Seminar

CTPA segmentation to calculate biomarkers for pulmonary embolism risk stratification

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Pulmonary Embolism (PE)

3rd leading cause of death in Europe

Blood cloth (thrombus) blocking pulmonary arteries

- systemic hypotension

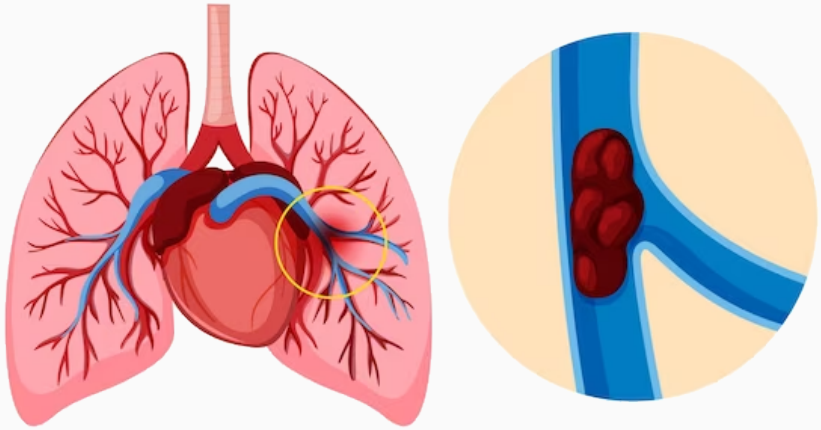

Figure 1: Pulmonary embolism (https://fr.freepik.com/photos-vecteurs-libre/embolie)

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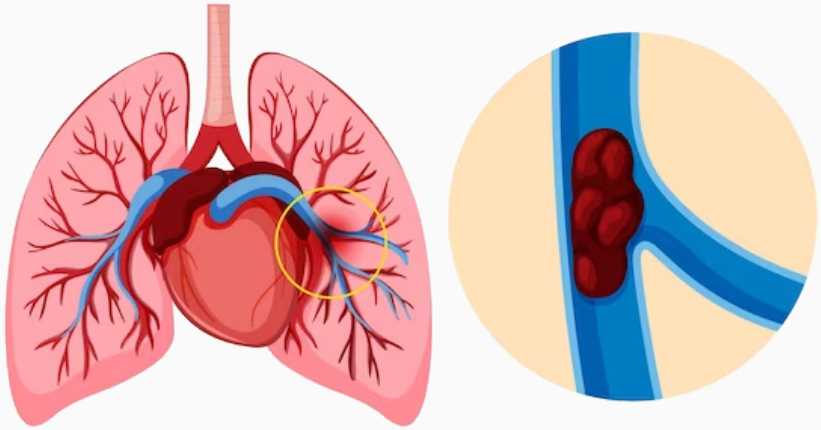

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Need to quantify the severity of the PE

Current PE risk stratification

Categories of risk of death after 30 days [1]

- low, intermediate, and high
- determines the patient's management protocol and treatment [2]

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Biomarkers [3]

- functional biomarkers
  - protein levels in the blood linked with heart failure
- morphological biomarker
  - right-to-left ventricle (RV/LV) diameter ratio

PERSEVERE

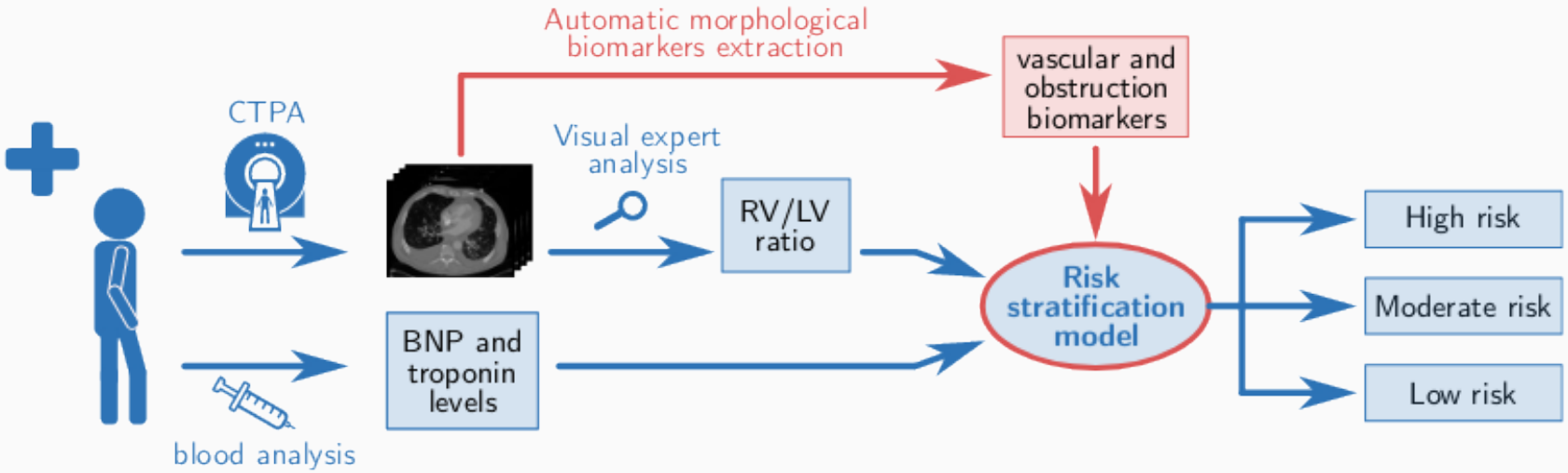

Figure 2: Current PE patient prognosis evaluation procedure in blue, and the modification proposed in the PERSEVERE project in red. [3]

PERSEVERE

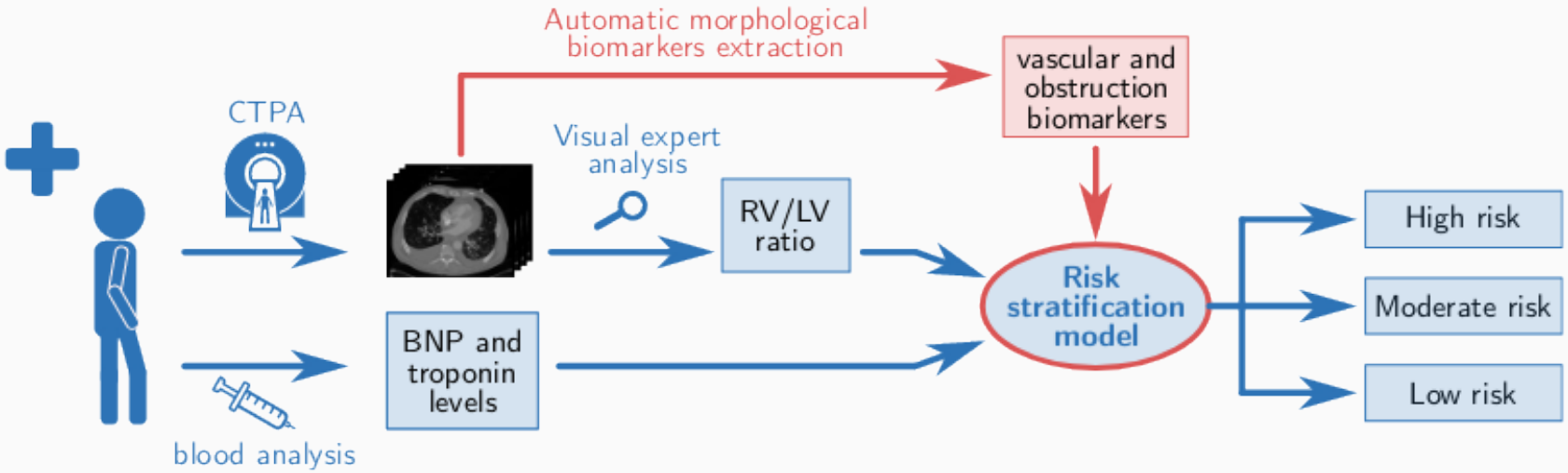

Figure 2: Current PE patient prognosis evaluation procedure in blue, and the modification proposed in the PERSEVERE project in red. [3]

Our work focused on the RV/LV ratio

Why the RV/LV ratio ? [4] [5]

PE prevents part of the lungs from oxygenating the blood

- RV pumps blood to the lungs
- RV pumps harder to oxygenate the same amount of blood
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RV/LV ratio > 1 $\Rightarrow$ PE

How is the RV/LV ratio is measured ?

