USING DEEP LEARNING AND MACROSCOPIC IMAGING OF PORCINE HEART VALVE LEAFLETS TO PREDICT UNIAXIAL STRESS-STRAIN RESPONSE

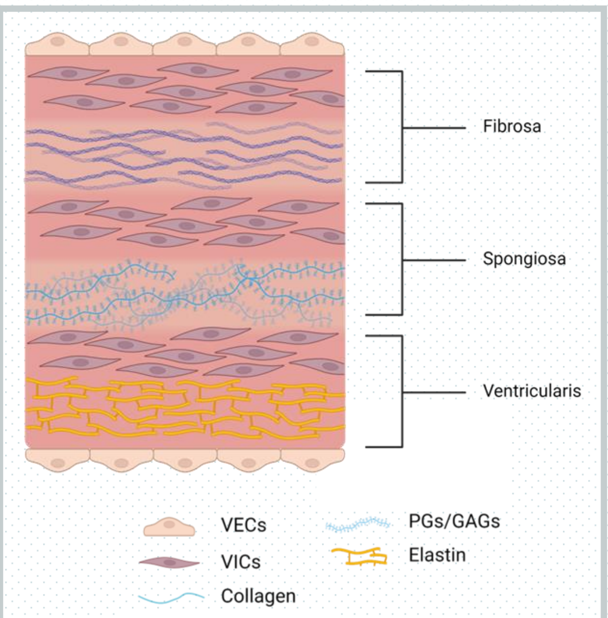
Luis Hector Victor, CJ Barberan, Richard G. Baraniuk, K. Jane Grande-Allen

ABSTRACT

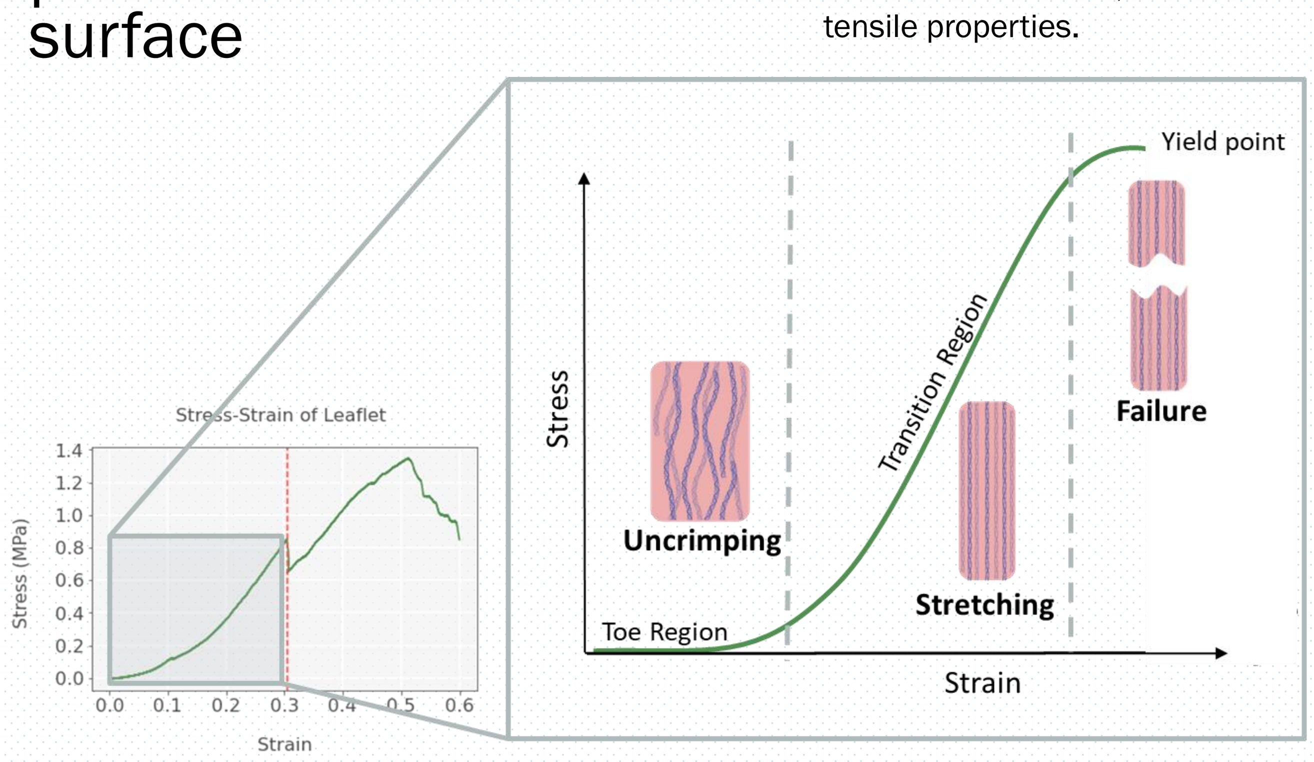
Heart valve leaflets' (HVLs) normal function can degrade due to disease, so it is important to **study leaflet mechanics to better design prostheses.** Mechanical testing is the standard for evaluating mechanical behavior, but a more readily available solution could use imaging and convolutional neural networks (CNNs). In this work, **we curated a dataset and used a CNN to predict the stress-strain response of HVLs.** We obtained good prediction results when using more samples and reconstructed to the toe and linear regions.

