Universitat Pompeu Fabra Barcelona

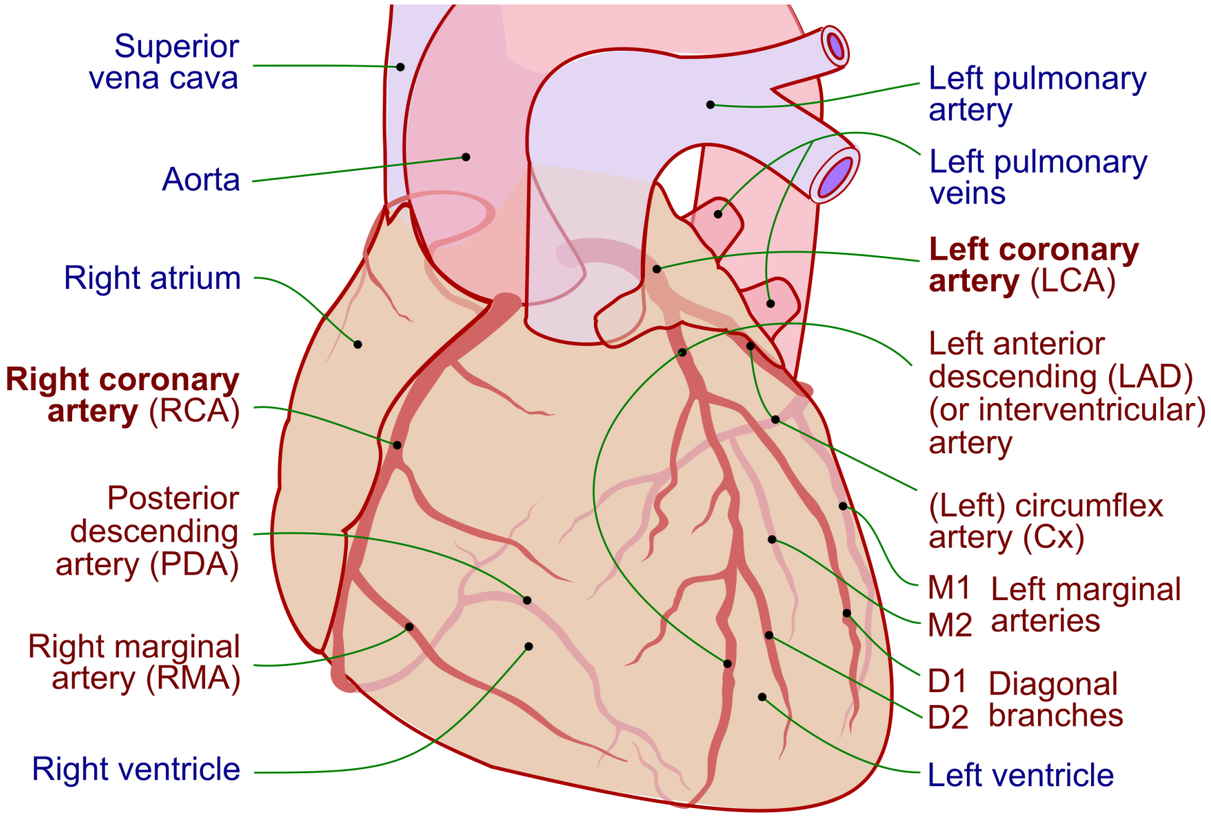
SANT PAU Dimension Lab

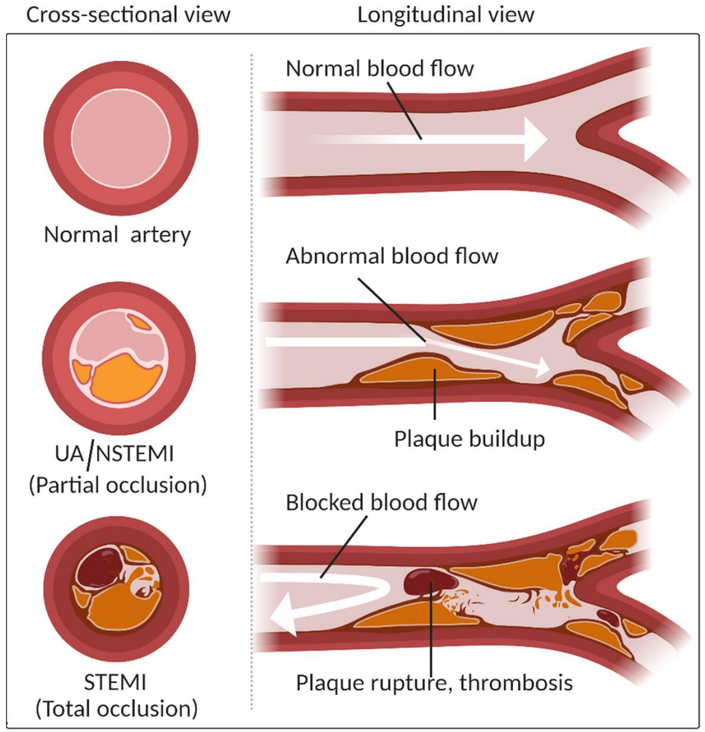
An Artificial Intelligence Framework for the Prioritization and Reporting of Coronary Artery Disease Patients in a Cardiac Imaging Unit

César Acebes Pinilla

Supervisors: Pr. Oscar Camara (UPF), Adrian Galdran (Tecnalia), Abdel Hakim Moustafa, MD (HSP)

Coronary Artery Disease (CAD)





Myocardial infarction causes 32% of all deaths worldwide

Lynch, P. J. Anatomy of the coronary tree (2010).
Surendran, A, et al.. *Metabolites* 2021