Slices where the ventricles are the largest

Ideally measured on echography [3]

- no known risk
- synchronized to heart rate
- not accessible in initial stage of PE

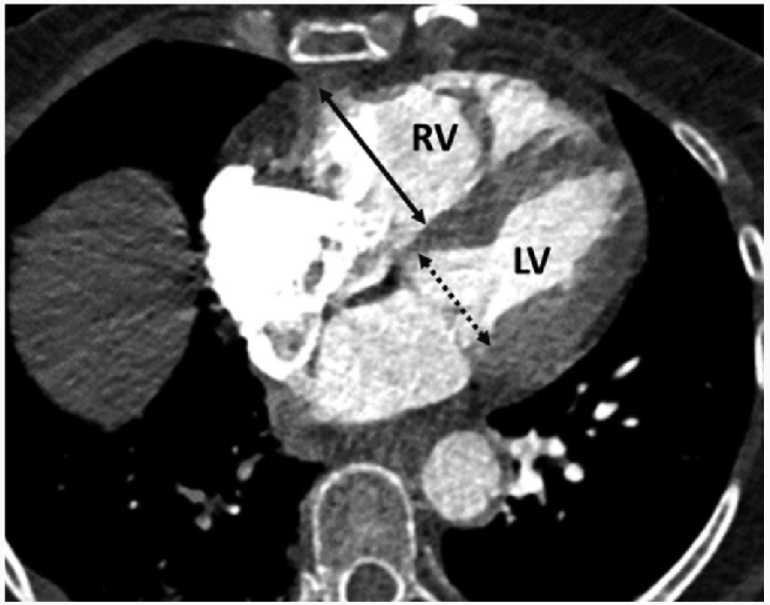

Figure 3: RV/LV diameter measurements on CTPA [6]

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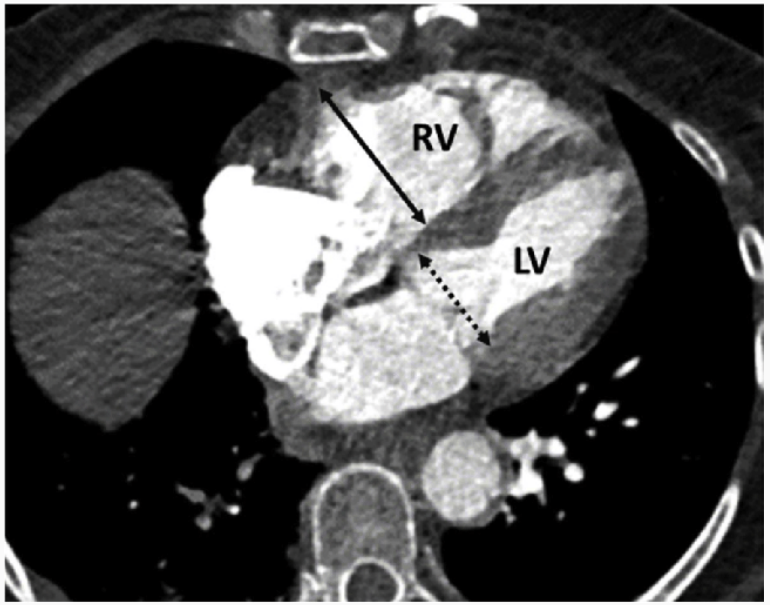

Figure 3: RV/LV diameter measurements on CTPA [6]

In clinic, the patients undergo a CTPA exam in 90% of cases [3]

CTPA (Computed Tomography Pulmonary Angiography) (1/2)

CT scan + injection of contrast dye + X-Ray [7]

- enhance the visibility of the pulmonary arteries

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Advantages [7]

- assess other cardiopulmonary conditions
- availability in the majority of hospitals
- non-invasiveness

CTPA (Computed Tomography Pulmonary Angiography) (2/2)

Disadvantages [7]

- dangerous radiations
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How to improve the RV/LV ratio ?

Our proposition

Measure the volumetric RV/LV ratio instead of the diameter RV/LV ratio

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Need segmentations of the RV and LV…

Segmentation

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- inter-observator and intra-observator variability

PERSEVERE's Dataset

No ground truth of ventricles

- No other CTPA dataset of ventricles annotated
  - Most research on PE is focused on segmentations of thrombus and pulmonary vascular tree

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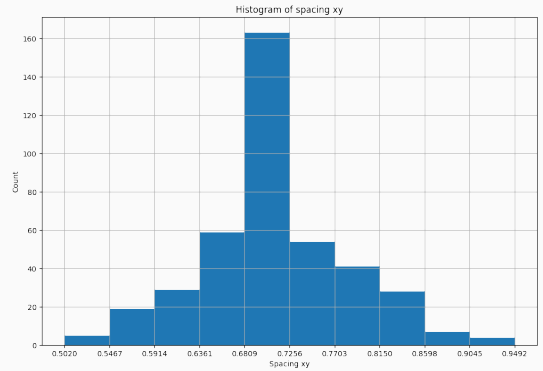
We chose to use the PERSEVERE's dataset

- CTPA of 428 patients of multiple PE risk categories
- Multiple scanners with different parameters
  - Voxels do not represent the same volume in the image

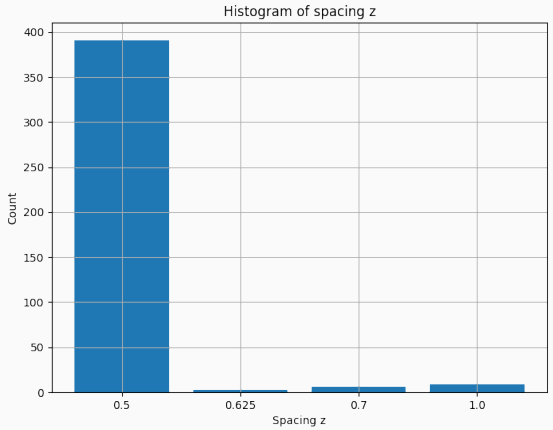
Dataset Resampling (1/2)

Different voxel spacings

- Histograms of voxel spacing to find the most common on the dataset
- Trilinear interpolation to resample the images
- Nearest neighbour interpolation to resample the ground truths



(a) Spacing XY



(b) Spacing Z

Figure 4: Histogram of the dataset spacing

Dataset Resampling (2/2)

Cropping

- TotalSegmentator [8] lung's masks with padding
- Arteries are in the lungs
- Ventricles are in between the lungs

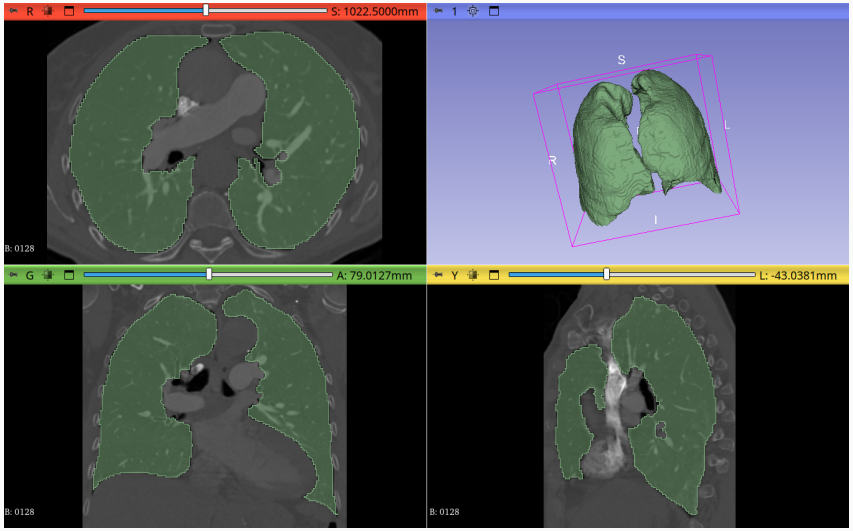


Figure 5: TotalSegmentator [8] lungs' masks

TotalSegmentator [8] is a publicly available model able to segment most anatomically relevant structures throughout the body

