European Commission
Directorate-General for Research and Innovation
Number 945119 – STOPSTORM

STOPSTORM Center Accreditation Program

Critical Structures Contouring Benchmark - Instructions and Guidelines

Dear STAR Centers,

Here you will find the instructions for contouring the organs-at-risk (OAR) for the critical structures used in the benchmark cases of the STOPSTORM.eu project.

Three cases are provided for this benchmark, and every case has a contrast-enhanced cardiac-CT which is already deformed to the primary planning-CT to contour the OAR in detail. Despite this having been a mandatory exercise for the STOPSTORM.eu centers, which was subsequently published [1], please enjoy this as a learning experience in the same way as it was for the creators and participants of this benchmark.

The estimated time for contouring is 4h per case for an experienced participant and 6h for unexperienced participants. Evaluation should be done via self-assessment in comparison to [1].

[1] Refining critical structure contouring in STereotactic Arrhythmia Radioablation (STAR): Benchmark results and consensus guidelines from the **STOPSTORM**.eu consortium.
Balgobind BV, Visser J, Grehn M, Marquard Knap M, de Ruysscher D, Levis M, Alcantara P, Boda-Heggemann J, Both M, Cozzi S, Cvek J, Dieleman EMT, Elicin O, Giaj-Levra N, Jumeau R, Krug D, Algara López M, Mayinger M, Mehrhof F, Miszczyk M, Pérez-Calatayud MJ, van der Pol LHG, van der Toorn PP, Vitolo V, Postema PG, Pruvot E, Verhoeff JC, Blanck O. Radiother Oncol. 2023 Dec;189:109949.

Instructions for Down-/ and Upload:

Please, use the ZENODO STOPSTORM Page for downloading the data which contains the two CTs and structure sets for all three cases (all in DICOM format) and the papers referenced in this document.

ZENODO STOPSTORM Community: https://zenodo.org/communities/stopstorm/

Import the three cases into your planning system including the contour template files. The planning-CT and the corresponding cardiac-CT are already pre-registered using deformed image registration. Do not alter the registration.

For the correct labeling of the structures, we provided the above-mentioned contour templates. There is one slice where you can find all the contours. Please delete our temporary contours from the templates and start contouring according to the guidelines presented in this document.

If you have any questions or issues regarding the contouring benchmark study or data import, feel free to contact Oliver Blanck (oliver.blanck@uksh.de) or Melanie Grehn (melanie.grehn@uksh.de).

Whole Heart (structure label: Heart)

Superiorly, the whole heart starts just inferior to the left pulmonary artery. For simplification, a round structure to include the great vessels as well can be contoured. Inferiorly, the heart blends with the diaphragm. Since cardiac vessels run in the fatty tissue within the pericardium, this should be included in the contours, even if there is no heart muscle visible in that area. (Feng et al.)

Chambers (structure label: Ventricle_L, Ventricle_R, Atrium_L, Atrium_R)

In Table 1 the anatomical landmarks for contouring the four chambers are described. (Milo et al).

Table 1
Delineation guideline for the four heart chambers on axial CT imaging without contrast.

Borders	Left atrium	Left ventricle	Right atrium	Right Ventricle
Cranial	Caudal and dorsal to the left pulmonary artery	Between the cranial part of the right ventricle and the left atrium, just after the bifurcation of LMCA	Between the pericardium and right side of the root of the aorta just ventral to the ventral limit of superior vena cava	The boundary between the pulmonary trunk and the right ventricle is indicated by the aortic valve
Caudal	Just above the coronary sinus. On an axial CT-scan, usually one slide above	Blends with the diaphragm	5–10 mm after the departure of inferior vena cava	Blends with the diaphragm
Ventral	Ascending aorta to the ostium in the left ventricle, after which the ventral wall of the left atrium forming the dorsal limit of the crux	The right ventricle in an imaginary straight line from the anterior interventricular groove to the interatrial septum.	Cranially the right atrioventricular groove forming a triangle of fatty tissue, and more caudally the ventral part is close to the pericardium and right limit of the right ventricle	Following the pericardium
Dorsal	Follows the pericardium	Cranially the left atrium and the left atrioventricular groove. More caudally the pericardium	Cranially the superior vena cava until the ostium in the right atrium, and further caudal the right part of left atrium separated by the interatrial septum	Cranially aorta and the left ventricle, before becoming the anterior limit of the crux and further caudal the pericardium
Left	Cranially left auricle and the fatty tissue of the left atrioventricular groove, and further caudal the right wall of the left ventricle	Following the pericardium	Ascending aorta to the ostium in the left ventricle, after which the left wall of right atrium forming the right limit of the crux	Left ventricle
Right	Cranially the superior vena cava and the right pulmonary artery / pericardium and further caudal the dorsal/ dorsomedial limit of the right atrium	Cranially aorta to below the aortic ostium, and caudally the right part of the left ventricle is representing the left part of the crux	Following the pericardium	Cranially the triangle of fatty tissue formed by the right atrioventricular groove and more caudally the left limit of the right atrium. After the caudal limitation of the right atrium, the right wall of the right ventricle is in close relation to the pericardium