Image Acquisition at Hospital de Sant Pau

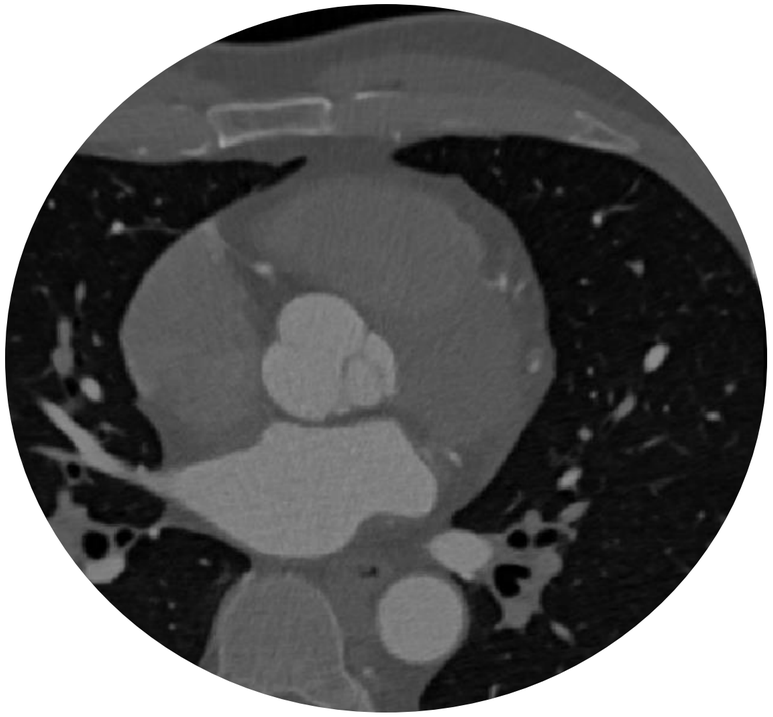
Image acquisition

Image analysis

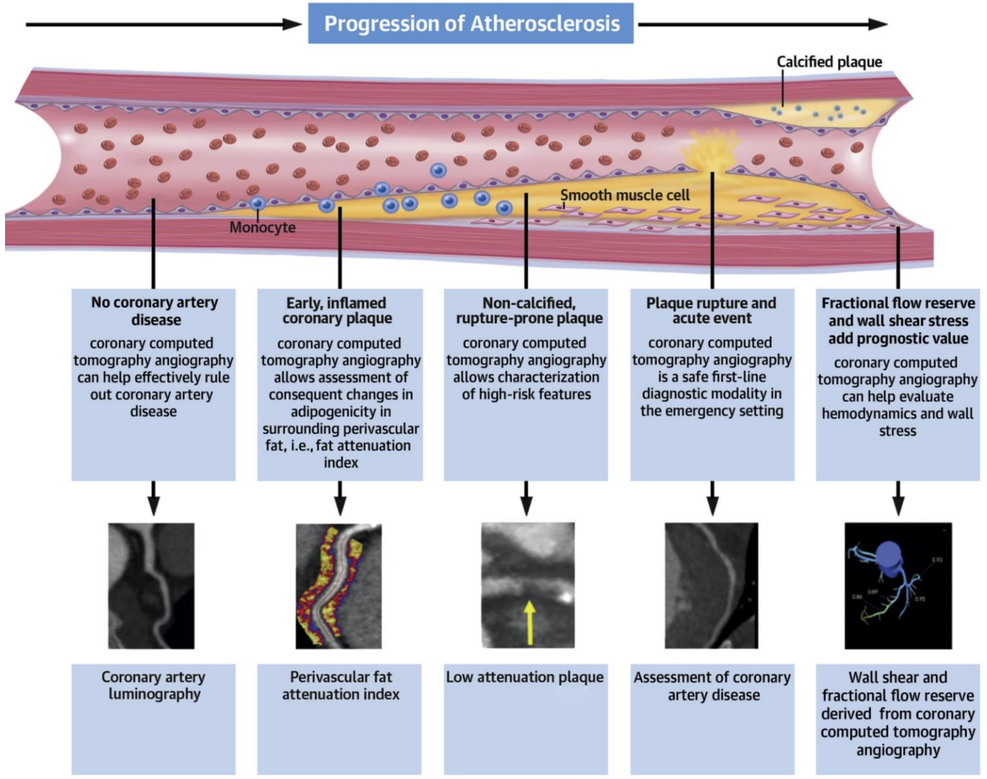
Reporting

Coronary Computed Tomography Angiography (CCTA): standard of care according to guidelines

CCTA image



Source: Hospital de Sant Pau



Juhani Knuuti, et al. European Heart Journal, Volume 41, Issue 3, 14 January 2020, Pages 407–477
Abdelrahman, K.M.. *JACC*, , vol. 76, no. 10, pp. 1226–1243, Sep. 2020.

IMAGE ACQUISITION AT HOSPITAL DE SANT PAU

Image acquisition

Image analysis

Reporting

RIS: Radiology Information System

Patient information and information on how the CT study should be conducted

manual introduction

CLINICAL DATABASE OF THE CARDIAC IMAGING UNIT

CT studies

Information regarding the study (radiation dose administered, etc.)

manual introduction

PHILIPS CT

Images (DICOM)

PHILIPS Workstation

Images (DICOM)

PACS

SIEMENS CT

Images (DICOM)

SIEMENS Workstation

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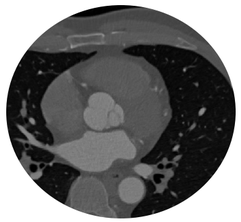


