconstruction image.

Figure 8: Lesion Insertion tab for Define Lesion sub-tab.

Table 5: Elements from Figure 8

Element	**Name**	**Description**
Panel	**3D Volume Viewer**	**Preview of the image volume with lesion insertion.**
Image	3D Volume Viewer	The 3D image of the selected patient study appears along the sagittal, coronal, and transverse planes. The user can scroll through the image using their mouse or can select to triangulate in three the three orthogonal slices by clicking on the image.

Slider	0-maximum intensity pixel	The user can adjust the maximum intensity of the PET image, between 0 and the maximum intensity pixel in the image. The image units depend on the corresponding project configuration setting.
List	PET Colormap	The user selects the colour map used for the PET images.
Slider	Fusion Factor	The user selects the ratio of image intensity between the CT and PET images.
Panel	**Define Reference object**	**The user selects a reference region for the intensity levels in the simulated lesion object.**
Field	Object Name	The user selects a name for the reference object.
Field	Object Location	The user selects a location for the reference object. This can be done by manually writing the location or selecting a location using the crosshairs on the 3D volume viewer.
List	Shape	The user selects the shape for the reference object. The shape selection is currently limited to a homogenous sphere (i.e., the average intensity of the pixels within the sphere).
Field	Radius (mm)	The user selects a radius for the reference object, in mm.
Button	Add Reference Object	The reference object is added.
Panel	**Define Lesion Object**	**The user selects parameters for the simulated lesion object.**
Field	Object Name	The user selects a name for the lesion object.
Field	Object Location	The user selects a location for the lesion object. This can be done by manually writing the location or selecting a location using the crosshairs on the 3D volume viewer.
List	Shape	The user selects a shape for the lesion object. The shape selection includes a sphere and a blobby sphere*.
Field	Radius (mm)	The user selects the radius of the lesion object, in mm.
List	PET Intensity Mode	The user selects the intensity mode for the lesion object on the PET image. The intensity modes include 'Bq/cc' (native PET intensity value in units of Bq/cc), 'SUV' (intensity value in units of standard uptake values by body weight), 'Lesion: Background' (relative to background), and for each reference object 'Lesion:{Reference object name}' (relative to the reference object).
Field/List	PET Intensity	The user selects the intensity for the lesion object for the PET image, based on the intensity mode. The intensity level can be written in the field, while the texture can be selected in the list. The texture options include 'Final: Homogenous' (equal intensity across lesion), 'Final: Maintain Texture' (average value changed but texture is the same), and 'Incremental'(additional over background).
Field/List	CT Intensity	The user selects the intensity for the lesion object on the CT image, in Hounsfield Units. The intensity level can be written in the field, while the texture can be selected in the

		list. The texture options include 'Final: Homogenous' (target uniform intensity across lesion), 'Final: Maintain Texture' (target average value is specified and existing image texture is preserved), and 'Incremental' (intensity is added to the existing background activity in the image).
Button	Add Object	The object is added to the list of lesion objects to simulate.
Panel	**Lesion Objects to Simulate**	**The list of lesion objects defined for simulation.**
List	Lesion Objects to Simulate	The lesion objects are listed here to be simulated. The objects can be selected by the user, which populates the Define Lesion Object Panel fields.
Button	Remove Object	The selected lesion object, from the lesion objects to simulate list, is deleted.
Panel	**Simulation Settings**	**The user selects the image simulation and reconstruction settings.**
List	Image Reconstruction Profile	The user selects the type of reconstruction method from a drop-down list. These are defined in the *Recon settings* as described in section 7.3.
Table	Parameter Values	The parameters of the selected image reconstruction profile are listed, and can be edited by the user.
List	Bed Range	The user selects the bed range for the reconstruction with the lesion object, the options are 'All beds' and 'Bed range with lesions'.*
Checkbox	Keep Lesions	When selected, the file and lesions stay in the 'Define Lesion' tab, which can be edited to be queued again.
Button	Queue Sim	The lesion objects will be added to queue to be simulated, using the parameters and bed positions that the user selected.

* denotes feature identified as not fully validated.

6.3　Job Queue Sub-Tab

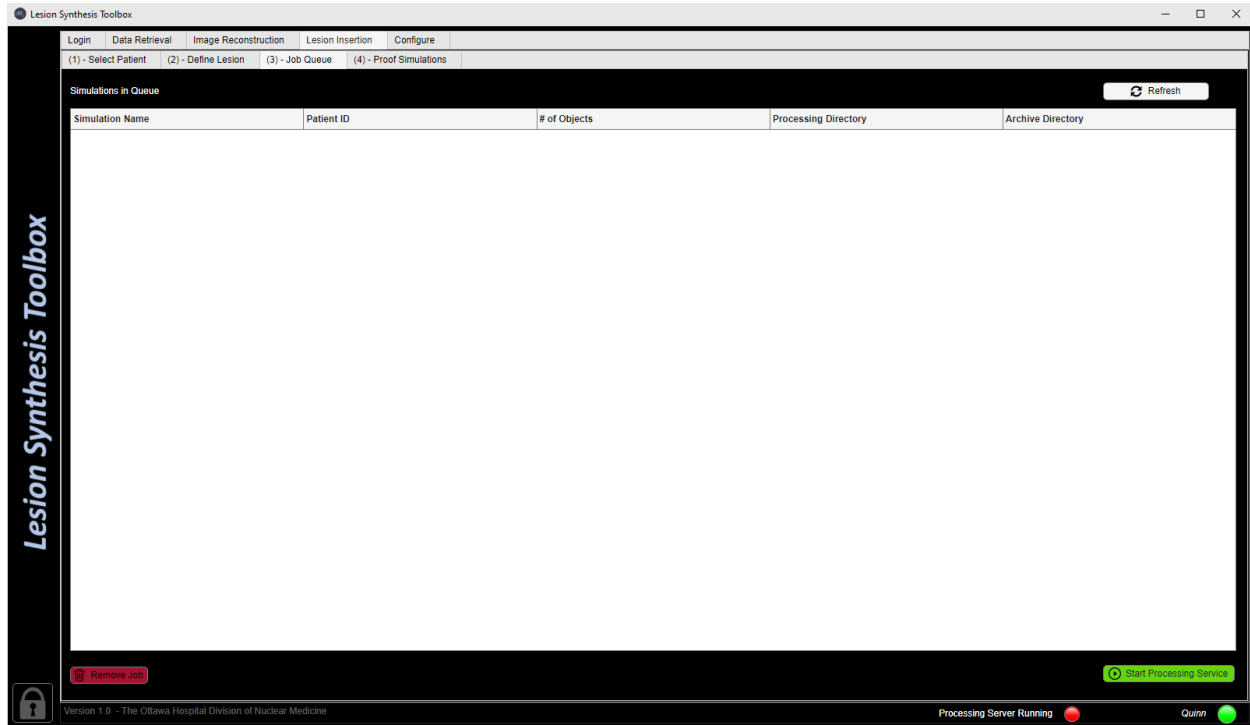In this tab, the job queue is displayed, and the lesion studies can be simulated.