Limits of the ventricles (1/3)

- Segmentation of the endocardium
- Do not include the myocardium
- The separation between the myocardium and the endocardium is clearer for the LV

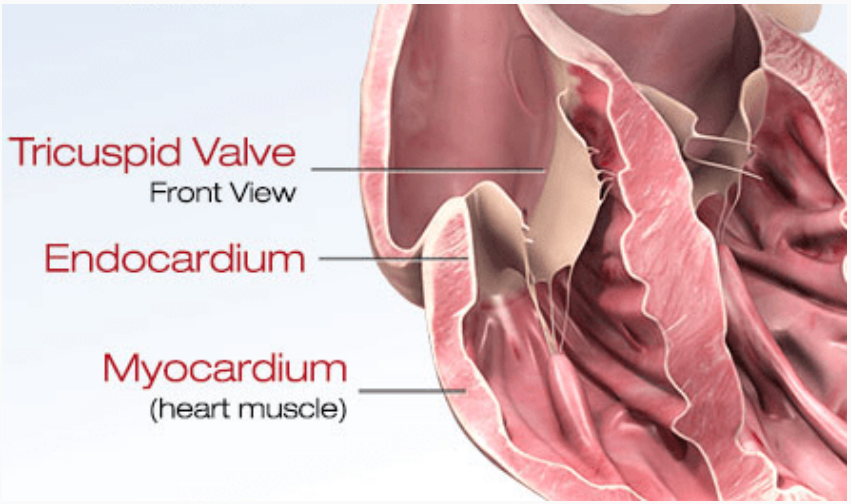


Figure 6: Heart wall layers (https://www.heart.org/en/health-topics/myocarditis)

Limits of the ventricles (2/3)

- Ventricle volume stops at the pulmonary valve (in red)
- The washed out agent is also part of the ventricle volume (on the right side)

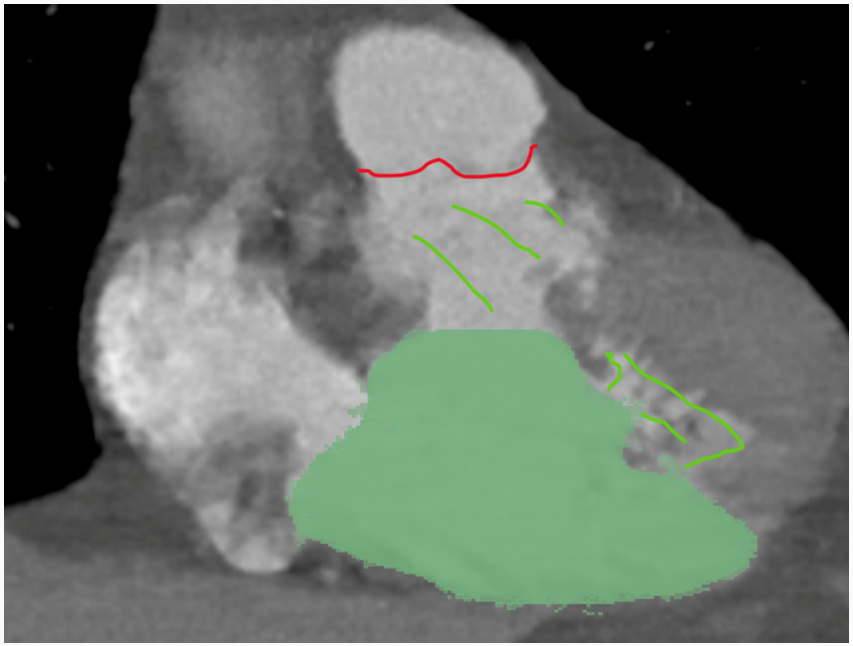
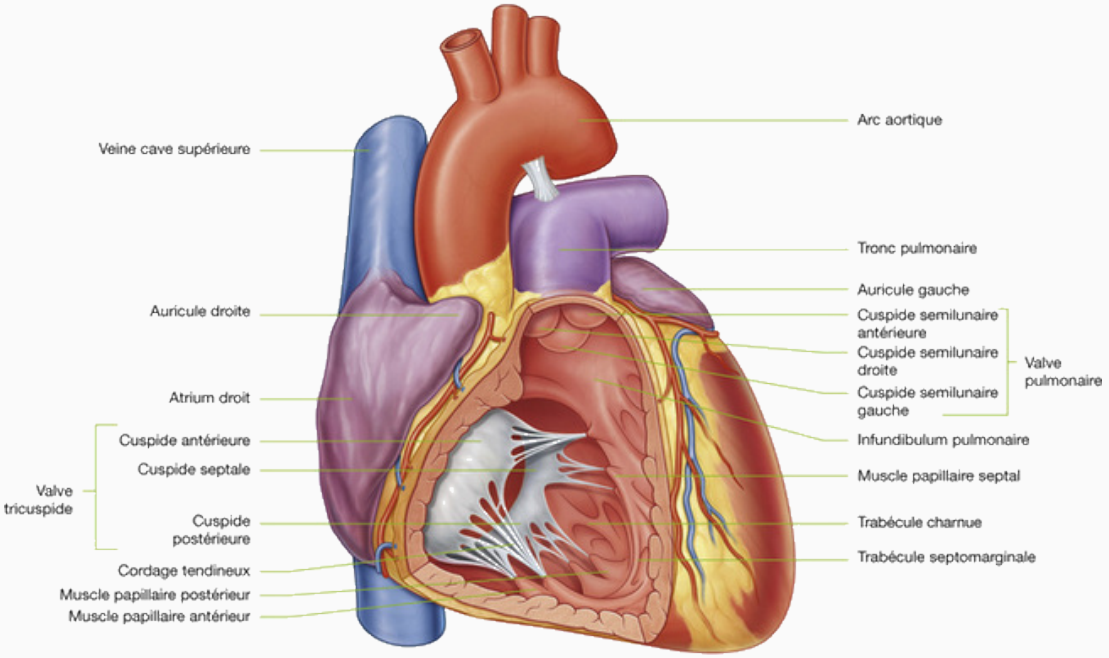
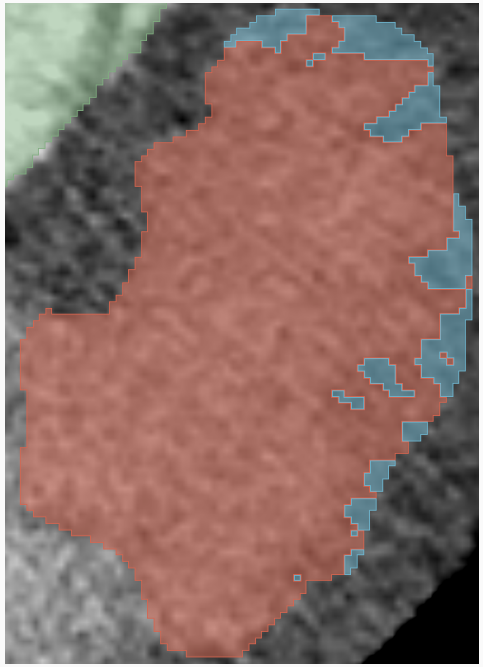


Figure 7: LV segmentation and markers for upper limit

Limits of the ventricles (3/3)



(a) Diagram of the anterior surface of the heart (https://clemedicine.com/3-thorax/)



(b) LV segmentation in red with papillary muscles added in blue

Figure 8: Segmentation correction : Papillary muscles

For practical reasons and standardization, the papillary muscles are often included in the volume calculation, even if they are part of the wall and not of the ventricular cavity itself.

