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Machine Learning Prediction of Tissue Strength and Local Rupture Risk in Ascending Thoracic Aortic Aneurysms

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Abstract: A Multi-layer Perceptron (MLP) neural network model [1] is developed to predict the strength of ascending thoracic aortic aneurysm (ATAA) tissues using tension-strain data and assess local rupture risk. The data were collected through *in vitro* inflation tests on ATAA samples from 12 patients who underwent surgical intervention [2]. An inverse stress analysis was performed to compute the wall tension at Gauss points. Some of these Gauss points are at or near sites where the samples eventually ruptured, while others are at locations where the tissue remained intact. A total of 27,648 tension- strain curves, including 26,676 2223 nonrupture and 972 rupture were garnered and each fitted to a third order NURBS function with 3 knot intervals. A typical fitted curve is shown in Fig. 1, which has a J-shape with a compliant elastin-dominated region at the low strain range, a transition phase in the middle, and a stiff collagen-dominated region at the high strain end. Eight features associated with the low strain region response are extracted: the tension, strain, slope and curvature at the maximum curvature point and a transition point (Figure 1). These features are subsequently fed to the machine learning model.

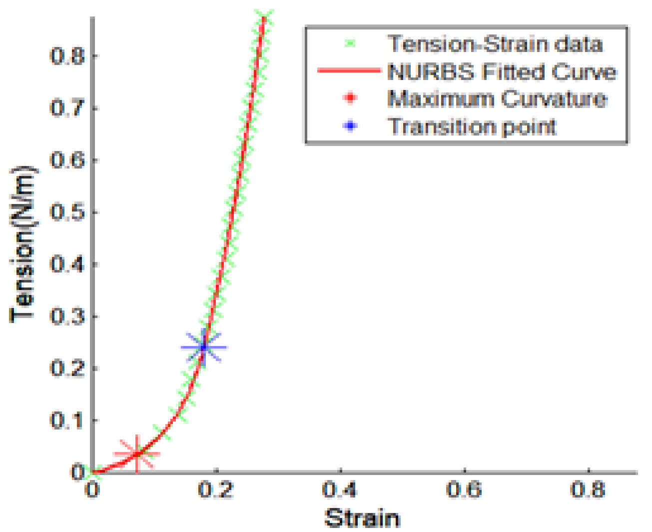

Figure 1. ATAA tension strain curve

As a first step, the model is trained using data in the rupture group. A 12-fold cross-validation method is employed. Specifically, among all 12 samples, the model is repeatedly trained using data from 11 samples and tested on the one left. Fig. 2 shows the predicted rupture tension vs actual rupture tension. As we can see from the figure, the strength is well predicted. The average mean absolute error (AMAE) and average cross-validation R^2 score are 0.096 and 0.954, respectively.

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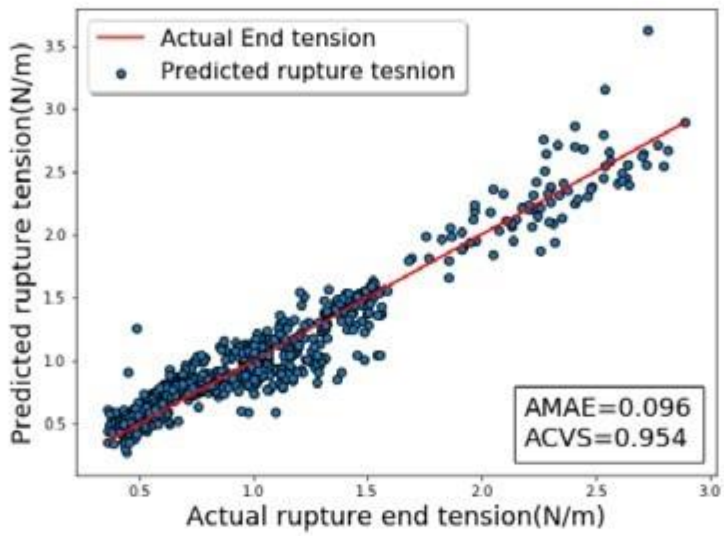

Figure 2. training dataset performan

The results above confirm the feasibility of predicting the ATAA tissue strength using pre-rupture responses features extracted from the tension-strain curves. To further validate the model, we use the same protocol to train the model; however, the trained model is applied to all curves in both rupture and nonrupture groups in each sample. Fig. 3(a) shows the predicted strength versus the end tension in all curves. The results are evaluated from two perspectives. First, within the non-rupture group, we consider a strength prediction greater than the end tension as a positive prediction (PP), otherwise a negative prediction (NP), The positive predictions account for around 86 % for all samples (Fig. 3(b)), indicating that the model is reasonably trustworthy in terms of PP output. Secondly, a local rupture risk factor, which is the ratio of the end tension to the predicted rupture tension, is defined. The risk factor distribution and the actual rupture image for each sample are compared and presented in Fig. 4 (only 10 samples showed due to the page limit). A purple square is used to mark the 'hot spot' (regions of peak risk factor) and the location of the onset of rupture. samples). These two spots match generally well in 10 samples (including two unshown samples). For sample 6 (the first one on rows 3 and 4), there are two 'hot spots' and one matches with the rupture location. For sample 2, the hot spot does not closely match the rupture site. However, this sample bears a V-shape crack in the proximity of the boundary. It is unclear where exactly the crack initiates, and also, it is possible that rupture is caused by fixture. In sum, these examinations further validate the model and demonstrate the promise of predicting local rupture propensity.