Segments of the Left ventricle wall (structure label: Ventricle_L_A, Ventricle_L_S, Ventricle_L_I, Ventricle_L_L)

In cardiology, the recommendation is to divide the myocardium into 17 segments. This is, however, impossible on a non-ECG gated, non-contrast CT scan. To simplify the segmentation of the left ventricle and with respect to the myocardial perfusion by the respective coronary arteries, the myocardium is divided into 4 segments: an anterior, inferior, septal and lateral segment. Contouring definitions are described in table 2. For contouring of the myocardial wall, we recommend using a brush, with a diameter of 8 mm; with this strategy the majority of the myocardial wall in both the end-systolic and end-diastolic phase will be included. (Milo et al)

Table 2
Delineation guidelines for Left ventricle segmentation.

Segmentname	Contour definition	AHA segment number [18]
Anterior	Cranially the ventral part constitutes the whole myocardium in the thickness to the cavity, which is approximately 10 mm, usually 3 slides on an axial CT scan. The lateral attachment between the left and right ventricle wall indicate the ventral limit, dorsal the limit is the lateral segment. The anterior segment represents 1/6 of the whole myocardium	1,7,13,17
Septal	The attachments of the right ventricle to the left ventricle is indicating the septal segment throughout its width from the basal to the apical cap, representing 2/6 of the whole myocardium	2,3,8,9,14
Inferior	There is a septum but no myocardium between the left ventricle and left atrium thus, the inferior segment starts after the left atrium is no longer visible on an axial CT scan. The limitation is the septal segment and the lateral free wall, representing 1/6 of the whole myocardium. The inferior segment is the most caudally part of the left ventricle on an axial CT scan, usually, there is no cavity on the last 3 slides of an axial CT scan corresponding with the thickness of the myocardium	4,10,15
Lateral	Between the ventral part of the left ventricle and cranially the left, dorsal limit of the left atrium and more caudally the inferior segment of the left ventricle. The lateral segment represents 2/6 of the whole myocardium	5,6,11,12,16

AHA segment number: The segment number corresponding to the 17-segment model recommended by the American Heart Association [18].

<u>Valves</u> (structure label: Valve_Aortic, Valve_Pulmonic, Valve_Tricuspid, Valve_Mitral)

A contrast-enhanced CT is mandatory to contour the valves according to Feng et al.

The aortic valve is found within the ascending aorta and seen in cross-section on axial CT. In a contrast scan, the leaflets typically create a “Y” within the lumen of the vessel.

The pulmonic valve is found within the pulmonary trunk and seen in cross-section on axial CT. In a contrast scan, the leaflets typically create an “X” within the lumen of the vessel.

The tricuspid valve is located between the right atrium and ventricle. It is difficult to see, but it is defined as the area where the blood pool between the atrium and ventricle is shared. Due to cardiac motion, this can appear to be discontinuous from axial CT slice to slice.

The mitral valve is located between the left atrium and ventricle. It is difficult to see, but it is defined as the area where the blood pool between the atrium and ventricle is shared.

Coronary arteries (structure label: A_LM, A_LAD, A_LCX, A_RCA):

Contouring the coronary arteries will be simplified for this Benchmark due to the complexity and anatomical variation. Moreover, proximal parts of the arteries are more at risk for major complications. Guidelines are adjusted from Duane et al.