Segmentations

Semi-manual segmentation

- No specialized model exists to segment ventricles on CTPA and no ground truth
- 3DSlicer [9]

Automatic Segmentation

- Pre-trained TotalSegmentator [8]
- U-Net 3D [10] we trained on the semi-manual segmentations

Results and analysis of the segmentations

Semi-manual segmentations

3DSlicer [9]

- Abdominal window
- Paint with thresholds
- Grow from seeds [11]
- Smoothing
- Islands

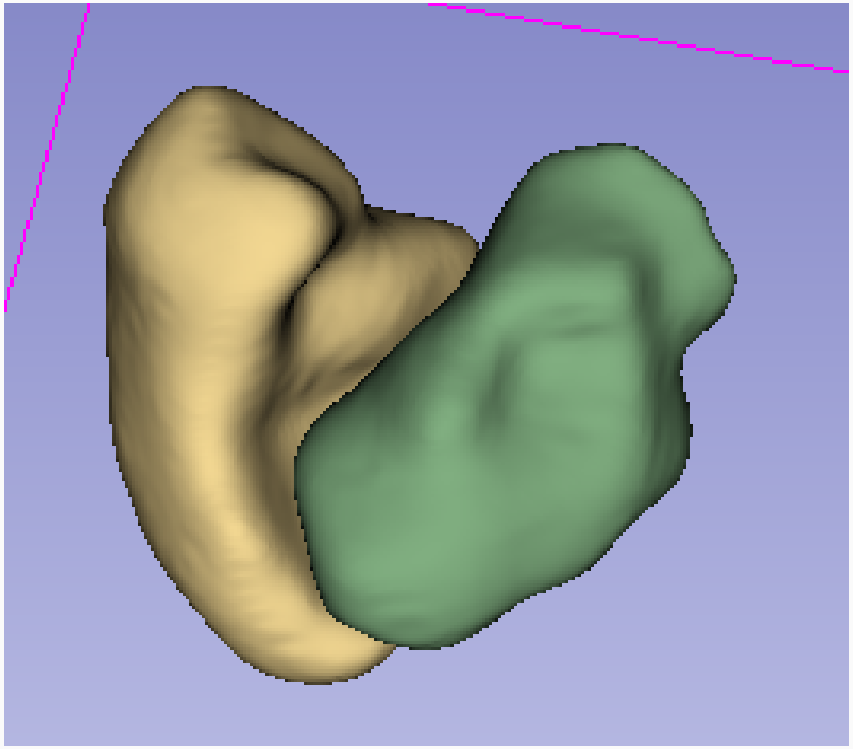


Figure 9: 3D semi-manual segmentation

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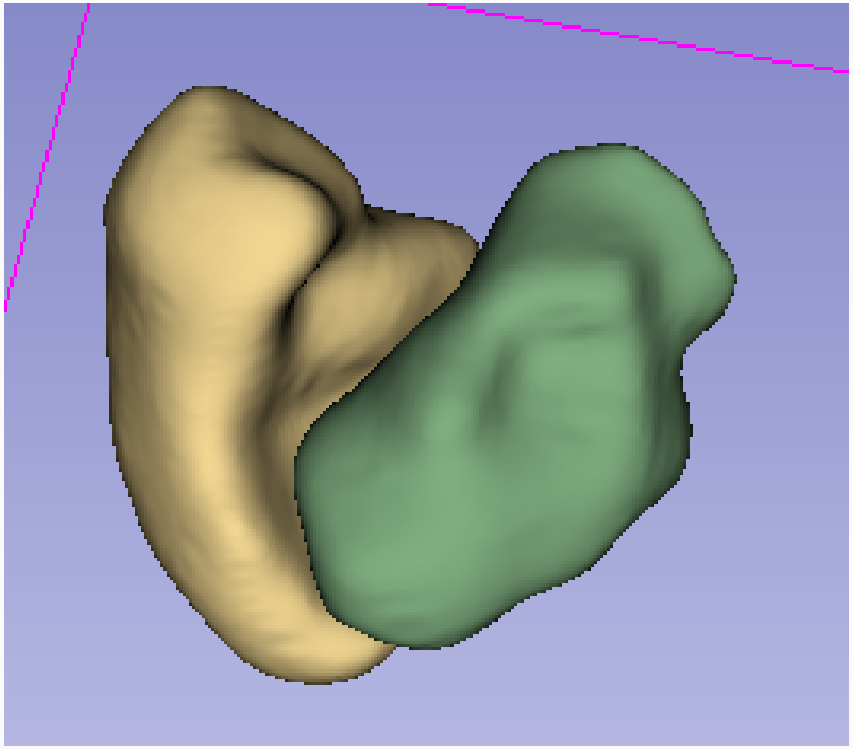


Figure 9: 3D semi-manual segmentation

13 segmentations performed (approximately 6 hours per segmentation)

U-Net 3D [10] training

Hyperparameters

- batch size: 2
- patch size: [192, 192, 64]
- max epochs: 600
- optimizer: Adam
- learning rate: 0.01
- loss function: Dice Loss + Cross Entropy Loss [12]

Data splitting

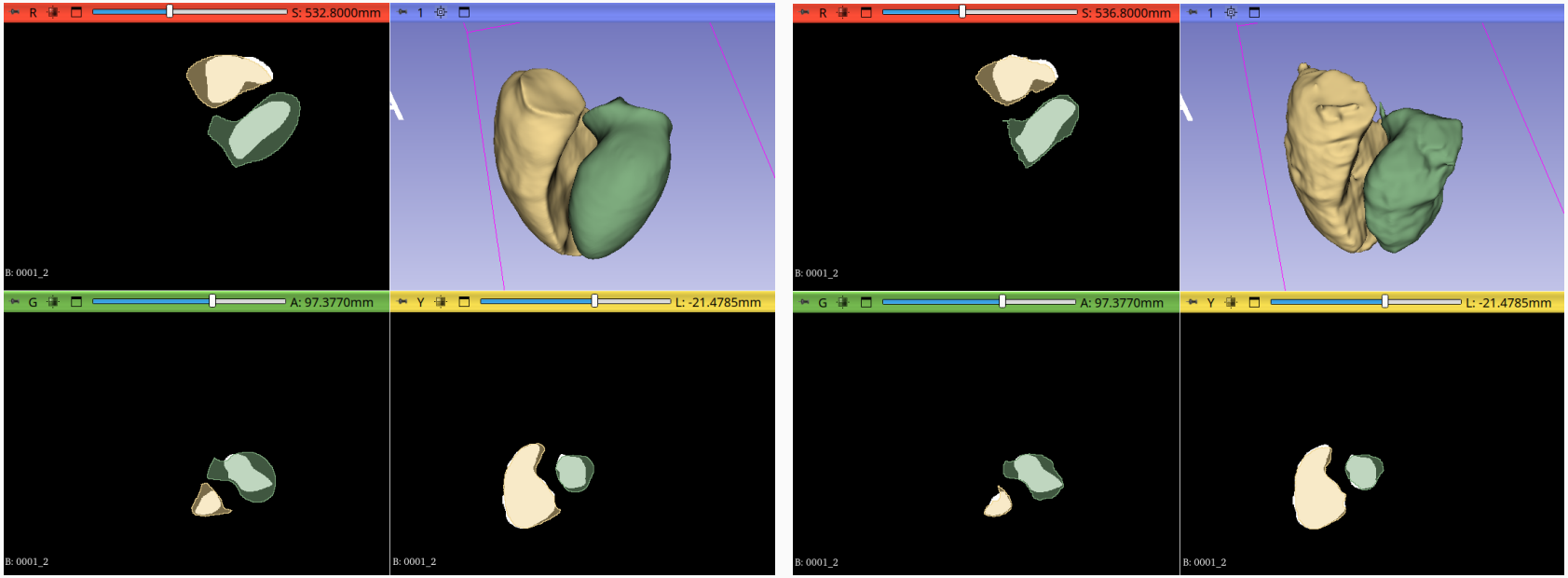
- Training: 8 patients
- Validation: 2 patients
- Test: 3 patients

Average Dice [13]

- Training: 0.916
- Validation: 0.845
- Test: 0.671

Trained for approximately 5 days

Automatic segmentations - Qualitative Results



(a) TotalSegmentator [8] **(b)** U-Net 3D [10]

