Finite element analysis of the impact of aortic leaflets calcifications on transcatheter aortic valve implanation

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Introduction

Transcatheter aortic valve implantation (TAVI): biological heart valve mounted on a stainless steel balloon-expandable stent, implantable percutaneously via standard catheter-based techniques [1].

Clinical applications:

- Treatment of symptomatic patients with calcific aortic stenosis (CAS)
- Standard of care in non-operable patients
- Versatile alternative for patients with several contraindications for surgery

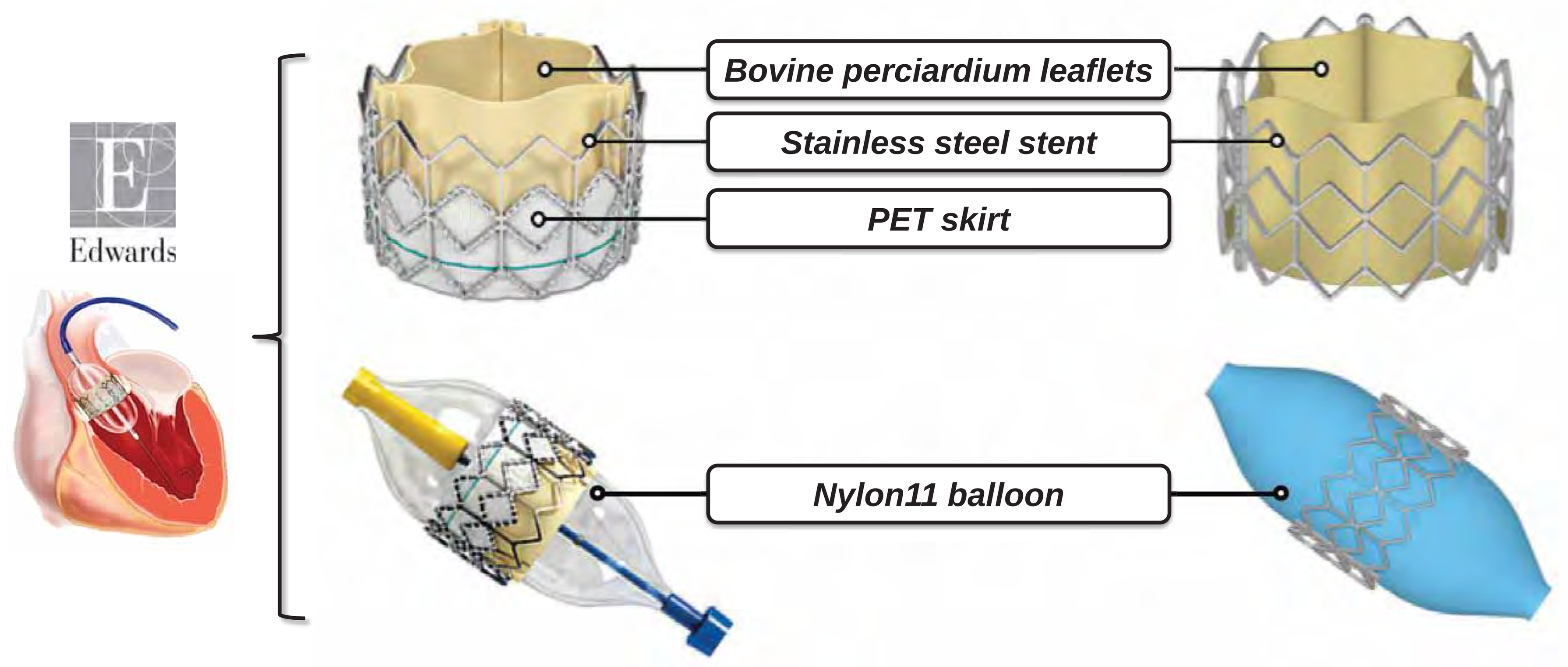


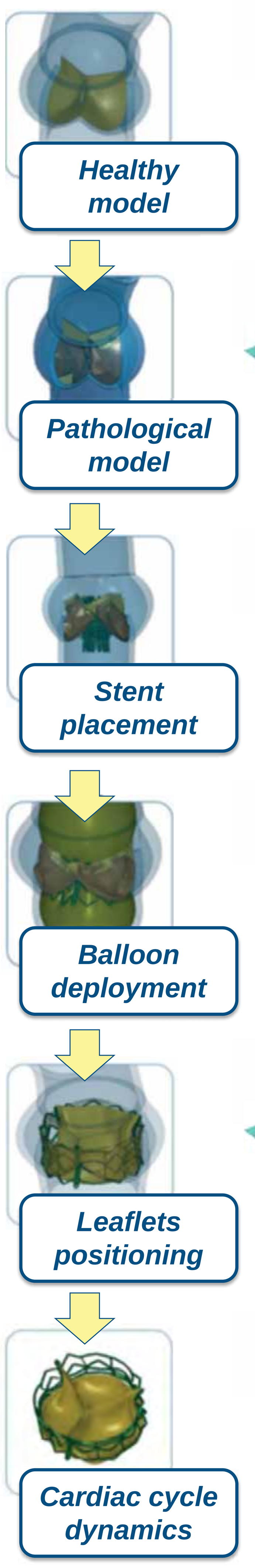
Fig. 1 Balloon-expandable Edwards SAPIEN (26mm) and corresponding FE model.

Bioengineering aim

TAVI candidates often present calcified aortic leaflets with heterogeneous degrees and patterns of calcium deposits which may severely impact on the *in vivo* implant outcomes [2]. Finite element (FE) analysis was exploited to investigate the influence of aortic calcifications on TAVI outcomes and assess TAVI-related complications, usually exacerbated by calcific deposits.

Materials and Methods