Left main coronary artery: From the left lateral ascending aorta running between the left atrium and the pulmonary artery to the bifurcation into left anterior descending and circumflex coronary arteries (~1.5 cm in length).

Left anterior descending coronary artery: from the end of the left main coronary artery passing anteriorly behind the pulmonary artery. It then descends anterolaterally in the anterior interventricular groove and continues in the interventricular groove and extending to the apex. Approximately 5 cm should at least be contoured.

Left Circumflex coronary artery: From the end of the left main coronary artery running in the left atrioventricular groove for approximately 2 cm in length and then running along the left atrioventricular groove posteriorly extending to the crux of the heart. Approximately 5 cm should at least be contoured.

Right coronary artery: From the anterior aspect of the ascending aorta descending in the right atrioventricular groove to the acute heart border (horizontal heart border extending from the lower right edge of the heart to the apex formed mainly by the right ventricle) and then running medially along the right atrioventricular groove posteriorly to the crux of the heart. Approximately 5 cm should at least be contoured.

Aorta (structure label: A_Aorta)

The Aorta is contoured as one structure. Starting from the left ventricle de ascending aorta continues in de aortic arch and then descends to approximately 3 cm below the diaphragm.

Pulmonary Arteries (structure label: A. Pulmonary)

The main pulmonary artery starts at the cranial side of the right ventricle, ventrally from the Aorta. It then bifurcates into the left and right pulmonary artery. These should be contoured until the bronchus.

Vena Cava Superior (structure label: V_Venacava_S)

The Vena cava superior starts from the right ventricle and will be contoured till the level of the aortic arch.

Vena Cava Inferior (structure label: V_Venacava_I)

The Vena cava inferior starts caudally from the vena cava superior at the right ventricle. It will be contoured until the hilus of the liver.

<u>Nodes</u> (structure label: SAN, AVN)

The sinoatrial node and atrioventricular node are not visible on a CT-scan. Therefore, the delineation guide by Loap et al will be used. Step by Step delineation are described in fig 1 and fig 2 of the paper.

