AORTIC CALCIFICATIONS LOCALLY AFFECT DISSECTION BEHAVIOR

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Introduction

Acute aortic dissection (AAD) is a life-threatening condition in which a tear propagates through the wall of the aorta. Nearly 18% of AAD patients die before reaching the hospital, and 63% die within 30 days[1]. Improving patient outcomes from these potentially lethal events is largely dependent on screening high-risk patients. Aortic calcification is one of the most prevalent comorbidities of AAD[2]. A recent study found that the nearest calcification was on or slightly distal to the initiating intimal tear in over 60% of ADDs[2], suggesting a local effect on the aorta's propensity for dissection. However, the local mechanics remain unknown. This study correlates calcification locations from micro-CTs (μCT) to local peel tensions to assess the hypothesis that calcifications have a local effect on delamination of the aorta.

Methods

Sample Preparation: Samples were cut from three human cadaveric aortas (73F, 75M, 86F, Anatomy Bequest Program, U of Minnesota). Twenty-two (22) samples were identified as thoracic aorta samples with a μCT-detected calcification. **μCT Analysis:** Samples were scanned with an average resolution of 95.5 μm (NSI, Rogers, MN). Image analysis was performed using MATLAB (Fig. 1A). All calcified samples were computationally segmented into three regions: 1) >2mm before the calcification (control), 2) <2mm before the calcification, and 3) a calcification region starting at the calcification front and extending 2mm distal to the lesion. **Peel Testing:** Medial incisions were made to initiate peel propagation. Both "arms" of the incised sample were clamped, loaded onto a uniaxial testing machine (MTS, Eden Prairie, MN) equipped with 10N load cells, and pulled at 10 mm/s (Fig. 1B). Peel tension was defined as peel force divided by the sample width.

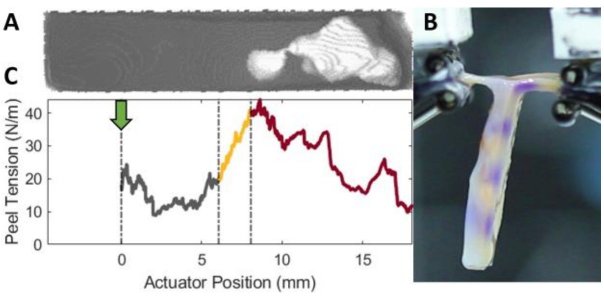

Figure 1: A) 3D rendering of μCT scan showing vessel wall (grey) and calcification (white). B) Peel Test. C) Local peel tension (start marked by green arrow) mapped to its location within the sample shown above. The curvature is divided into regions: >2mm before the calcification (grey), <2mm before the calcification (gold), and on the calcification (maroon).

Results

Peel tension behavior varied across sample regions (Fig. 1C). Fig. 2 shows the average minima, maxima, means, standard deviation (σ, used as a measure of mechanical heterogeneity), and slopes (calculated by fitting a linear model to tension vs. displacement) for each region. The difference between the minima for region 2 and regions 1 and 3 were significant (p=0.0049 and p=0.0104, respectively), demonstrating a rise in the minimum peel tension approaching a calcification and a drop in tension adjacent to a calcification. The calcified regions were the most heterogeneous, significantly different from region 2 (p=0.0196). Slopes varied greatly, but tended to be positive before calcifications and negative in calcified regions with significant differences between regions 1 and 3 (p = 0.0089).

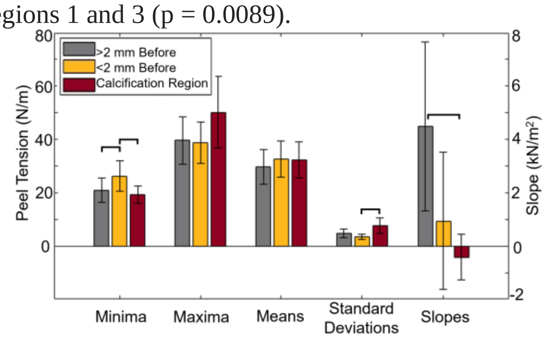

Figure 2: Average regional minima, maxima, means, and standard deviations for peel tension (N/m), and slopes (kN/m^2). Error bars are 95% confidence intervals. Significant differences ($p < 0.05$) are indicated with brackets.

Discussion

The results demonstrate that aortic calcifications have a local effect on dissection. In general, the peel tension of samples with calcifications exhibited a "rise and fall" trend, captured by the rise and fall of the local minima, increase in the local heterogeneity, and the slopes turning from positive to negative when the peel front hits the calcified region (Fig. 2). This behavior suggests that calcifications might be initially protective against peel propagation but result in more brittle failure events when the local yield strength is exceeded. This study is, to our knowledge, the first to correlate media peel mechanics to CT imaging, a routine modality for clinical monitoring/diagnostics, and thus potentially valuable in assessing aortic wall failure risk.

References

1. *Eur J Cardiothorac Surg*, 50:1111-1117, 2016.
2. *PLoS One*, 14(7)e0219461.

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