Figure 9: Lesion Insertion tab for Job Queue sub-tab.

Table 6: Elements from Figure 9

Element	Name	Description
Button	Refresh	The queue list is refreshed.
List	Simulation Queue	The job queue for lesion simulation is displayed. The user can select a job on the queue.
Button	Remove Job	The selected job on the simulation queue is deleted.
Button	Start Processing Service	Starts the background image reconstruction and lesion simulation service.

6.4   Proof Simulations Sub-tab

The proof simulations tab allows for viewing the reconstructions after adding the lesion objects.
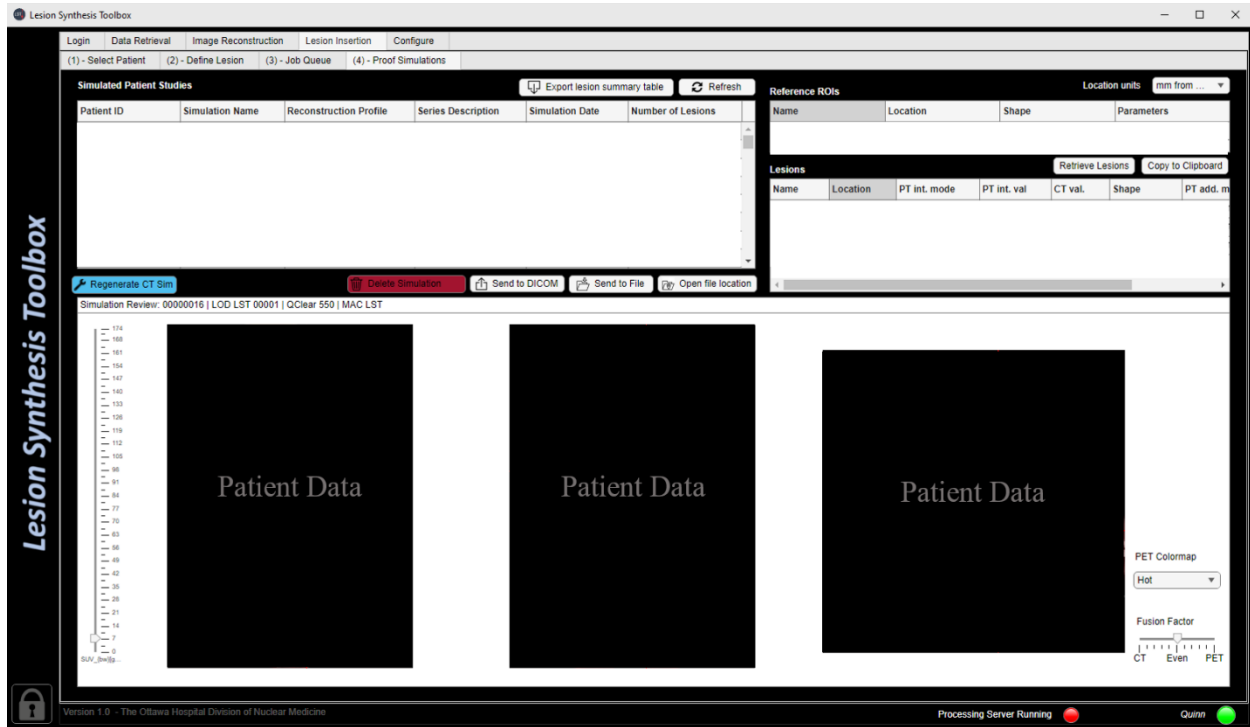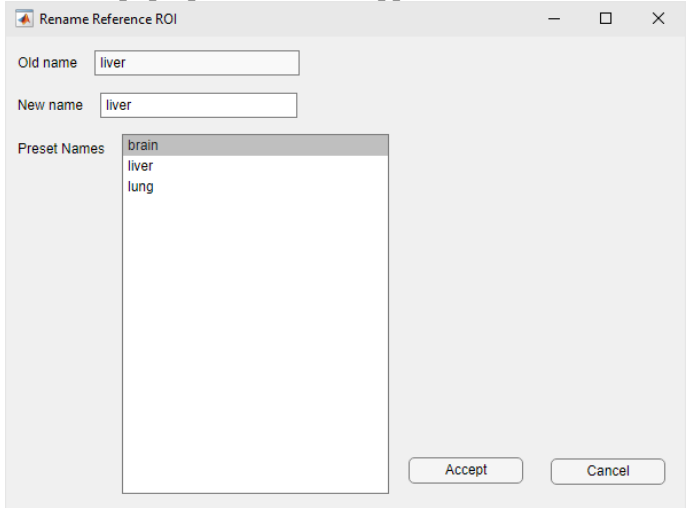

Figure 10: Lesion Insertion tab for Proof Simulations sub-tab.