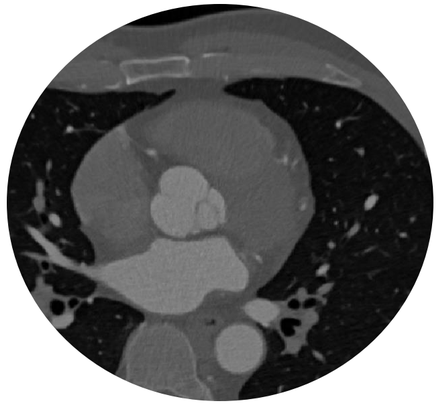
Image Analysis and Diagnosing

Image acquisition

Image analysis

Reporting

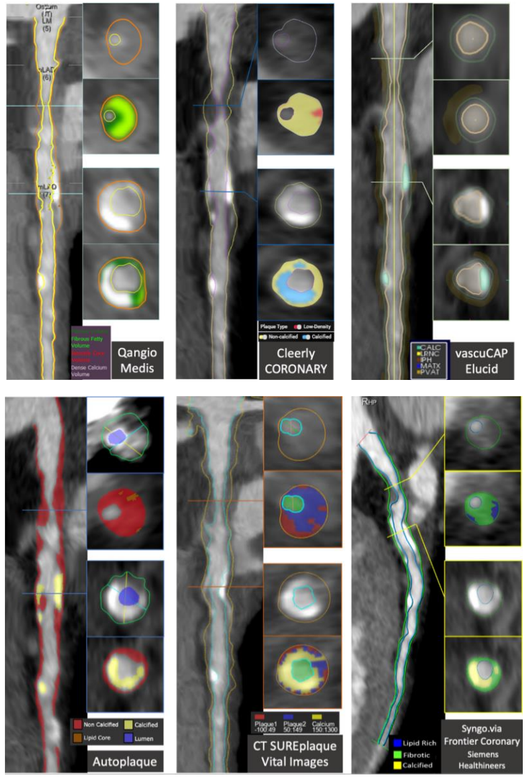
CCTA image



Visual assessment of the stenosis degree and location

Visual assessment of the plaque burden and composition

Visual detection of other clinical findings



Automated solutions: generally unused due to their unreliability

Williams M. C., et al,, JCCT, Mar. 2022.

IMAGE ANALYSIS AND DIAGNOSING

Image acquisition

Image analysis

Reporting

RIS: Radiology Information System

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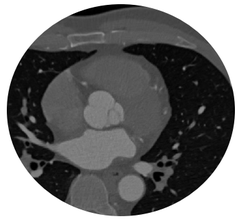


SIEMENS software (syngo.via)

Image analysis and manual feature extraction

manual introduction

Features derived from the image analysis

- Stenosis quantification
- Plaque quantification
- Other clinical findings

Other unorganized data: ECGs, clinical analyses, etc.

REPORTING

Image acquisition

Image analysis

Reporting

Usually: free-text reporting

At Hospital de Sant Pau: structured report, using an internally developed tool

According to CAD-RADS 2.0

Degree of luminal diameter stenosis	Terminology
0%	No visible stenosis
1–24%	Minimal stenosis
25–49%	Mild stenosis
50–69%	Moderate stenosis
70–99%	Severe stenosis
100%	Occluded

Grading Scale for plaque burden: Terminology	Overall plaque burden
P1	Mild amount of plaque
P2	Moderate amount of plaque
P3	Severe amount of plaque
P4	Extensive amount of plaque

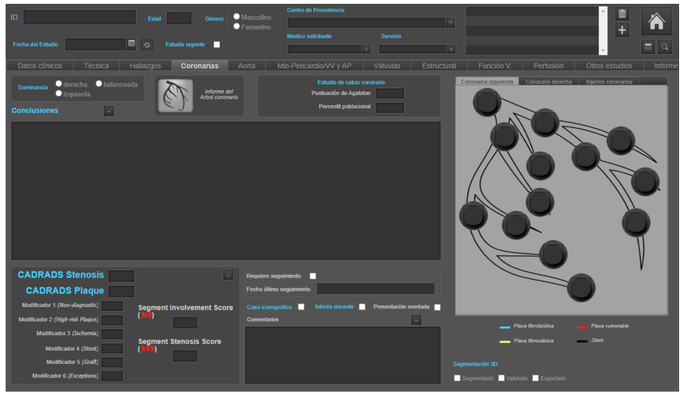
Grading scale for Ischemia detection: Terminology	Meaning
Modifier I	Indicates that CT Ischemia test was performed either with CT-FFR or myocardial CTP
I+	Indicates that CT-FFR or CTP demonstrates lesion-specific ischemia or reversible perfusion defect
I−	Indicates that CT-FFR or CTP is negative for lesion specific ischemia or reversible ischemia[a]
I ±	Indicates that CT-FFR or CTP is borderline

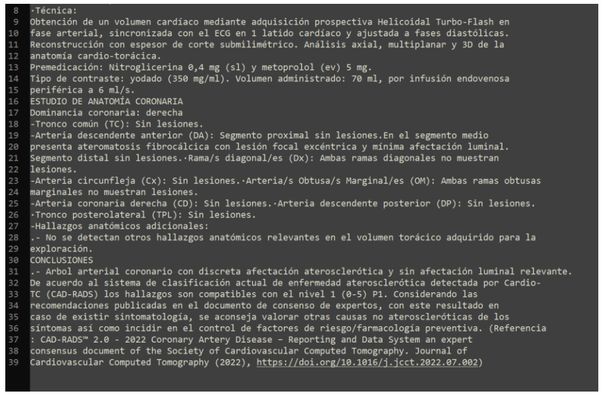
CLINICAL DATABASE OF THE CARDIAC IMAGING UNIT

