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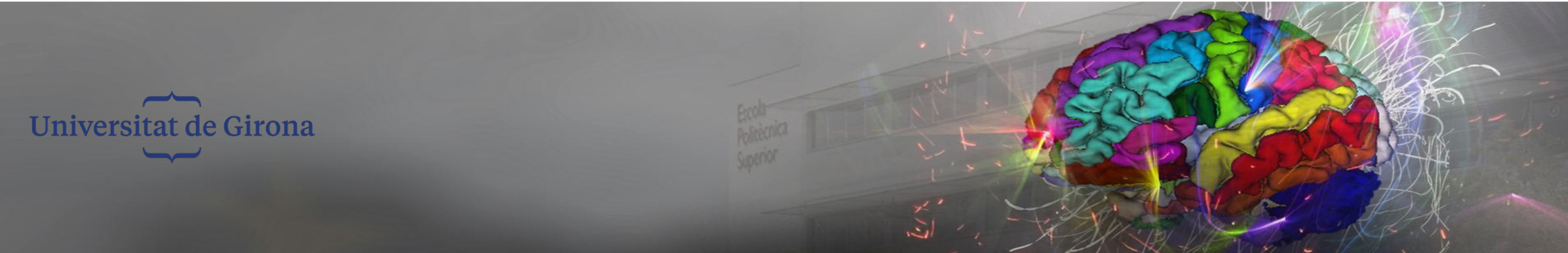
Ultrasound-based carotid stenosis measurement and risk stratification in diabetic cohort: a deep learning paradigm

Xavier Beltran, Luisana Alvarez, Hossain Imran



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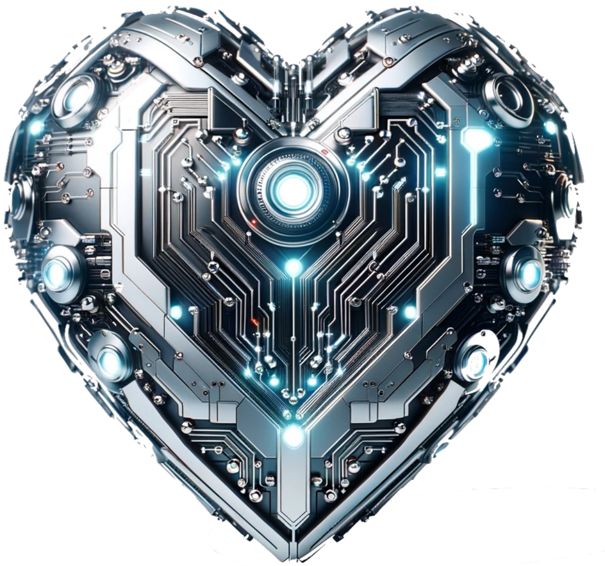
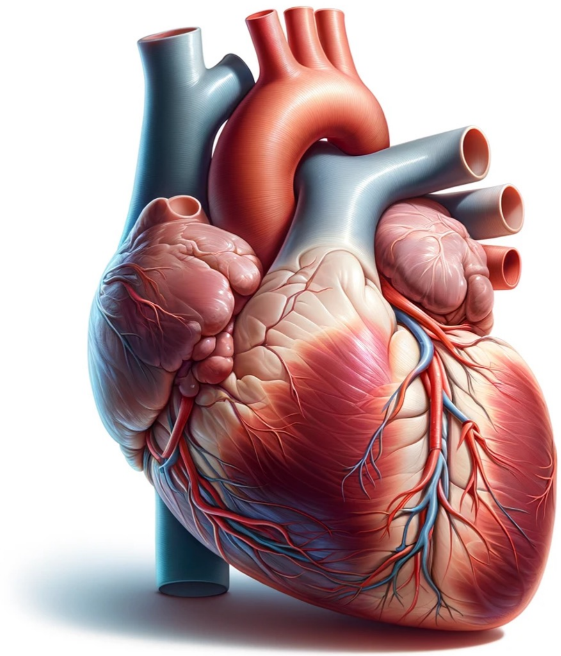


Our Objective

The main objectives of this seminar are:

- To enhance our understanding of cardiovascular and neurological disorders, with a focus on carotid stenosis and stroke risk.
- Explain the approach of the selected paper.
- Discuss about the results obtained and the implication of Deep Learning.
- Propose some future approaches that could be developed in order to improve this paper's results.