INTRO & BACKGROUND

- Treating calcific HV disease requires prostheses and understanding of mechanics
- Mechanics are dominated by collagen fibers in fibrosa
- Collagen in fibrosa can be captured with macroscopic pictures of HVL aortic surface



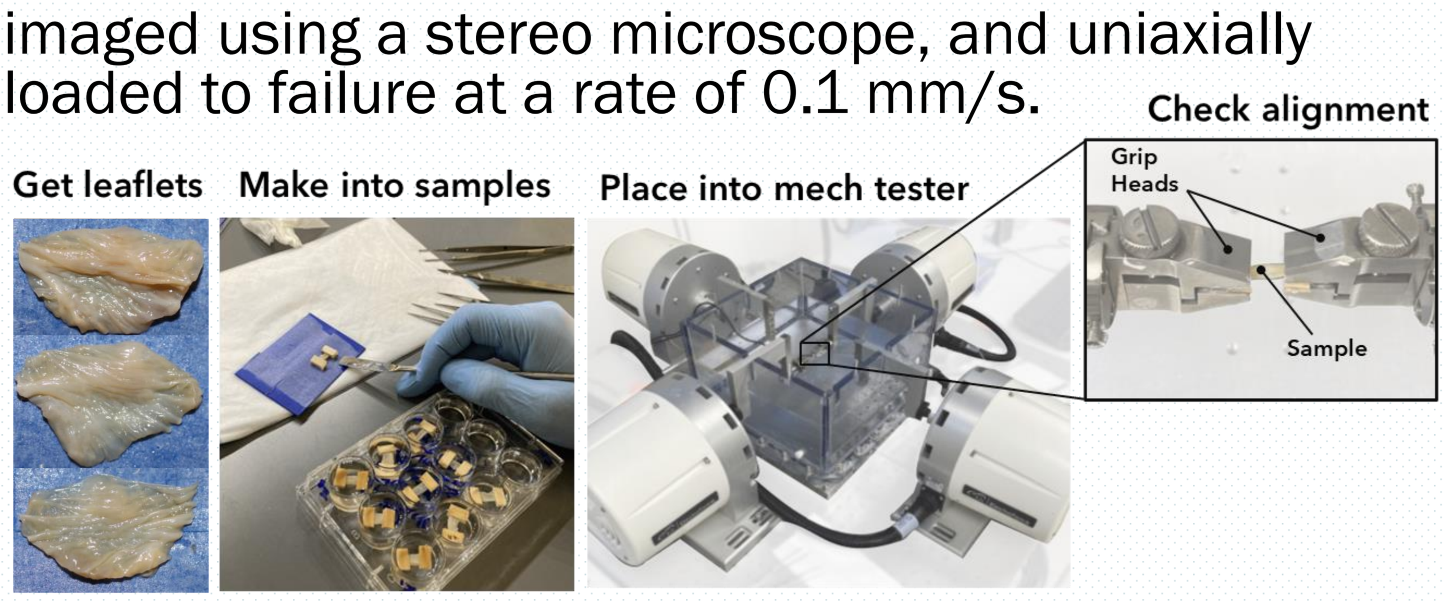
Three layers of HVLs. Each layer contributes to overall mechanics, but fibrosa dominates tensile properties.



Characteristic stress-strain response of HVLs. Behavior consists of a non-linear toe region, a linear transition region, and yield points, where we can see either micro or macro tearing of tissue.

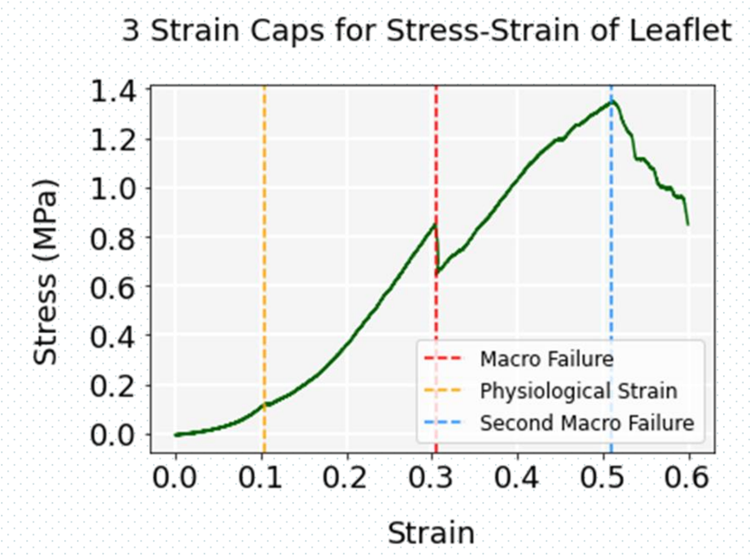
METHODS

MECHANICAL TESTING. 51 samples were prepared, imaged using a stereo microscope, and uniaxially loaded to failure at a rate of 0.1 mm/s.