Aortic root (AR) dynamics was simulated under physiological, pathological (CAS) and postoperative conditions after a balloon-expandable TAVI. The procedure was simulated through a dedicated FE workflow (Fig. 2) using the explicit solver LS-DYNA© v. 971 (LSTC, Livermore, CA, USA).



STEP 1

Complete three-dimensional (3D) aortic root model [3] with native and healthy aortic valve leaflets

STEP 2

3D calcific deposits replicated from *ex vivo* measures

STEP 3

- Prescribed radial displacement to 12 rigid planes
- Transapical delivery

STEP 4

- Balloon expansion
- Stent deployment to the nominal stent diameter of 26mm

STEP 5

- Prosthetic leaflets insertion in the deployed stent through *ad hoc* kinematic nodal relocation [4]
- Reprodcution of end-diastolic TAVI configuration

STEP 6

- FE simulation of aortic root dynamics throughout an entire cardiac cycle

Fig. 2 FE Workflow of the complete TAVI virtual procedure

Results and Discussion

CAS effects on TAVI procedure. Only 35% of leaflets area was free from calcific deposits (total calcific volume = 622 mm^3) with an asymmetrical redistribution of calcification between AV leaflets. AV dynamics showed analogies with stenotic aortic valves behavior: aortic orifice area (AOA), during systole, presented a reduction of approximately 60% with respect to the healthy model (1.35 cm^2 vs. 3.74 cm^2).

