Machine learning-based prediction of contrast enhancement in transcatheter aortic valve replacement CT

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INTRODUCTION

Achieving appropriate image contrast in transcatheter aortic valve replacement (TAVR) CT is complicated by the two-step scanning protocol, broken into an ECG-gated thoracic acquisition and a non-gated abdominal acquisition.

Additionally, a relatively large fraction of TAVR patients have reduced kidney function, posing concerns about large contrast dosages[1].

This work presents a novel machine learning-based approach to predict contrast enhancement in TAVR CT.

AIM

To predict contrast enhancement in TAVR CT using machine learning with patient information and acquisition parameters known *a priori*.

METHOD

Model architecture: two sequential neural networks were built using the TensorFlow framework:

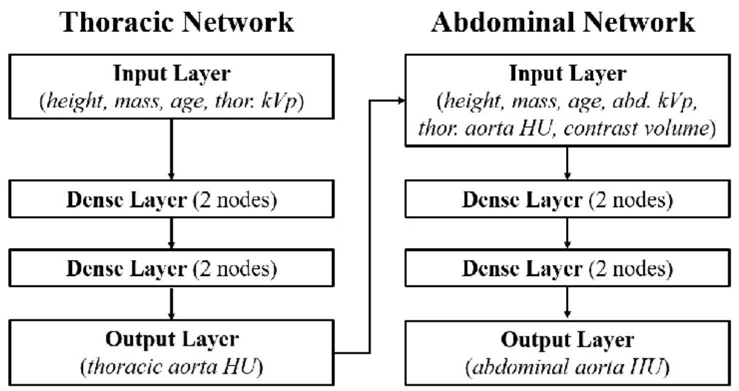

Figure 1: Diagram of neural network architecture. thor. = thoracic, abd. = abdominal.

Datasets: 212 retrospective exams:
- 64% training
- 16% validation
- 20% test

Training/testing labels: mean aortic enhancement in ROIs drawn:
- near the aortic root (thoracic network)
- in the abdominal aorta (abdominal network)

Training loss metric: mean squared error (MSE)

Overall performance metric: mean absolute error (MAE)

RESULTS

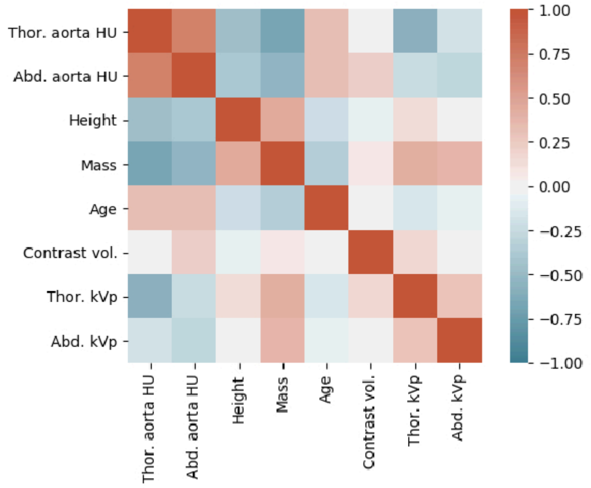

Figure 2: Correlation heat map of patient and acquisition parameters. A range of patient-specific parameters were initially considered as inputs, but only those that more highly correlated with aortic enhancement were ultimately included. Thor. = thoracic, Abd. = abdominal., vol. = volume.

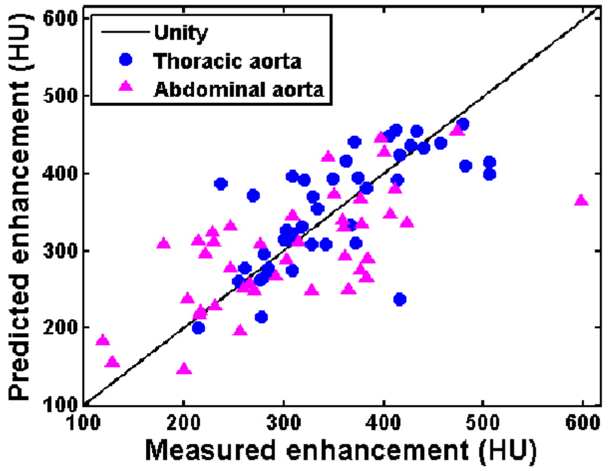

Figure 3: Plot of thoracic and abdominal aortic enhancement predicted for the test dataset as a function of the mean measured aortic enhancement values.

Table 1: Model performance results for training and testing datasets.

Metric	Thoracic aortic enhancement		Abdominal aortic enhancement	
Data	Train	Test	Train	Test
MAE (HU)	41	41	64	54
Error STD (HU)	53	56	83	70
RMSE (HU)	53	56	83	71