Table 7: Elements from Figure 10

Element	Name	Description
List	Simulated Patient Studies	A list of the patient studies that have been simulated appears here. The user can select a study to view.
Button	Export Lesion Summary Table	An excel spreadsheet is generated containing a list of the lesion objects and their parameters in the project simulations. See 6.4.1 for more details.
Button	Refresh	The simulated patient studies list is refreshed.
Button	Regenerate CT Sim	When clicked, the selected patient's CT is regenerated with the lesions included. This can be used if there is an issue creating the CT lesions.
Button	Delete Simulation	The selected patient simulations will be deleted.
Button	Send to DICOM	The selected patient study is sent to a DICOM file on another server, which can be specified in the 'Configure' tab.
Button	Send to File	The selected studies are sent to a folder specified by the user. The studies include the CT and PET images, but not the ground truth values of the lesions.
Button	Open File Location	The location of the patient simulation file is opened.
Drop Down List	Location Units	The units for location of points in the image are defined. The user can select either 'pixel', 'mm from centre', or

		'mm from origin'. Note that the unit that is selected will appear in the Excel 'Lesion Summary Table'.
List	Reference ROIs	The location of the reference regions of interest are listed using the units selected by the user. To rename the reference ROI's, the user can right click on the ROI and a pop-up window will appear, as seen in Figure 11: Renaming a reference region of interest, with a list of preset names available.
Button	Retrieve Lesions	The selected patient's original reconstruction file is opened in the 'Define Lesion Sub-Tab with lesions added to the 'Lesion Objects to Simulate' list. Note that this does not edit the simulated image, it recreates the 'Define Lesion Sub-Tab before simulation.
Button	Copy to clipboard	The list of lesions for the selected patient study is copied to clipboard.
List	Lesions	The lesions are listed for the selected patient study with the parameters of the lesion, including name, size, shape, location, and intensity (mode, PET, and CT). To rename the lesions, the user can right click on the lesion and a pop-up window will appear as seen in Figure 12: Renaming a lesion, with a list of preset names available.
Image	Simulation Review	The selected patient study containing lesion objects is displayed on the screen using three views, the sagittal, coronal, and transverse view.
Slider	0-maximum intensity pixel	The user can adjust the maximum intensity of the PET image, between 0 and the maximum intensity pixel in the image. The image units depend on the corresponding project configuration setting.
Drop Down List	PET Colormap	The user can select the colormap for the PET image.
Slider	Fusion Factor	The user can select the ratio of intensity for the PET and CT images.

6.4.1 Lesion Summary Table

When the *Export lesion summary table* button is pressed, the user is prompted to select a location and name of the Excel spreadsheet with the resulting ground-truth data for all the lesions in the project. By default, the file will be named *{Project Name}-ground truth.xlxs* and will be saved in the *simulation archive directory*.

The location coordinate system and units in the spreadsheet depend on the selection in the *Location Units* drop-down list.

The parameters saved to the file are listed below.

- Patient ID
- Simulation Name
- Reconstruction Profile
- Series Description
- Simulation Date
- Lesion Name
- Location Coronal [location units]
- Location Sagittal [location units]
- Location Transaxial [location units]
- PET Intensity Mode
- PET Intensity Value
- CT Intensity Value
- Shape
- Shape Parameters

- Reference Lesion Activity (Bq/cc)
- Baseline Background activity (Bq/cc)
- Target Lesion Activity (Bq/cc)
- Surrounding Margin (mm)
- Surrounding Mean PET Intensity
- Surrounding SD PET Intensity
- Surrounding Min PET Intensity
- Surrounding Max PET Intensity
- Age (years)
- Sex
- Height (m)
- Weight (kg)
- Injected Activity (Bq)

6.4.2 Renaming simulation objects

Lesions and reference ROIs in the corresponding tables on the right side of the screen can be renamed (and the corresponding LesionParams.mat file updated), by selecting the object, right clicking on it, and selecting rename. A corresponding dialogue (see Figure 11 and Figure 12) is displayed where the new name can be typed manually, or selected from a default list of names.
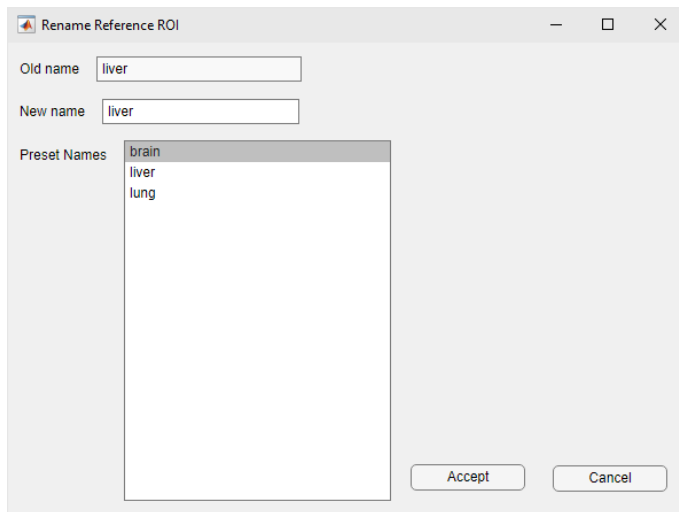

Figure 11: Renaming a reference region of interest, with a list of preset names available.
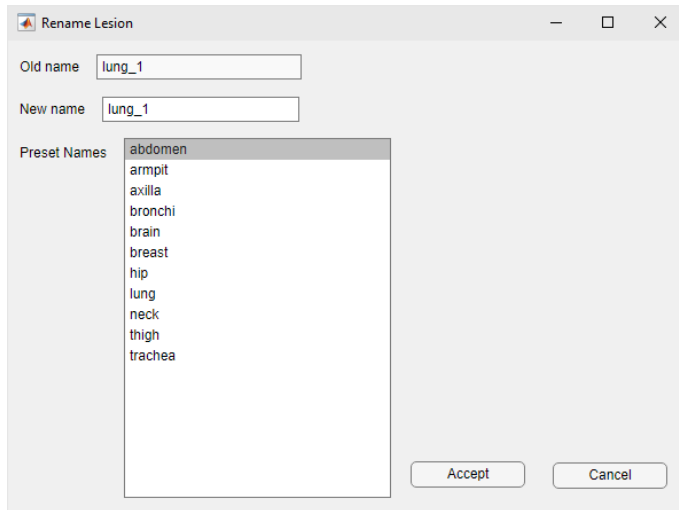
Figure 12: Renaming a lesion, with a list of preset names available.

