THE EFFECT OF SIZE AND PROXIMITY OF MICRO-BEADS ON THE RUPTURE THRESHOLD OF ATHEROMA CAP LABORATORY MODELS

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Introduction

The mechanical vulnerability of the atherosclerotic cap is a crucial risk factor in asymptomatic fibroatheromas. Our research group demonstrated using numerical modeling that microcalcifications (μCalcs) located in the fibrous cap can multiply the tissue background stress by a factor 2-7[1-3]. We showed how this effect depends on the size and the ratio of the gap between particles pairs (h) and their diameter (D) along the tensile axis. In this context, we studied the impact of micro-beads of varying diameters and concentration on the rupture of human fibroatheroma laboratory models.

Methods

We created silicone-based (DowsilEE-3200, Dow Corning) dumbbell-shaped models (80%-scaled ASTM D412-C) of arterial tissues. Samples were divided into three groups: (1) without μBeads (control, n=12), (2) with μBeads of varying diameter (D=30,50,100μm) at a constant concentration of 1% weight (n=36), (3) with μBeads of constant diameter (D=50μm) at different concentrations (3% and 5% weight) (n=24). Before testing, samples were scanned under Micro-CT, at a resolution of 4μm. Images were then reconstructed in NRecon (SkySCan, v.2014) and structural parameters obtained in CTan (SkyScan, v.2014). These data were used to calculate the number of beads and their respective h/D ratio in a custom-made MATLAB script. We tested the samples using a custom-made micro material testing system equipped with real-time control and acquisition software (LabVIEW, v. 2018, NI). The reaction force and displacement were measured by the system and images of the sample were recorded by a high-resolution camera. The true stress and strain profiles of each sample were obtained by means of Digital Image Correlation (DIC).

Results

Samples with and without μBeads exhibited a distinct hyperelastic behaviour typical of arterial tissues **(Fig1)**.

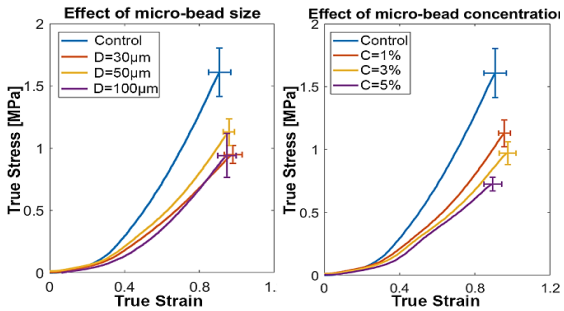

Figure1: True stress-strain curves of samples with μBeads of varying diameter (Left) and concentration (Right) against control group. Error bars represent ±SD of ultimate stress and strain.

Comparison of the mean ultimate stress (UTS) between groups was performed by one-way ANOVA test followed by post-hoc pairwise comparison. Regardless of the group, the presence of μBeads determined a statistically significant reduction in UTS **(Fig2).** Increasing the μBeads concentration was also positively correlated with lower stresses at rupture as more clusters formed resulting in lower values of h/D **(Table1)**.

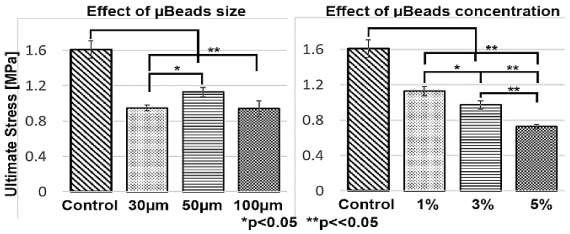

Figure2: Bar-charts of UTS±SD for each group.

	30	50	100	1%	3%	5%
# Beads	4348	302	13	302	876	1526
# Close Beads	22	6	0	6	59	81
h/D	3.1	3.4	>4	3.4	2.5	2.3
UTS Drop	41%	30%	42%	30%	40%	55%

Table 1: List of the average number of μBeads, the number of μBeads close to each other (h/D<4), the lowest h/D value and the amount of UTS reduction for each group with μBeads.

Discussions

Our results clearly capture the influence of μBeads on the rupture threshold of a vascular tissue mimicking material. In fact, samples with μBeads exhibit levels of UTS that are around two times lower than the control group. This effect appears to be dependent on the μBeads proximity, as lower h/D correlates with higher UTS reductions. On the other hand, the effect of particle size is not apparent for the diameters considered in this study. The plausible explanation for the observed change in rupture threshold is the increase in stress concentration around spherical μBeads, which we have previously shown in analytical and numerical studies [1-3]. Our experimental observations support our previous studies suggesting that μCalcs located within the fibroatheroma cap may be responsible for significantly increasing the risk of cap rupture that precedes myocardial infarction and sudden death.

References

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