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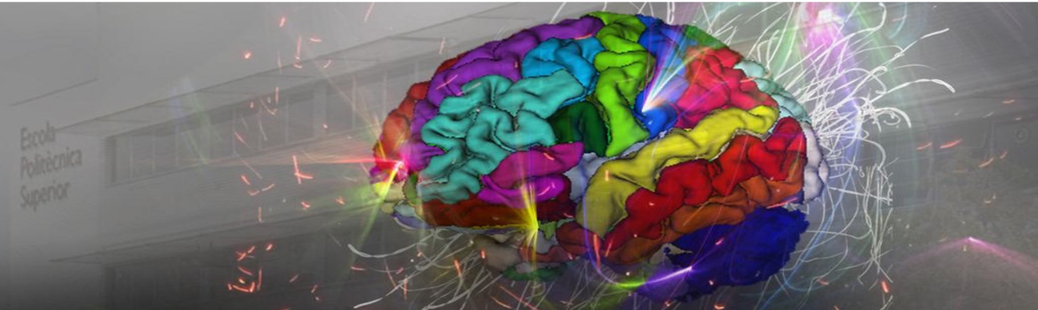
INTRODUCTION



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Introduction

Reference paper:

Ultrasound-based carotid stenosis measurement and risk stratification in diabetic cohort: a deep learning paradigm

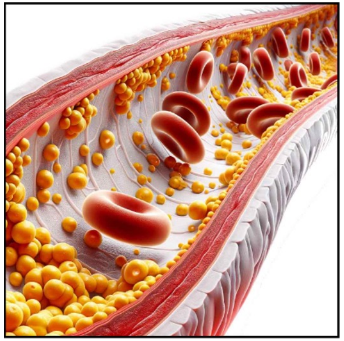
Luca Saba[1], Mainak Biswas[2], Harman S. Suri[3], Klaudija Viskovic[4], John R. Laird[5], Elisa Cuadrado-Godia[6], Andrew Nicolaides[7,8], N. N. Khanna[9], Vijay Viswanathan[10], Jasjit S. Suri[11]

Introduction

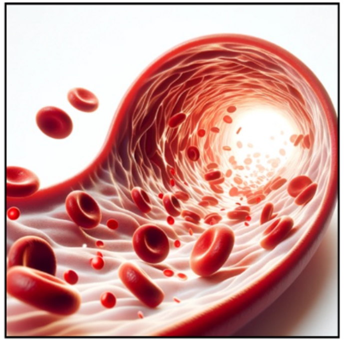
Important concepts:

- **Atherosclerosis:** Hardening and narrowing of arteries due to plaque buildup, often leading to cardiovascular diseases.
- **Lumen:** The inner open space or cavity of a blood vessel through which blood flows.
- **Stenosis:** Abnormal narrowing of blood vessels or valves, impeding blood flow and straining the heart.
- **Risks associated with carotid stenosis:** Increased likelihood of stroke, transient ischemic attacks, and impaired blood supply to the brain.

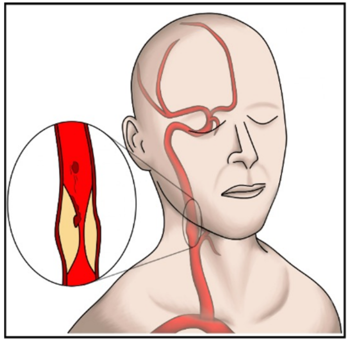
Atherosclerosis



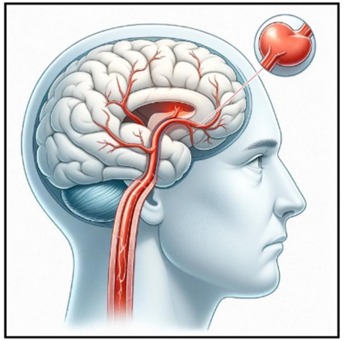
Lumen



Stenosis



Stroke



Introduction

Which type of imaging can we use to detect stenosis:

Image modality used in the paper

Magnetic Resonance (MR)

- ❑ Pros: Excellent option to capture soft tissue plaque composition.
- ❑ Cons: High scanning cost, limited gantry size, scanning time, and limited for patients with metals inside their body.