Patient information

Study information

Variables derived from the image analysis





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·Técnica:
Obtención de un volumen cardiaco mediante adquisición prospectiva Helicoidal Turbo-Flash en
fase arterial, sincronizada con el ECG en 1 latido cardiaco y ajustada a fases diastólicas.
Reconstrucción con espesor de corte submilimétrico. Análisis axial, multiplanar y 3D de la
anatomia cardio-torácica.
Premedicación: Nitroglicerina 0,4 mg (sl) y metoprolol (ev) 5 mg.
Tipo de contraste: yodado (350 mg/ml). Volumen administrado: 70 ml, por infusión endovenosa
periférica a 6 ml/s.
ESTUDIO DE ANATOMÍA CORONARIA
Dominancia coronaria: derecha
-Tronco común (TC): Sin lesiones.
-Arteria descendente anterior (DA): Segmento proximal sin lesiones.En el segmento medio
presenta ateromatosis fibrocálcica con lesión focal excéntrica y mínima afectación luminal.
Segmento distal sin lesiones.·Rama/s diagonal/es (Dx): Ambas ramas diagonales no muestran
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marginales no muestran lesiones.
-Arteria coronaria derecha (CD): Sin lesiones.·Arteria descendente posterior (DP): Sin lesiones.
·Tronco posterolateral (TPL): Sin lesiones.
-Hallazgos anatómicos adicionales:
.- No se detectan otros hallazgos anatómicos relevantes en el volumen torácico adquirido para la
exploración.
CONCLUSIONES
.- Arbol arterial coronario con discreta afectación aterosclerótica y sin afectación luminal relevante.
De acuerdo al sistema de clasificación actual de enfermedad aterosclerótica detectada por Cardio-
TC (CAD-RADS) los hallazgos son compatibles con el nivel 1 (0-5) P1. Considerando las
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caso de existir sintomatología, se aconseja valorar otras causas no ateroscleróticas de los
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: CAD-RADS™ 2.0 – 2022 Coronary Artery Disease – Reporting and Data System an expert
consensus document of the Society of Cardiovascular Computed Tomography. Journal of
Cardiovascular Computed Tomography (2022), https://doi.org/10.1016/j.jcct.2022.07.002)
```

Structured and stored in the database for the generation of a template-based report

Preliminary report

Non pathological cases: around 30 min

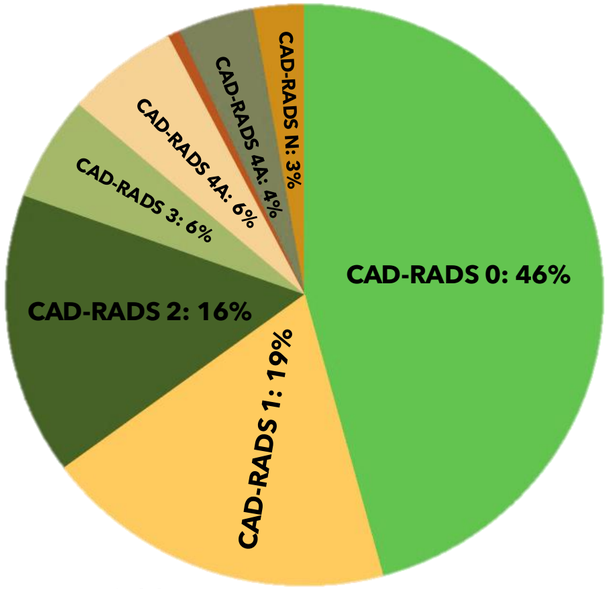
More complex cases: 1-2 hours

Cury, R.C., Radiology: Cardiothoracic Imaging, vol. 4, no. 5, Oct. 2022.

PROBLEMS DETECTED IN THIS PROCESS

Elevated reporting time for non-complex cases

Low risk and normal cases (CAD-RADS 0 or 1) during 2017-2022 at Hospital de Sant Pau: 65% of 5188



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Fragmentation of the workflow

Lack of automatization

No patient prioritization

Infra-use of their tool!

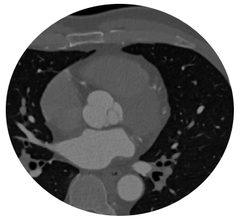
What's our plan?

What's our plan?