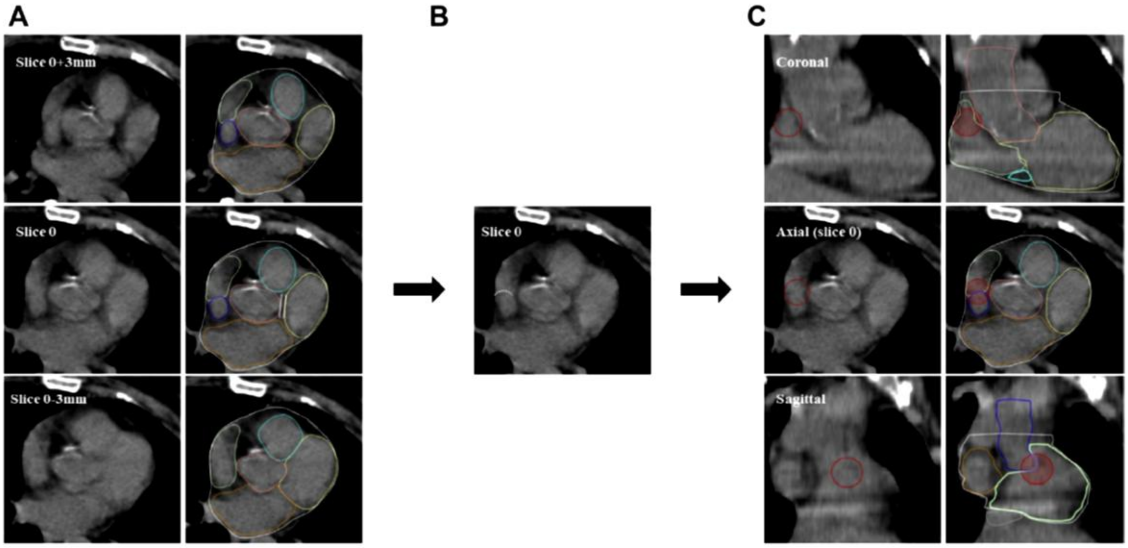

Fig. 1 Step-by-step delineation of the sinoatrial node (SAN). Slice thickness is 3 mm. The heart (white), aorta (pink), superior vena cava (SVC; blue), inferior vena cava (gray), right atria (light green), left atria (orange), right ventricle (cyan), and left ventricle (yellow) have been delineated. (A) Identify the lowest computed tomography (CT) slice where the aorta appears separated from the left ventricle (identified as Slice 0 on the provided example). Separation between the aorta and left ventricle is materialized by white brackets on Slice 0. (B) Identify on this CT slice (Slice 0) the SVC and right auricle (identification of SVC contours is eased by scrolling up and down the CT slices). The junction between the SVC and right auricle is materialized by a white dotted line. (C) The SAN is delineated by the 2-cm diameter sphere centered on the junction between the SVC and right auricle on this slice (Slice 0), so that the border of this sphere is in contact with the right border of the heart without exceeding the cardiac contours. The SAN spherical contours (red) are provided in the coronal, axial, and sagittal planes.

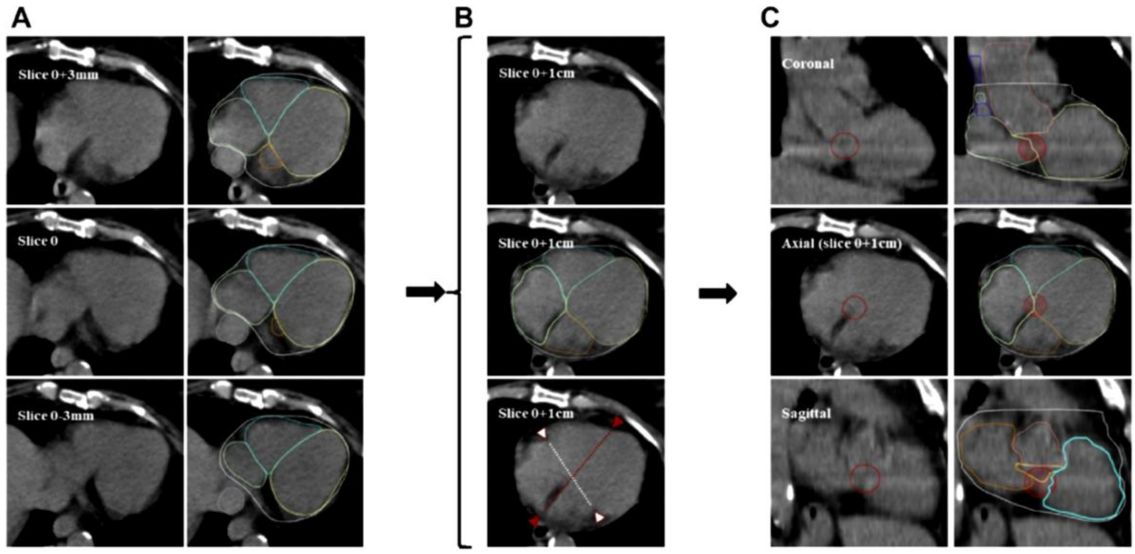

Fig. 2 Step-by-step delineation of the atrioventricular node (AVN). The slice thickness is 3 mm. The heart (white), aorta (pink), superior vena cava (SVC; blue), inferior vena cava (gray), right atria (light green), left atria (orange), right ventricle (cyan), and left ventricle (yellow) have been delineated. (A) Identify the lowest computed tomography (CT) slice where the left atrium is visible, posteriorly to the left ventricle (identified as Slice 0 on the provided example). (B) Scroll up to the CT slice situated 1 cm above (identified as Slice 0 + 1 cm). On this slice, the left and right atrioventricular grooves (white triangles) and interatrial and interventricular grooves (red triangles) can be identified without contrast media injection. The atrioventricular groove plane is materialized by the white dotted line between the atrioventricular grooves and septal plane by the red dotted line between the interatrial and interventricular grooves. Identify the intersection of these 2 planes. (C) The AVN is delineated by the 2-cm diameter sphere centered on the intersection of the atrioventricular groove and septal planes on this slice (Slice 0 + 1cm). The AVN spherical contours (red) are provided in the coronal, axial, and sagittal planes.

<u>Lungs</u> (structure label: Lung_R, Lung_L)

Limited to the air-inflated lung parenchyma without inclusion of the fluid and atelectasis visible on the CT image. Automated contouring tools can be used; however, appropriate thresholds, specific to each CT scan, should be chosen. Reviewing and editing the auto contoured structures is always required. The proximal bronchial tree should be excluded, and small sized vessels (<1 cm or vessels beyond the hilar region) should be included. Kong et al.