Computed Tomography (CT)

- ❑ Pros: Scanning time.
- ❑ Cons: High radiation.

Ultrasound (US)

- ❑ Pros: Captures soft tissue plaque composition, low cost, non-invasive and radiation-free.
- ❑ Cons: Limited penetration depth and very noisy images.

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METHODOLOGY

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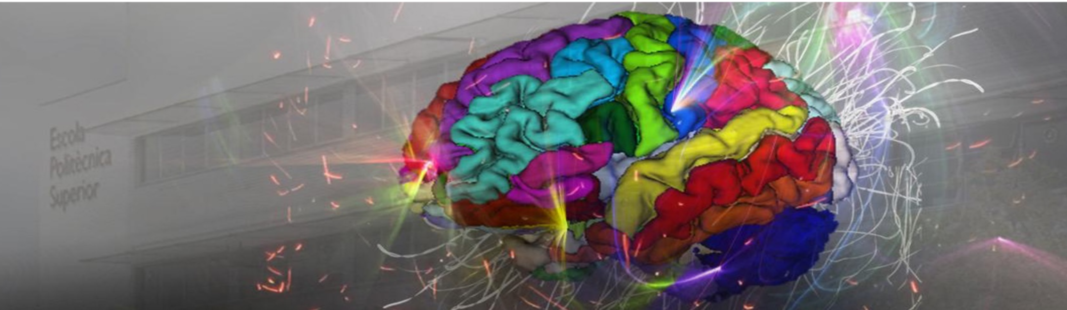


Methodology

Dataset:

- The dataset contains **204 patients** including **157 men/47 women** (77.0% vs. 23.0%) with mean **age 69±11** years.
- **407** CCA B-mode **Ultrasound** images were taken from the 204 patient's left and right carotid arteries.

Toho University, Japan

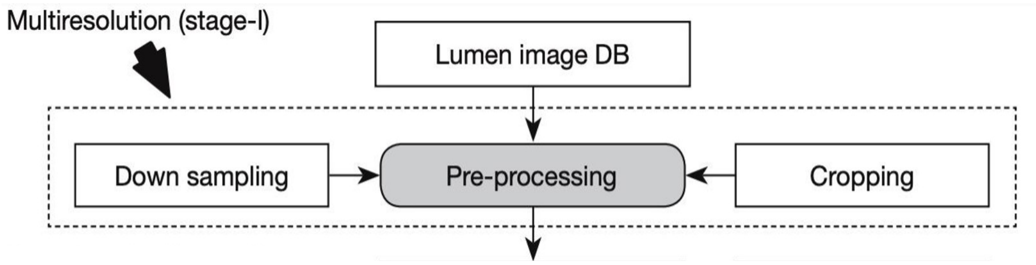
Main Pipeline:

Stage I: multiresolution based pre-processing → Stage II: DL-based lumen detection → Stage III: LI-far and near wall delineation and measurement → Stage IV: stenosis measurement & PE