Figure 10: Automatic 3D segmentations of cardiac ventricles

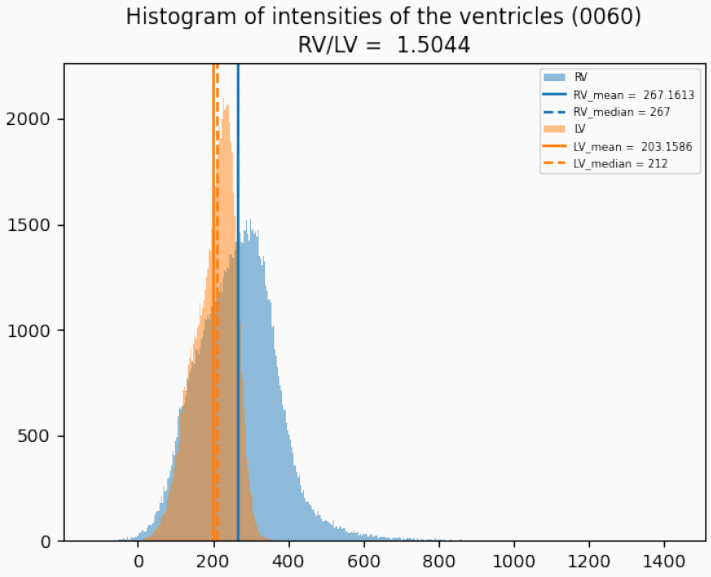
- TotalSegmentator [8] generally oversegments the ventricles
- U-Net 3D [10] gives reasonable segmentations but they are not smooth
- The groundtruths (in white) are not yet corrected and seem to undersegment the ventricles

Automatic segmentations - Quantitative Results

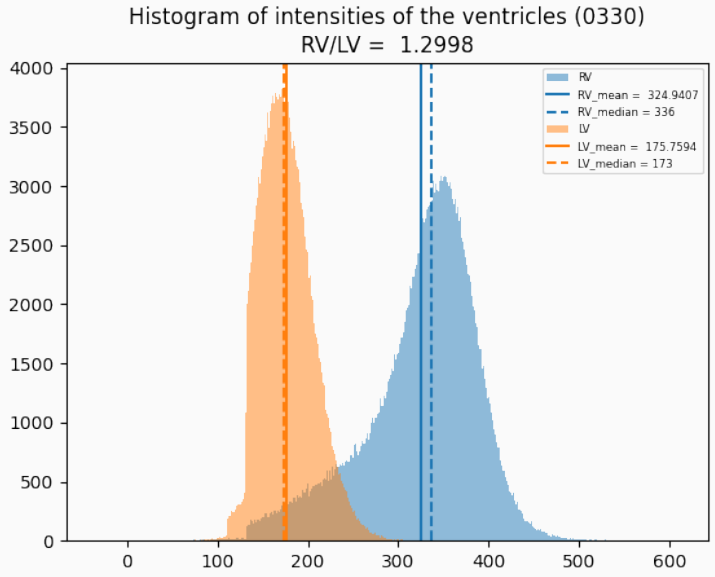
		TotalSegmentator [8]	U-Net 3D [10]
DSC [13]	RV	0.625	0.853
	LV	0.598	0.775
ASSD [13]	RV	13.448	3.562
	LV	15.065	4.972
95HD [14]	RV	34.443	14.362
	LV	42.355	15.273
β_0 [15]	RV	1.0	1.222
	LV	1.154	1.222
β_1 [15]	RV	0.0	7.556
	LV	0.154	4.889
β_2 [15]	RV	0.0	5.222
	LV	0.0	3.111

Table 1: Table of automatic segmentations results based on the 13 semi-manual segmentations

Analysis - Histogram of ventricles intensities



(a) PE patient with intermediate risk of death



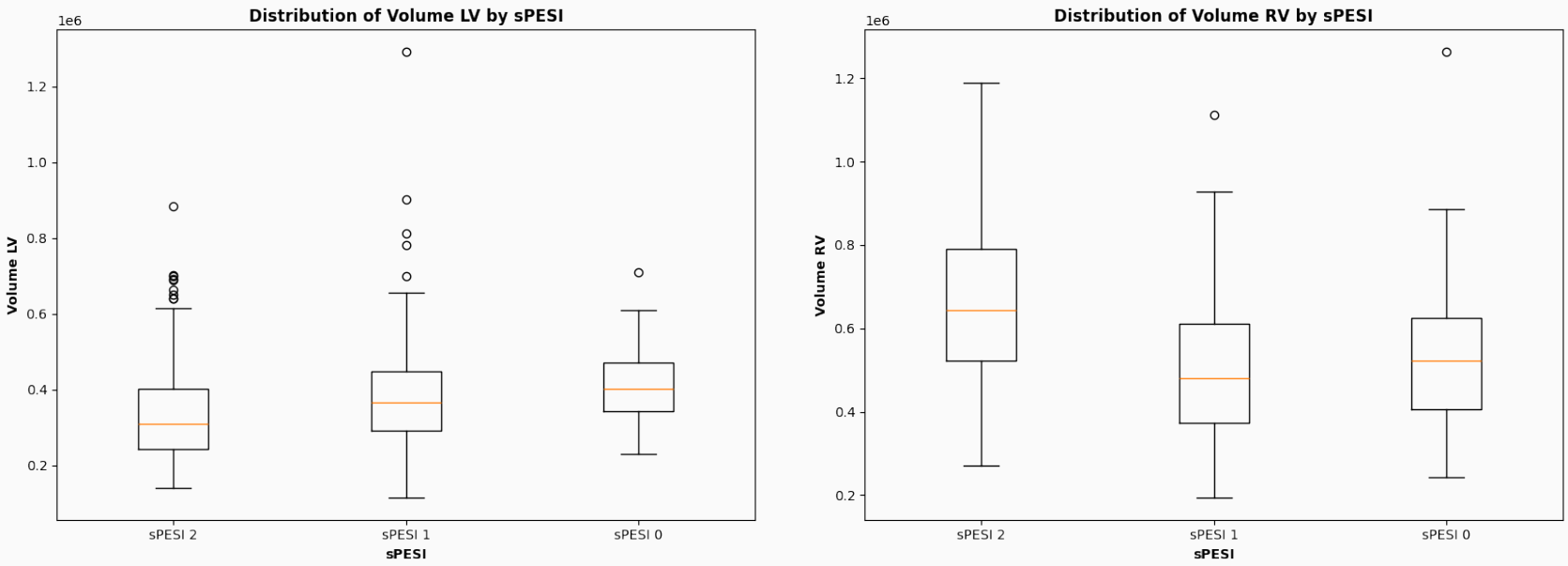
(b) PE patient with low risk of death

Figure 11: Histogram of ventricles intensities

Since patients with severe PE's heart must pump harder to oxygenate the same amount of blood, the quantity of contrast product in the RV should be higher than in the LV

- the intensity histograms depend too much on external factors

Analysis - Ventricles' volume distribution



(a) Left ventricle

(b) Right ventricle

Figure 12: Ventricles' volume distribution by simplified Pulmonary Embolism Severity Index (sPESI)

For PE patients with sPESI of 2, the volume of the LV is lower in average, whereas the volume of the RV is higher