<u>Trachea</u>

The trachea is contoured cranially from the aortic arch till it divides in the left and right main bronchus at the carina.

<u>Bronchus</u>

The main bronchus can be contoured using mediastinal windows on the CT scan to correspond to the mucosal, submucosa, and cartilage rings and airway channels associated with these structures. It can be contoured as one structure until the 2nd division.

<u>Esophagus</u>

The esophagus should be contoured using mediastinal windowing on CT to correspond to the mucosa, submucosa, and all muscular layers out to the fatty adventitia. Cranial the esophagus contour should begin at the level of aortic arch and continue including the gastroesophageal junction (GEJ) until it ends at the stomach. Kong et al.

<u>Stomach</u>

The stomach, separated into cardia (near the heart), fundus, body, and antrum and pylorus, should be contoured as one organ. The cardia begins caudal to the GEJ. The gastric fundus, the most cephalad portion of the stomach, abuts the left hemi diaphragm, and is to the left and superior to the cardia. The body is the central, largest portion of the stomach and the antrum is the gateway into the pylorus, the sphincter opening into the duodenum. Jabbour et al.

<u>Spinal Canal</u>

The spinal canal should be contoured according to the bony limits. The contour can start from the level of the aortic arch until 3 cm under the diaphragm.

<u>ICD</u>

The device will be clearly visible on the planning-CT.

Final Note: If the target area is next to the thoracic wall, then this should be contoured for planning and documentation purposes (not relevant for this planning study).

References

Development and validation of a heart atlas to study cardiac exposure to radiation following treatment for breast cancer. *Feng M, Moran JM, Koelling T, Chughtai A, Chan JL, Freedman L, Hayman JA, Jagsi R, Jolly S, Larouere J, Soriano J, Marsh R, Pierce LJ. Int J Radiat Oncol Biol Phys. 2011 Jan 1;79(1):10-8.*

A cardiac contouring atlas for radiotherapy. *Duane F, Aznar MC, Bartlett F, Cutter DJ, Darby SC, Jagsi R, Lorenzen EL, McArdle O, McGale P, Myerson S, Rahimi K, Vivekanandan S, Warren S, Taylor CW. Radiother Oncol. 2017 Mar;122(3):416-422.*

Delineation of whole heart and substructures in thoracic radiation therapy: National guidelines and contouring atlas by the Danish Multidisciplinary Cancer Groups. Milo MLH, Offersen BV, Bechmann T, Diederichsen ACP, Hansen CR, Holtved E, Josipovic M, Lörincz T, *Maraldo MV, Nielsen MH, Nordsmark M, Nyström PW, Pøhl M, Rose HK, Schytte T, Yates ES, Lorenzen EL. Radiother Oncol. 2020 Sep;150:121-127.* + Supplementary Atlas

A Radiation Therapy Contouring Atlas for Cardiac Conduction Node Delineation. *Loap P, Servois V, Dhonneur G, Kirov K, Fourquet A, Kirova Y. Pract Radiat Oncol. 2021 Feb 6:S1879-8500(21)00046-1*

Consideration of dose limits for organs at risk of thoracic radiotherapy: atlas for lung, proximal bronchial tree, esophagus, spinal cord, ribs, and brachial plexus. *Kong FM, Ritter T, Quint DJ, Senan S, Gaspar LE, Komaki RU, Hurkmans CW, Timmerman R, Bezjak A, Bradley JD, Movsas B, Marsh L, Okunieff P, Choy H, Curran WJ Jr. Int J Radiat Oncol Biol Phys. 2011 Dec 1;81(5):1442-57.*

Upper abdominal normal organ contouring guidelines and atlas: a Radiation Therapy Oncology Group consensus. *Jabbour SK, Hashem SA, Bosch W, Kim TK, Finkelstein SE, Anderson BM, Ben-Josef E, Crane CH, Goodman KA, Haddock MG, Herman JM, Hong TS, Kachnic LA, Mamon HJ, Pantarotto JR, Dawson LA. Pract Radiat Oncol. 2014 Mar-Apr;4(2):82-89.*