Prediction of Heart Failure Incidence through Pectoralis Muscle Quality: Semantic Segmentation in Chest Computed Tomography

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1. Introduction

- Deep Learning, specifically computer vision, can be applied to image-based analysis to segment regions of interest.
- We hypothesized that the use of deep learning derived pectoralis muscle measurements (IMAT) and its subcomponents (PAT and EML) can be used to predict incident heart failure when combined with MRI measurements of heart function and clinical data.

2. Methods

- We developed an automated pipeline for extraction of the pectoralis muscle and subcutaneous adipose tissue at the CT section immediately above the aortic arch.
- We applied semantic segmentation through Pixellib and Mask R-CNN to provide high-throughput, reproducible measurements of the SAT, PMAT, IMAT, PAT, and EML that have a strong correlation with manual measurements.

3. Results

- Higher IMAT and PAT indices were associated with a higher risk of incident heart failure within a population-based multiethnic cohort of participants in crude and stepwise, adjusted models.
- Analyses repeated using raw area (cm^2) measurements instead of indexed measurements revealed similar associations, with fully adjusted models conferring a 5% (IMAT) and 8% (PAT) increased risk of incident heart failure with every 1 cm^2 increase.

4. Discussion

- The ability to use IMAT and PAT indices as a predictor of incident heart failure is significant not only as a prognostic variable for improving risk prediction models, but it is also potentially useful in monitoring at-risk individuals.
- The study is limited in that it does not validate the findings outside the MESA cohort as well as consists of few (n=44) eligible events.