7   *Configure Tab*

In the configure window, the settings for the toolbox can be adjusted.

7.1   General settings
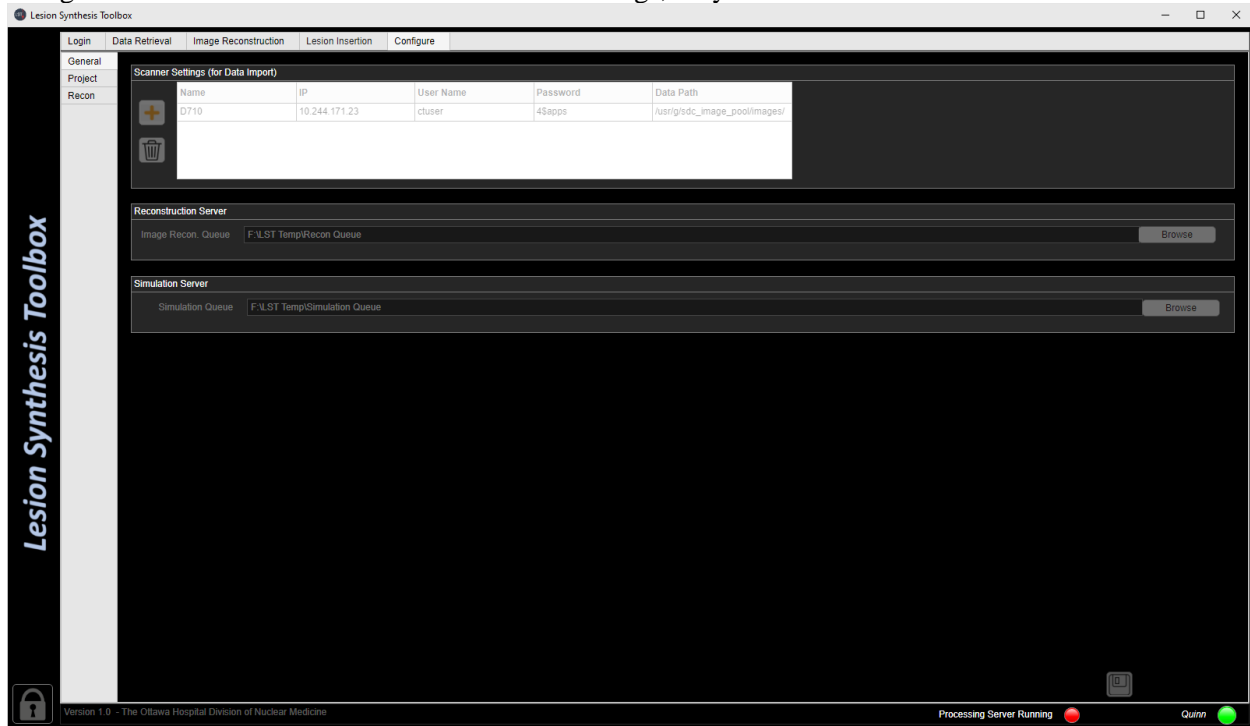The general tab includes the scanner and server settings, only accessible to admin users.

Figure 13: Configure tab for general settings

Table 8: Elements from Figure 13

Element	Name	Description
List	Scanner Settings	The settings for the available scanners are listed, and only accessible to the admin user. The admin user can select a scanner from the list.
Button	Add ➕	The admin user can add a scanner.
Button	Delete 🗑	The selected scanner is removed from the list.
Button	Save 🖫	The scanner settings are saved.
Field	Image Recon. Queue	The admin user can add the directory for the reconstruction queue.
Field	Simulation Queue	The admin user can add the directory for the simulation queue.
Button	Browse	The user can use browse to select a directory from the file explorer instead of manual inserting it in the two fields above.

7.2 Project settings

The project tab contains the list of projects for the user, including the parameters for each project.
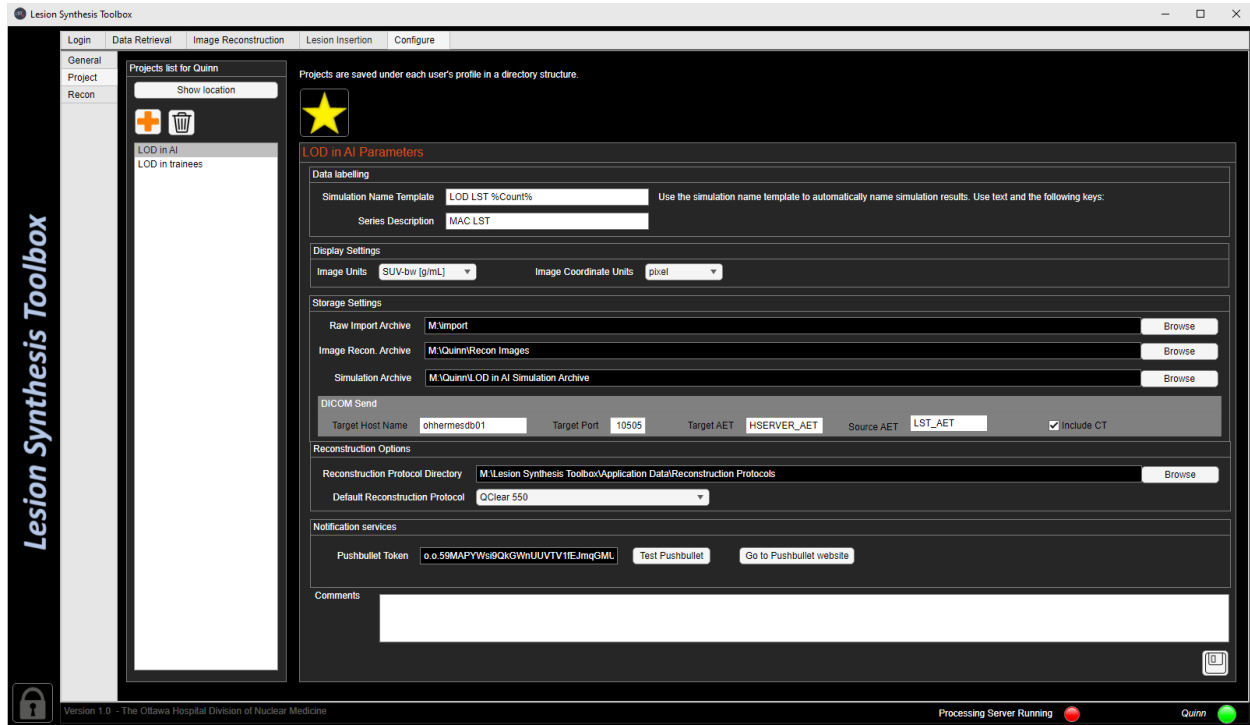