PUT THAT TOOL ON STEROIDS

AUTOMATE THE IMAGE ANALYSIS PROCESS

Current workflow



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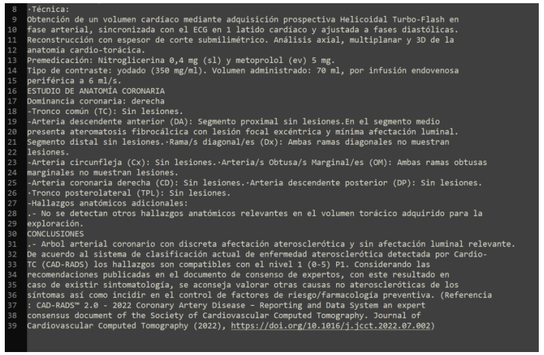
- **Plaque quantification**
- **Other clinical findings**

Report generation



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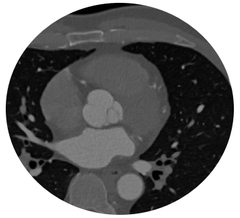

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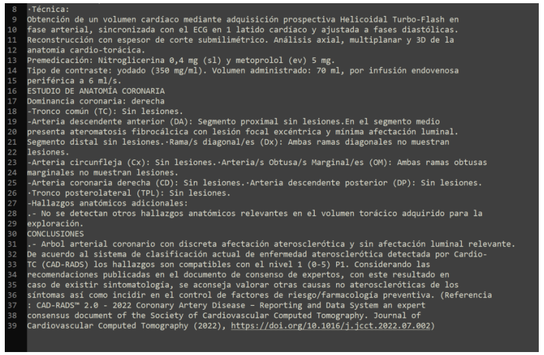
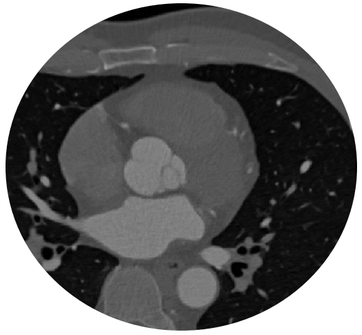
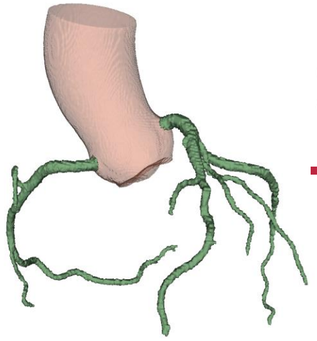


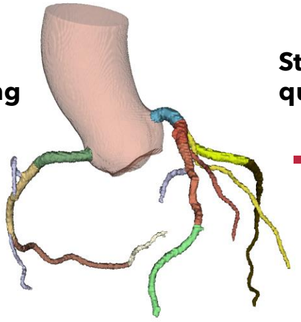
Proposed workflow



Automated segmentation



Coronary artery labeling



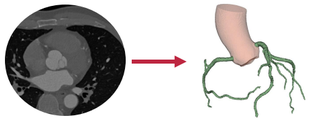
Stenosis quantification

Patient prioritization

Priority Group
Critical
Critical
Critical
High
High
High
Medium
Medium
Medium
Medium
Low
Low
Low
Low
Low

Report generation

AUTOMATED CORONARY SEGMENTATION



Development of the centerline-Cross Entropy (clCE) loss function

Created to preserve accuracy and improve topological coherence of the segmentations

$$\mathcal{L}_{\text{clCE}}(\mathbf{T}, \widehat{\mathbf{P}}) = \text{CE-}\mathcal{T}_{\text{prec}}(\mathbf{T}, \widehat{\mathbf{P}}) + \text{CE-}\mathcal{T}_{\text{recall}}(\mathbf{T}, \widehat{\mathbf{P}})$$

where

$$\text{CE-}\mathcal{T}_{\text{prec}}(\mathbf{T}, \widehat{\mathbf{P}}) = \frac{1}{\|\mathbf{S_T}\|_1}\mathcal{L}_{\text{CE}}(\mathbf{T}, \widehat{\mathbf{P}}) \odot \mathbf{S_T} = \frac{1}{\|\mathbf{S_T}\|_1} \sum_{i \mid \mathbf{x}_i \in \mathbf{S_T}} \mathbf{T}_i \log(\widehat{\mathbf{P}}_i)$$

and

$$\text{CE-}\mathcal{T}_{\text{recall}}(\mathbf{T}, \widehat{\mathbf{P}}) = \frac{1}{\|\mathbf{S}_{\widehat{\mathbf{P}}}\|_1}\mathcal{L}_{\text{CE}}(\mathbf{T}, \mathbf{P}) \odot \mathbf{S_T}$$

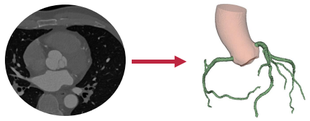
$$= \frac{\sum_i (\mathbf{T}_i \log(\mathbf{P}_i) + (1 - \mathbf{T}_i) \log(1 - \mathbf{T}_i)) \cdot \mathbf{P}_i}{\sum_i \mathbf{P}_i}$$

Some of the strongest points are:

- **Better segmentation accuracy and topology preservation in 2D and 3D datasets with respect to without it.**
- **Notable improvement of segmentation accuracy with respect to cl-Dice.**

C. Acebes, et al., "The centerline-Cross Entropy loss for vessel-like structure segmentation: better topology consistency without sacrificing accuracy," (MICCAI, 2024)

AUTOMATED CORONARY SEGMENTATION



What's a good segmentation method? (clinically speaking)

Benchmarking loss functions considering anatomical relevance

C. Acebes, et al., "A Clinically-Informed Benchmark for Topology-Aware Coronary Artery Segmentation," (Submitted to MICCAI 2025)

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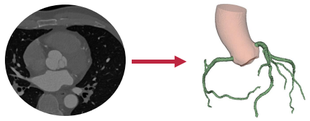


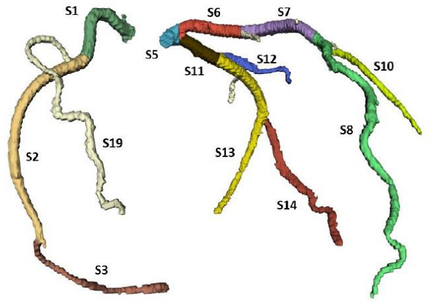
What's a good segmentation method? (clinically speaking)