Analysis - Volumetric ventricles ratio distribution

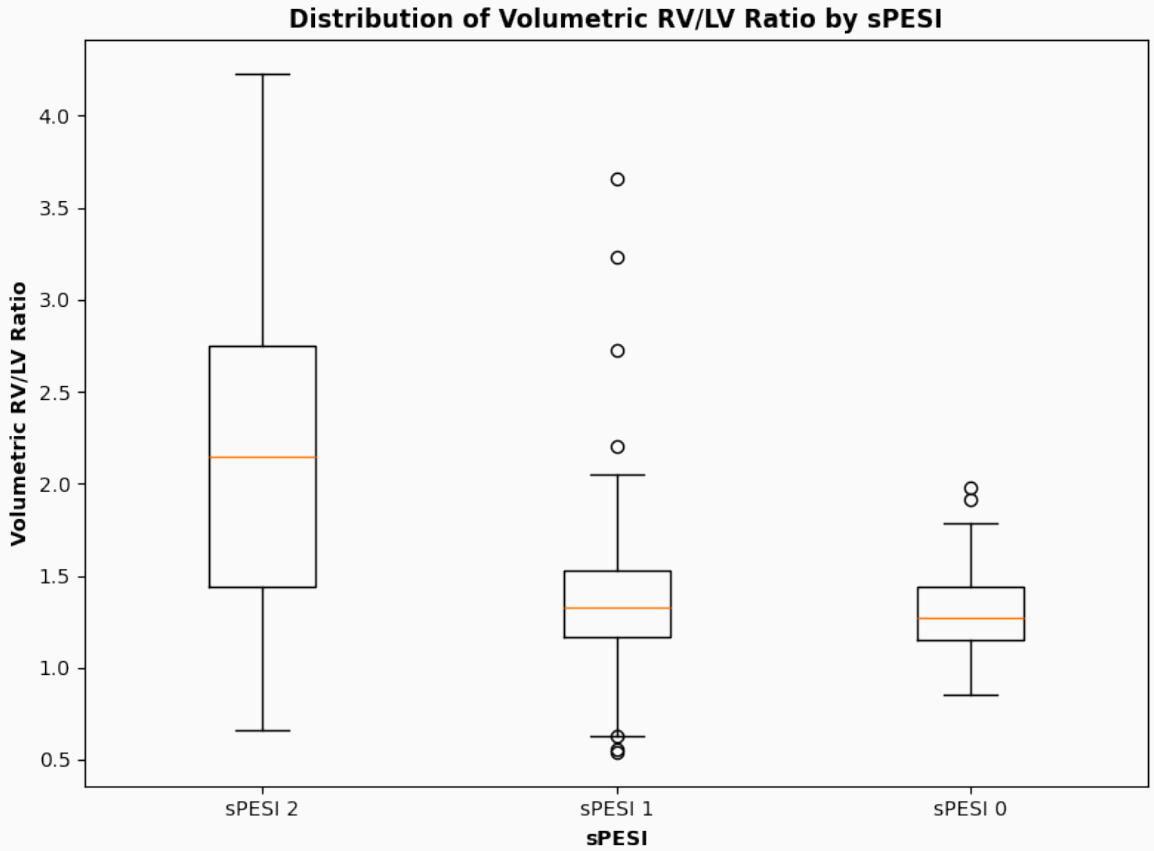


Figure 13: Volumetric ventricles ratio distribution by sPESI

The volumetric ventricles ratio is similar for PE patients of sPESI 0 and 1, but significantly higher for PE patients of sPESI 2

Conclusion

- Refactoring of a repository aimed at facilitating the experimentation of vascular segmentation models

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Conclusion

- Refactoring of a repository aimed at facilitating the experimentation of vascular segmentation models
- Resampling of the PERSEVERE dataset
- Scripts for cardiac ventricles' volume and volumetric ratio analysis from segmentations
- **Main contribution : 13 semi-manual segmentations and segmentation model for cardiac ventricles**
  - 415 automatic segmentations of the ventricles

Future work

- Active Learning to correct the segmentations

Future work

- Active Learning to correct the segmentations
- GNN for PE risk stratification
  - Embolism parameters
  - Arteries parameters
  - Volumetric ventricles ratio

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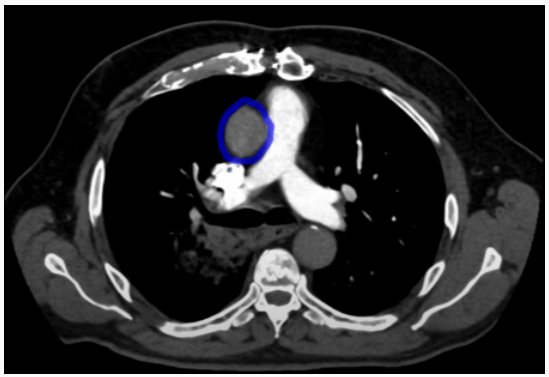
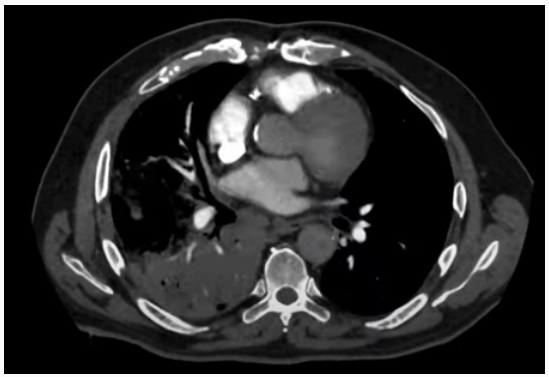
Slides de backup

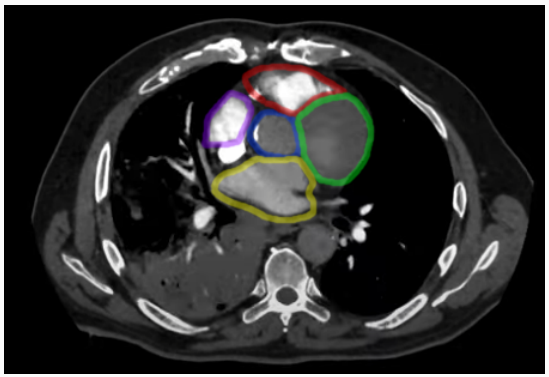
Localisation of the ventricles



(a) blue: ascending aorta



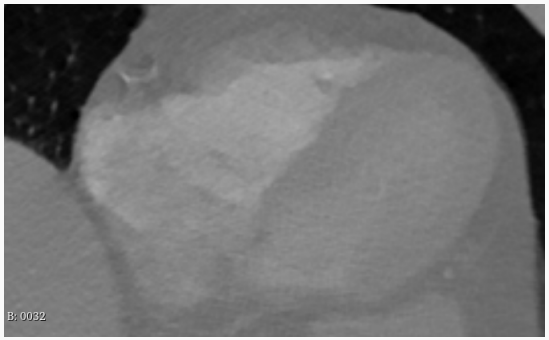
(b) Slice where the ascending aorta is connected to the LV



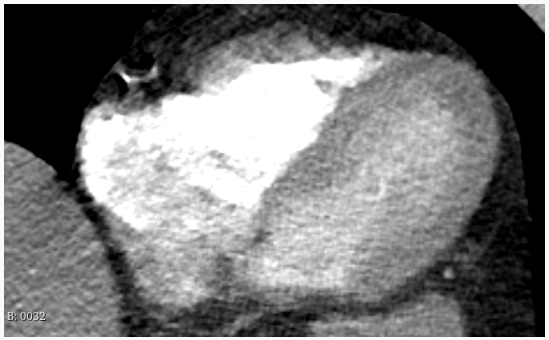
(c) blue: ascending aorta ; green: LV ; red: RV; yellow: left atrium; purple: right atrium

Figure 14: Localisation of the ventricles (https://youtu.be/8WUgH4WHlLE?si=uk5pXg1hqpcg8VJl&t=1111)

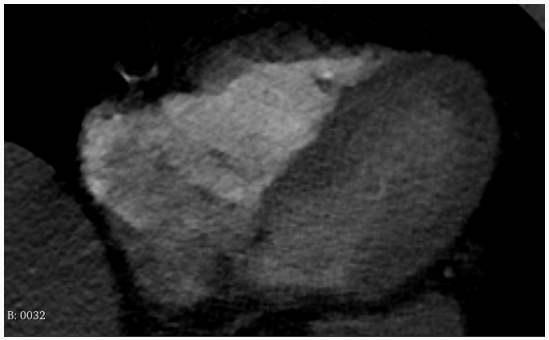
Abdominal window (1/2)