Figure 14: Configure tab for project settings

Table 9: Elements from Figure 14

Element	Name	Description
Panel	**Projects List for {User}**	**The list of projects that the user has created are listed. The user can select a project and see the parameters on the screen.**
Button	Show Location	The location of the project file is opened in the File Explorer.
Button	Add ➕	A new project is created.
Button	Delete 🗑	The selected project file is deleted.
Button	Star ⭐	The user can select the default project that is opened when the user logs into the program.
Panel	**{Project Name} Parameters**	**The parameters for the selected project can be changed.**
Field	Simulation Name Template	The user can set a name to automatically name the simulation results. The user can still manually change the simulation name in the 'Define Lesion Sub-Tab.
Field	Series Description	The user can input the series description name to be identified in PACS using DICOM tag (0008,103E).

Drop-Down List	Image Units	The user can set the units for the reconstructed images. The user can select from 'Activity [Bq/cc]' and 'SUV-bw [g/ml]'.
Drop-Down List	Image Coordinate Units	The user can select the coordinate system for the reconstructed images. The user can select from 'pixel', 'mm from centre', and 'mm from origin'.
Field	Raw Import Archive	The user can enter the directory path for the raw imports, or use the browse button.
Field	Image Recon Archive	The user can enter the directory path for the reconstructed images, or use the browse button.
Field	Simulation Archive	The user can enter the directory path for the simulated images, or use the browse button.
Button	Browse	The user can use the browse buttons to select the directory path for the field in line with the respective buttons.
Field	Target Host Name	The user can enter the name of the target host that the DICOM files will be sent to.
Field	Target Port	The user can enter the target port number that the DICOM files will be sent to.
Field	Target AET	The user can enter the target DICOM node AE title.
Field	Source AET	The user can enter the source DICOM node AE title.
Checkbox	Include CT	When selected, the CT images are included in the DICOM file.
Field	Reconstruction Protocol Directory	The user can enter the directory path for the reconstruction protocol, or use the browse button.
Drop-Down List	Default Reconstruction Protocol	The user can select the default reconstruction protocol that will be used for this project, from the list of reconstruction protocols defined in the corresponding *Configure / Recon settings* (see 7.3).
Field	Pushbullet Token	The user can enter their Pushbullet ID for receiving notification alerts on their mobile device.
Button	Test Pushbullet	The user can test the notification system to ensure it is active.
Button	Go to Pushbullet Website	The website for the pushbullet is opened.
Field	Comments	The user can add additional comments to the project file.
Button	Save 🖻	The project parameters are saved under the project name in the projects list.

7.3   Recon settings

The recon tab displays the reconstruction modes and the parameters for each mode.
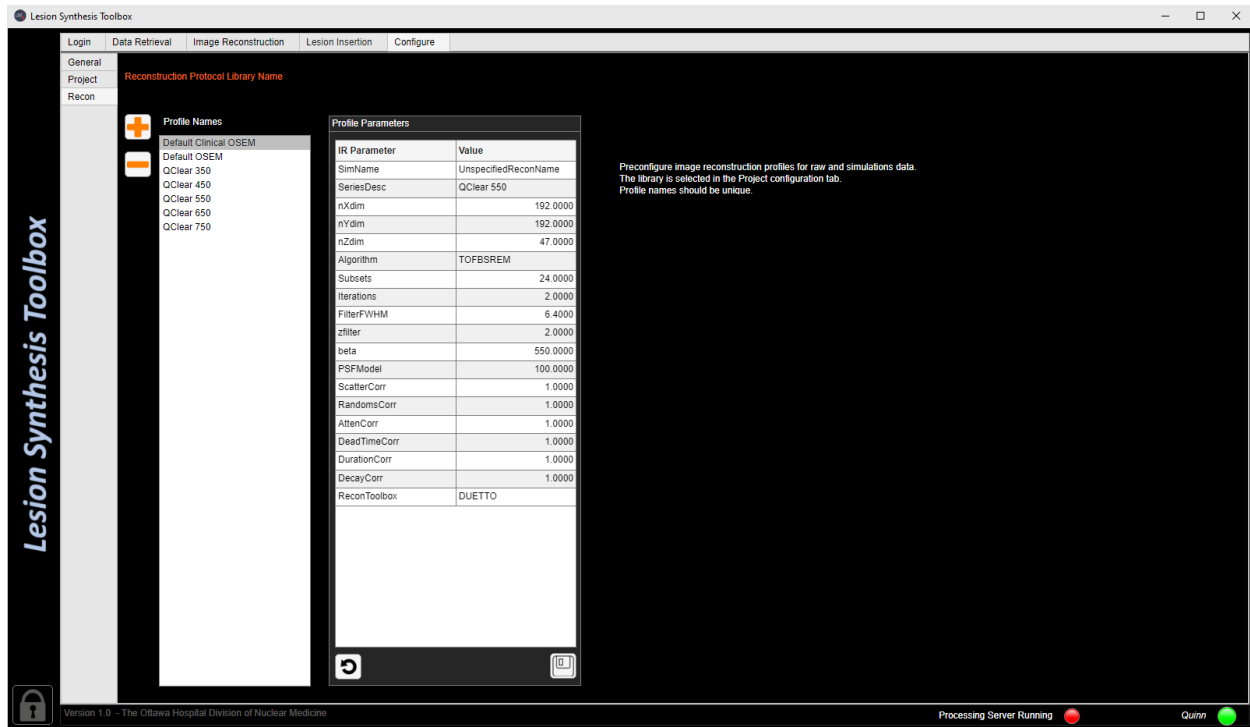