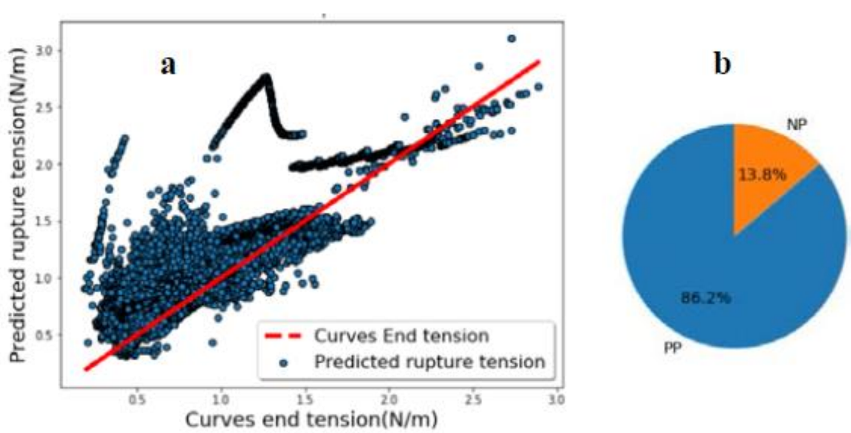

Figure 3. Predicted strength and percentage distribution

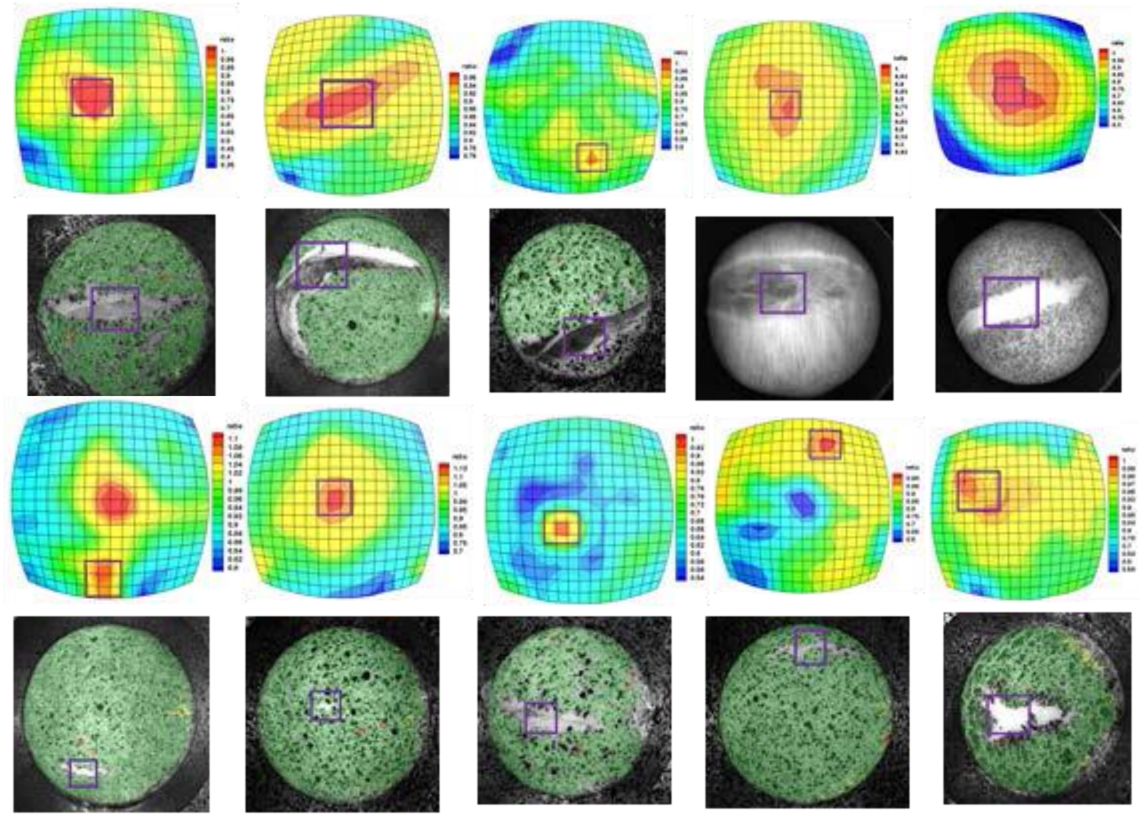

Figure 4. Risk factor distribution and the actual rupture image

Keywords: ATAA; machine learning; strength; rupture

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