Figure 1

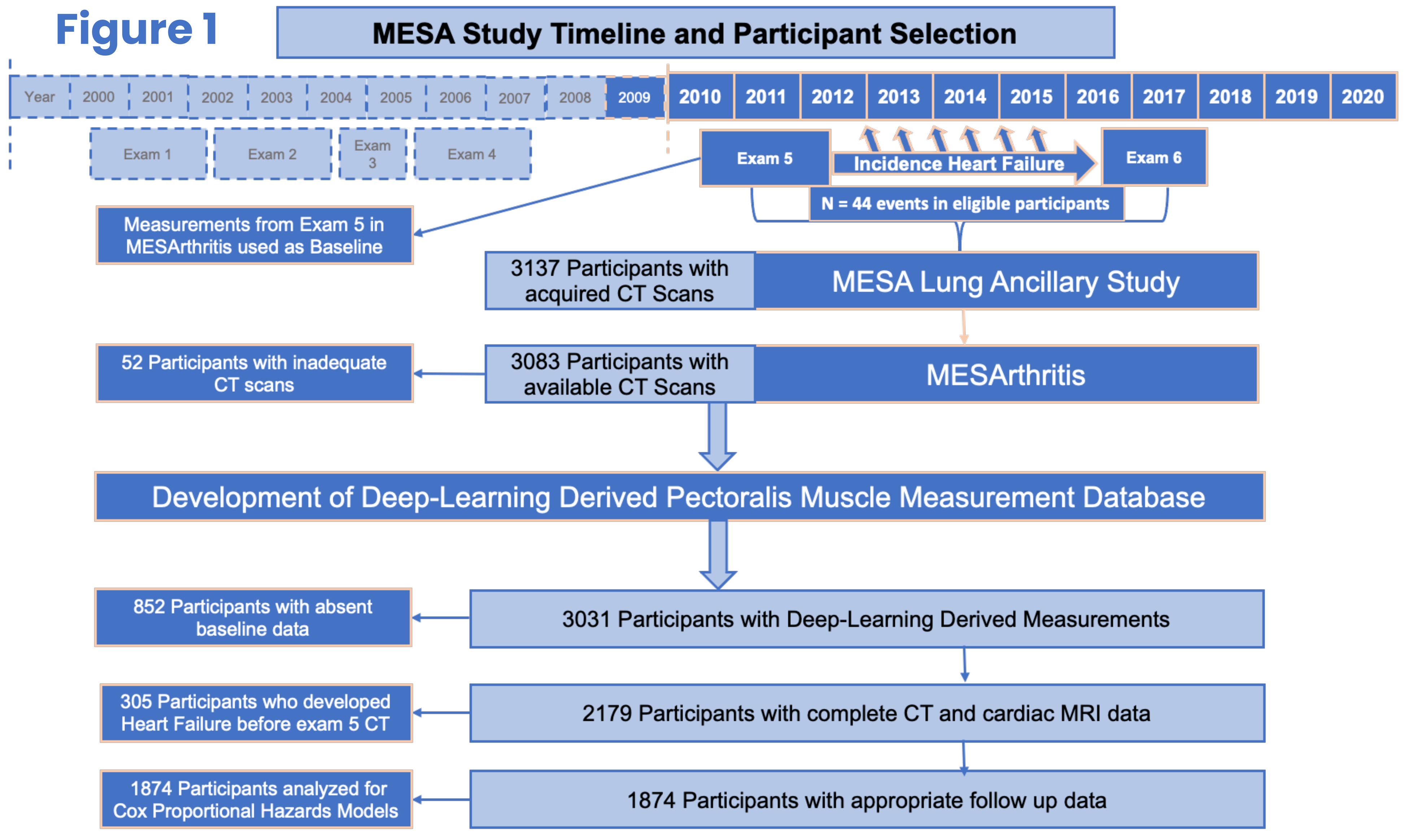

Figure 1: Overview of participants in the Multi-Ethnic Study of Atherosclerosis (MESA), including the inclusion and exclusion criteria.

LEGEND

SAT = Subcutaneous Adipose Tissue
PMAT = Pectoralis Muscle Area
IMAT = Intermuscular Adipose Tissue
PAT = Perimuscular Adipose Tissue
EML = Extramyocellular Lipids

Figure 2: Automated Selection of images above the aortic arch using pixel intensities of the mediastinum

Figure 2

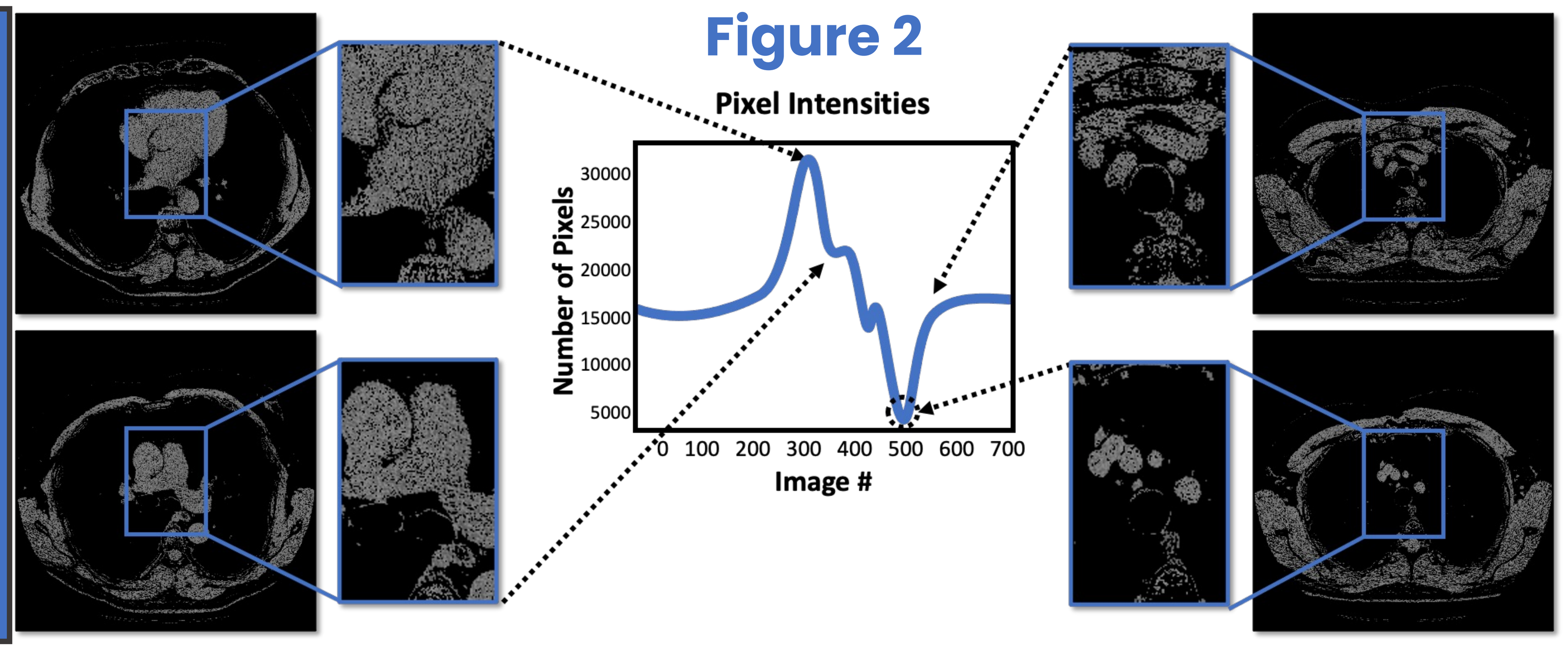

Table 1: Dice similarity coefficient and over intersection over union for manual measurements (n=240) versus the automated segmentation in the holdout testing group. Scores are also presented for individual segmented regions