Figure 15: Configure tab for reconstruction settings

Table 10: Elements from Figure 15

Element	Name	Description
Button	Add ➕	The user can add a new reconstruction profile, with a unique profile name.
Button	Delete ➖	The user can remove a reconstruction profile from the profile names list.
List	Profile Names	The reconstruction profiles are listed, and can be selected by the user to be viewed or deleted.
List	Profile Parameters	The parameters for the selected reconstruction profile are displayed.
Button	Refresh 🔄	The parameters for the selected reconstruction profile is reverted to default.
Button	Save 🖫	The reconstruction profile is saved.

8 Tutorials

8.1 Importing Data

Data can be imported on the Data Retrieval Tab, as seen in Figure 3.

(1)   Select the scanner from the drop down 'Scanner' menu.
(2)   Next, select the date range using the following drop-down menu titled 'Date Range'.
(3)   Click the button 'Connect' to load the data.
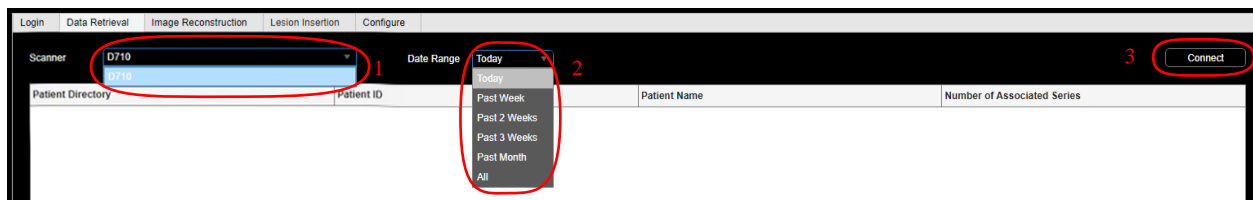
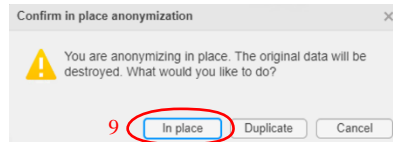

A list of patient files will appear in the table below.

(4)   Select a file and it will appear in the study investigator at the bottom of the window. Click the check box next to the file in the study investigator to select the study.
(5)   The 'Anonymize Imported Studies' checkbox can selected to provide patient privacy.
(6)   Once selected, the study can be imported by clicking the 'Import Selected Studies' button on the bottom right corner of the window.
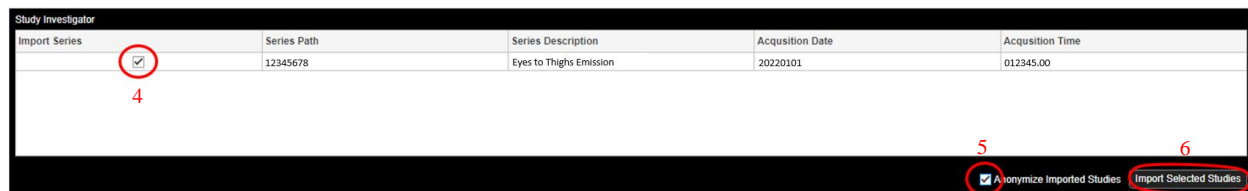
(7)   If the file is to be anonymized, a window (Figure 4) will appear which includes fields to change the patient's name, surname, ID, and date of birth.
(8)   Click 'Ok' when finished anonymizing the patient information.
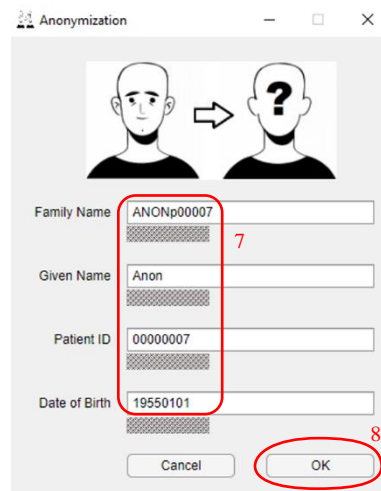
(9)   A new window will appear (Figure 5) with the option to anonymize in place or create a copy. If the anonymization is done in place, the file downloaded to the LST will be overwritten with an anonymized version, but will not affect the original file on the scanner.

The importing process may take a couple of minutes to complete. The imported studies will appear in the next tab (Image Reconstruction Tab).

8.2 Reconstructing Data

On the Image Reconstruction Tab, the imported patient files are listed in the 'Available Studies' table.