(a) Default window



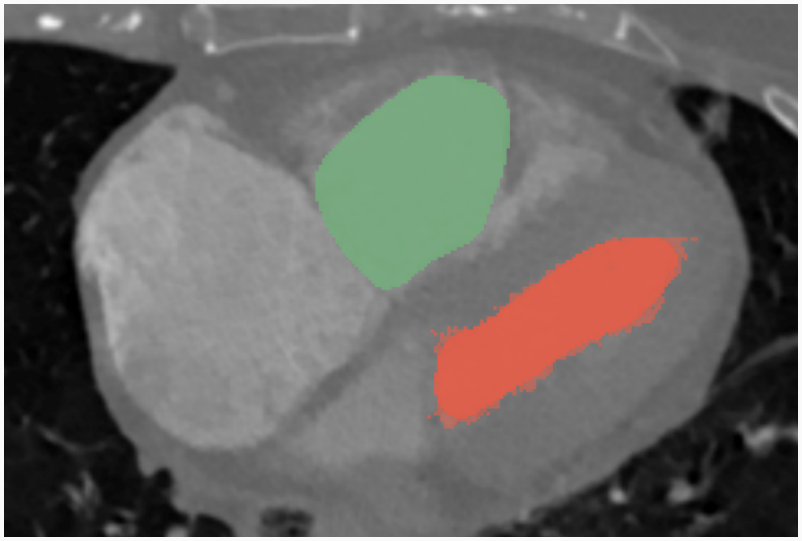
(b) Abdominal window preset



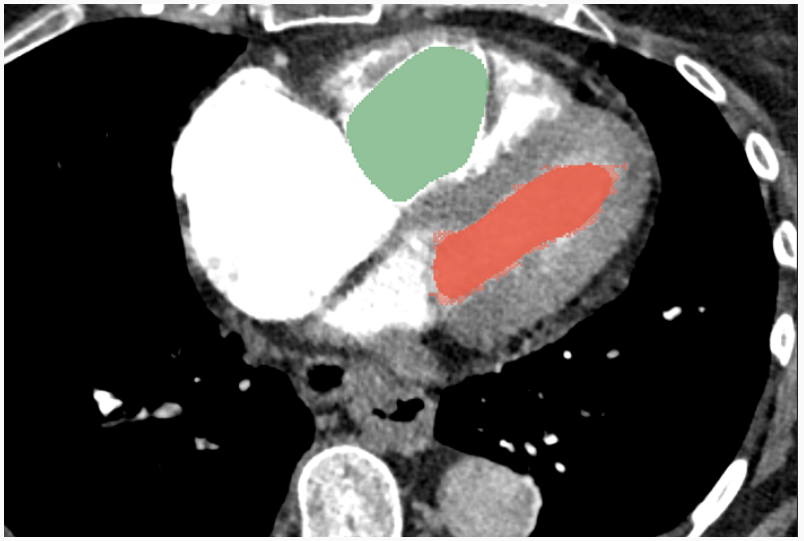
(c) Manually adapted window

Figure 15: Different 3DSlicer windows used for segmentation

Abdominal window (2/2)



(a) Segmentation on default window



(b) Same segmentation on media intestinal window

Figure 16: Same segmentation on different windows

Analysis - Volumetric ventricles ratio distribution

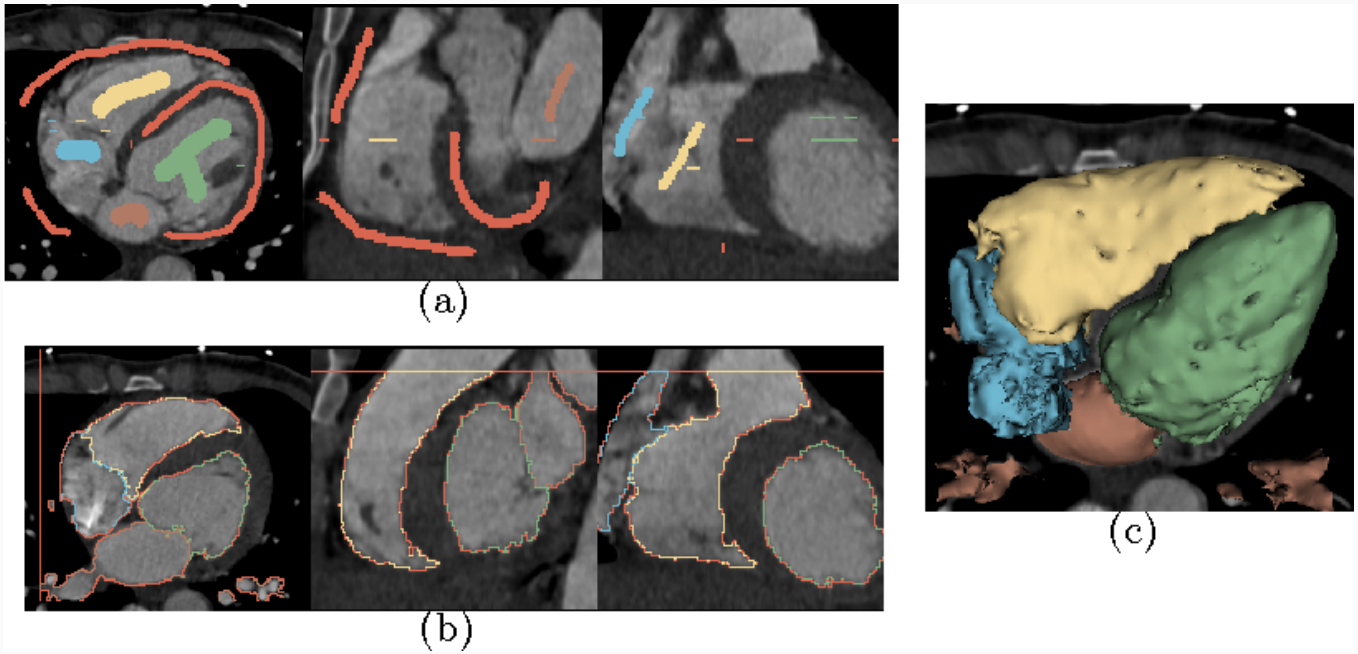


Figure 17: Growing regions [11]

Analysis - Pair of ventricles volume and ratio (1/3)