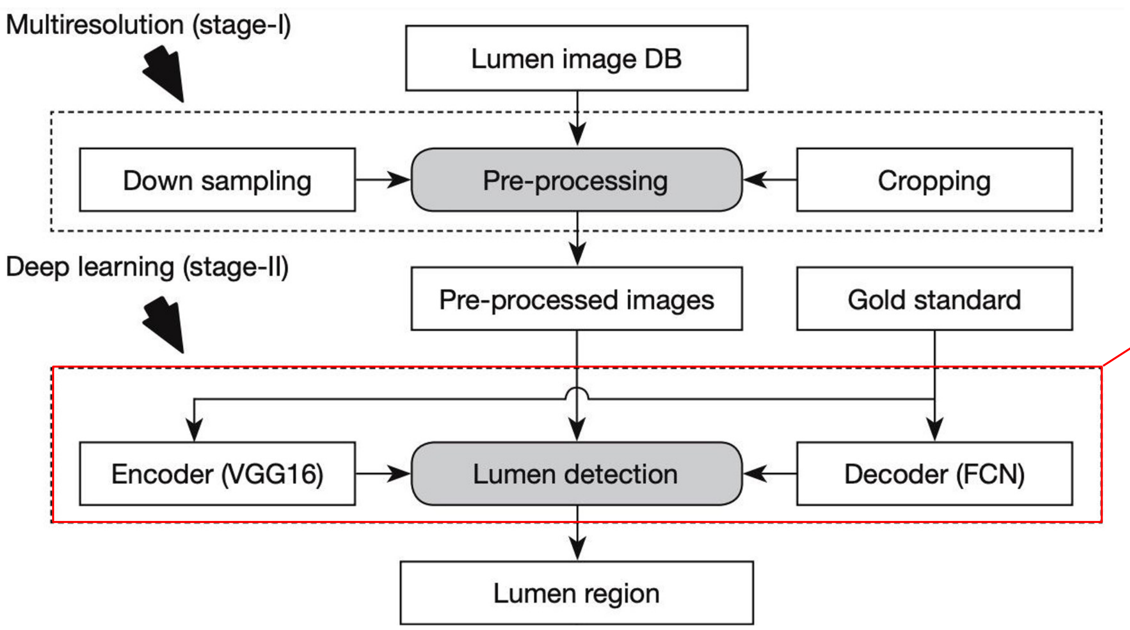
Methodology:Preprocessing

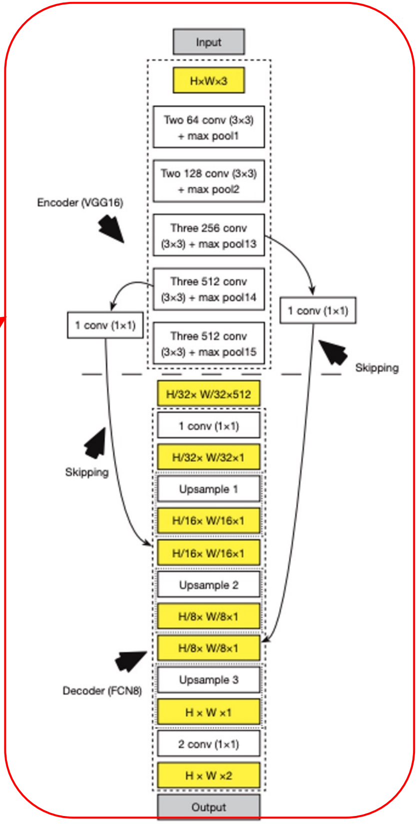
Multi-resolution Pre-processing:

- **Automatic Image Cropping:** To remove unwanted parts and text from both lumen image and the ground truth.
- **Lumen Binarization:** To extract the binary lumen region from the ground truth.
- **Image Cleaning:** To remove noise generated during image acquisition.
- **Image downsampling:** To reduce the computational time.



Methodology





- Segmentation: **VGG16** architecture for encoder + FCN with up-sampling for decoder

10-fold cross-validation

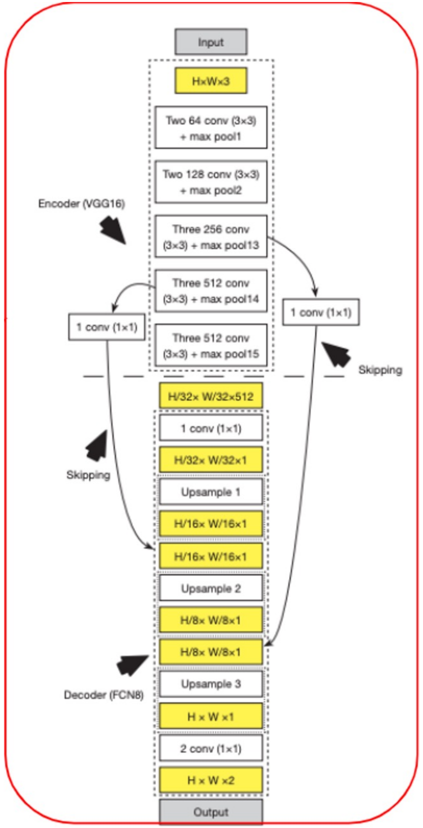
Methodology

Encoder:

- **VGG 16 Pre-trained model:** 13 convolution layers, 5 max pooling layers to extract features from the images.
- **Activation Function:** ReLU for faster training and avoiding the vanishing gradient issue.
- **Weights:** initialized using the pretrained VGG16 weights on ImageNet.