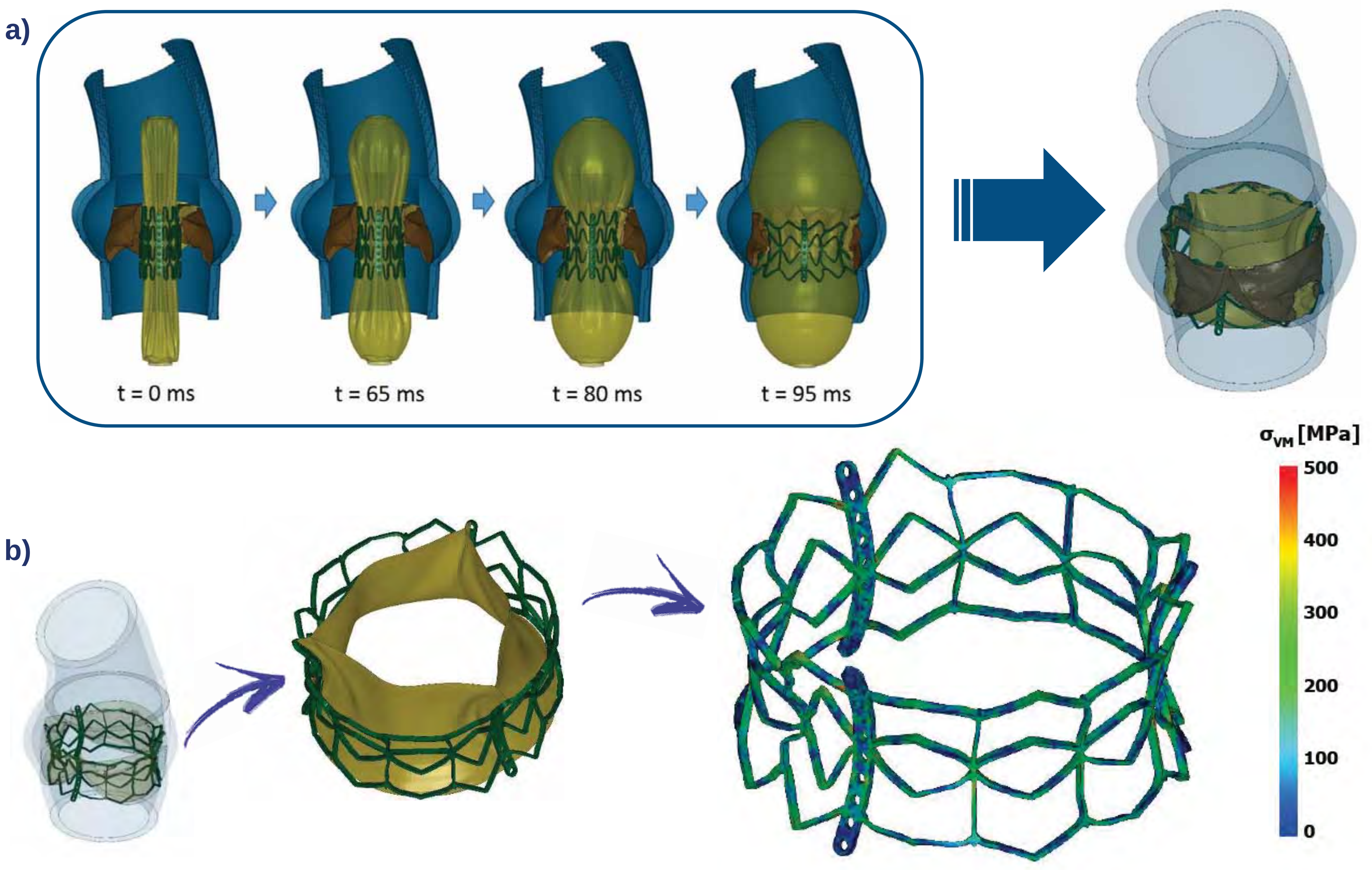


Fig. 3 a) Balloon expansion and deployed TAVI configuration; **b)** resultant configuration of prosthetic leaflets and Von Mises stress computed on the stent.

Calcific deposits prevented a symmetric TAVI deployment, causing the hourglass-shaped configuration of the stent (Fig. 3) and the asymmetric TAVI deployment into the AR, as visible comparing the radial dislocation of the device in the three commissural regions (Fig. 4).