Data collection. HVLs were first extracted from porcine hearts, fixed with 2% glutaraldehyde, imaged, sectioned along the same axis into rectangular strips, and tested in a water-based salt solution.

CURVE RECONSTRUCTION. $Y = a_1x + a_2x^2 + a_3x^3$, approximates unique stress-strain response to a strain cap per HVL; [a1, a2, a3] vary per sample.



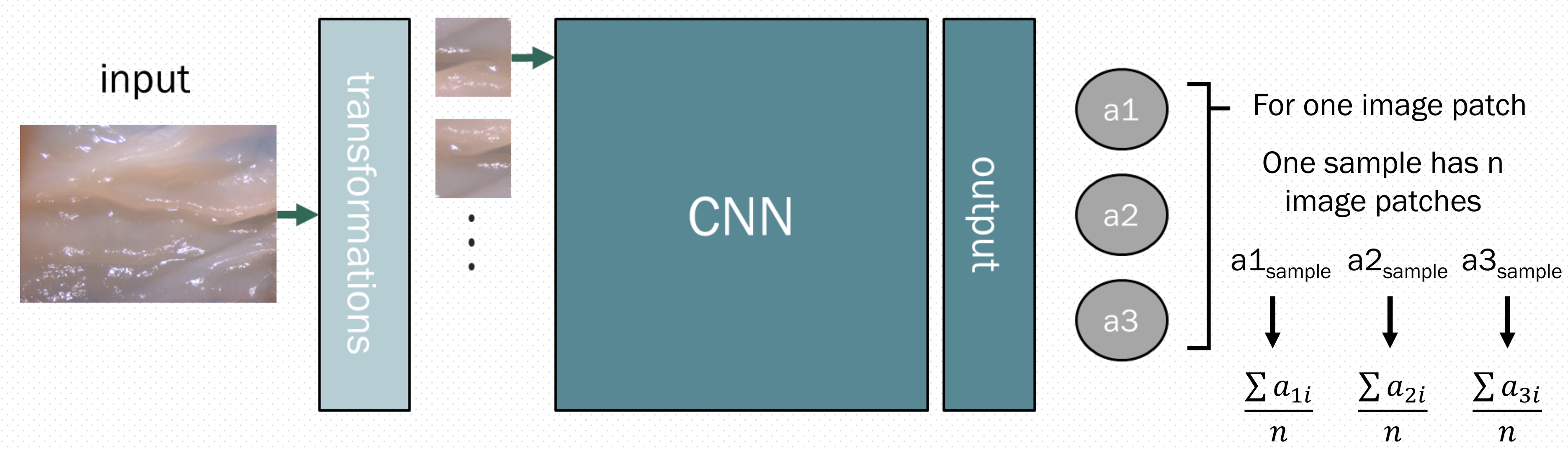
Strain caps. HVL data usually analyzed to physiological strain, typically defined as 10% strain.

METHODS CONT.

COEFFICIENT PREDICTION. A CNN is used to predict a sample's coefficients for stress-strain curve reconstruction. We used and compared the results from Alexnet, VGG11, and Resnet18.

TRAINING. A sample's image is augmented into image patches that share coefficient values.

TESTING. A sample's overall predicted coefficients are taken from the mean of its image patches' coefficient values.



DL framework for predicting stress-strain response from HVL images. An image is taken of a single HVL sample, and this image is transformed into several "image patches". A CNN architecture then predicts the three coefficients for each image patch. To get a single sample's overall coefficients, the mean is taken from its image patches' a1, a2, and a3 values.

THREE EXPERIMENTS.