Benchmarking loss functions considering anatomical relevance

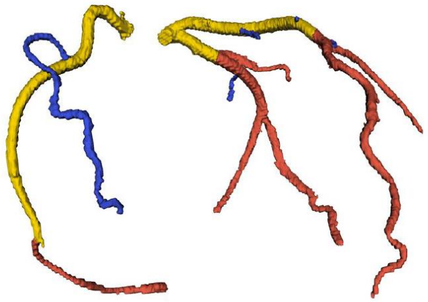
1. Classify coronary segments by vessel relevance

Original annotation

Division by segments



Classification by segment importance



Primary segments (yellow):
Critical vessels for interventions

Secondary segments (red):
Relevant for disease diagnosis

Tertiary segments (blue):
Important for full vessel tracking

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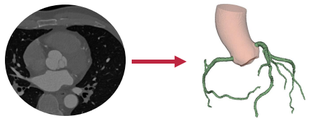

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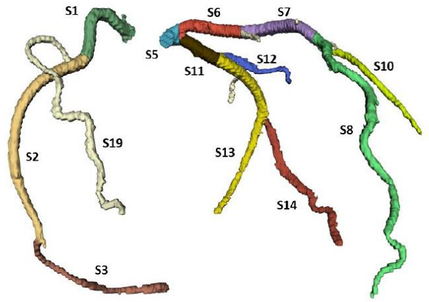

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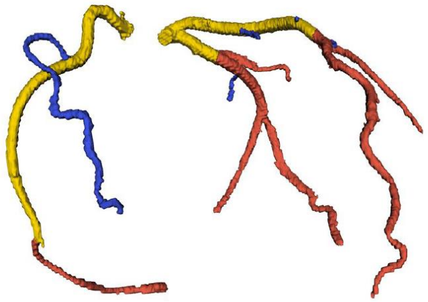

Primary segments (yellow):
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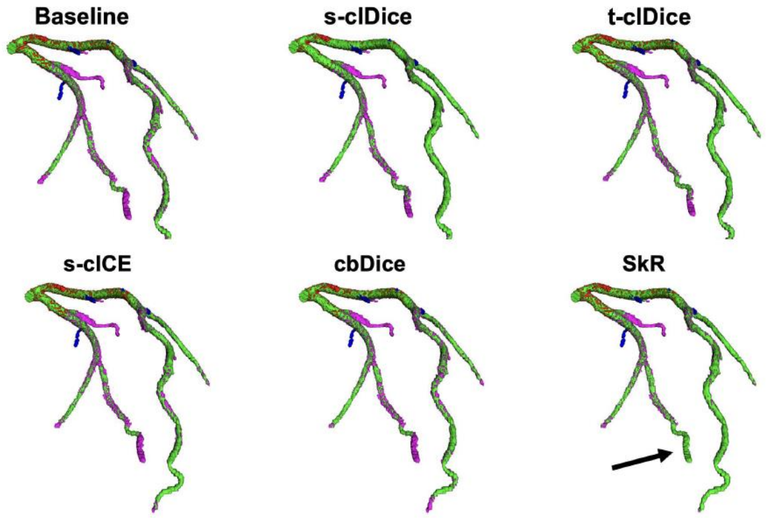
2. Compare performance of loss functions on these segments

Loss	Full coronary tree		Primary segments		Secondary segments		Tertiary segments	
	Recall	$\mathcal{T}_{\text{Recall}}$	Recall	$\mathcal{T}_{\text{Recall}}$	Recall	$\mathcal{T}_{\text{Recall}}$	Recall	$\mathcal{T}_{\text{Recall}}$
Baseline	84.16	86.80	90.60	98.02	72.49	82.41	52.61	61.52
s-clDice	**86.66**	89.42	91.56	98.43	77.51	85.14	61.73	70.59
t-clDice	85.96	88.81	**91.80**	**98.65**	74.77	84.13	56.44	66.50
clCE	84.56	87.21	90.54	98.10	73.08	81.82	53.84	62.04
cbDice	84.53	83.31	91.09	97.97	70.46	76.68	46.17	49.64
SkR	86.61	**90.83**	90.08	98.13	**80.31**	**88.19**	**63.29**	**74.87**



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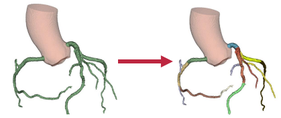
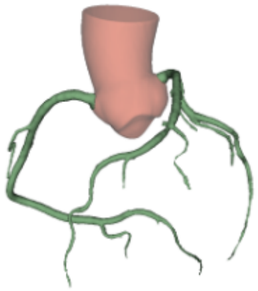
CORONARY ARTERY LABELING



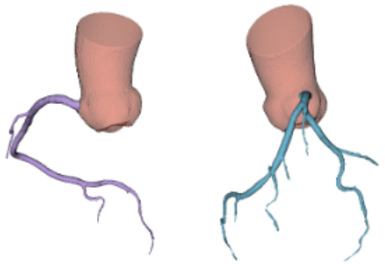
INPUT (NIfTI)

Coronary artery tree segmentation



python

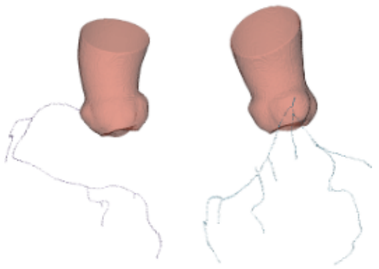
RCA and LCA separation



python

Skeletonization

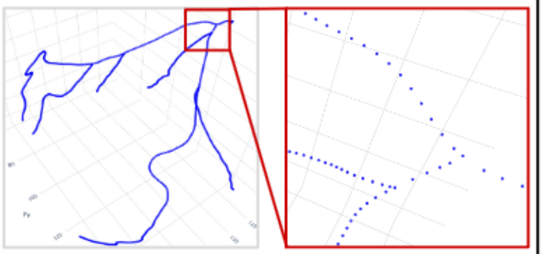
skeletonize_3d() from Scikit-image



python

Voxel-to-points transformation

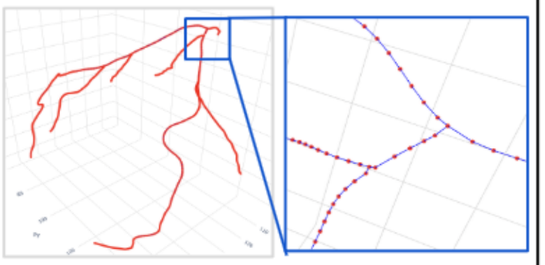
Nibabel and NumPy libraries



python

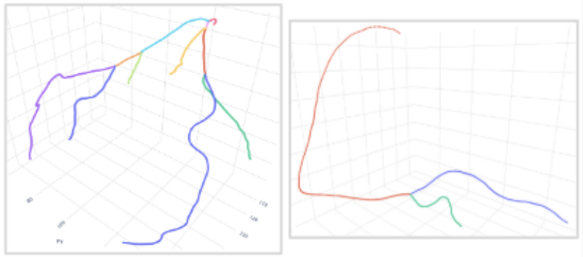
Graph formation

Minimum Spanning Tree (MST)



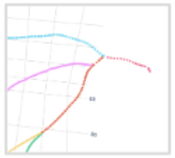
python

Pre-segmenting via bifurcations

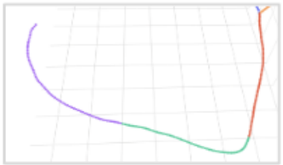


python

Pre-segments union



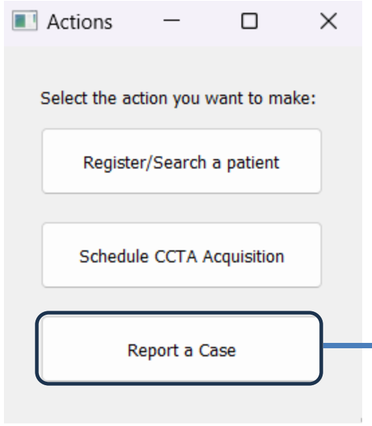
Pre-segments division



Label correctly using topological rules

- Segment 1: pRCA
- Segment 2: mRCA
- Segment 3: dRCA
- Segment 4: R-PDA
- Segment 5: LM
- Segment 6: pLAD
- Segment 7: mLAD
- Segment 8: dLAD
- Segment 9: D1
- Segment 10: D2
- Segment 11: pCx
- Segment 12: OM1
- Segment 13: LCx
- Segment 14: OM2
- Segment 16: R-PLB
- Segment 17: RI
- Segment 19: tertiary

PATIENT PRIORITIZATION



Working List

Working List

Urgent study	Order	Patient	Priority	CAD-RADS	Clinical info	Notes	Explainability	