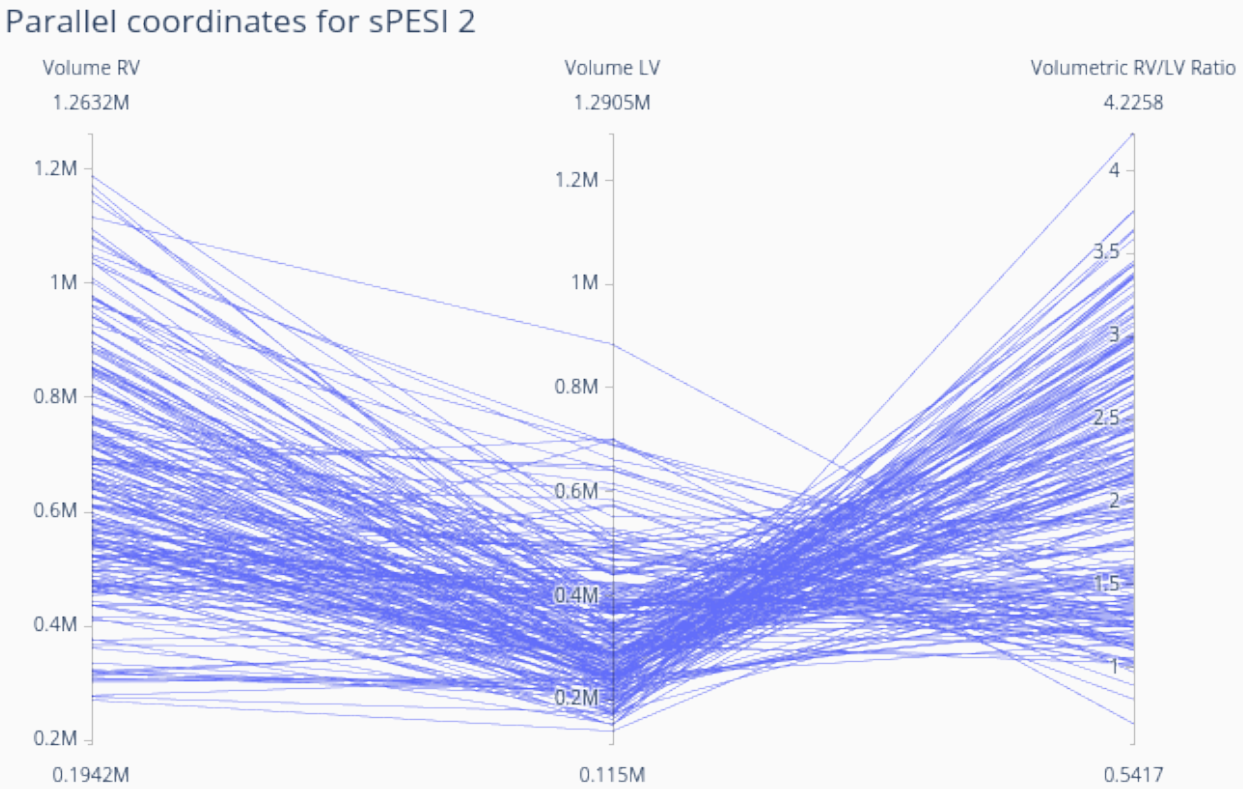


Figure 18: Parallel coordinates of ventricles volumes of PE patient with sPESI 2

Analysis - Pair of ventricles volume and ratio (2/3)

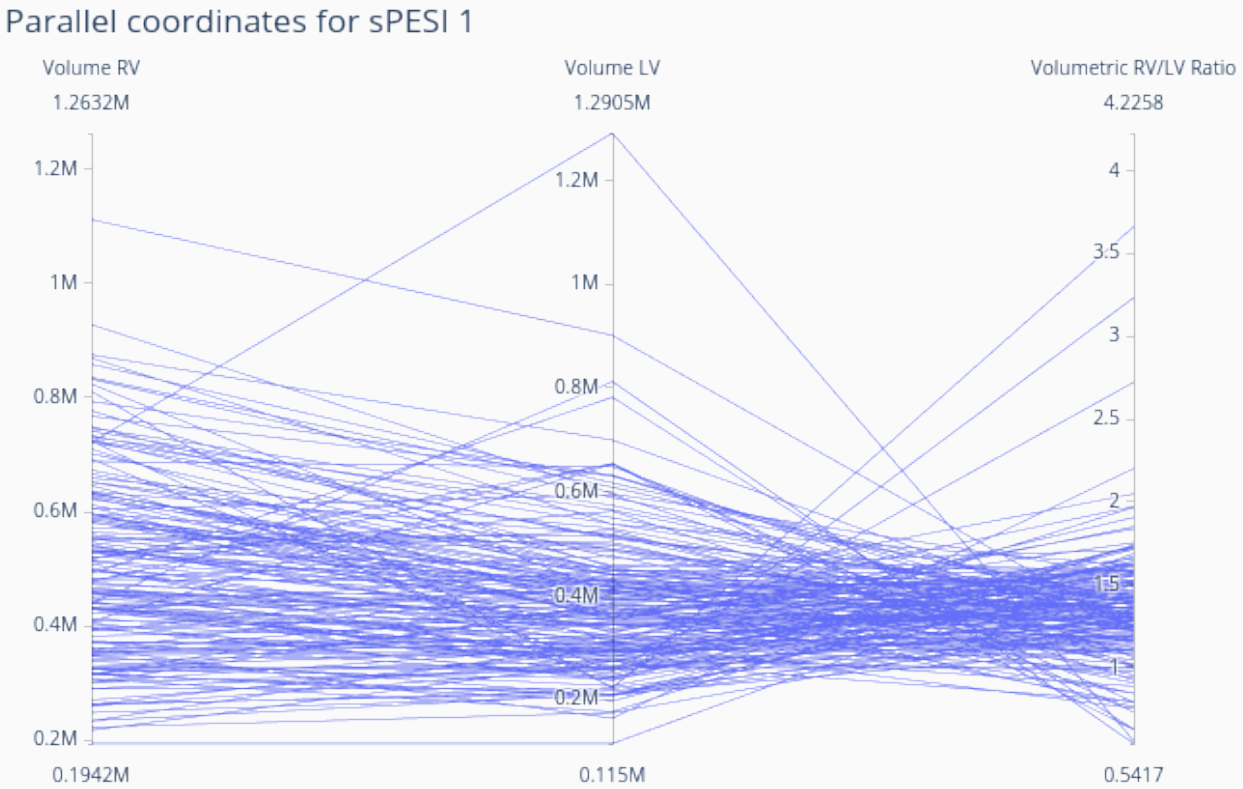


Figure 19: Parallel coordinates of ventricles volumes of PE patient with sPESI 1

Analysis - Pair of ventricles volume and ratio (3/3)

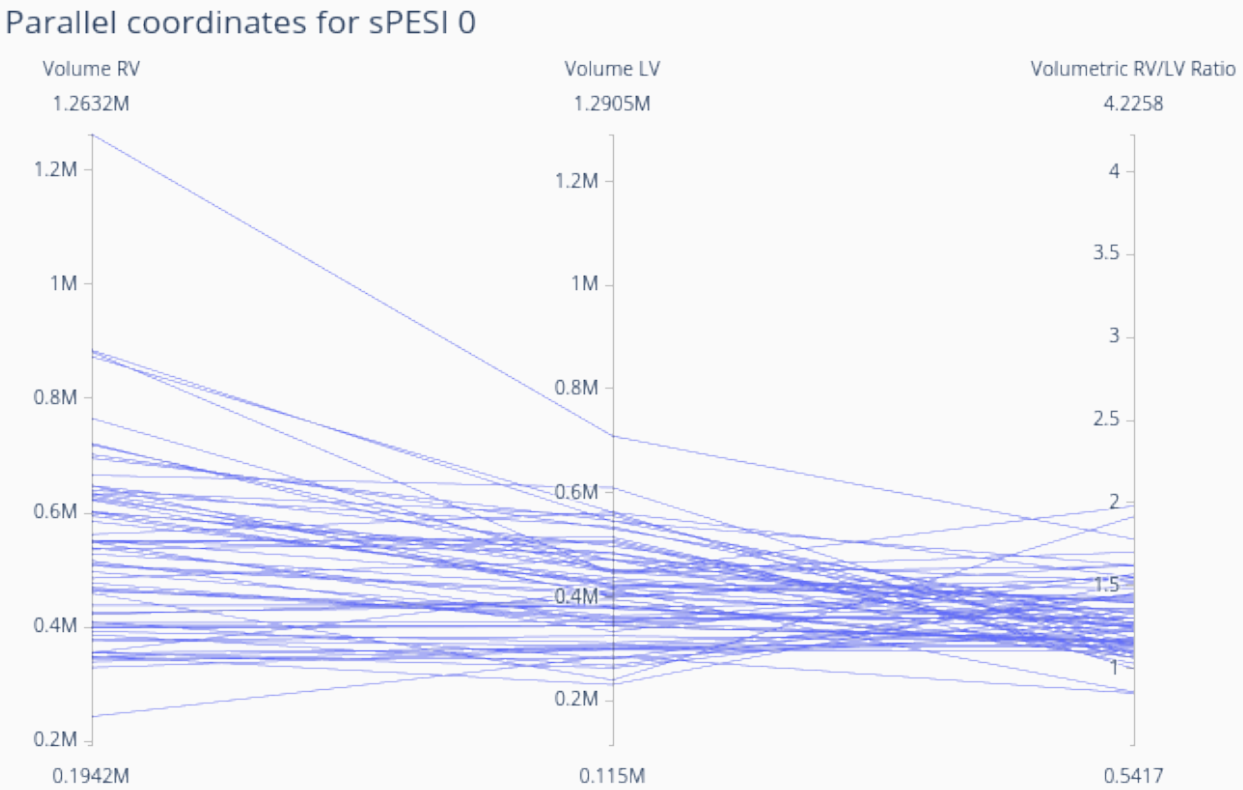


Figure 20: Parallel coordinates of ventricles volumes of PE patient with sPESI 0