(1) Select a study to be reconstructed from the table of available studies.
(2) If the file that was not anonymized when imported, it can be anonymized by selecting the 'Anonymize' button and choosing whether or not to anonymize in place. To see how to do anonymization refer to the tutorial '8.1. Importing Data'.
(3) Choose a reconstruction method from the drop-down list 'Recon. Profiles' on the top right of the screen. The reconstruction parameters for the selected method will appear in the table below.
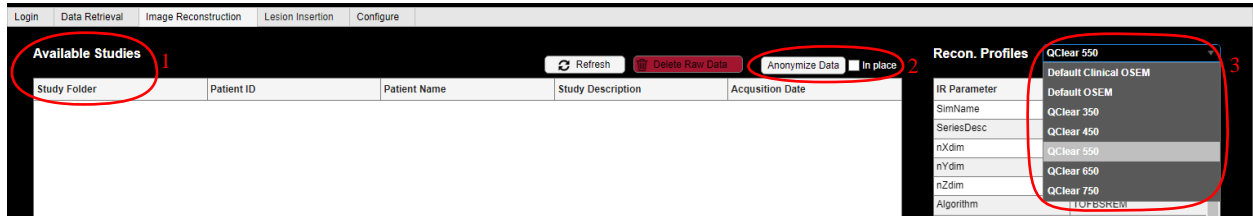

(4) Click 'Queue Reconstruction' to add the reconstruction to the job queue.
(5) The job queue can be seen at the bottom of the tab.
(6) To remove a job from the queue, select the job from the queue and click 'Remove Job'.
(7) When the queue is ready, click 'Start Processing Service' to start processing the job queue. The reconstructed files can be found on the 'Lesion Insertion: Select Patient' tab.

8.3 Define lesions

On the Lesion Insertion tab, the first sub-tab (Select Patient) should automatically open.

(1) Select the patient file that will be used for lesion synthesis.
(2) If the study was newly added and does not appear, the list can be refreshed by clicking 'Refresh'.
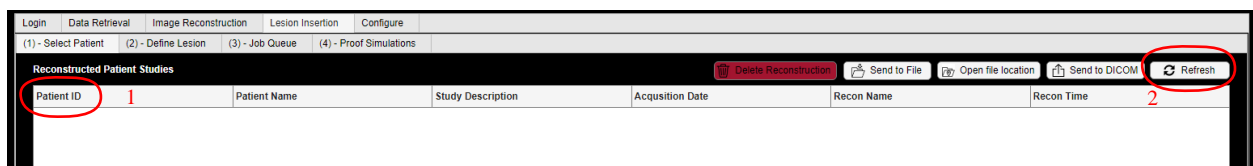
(3) The preview of the selected study will be shown at the bottom of the page, with a 3D view. The intensity of the image can be adjusted using the slider on the left of the 3D view.

(4) Click the 'Select Study' button and it will open the study in the next sub-tab (Define Lesion).

(5) The 3D viewer shows the fused PET and CT data on the top of the screen, with information about the patient on the top bar.

(6) Adjust the PET colormap and fusion factor on the right,

(7) And intensity level on the left, until it is best for viewing.

(8) The focal point on the image can be selected by clicking on one or more views. Adjusting the focal point will populate the 'Object Location' fields, so that they do not need to be entered manually.
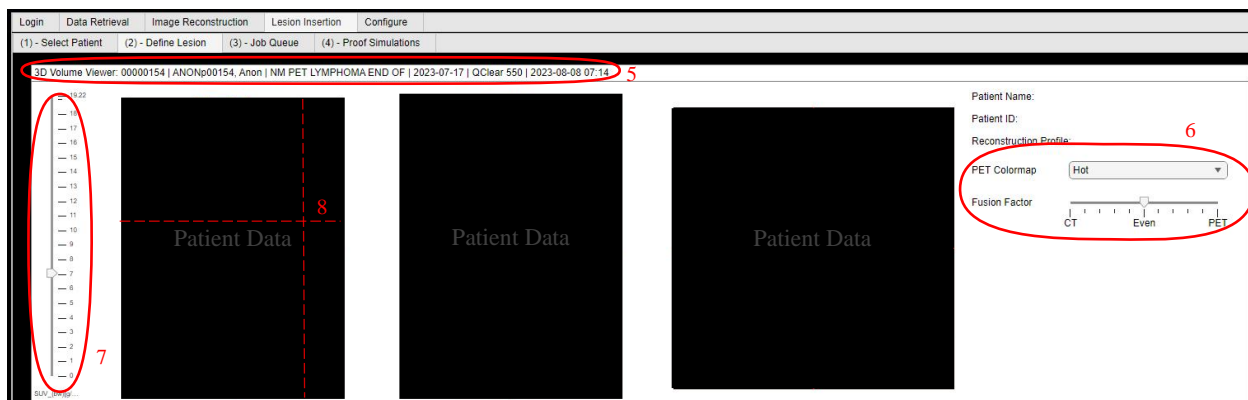
Before adding any objects, a reference object should be set in the 'Define Reference Object' panel. This allows the lesion intensity to be relative to another organ, typically the liver.

(9) The reference object name is automatically populated with Ref_{reference object number}, but can be manually changed to the region name. Set the object location, either by manually typing in the coordinates or by selecting the focal point on the image. Enter the shape and radius values. ROIs can be removed by selecting from the list and clicking 'Remove Reference Object'.

(10) The object name is automatically populated with Object_{object number}, but can be manually changed to reflect the type of lesion. The location can be set manually or by selecting the focal point on the image. Select the shape and radius of the object.

(11) Adjust the PET intensity mode, level, and overlay method, as well as the CT intensity in Hounsfield Units and the overlay method. Add the lesion by clicking 'Add Object' and repeat for as many lesions as needed.

(12) A list of lesions to simulate will be populated as lesions are created. Select a lesion to remove, or create another lesion with the same parameters, but ensure to change location coordinates to prevent possible issues.

(13) Select a reconstruction profile for the image reconstruction from the drop-down menu,

(14) And adjust the parameters in the table or bed range if needed. If the same reconstruction is to be repeated with different parameters, select 'Keep lesions' to keep the patient and lesions in the 'Define Lesion Sub-Tab. Queue the simulation once all lesions are added, and the 'Job Queue Sub-Tab will open.
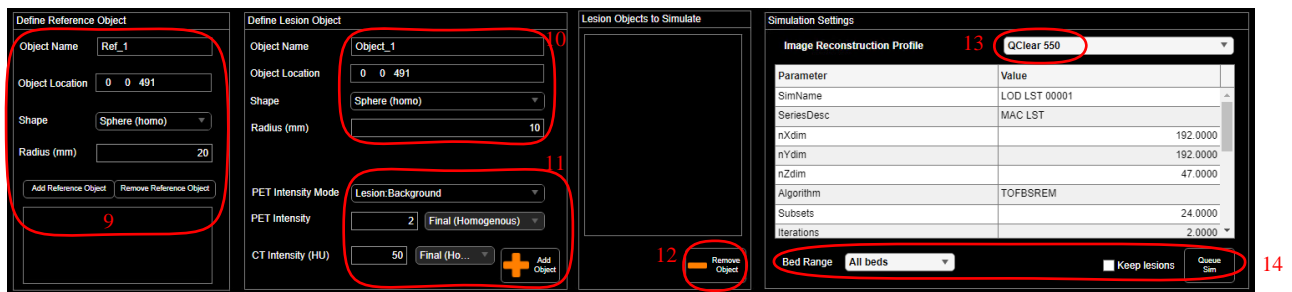
(15) Jobs can be selected from the list to be removed from the job queue.