False	1 (before: 5)	Patricio Rios	HIGH	-	Checkup, patient without cardiologic symptomatology or known coronary art	Coronary bypass	+	Report
False	2 (before: 1)	Lorenzo Humberto Carballo Benito	HIGH	-	Assessment of revascularized coronary artery disease	Coronary bypass	+	Report
False	3 (before: 10)	Ana Belén de Girón	HIGH	4A	No information		+	Validate
True	4 (before: 7)	Custodio Grande-Salgado	HIGH	4A	Other		+	Validate
False	5 (before: 4)	Ramón Acero Pulido	HIGH	4A	Other		+	Validate
True	6 (before: 14)	Berto Solsona Plaza	HIGH	4A	Other		+	Validate
False	7 (before: 15)	Graciana Ojeda Hernando	MEDIUM	3	Other		+	Validate
False	8 (before: 3)	Francisco Jose Samper Cabrero	MEDIUM	3	No information		+	Validate
False	9 (before: 2)	Nayara Agustí	MEDIUM	-	Other	Suboptimal	+	Report
False	10 (before: 11)	Agapito Arregui Ródenas	MEDIUM	-	Chest pain/atypical symptoms in patient without known CAD		+	Report
False	11 (before: 12)	Fernando Alba Castellanos	LOW	2	Assessment of revascularized coronary artery disease		+	Validate
False	12 (before: 8)	María Belén de Sanz	LOW	2	No information		+	Validate
True	13 (before: 6)	Victorino Parra Ruiz	LOW	2	Assessment of revascularized coronary artery disease		+	Validate
False	14 (before: 9)	Anastasio Nevado	LOW	2	Chest pain/atypical symptoms in patient without known CAD		+	Validate
False	15 (before: 13)	Matías Chaparro Franch	LOW	2	Other		+	Validate

PATIENT PRIORITIZATION AND EXPLAINABILITY

Explainability

Clinical Information

- Patient presenting Typical chest pain and under the consultation motive: Other.
- Patient has a Pre-Test Risk Score of 42.52%.
- Patient does not have any previous procedures reported.
- Study was an URGENT request.

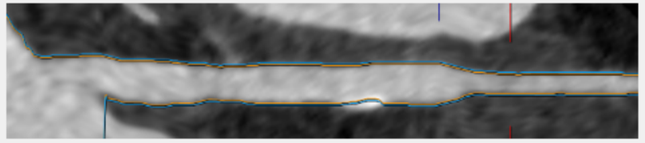
Image Analysis Information

Patient has a CAD-RADS value of 5
Maximum stenosis degrees of the main vessels are LAD=25-49, Cx=1-24 and RCA=25-49.

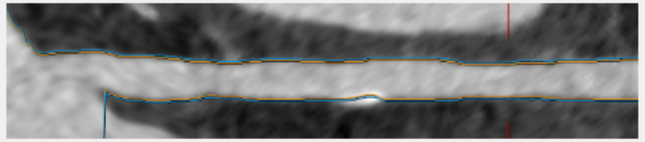
Patient presents a detected calcium score of 63 through Agatston score.

Curved Planar Reformations (CPR)

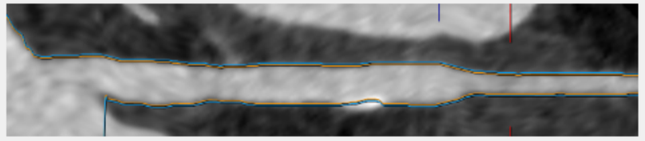
LAD



Cx



RCA



Working List

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Urgent study	Order	Patient	Priority	CAD-RADS	Clinical info	Notes	Explainability	
True	1 (before: 12)	Alejo Mendez-Llamas	HIGH	5	Other		+	Validate
False	2 (before: 9)	Cecilia Portillo	HIGH	4A	Chest pain/atypical symptoms in patient without known CAD		+	Validate
False	3 (before: 7)	Maximino Ramón	HIGH	4A	Assessment of revascularized coronary artery disease		+	Validate
False	4 (before: 2)	Javi Alcolea Trillo	MEDIUM	3	Checkup, patient without cardiologic symptomatology or known coronary artery disease		+	Validate
False	5 (before: 6)	Angelita Garriga-Torrents	MEDIUM	3	Other		+	Validate
False	6 (before: 14)	Raquel Carrera-Aznar	MEDIUM	-	Other		+	Report
False	7 (before: 3)	Aureliano Torrecilla	LOW	2	Other		+	Validate