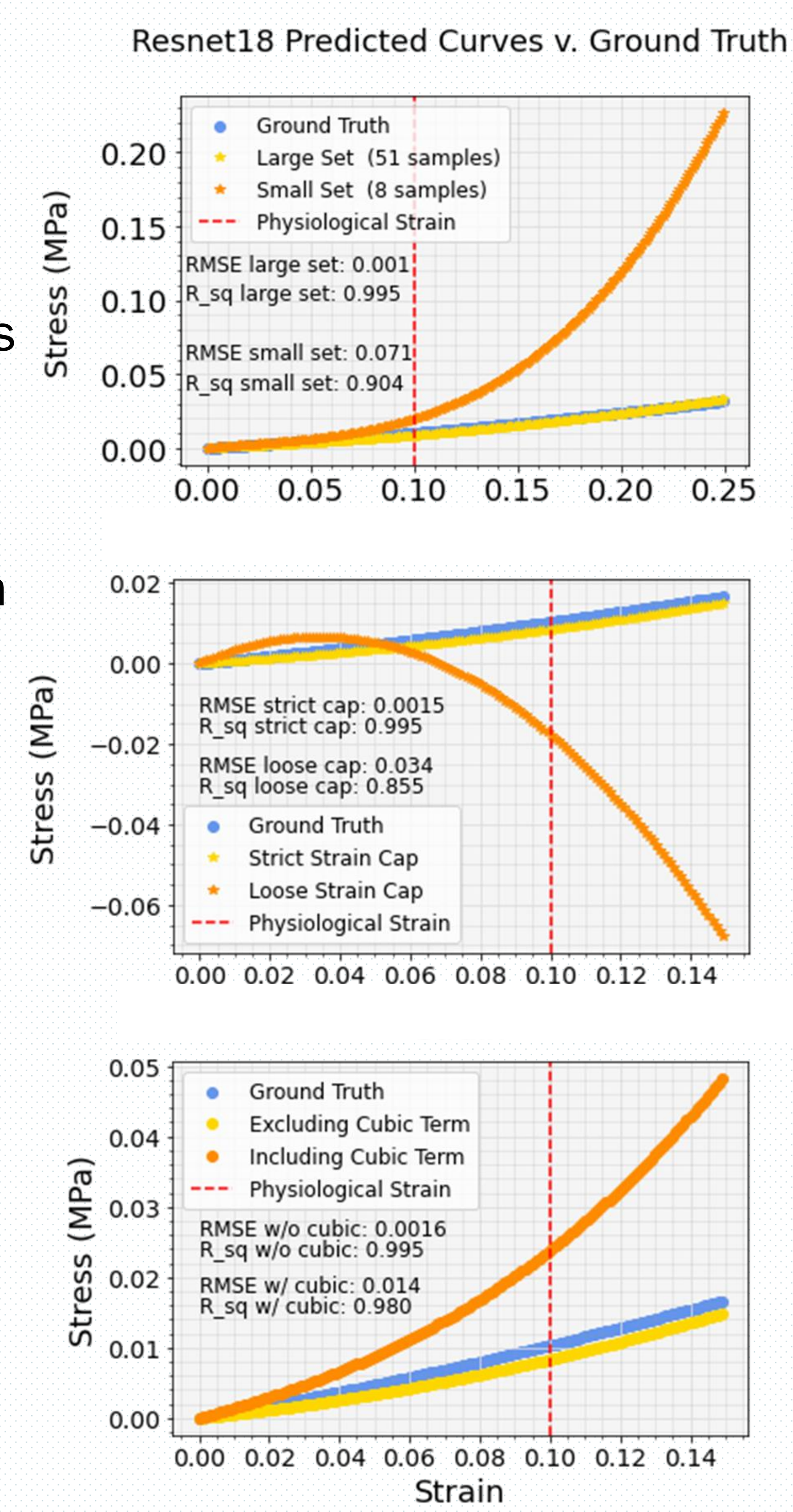
1. Performance when using a few samples, 8, vs. many samples, 51.
2. Performance when different strain caps are considered.
3. Performance when two, not three, coefficients are considered.

RESULTS

1. Performance increases when using more samples
2. Performance increases for lower strain caps. Loose strain cap was hand-picked near yield point.
3. Performance increases when only predicting linear and quadratic terms since cubic term has high variability.

Test MAE by CNN architecture and strain cap. Test MAE is smallest at lower strain caps.

Architecture	Ground Truth Threshold – Strain %	Test MAE
Alexnet	5	2.40
VGG11	5	1.98
Resnet18	5	**1.83**
Alexnet	10	3.99
VGG11	10	**3.66**
Resnet18	10	3.81
Alexnet	15	6.97
VGG11	15	**5.34**
Resnet18	15	6.64
Alexnet	Loose	8.37
VGG11	Loose	8.36
Resnet18	Loose	**7.90**



Results from experiments 1, 2, 3 for one sample. Test MAE is smallest at lower strain caps.

CONCLUSION

CNNs can accurately predict the linear and quadratic terms for reconstructing an individual sample's stress-strain response from macroscopic imaging of their aortic surface.

ACKNOWLEDGEMENTS

NIH 3UL1TR003167 - 03W1

NEURAL INFORMATION PROCESSING SYSTEMS

LXAI

GRANDE-ALLEN LAB