Decoder:

- **3 upsampling layers** of FCN for lumen segmentation.
- **2 Skip connections** to recover the spatial resolution in the output.
- **50% dropout** strategy is used to avoid overfitting.

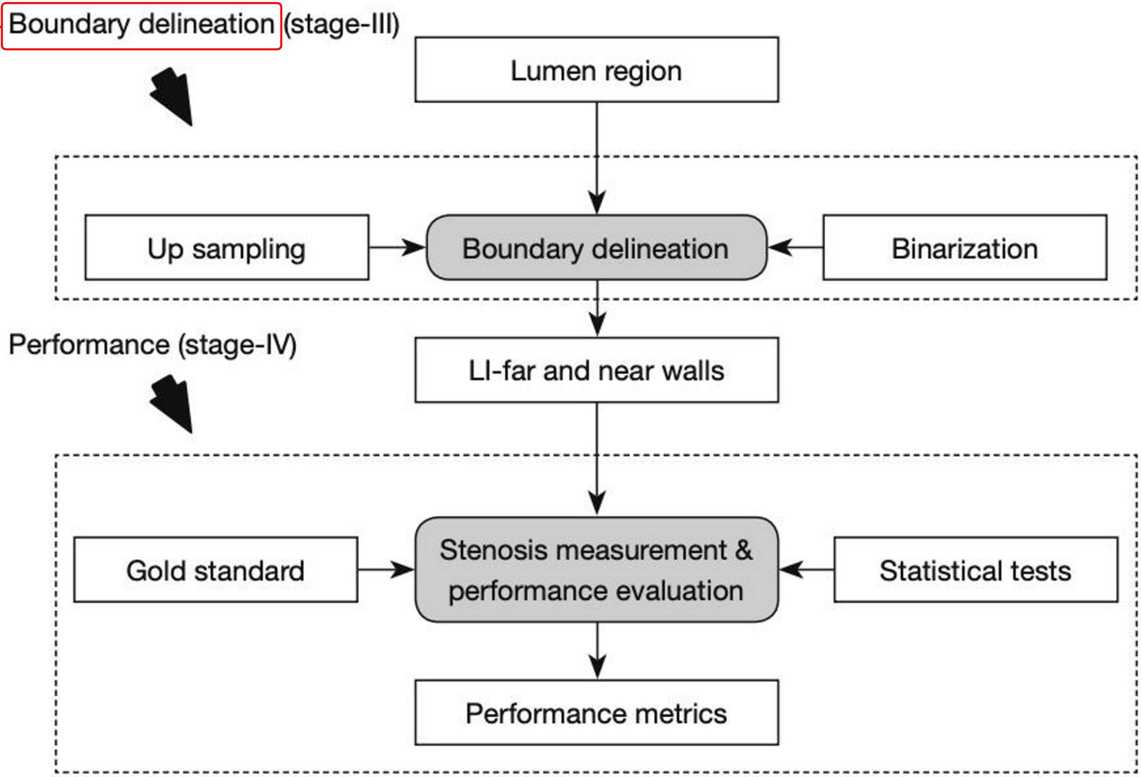


10-fold cross-validation

Methodology

LI-far and LI-near border extraction from the segmentation

LI: lumen intima



Methodology

Stenosis Severity Index (SSI) calculation:

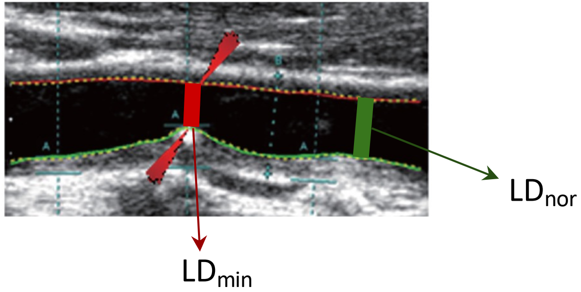
- The **lumen diameter** (**LD**) is calculated from LI-far and LI-near extracted borders using the **polyline distance metric** (**PDM**).

$$LD\,(i) = D_{PDM}(LI_{far}(i) : LI_{near}(i))$$

- SSI is calculated according to the **NASCET criteria***.

$$\mathrm{SSI}(\%) = \left(1 - \frac{LD_{\min}}{LD_{nor}}\right) \times 100\%$$

where **LD_{min}** and **LD_{nor}** are the minimum and normal lumen diameters in the image.