Table 1: Intersection Over Union and Dice Similarity Coefficients of our Deep-Learning Model	
Intersection Over Union (95% Confidence Interval)	Dice Similarity Coefficient (95% Confidence Interval)
Overall	
0.822 (0.815, 0.829)	0.901 (0.895, 0.906)
Left Pectoralis Muscle	
0.789 (0.780, 0.798)	0.879 (0.871, 0.886)
Right Pectoralis Muscle	
0.789 (0.780, 0. 798)	0.879 (0.871, 0.887)
Subcutaneous Adipose Tissue	
0.750 (0.738, 0.763)	0.851 (0.840, 0.861)

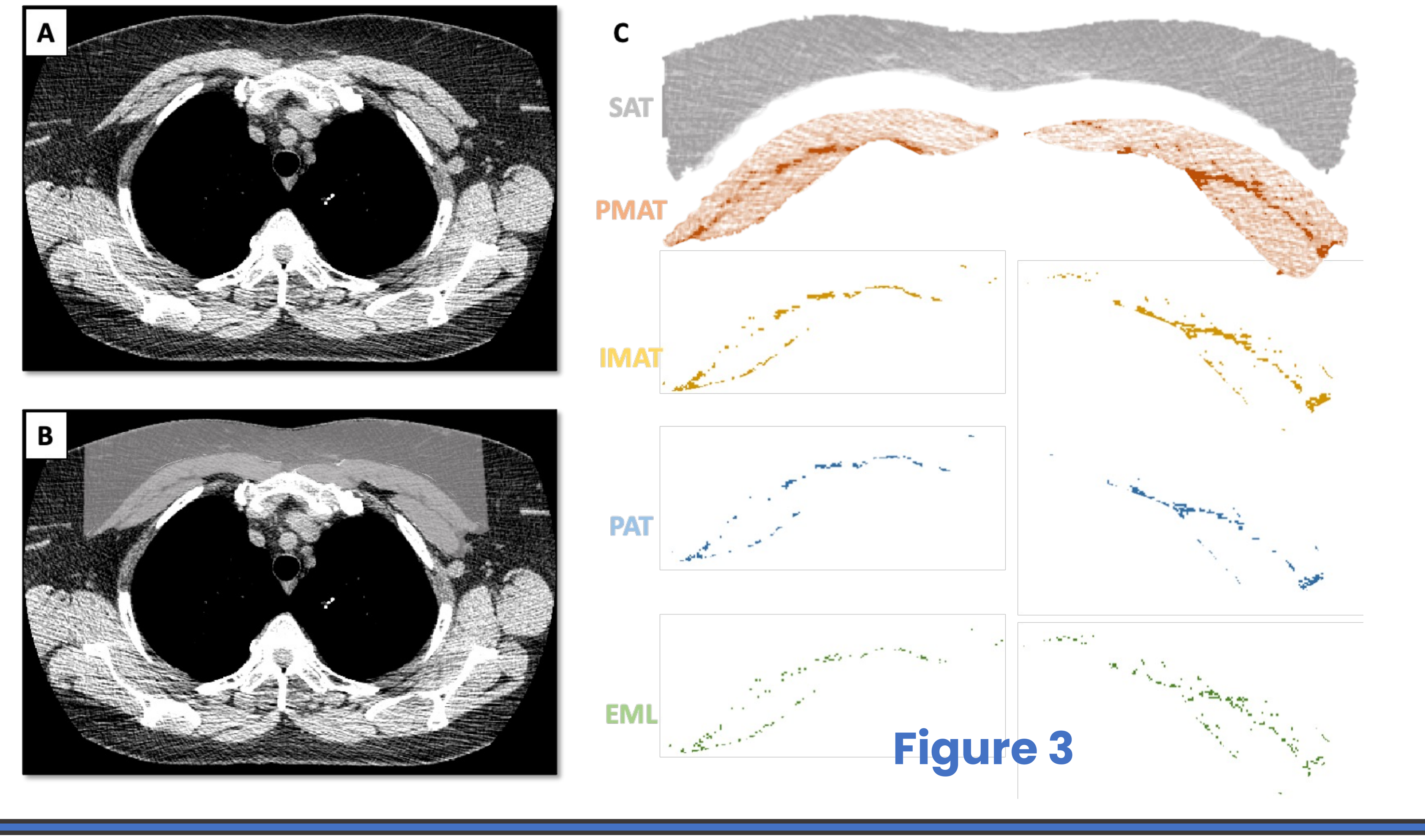

Figure 3: Semantic segmentation schematic. (**A**) Original CT frame directly above the aortic arch with 350W:50L windowing. (**B**) Mask R-CNN segmentation. (**C**) Separation of SAT and PMAT. Adipose within the PMAT is determined by thresholding of pixel values.

Table 2: Cox Proportional Hazard Models using Pectoralis Muscle Indices to predict Incident Heart Failure

	Crude Models[1]		Demographic[2]		Clinical[3]	
Muscle Parameter	Hazard Ratio (95% Confidence Interval)	p-value	Hazard Ratio (95% Confidence Interval)	p-value	Hazard Ratio (95% Confidence Interval)	p-value
Pectoralis Muscle Index[6]	0.97 [0.92, 1.03]	0.360	0.99 [0.93, 1.06]	0.785	0.98 [0.92, 1.05]	0.590
Intermuscular Fat Index[7]	**1.13 [1.02, 1.26]**	**0.017**	**1.15 [1.03, 1.29]**	**0.013**	**1.13 [1.00, 1.26]**	**0.044**
Extramyocellular Fat Index[8]	1.40 [0.94, 2.09]	0.100	1.44 [0.95, 2.19]	0.089	1.31 [0.85, 2.01]	0.220
Perimuscular Fat Area Index[9]	**1.18 [1.04, 1.34]**	**0.009**	**1.22 [1.06, 1.40]**	**0.006**	**1.19 [1.03, 1.38]**	**0.021**