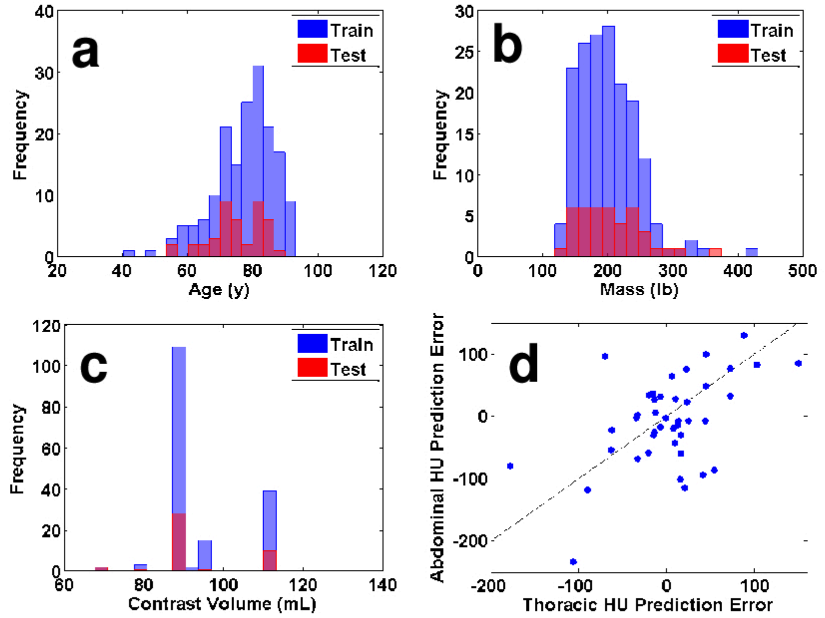

Figure 4: Patient-specific parameter distributions are displayed as histograms for patient age (a), mass (b), and contrast injection volume (c) for training and testing datasets. The correlation between the predicted abdominal and thoracic aortic enhancement in HU is also plotted (d).

Test dataset results:

- The absolute error in predicted thoracic and abdominal aortic enhancement was > 50 HU in 29% (i.e., 12/42) and 45% (i.e., 19/42) of cases, respectively.
- Prediction performance was worse in cases where the test data was not well-represented by the training data: age < 60 years (**Figure 4a**), weight > 350 lb (**Figure 4b**), and contrast injection volume of 70 mL (**Figure 4c**).
- Predicted thoracic aortic enhancement influenced predicted abdominal aortic enhancement (**Figure 4d**). In 8/19 cases, when the error in predicted thoracic HU exceeded 50 HU, the error in predicted abdominal aortic HU similarly exceeded 50 HU.

ONGOING WORK

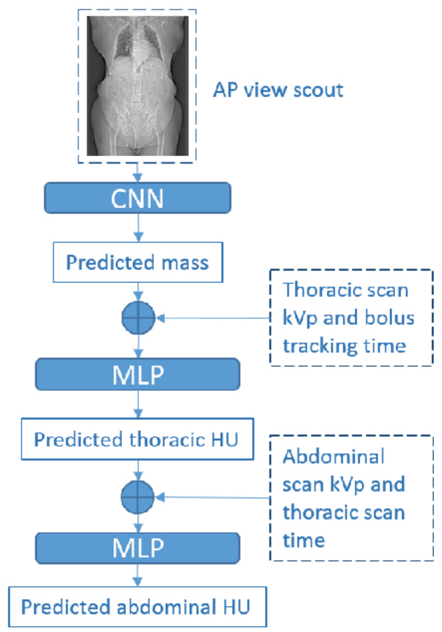

Figure 5: Hybrid deep learning model architecture.

- A hybrid deep learning model is also being developed to predict thoracic and abdominal aortic enhancement in TAVR CT.
- The hybrid model includes both a convolutional neural network (CNN) with an input scout image, and multi-layer perceptrons (MLP) with patient-specific numerical inputs (**Figure 5**).
- Representative test data results are given in **Figure 6**.

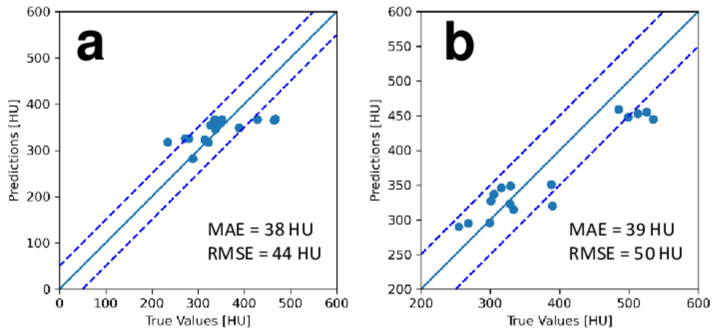

Figure 6: Plots of thoracic (a) and abdominal (b) aortic enhancement predicted for the test dataset as a function of the mean measured aortic enhancement values. The solid line indicates zero prediction error. The dashed lines indicate prediction errors of ±50 HU.

CONCLUSIONS

- The simple, sequential neural networks developed in this work demonstrate promise for predicting contrast enhancement in TAVR CT using retrospective data and information known *a priori.*
- In general, enhancement of the thoracic aorta was predicted more accurately and precisely than enhancement of the abdominal aorta (**Figure 3**).
- The higher MAE and RMSE (**Table 1**) for predicted abdominal aortic enhancement may be attributable to:
  - the dependence of the predicted abdominal aortic HU on the predicted thoracic aortic HU (**Figure 4d**), and
  - increased biological dispersion of the contrast agent in the abdomen.
- Variance in prediction performance may have also been influenced by exclusion of parameters that were not available retrospectively in all cases, but which were likely to impact the observed enhancement (e.g., injection rate).
- Ongoing work is exploring the use scout images as inputs to a hybrid model (**Figure 5**) in order to improve the potential clinical workflow by limiting the amount of patient information that would need to be gathered from sources other than the scanner computer.
- Using prospective data, it is expected that a well-trained neural network could:
  - predict whether TAVR CT images would have appropriate enhancement,
  - identify when additional contrast dosage may be necessary for adequate enhancement, and
  - identify high-contrast exams where contrast dose reduction may be possible.
- This work demonstrates a step towards personalized contrast optimization.

ACKNOWLEDGEMENTS

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REFERENCES

1 **Achenbach S et al**. SCCT expert consensus document on computed tomography imaging before transcatheter aortic valve implantation (TAVI)/transcatheter aortic valve replacement (TAVR). *J Cardiovasc Comput Tomogr 2012; 6: 366-380.*

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