Risk stratification:

- From the SSI, the **risk of cerebrovascular events** can be assessed.

- According to the SSI value, a class can be assigned
  - low risk if *SSI* < 25 %
  - moderate risk if 25 < *SSI* < 50 %
  - high risk if *SSI* > 50%

* North American Symptomatic Carotid Endarterectomy Trial

Methodology

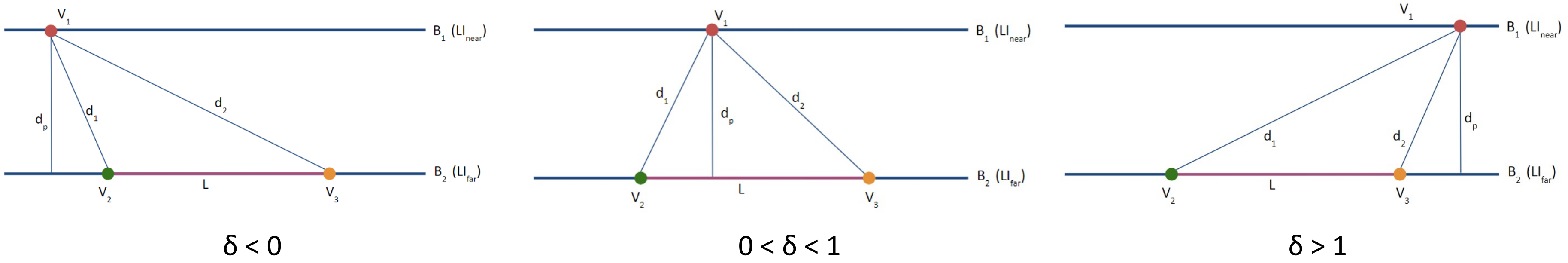
Extra information: How is LD calculated using PDM? (I)

1. $D(V_1, L)$: **polyline distance** between a point in B_1 and a segment in B_2:

$$D(V_1,L)=\begin{cases} |d_p| & 0<\delta<1 \\ min(d_1,d_2) & \delta<0, \delta>1 \end{cases}$$

where δ represents the position of V_1 with respect to L

$$\delta=\frac{(y_3-y_2)(y_1-y_2)+(x_3-x_2)(x_1-x_2)}{(x_3-x_2)^2+(y_3-y_2)^2}$$

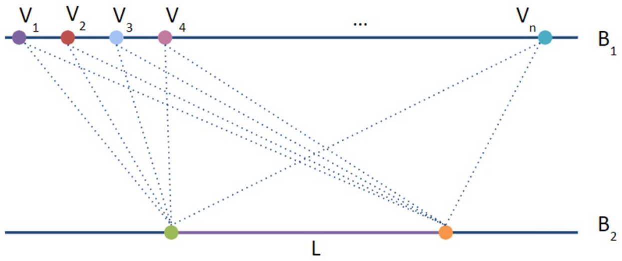


Methodology

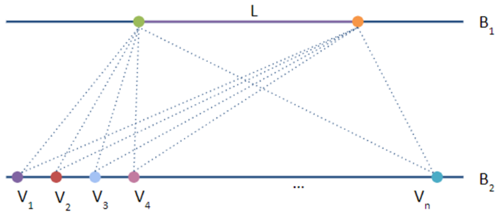
Extra information: How is LD calculated using PDM? (II)

2. Obtain $D(V_i, L)$ for all the points V_i in B_1. The sum of all $D(V_i, L)$ is $\mathbf{D(B_1, B_2)}$.

$$\boxed{D(B_1,B_2)=\sum_{i=1}^{N} D\left(V_i, S_{C_2}\right)}$$



3. Repeat 1 and 2 but setting B_2 as reference boundary and the segment L in B_1 $\rightarrow$ $\mathbf{D(B_2, B_1)}$



4. Obtain the PDM between B_1 and B_2, that finally represents the lumen diameter (LD) .

$$D_{PDM}(B_1 : B_2) = \frac{D(B_1, B_2) + D(B_2, B_1)}{(\#points \in B_1 + \#points \in B_2)} \longrightarrow LD\,(i) = D_{PDM}(LI_{far}(i) : LI_{near}(i))$$