(16) If the processing service is not already running, start it by selecting the green button at the bottom of the screen. A progress window will open, as is described in Section 9 below.

8.4   Check lesions

On the last sub-tab of the 6.4Lesion Insertion tab (Proof Simulations), the simulated lesions can be checked.

(1) The list of files with simulated lesions can be seen at the top of the tab. Select a patient file to be viewed.

(2) The simulated lesions and their properties are shown on the top right of the tab, as well as the reference ROI. Reference ROIs and lesions can be selected from the lists.

(3) The selected lesion or ROI will be shown on the images, with the cross-hairs pinpointing the location. The view can be adjusted using the slider and menu in the bottom right.

(4) Once the data is reviewed, it can be exported to a file folder.
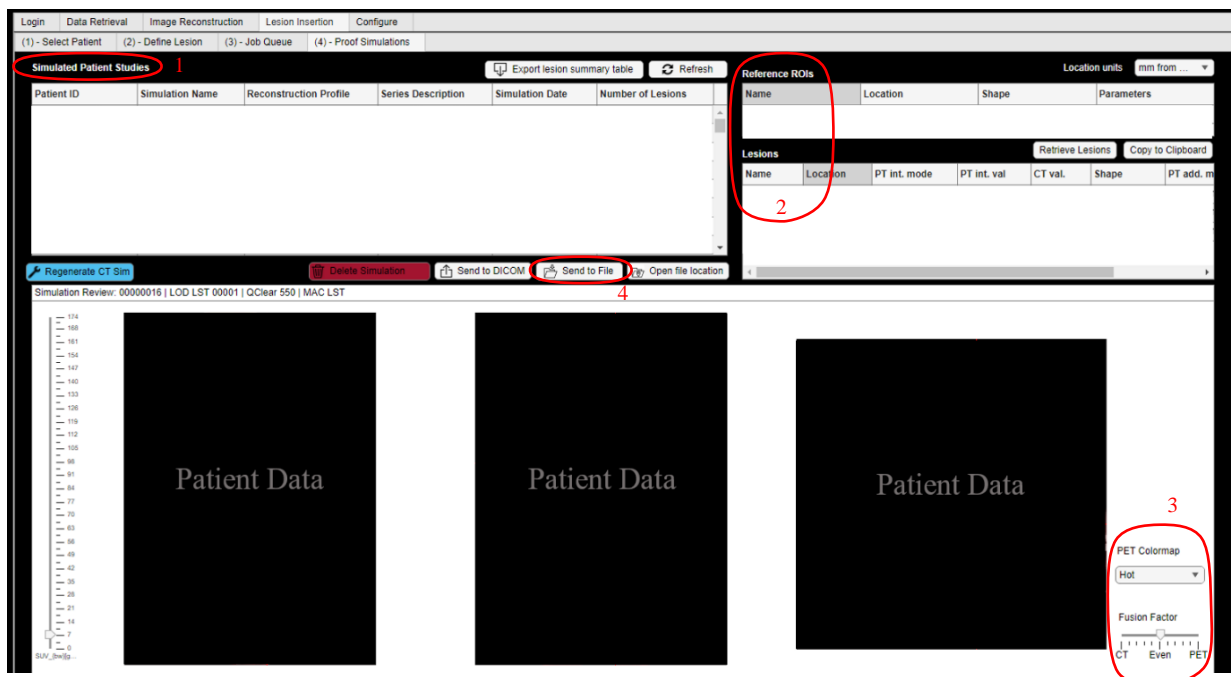
9   *Image Reconstruction and Lesion Synthesis Service*

Image reconstruction and lesion simulation are computationally demanding. Depending on computer resources, these may require minutes to hours per image series. These processes are implemented as a computer service, for serial processing, which is especially advantageous in settings where the computer is acting as a web app service for multiple users. The lesion synthesis toolbox processing service (LSTProcessingService.m) is a MATLAB script that monitors directories for queued reconstruction and simulations. These are run one at a time using parallel processing for multiple bed positions.

The LST Processing Service can be launched from within the LST Toolbox, where a separate MATLAB instance is started in the background, enabling to continue using the LST Toolbox. Likewise, the LST Processing Service can be launched in MATLAB command line using the following parameters:

LSTProcessingService(command, dataDirs) where command can be any of the following:

- 'start' - start the server as a background service.
- 'stop' or 'kill' - stop the server.
- 'one time' - run the processing routine once for the existing files and then stop (i.e., not as a service)

Example uses are:

- LSTProcessingService('start',{'F:\LST Temp\Simulation Queue','F:\LST Temp\Recon Queue'})
- LSTProcessingService('stop')
- LSTProcessingService('one time',{'F:\LST Temp\Simulation Queue','F:\LST Temp\Recon Queue'})

10 References

[1]   Gabrani-Juma H, Al Bimani Z, Zuckier LS, Klein R. Development and validation of the Lesion Synthesis Toolbox and the Perception Study Tool for quantifying observer limits of detection of lesions in positron emission tomography. J. Med. Imaging 2020; **7**(02): 1.

[2]   Juma H. Lesion Synthesis Toolbox: Development and Validation of Dedicated Software for Synthesis of Lesions in Raw PET and CT Patient Images (Carleton University, 2019).

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