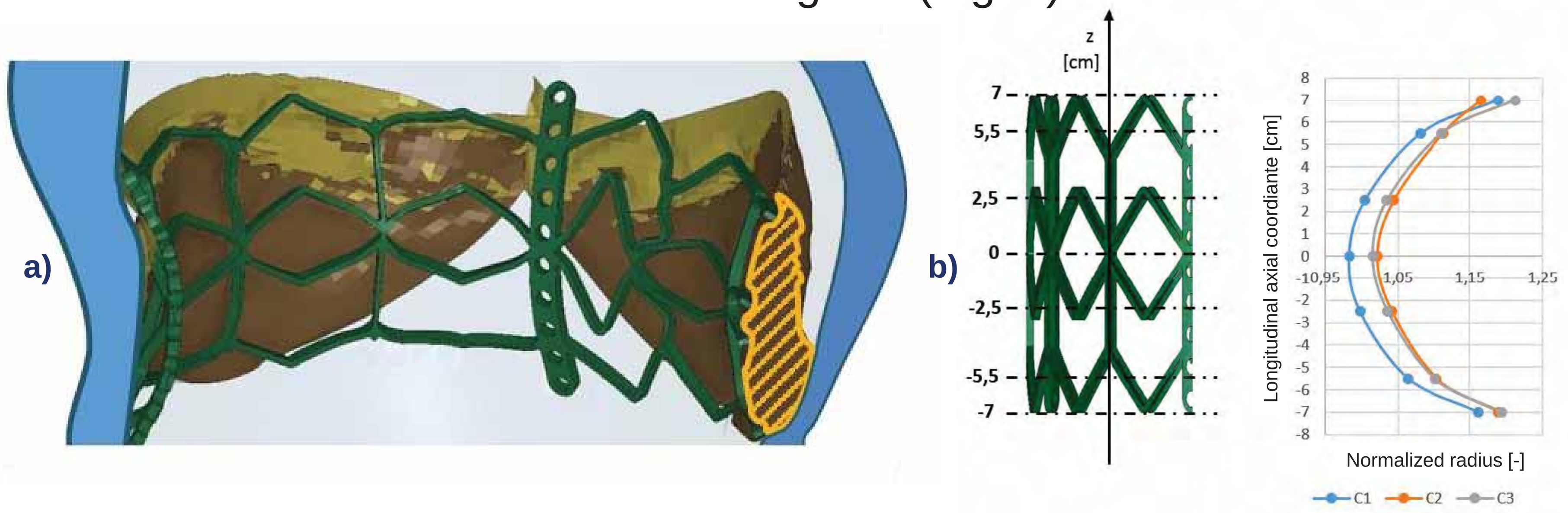


Fig. 4 a) Hourlass-shaped TAVI configuration and, **(b)** along the longitudinal axis of the device, the radial asymmetrical dislocation of the commissural bars of the TAVI ring.

Dynamics of prosthetic aortic leaflets. The distorted stent deployment resulted in a localized gap between AR wall and TAVI stent; however, the systolic valvular opening was not affected, with a percentage AOA increase of +262% (4.88 cm^2) with respect to CAS model. During valve closure, prosthetic leaflets presented a similar kinematics and achieved a complete coaptation, with no noticeable residual prolapse (Fig. 5).

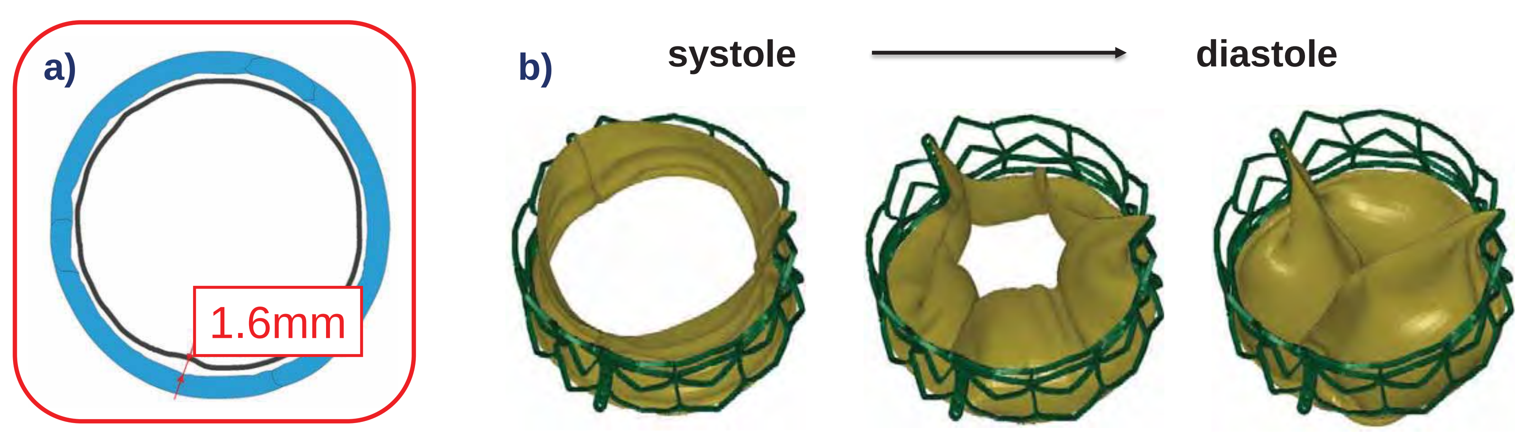


Fig. 5 a) Resulting gap between AR wall and the prosthetic TAVI ring; **b)** aortic prosthetic valvular dynamics during the cardiac cycle.

Discussion. Calcific deposits can severely impact on the deployed TAVI configuration, potentially threatening the outcomes of the procedure. FE modeling can be employed to prevent TAVI-related complications, support the ongoing optimization of TAVI procedure and provide clinicians with complementary information for the decision-making process.

References

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