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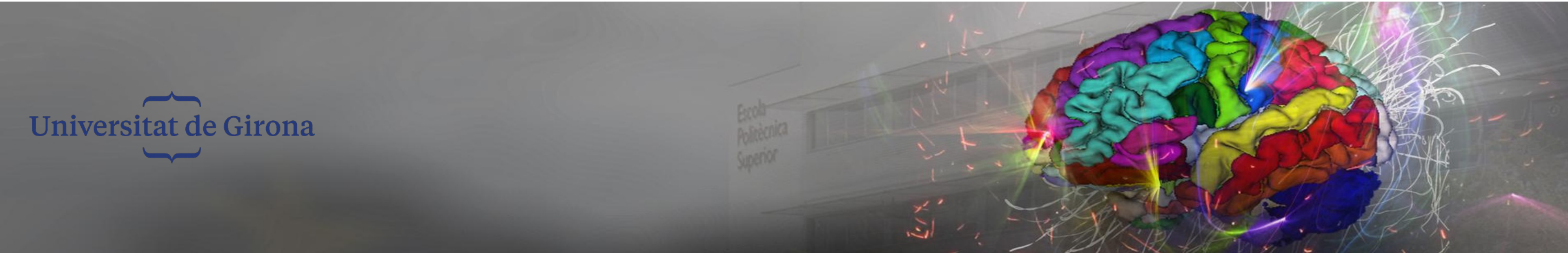
RESULTS



Results

The whole pipeline was evaluated for 3 different sets of ground truth, annotated by 3 different experts.

Quantitative results:

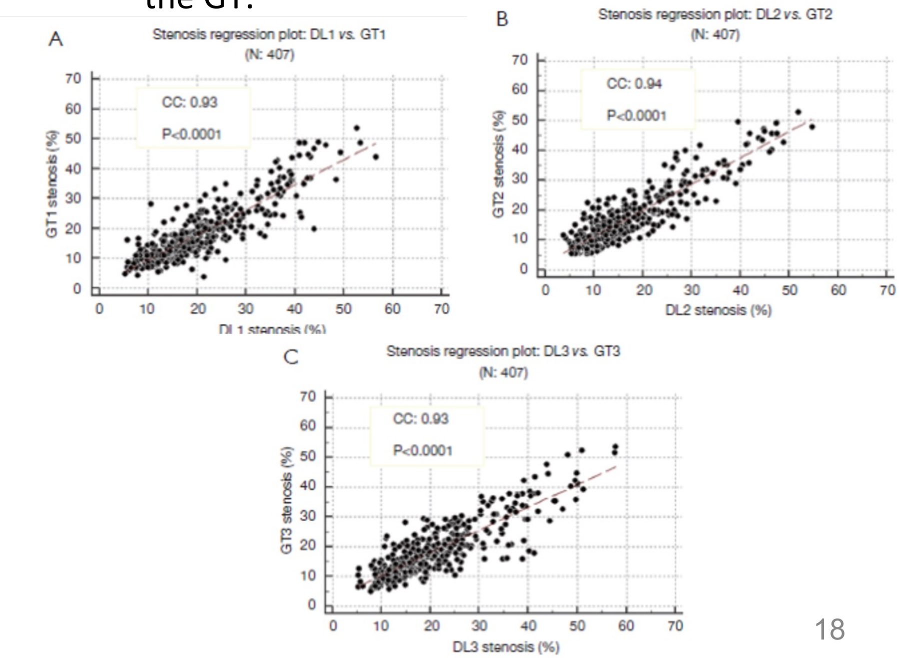
- **Precision-of-merit (PoM)** → evaluation of LD and SSI computation from the segmentation.

$$PoM_{SSI}(\%) = 100\% - \left[\left\{\frac{\sum_{i=1}^{N}\left(\frac{\left|SSI_{dl(i)} - SSI_{gt(i)}\right|}{SSI_{gt(i)}}\right)}{N}\right\} \times 100\%\right]$$

$$PoM_{LD}(\%) = 100\% - \left\{\frac{\sum_{i=1}^{N}\left(\frac{\left|LD_{dl(i)} - LD_{gt(i)}\right|}{LD_{gt(i)}}\right)}{N}\right\} \times 100\%$$