Subcutaneous Fat Index[10]	0.99 [0.97, 1.02]	0.634	1.01 [0.98, 1.04]	0.600	0.99 [0.96, 1.03]	0.754
	Partial Imaging (CAC score)[4]		**Full Imaging (CAC score + cardiac MRI)[5]**			
Pectoralis Muscle Index[6]	0.98 [0.92, 1.05]	0.607	0.97 [0.91, 1.04]	0.391		
Intermuscular Fat Index[7]	**1.12 [1.00, 1.26]**	**0.048**	**1.15 [1.03, 1.29]**	**0.017**		
Extramyocellular Fat Index[8]	1.30 [0.85, 1.99]	0.233	1.39 [0.91, 2.12]	0.130		
Perimuscular Fat Area Index[9]	**1.19]1.02, 1.39]**	**0.023**	**1.23 [1.06, 1.42]**	**0.006**		
Subcutaneous Fat Index[10]	1.00 [0.96, 1.03]	0.791	1.01 [0.97, 1.04]	0.717		

[1]Unadjusted Models
[2]Adjusted for Age, Race, and Sex
[3]Adjusted for Age, Race, Sex, Smoking Status, Hypertension, Hemoglobin A1C (%), Creatinine (mg/dl, and Moderate to Vigorous Physical Activity (MET-min/week)
[4]Adjusted for Age, Race, Sex, Smoking Status, Hypertension, Hemoglobin A1C (%), Creatinine (mg/dl, Moderate to Vigorous Physical Activity (MET-min/week) and log (Phantom Adjusted Total Agatston Calcium Score)
[5]Adjusted for Age, Race, Sex, Smoking Status, Hypertension, Hemoglobin A1C (%), Creatinine (mg/dl, Moderate to Vigorous Physical Activity (MET-min/week) and log (Phantom Adjusted Total Agatston Calcium Score), and Left Ventricular Mass Percentage of Predicted
[6]Pectoralis Muscle Area (cm^2) by Height(m^2)
[7]Intermuscular Fat Area (cm^2) by Height(m^2)
[8]Exyramyocellular Fat Area (cm^2) by Height(m^2)
[9]Perimuscular Fat Area (cm^2) by Height(m^2)
[10]Subcutaneous Fat Area (cm^2) by Height(m^2)

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