MODELING OF DRUG-COATED BALLOON INFLATION CORRELATES DRUG TRANSFER WITH VESSEL GEOMETRY AND BALLOON DESIGN

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Introduction

Drug-coated balloons (DCB) are designed to deliver drug-loaded coating at the arterial inflation site. While DCBs have shown efficacy in treating femoropopliteal peripheral artery disease, clinical and preclinical outcomes vary with lesion complexity and DCB technology [1,2]. To understand their variable performance, we developed and validated a 3D computational model of DCB inflation and correlated experimental coating distribution maps (CDM) following acute *in vivo* treatments of pig superficial femoral artery (SFA) with computationally predicted endoluminal maps of contact pressure (CP) in digital replicas.

Methods

Eight naive porcine SFAs were treated with (4x60 mm) commercial DCBs, followed by euthanasia at an average of 30 minutes post-treatment. Arterial segments containing the treatment site were excised and cut longitudinally, allowing for SEM imaging of the endolumen and CDM quantification. Angiographic data pre- and during treatment were utilized for SFA reconstruction and vessel material properties calibration. This facilitated the development of finite element (FE) replicas of the treated arteries and enabled the inflation of a reconstructed DCB model within them (Fig. 1A). Simulated DCB inflations accurately reproduced its benchtop pleated and unfolding configurations during resin inflation (Fig. 1B). This enabled prediction of the interfacial DCB-tissue CP (Fig 1Di-iii) and correlation with *in vivo* CDM (Fig. 1. Dii-iv).

Results

Quantification of SEM maps revealed sparse endoluminal CDM (19.23% and 4.97% of treatment area covered by coating on SFA1 and SFA2 respectively) with evident longitudinal stripes and dependency on the vessel anatomy. Correspondingly, simulations predicted heterogeneous balloon-vessel interaction, with elevated CP in parallel longitudinal stripes, at locations of balloon folds, with widths set by particular membrane layers (Fig. 1. C). High levels of proximal to distal tapering hindered coating delivery to the proximal half of the treatment site (Fig 1.Dii and Div); simulations correlated these observations with reduced CP and facilitated threshold CP estimation for effective coating delivery (0.14 atm) (Fig 1.Di and Diii). This allowed for the qualitative replication of CDM distribution across the different vessels (Fig 1.Dii and Div), as predicted by the validated FE simulations.

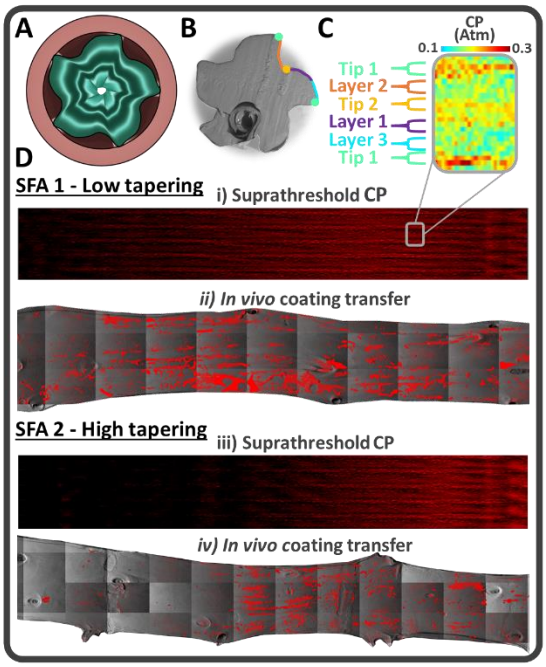

Figure 1: A. DCB unfolding simulation in the tapered vessel, B. Resin inflated DCB cross-section colored with the 3 repetitive layers and 2 tips of each fold, C. Correlation of DCB particular layers to CP colormap onto the tissue, at nominal inflation pressure, and D. suprathreshold CP distribution of two tapered arteries and their experimental CDM correlates at nominal inflation pressure.

Discussion

Modeling data imply that during inflation, drug-coating on DCB surfaces is pressed against the tissue at heterogeneous CPs driven by balloon fold geometries and unfolding dynamics, providing a mechanism for striped patterns of coating delivery, as confirmed by animal experiments. Moreover, porcine studies demonstrated a sensitivity of coating distribution to arterial taper, which was recapitulated and explained by computational modeling. These findings elucidate the influence of healthy vessel geometry and device design on drug delivery via DCBs. Application of the developed methodology to clinical lesions is underway, based on clinical imaging and incorporation of complex plaque morphologies and material heterogeneities.

References

1. Fanelli et al, Card. Intervent. Radiol., 37:898–907 2014.
2. Tzafriri et al, J Biomaterials, 260, 2020.

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