False	8 (before: 4)	Julia Arteaga Solís	LOW	2	Other		+	Validate
False	9 (before: 5)	Rafaela Araujo Tena	LOW	2	Chest pain/atypical symptoms in patient without known CAD		+	Validate
False	10 (before: 13)	Ramiro Piñol Paniagua	LOW	2	Chest pain/atypical symptoms in patient without known CAD		+	Validate
False	11 (before: 10)	Óscar Gimenez Juliá	LOW	2	Assessment of revascularized coronary artery disease		+	Validate
False	12 (before: 11)	Anselmo Arroyo Juárez	LOW	2	Other		+	Validate
False	13 (before: 15)	Manu Figuerola Villaverde	LOW	2	Other		+	Validate
False	14 (before: 8)	Cruz Santos Valle	LOW	2	Other		+	Validate
False	15 (before: 1)	Araceli Frías Alcolea	LOW	1	Nonspecific ECG/Holter alteration		+	Validate

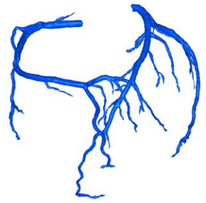
Next Steps and Plan

Improve Ground Truth for coronary artery segmentation

We are re-annotating open-access datasets using clinical criteria

Open access

Re-annotated



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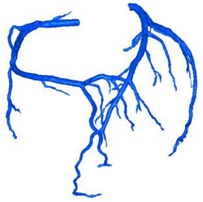

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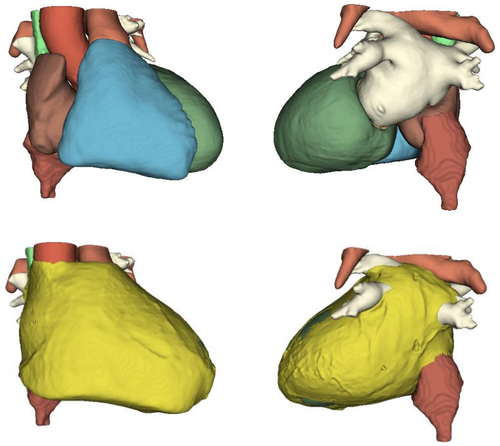
Add context other from coronary arteries into segmentation models

We are combining different nnU-Net-based pretrained models to add relevant context and get full advantage of the information in the CT



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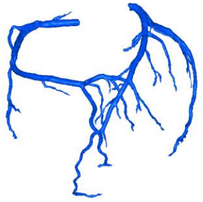

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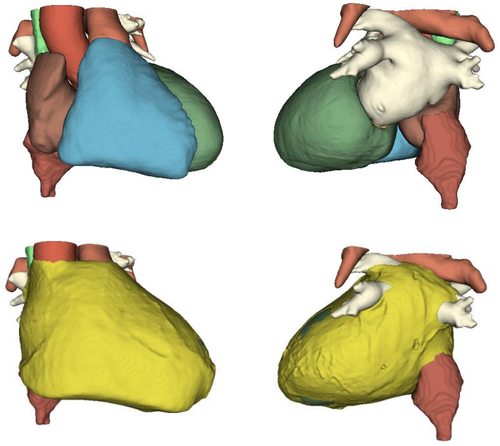
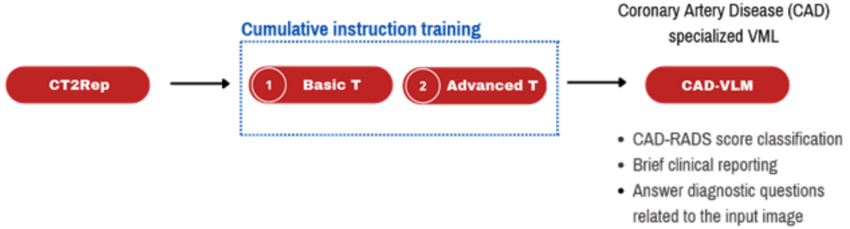


Explore VLMs to automatically interpret CT images and generate structured reports



Training data from Sant Pau database:

CT images

Features derived from the image analysis (structured)

Corresponding Radiologic reports

R. Holand et al., "Specialized curricula for training vision-language models in retinal image analysis," arXiv [cs.AI], 2024.
I. E. Hamamci, S. Er, and B. Menze, "CT2Rep: Automated radiology report generation for 3D medical imaging," arXiv [eess.IV], 2024.

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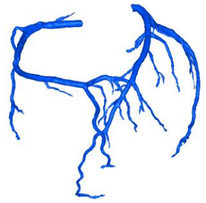

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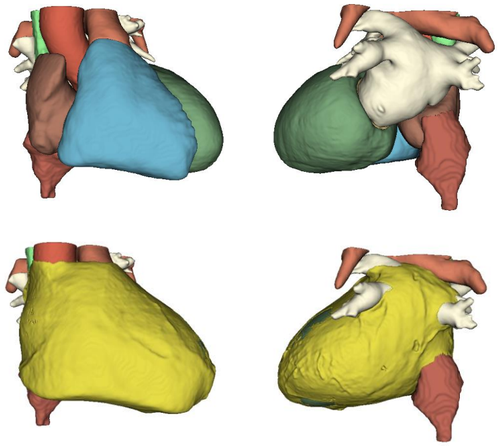

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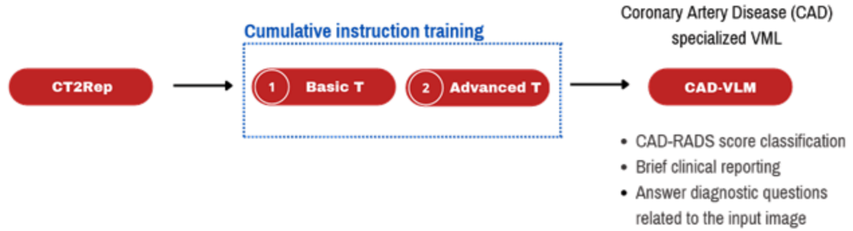

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Integration within Hospital Systems

Using the >10.000 CTs and structured data at Sant Pau

Open to collaborations 😉

Universitat Pompeu Fabra Barcelona

SANT PAU Dimension Lab

César Acebes Pinilla

Supervisors: Pr. Oscar Camara (UPF), Adrian Galdran (Tecnalia), Abdel Hakim Moustafa, MD (HSP)

THANKS FOR YOUR ATTENTION

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

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