	GT_1	GT_2	GT_3
PoM (LD) (%)	96.71	96.09	96.4
PoM (SSI) (%)	96.71	96.1	96.40
$r_{SSI\_predicted,\ SSI\_gt}$	0.93	0.94	0.93

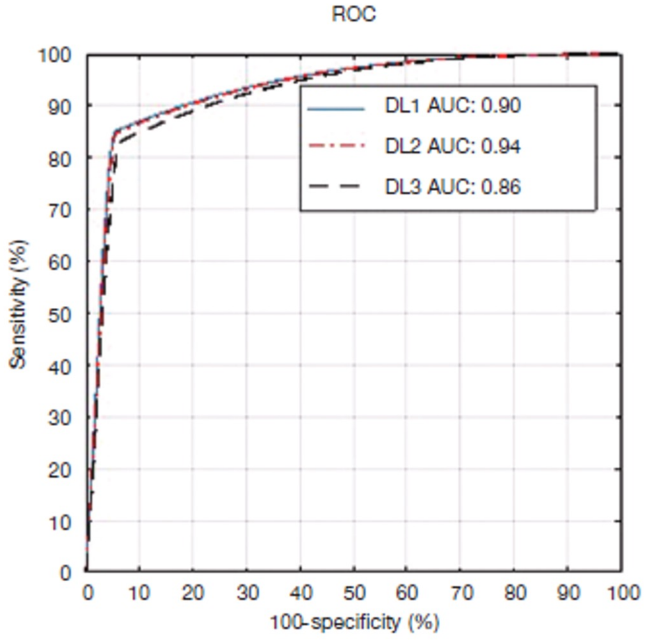
- Correlation between the obtained stenosis severity index (SSI) and the calculated from the GT.



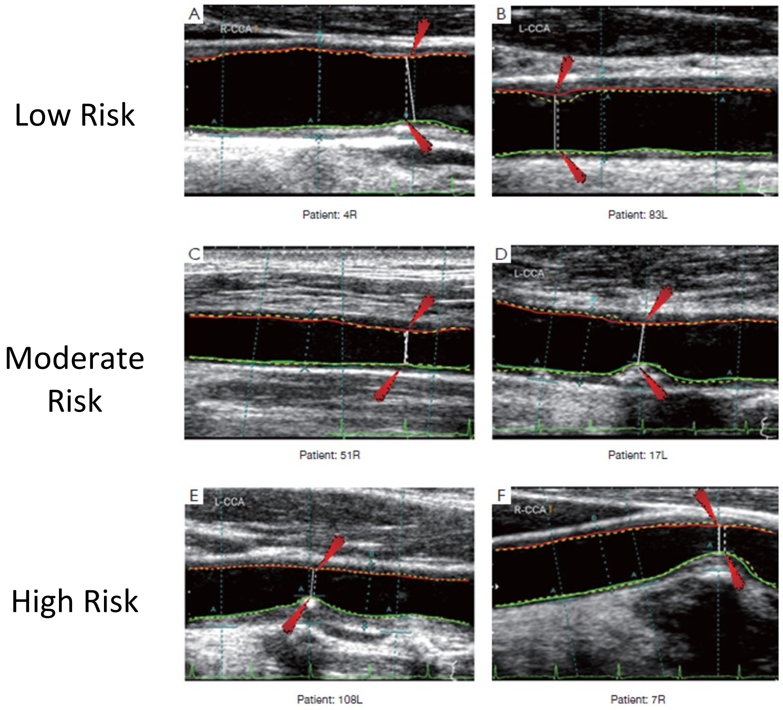
Results

The whole pipeline was evaluated for 3 different sets of ground truth, annotated by 3 different experts.

- **ROC analysis of risk characterization**: 3 classes (low risk, moderate risk, high risk).



Qualitative results



Conclusion

- This is the first Deep Learning based framework used for detecting lumen region and determining lumen diameter for stenosis detection from the Ultrasound Image.
- The presented Deep Learning system provided a stable performance in the inter-operator variability test, outperforming the traditional method.
- However, it requires a greater number of iteration during training phase for the better performance and the minimal error.
- In the scope of future work, other Deep Learning frameworks (e.g., U-Net, nnU-Net) can be used for lumen segmentation.
- In addition, other techniques such transformer-based approaches can be used in the future to tackle this challenge.

To know more…

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Q&A