NUMERICAL ANALYSIS OF THE INFLUENCE OF AORTIC CALCIFIC DEPOSITS ON TRANSCATHETER AORTIC VALVE IMPLANTATION

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Introduction

Transcatheter aortic valve implantation (TAVI) allows for the catheter-driven deployment of a prosthetic heart valve mounted on a balloon-expandable stent. Although successful in about 90% of symptomatic patients with calcific aortic stenosis (CAS), heavily calcified aortic valves (AV) may result in a higher incidence of aortic paravalvular leakage [1]. Thus, exploiting an exhaustive finite element (FE) approach, we simulated the TAVI procedure into three CAS-affected aortic root (AR) anatomies, to elucidate biomechanical risk factors for complications related to variable calcification patterns.

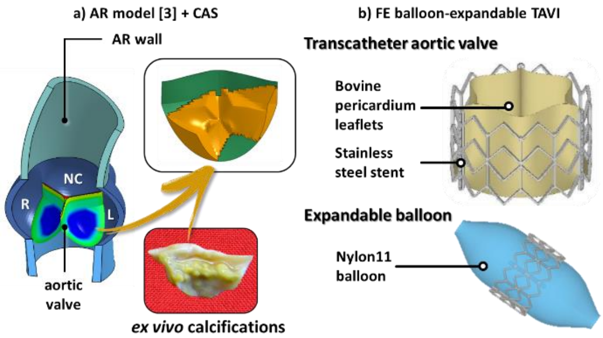

Figure 1: Numerical AR model with calcified AV leaflets (a) and FE model of the balloon-expandable TAVI (b).

Methods

An anatomically detailed and pressurized AR model [2] was complemented by three different patterns of AV leaflet calcifications, based on *ex vivo* measurements on explanted human calcific AVs at Luigi Sacco Hospital in Milan (Figure 1). AR wall tissue was assumed linear elastic and isotropic; AV leaflets anisotropy was reproduced with a multilayer fiber-reinforced approach [3] while the mechanical response of calcific deposits was assumed isotropic. For each variant, the insertion of the Edwards SAPIEN® 26mm device was simulated (Edward Lifesciences Inc, Irvine, CA): the behavior of the stainless steel stent was modeled with a bilinear elastic-plastic model based on a Von Mises yielding criterion. After stent crimping, a linear, isotropic and elastic balloon was expanded to reproduce the stent deployment [4]. Finally, we computed the prosthetic valve biomechanics accounting for the hyperelastic mechanical response derived from uniaxial tensile tests on six prosthetic leaflet specimens. All simulations were run in the FE explicit solver LS DYNA (LSTC, Livermore, CA).

Results

Calcifications markedly altered AV orifice, heavily limiting the leaflet outward motion (Figure 2). CAS-specific patterns of calcification resisted stent deployment, resulting in an hourglass profile with high Von Mises stresses at the plastic joints. The outward relocation of native calcified AV leaflets increased stresses on the calcific deposits and on the AR inflow tract, depending on the entity and spatial distribution of the calcific patterns. We noticed local stent distortions as well as localized gaps between TAVI stent and the surrounding AR tissues. In all the tested CAS-affected models, TAVI restored a larger orifice area (up to +152%), guaranteeing a complete diastolic coaptation.

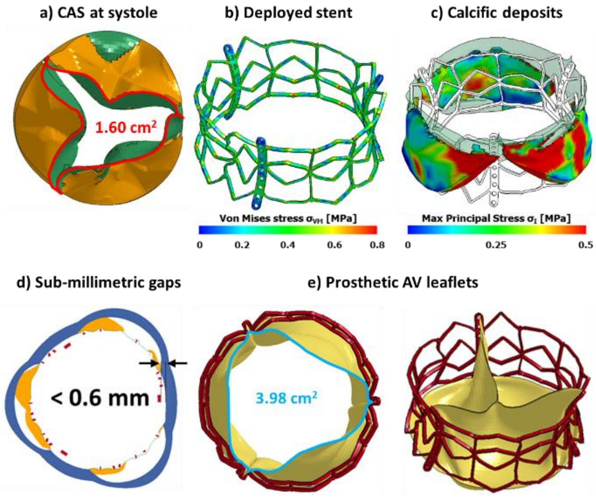

Figure 2: FE results of TAVI procedure in model 2.

Discussion

Developed FE models accounted for all the factors potentially involved in the mechanical interplay between native AR structures and the prosthetic device. Accordingly, biomechanical alterations following TAVI may be related to CAS-specific features, potentially corroborating cases of aortic paravalvular regurgitation [1]. FE models, if extensively tested, may elucidate the mechanisms of post-procedural complications and support the ongoing optimization of TAVI techniques.

References

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