TRANSCATHETER HEART VALVE IN TRANSCATHETER HEART VALVE: A COMPUTATIONAL STUDY

Roberta Scuoppo (1), Stefano Cannata (2), Caterina Gandolfo (2), Salvatore Pasta (1,4)

1. Dipartimento di Ingegneria, viale delle Scienze Ed.8, University of Palermo, Italy

2. Interventional Cardiology Unit, IRCCS ISMETT via Tricomi, 5, Italy

3. Department of Research, IRCCS ISMETT via Tricomi, 5, Italy

Introduction

Transcatheter aortic valve implantation (TAVI) is increasingly used to treat patients with severe aortic stenosis (AS) who are deemed inoperable or at high risk for surgical aortic valve repair. Thus, even in the absence of concerns about transcatheter aortic valve (TAV) durability, a substantial proportion of contemporary TAVI patients are expected to live sufficiently long to experience the degeneration and failure of TAV. In the case of device's failure, the therapeutic option for the treatment of structural TAV degeneration are limited to open-heart surgery and redo-TAVI (or TAV-in-TAV) [1].

This study aimed to develop a computational framework to simulate TAV-in-TAV as clinically performed in one patient with early failure of the implanted device. Patient-specific computational modelling was carried out to determine structural metrics of delivered devices while a parametric analysis of the implantation depth of the second TAVI procedure was performed to assess the impact of the relative device position [2].

Materials and methods

A 68-years old gentleman with severe AS was initially treated with a 23-mm SAPIEN 3 Ultra TAV at IRCCS ISMETT in 2019. After 3-year from TAVI, the device failure was treated by redo-TAVI with a 29-mm Evolut Pro device.

Pre-TAVI CT images were processed in Mimics (v.21, Materialize, Belgium) to reconstruct the aortic root anatomy and calcific plaques using semi-automatic thresholding. Since native valve leaflet were not clearly visible at CT scan, a parametric modelling approach was adopted generate the leaflet geometry using anatomic measurements and the CAD tool Rhinoceros (Rhinoceros v.7, McNeel & associates, USA). Once segmented regions were obtained, they were meshed using ICEM meshing software (v2021, ANSYS Inc., USA). Neo-Hookean models were adopted for both the aortic valve and native valve leaflets. The calcification had a linear-elastic model. Geometrical models of 23-mm SAPIEN 3 Ultra and 29-mm Evolut PRO device frames were obtained by reverse engineering of micro-CT images. Numerical analysis of the redo-TAVI procedure was developed in Abaqus/Explicit (v2021hf7, Dassault Systèmes, USA) using mass-scaling.

A parametric analysis of the TAV-in-TAV procedure was carried out by varying the implantation depth and device size with respect to the baseline model. Eccentricity and expansion indexes were calculated from both TAVI CT and redo-TAVI CT images and then compared to those predicted by computational analysis.

Results

Expansion index was used to quantify the level of agreement between FEA and CT images. Predictions of expansion index were in good agreement with CT-based measurements (ie, (ie, 120.8 ± 10% for CT-based measured of S3 versus 96.5 ± 14% for numerical-based measured of S3, while 90.6 ± 13% for CT-based measured of Evolut Pro versus 79.2 ± 21% for numerical-based measured of Evolut Pro).

Figure 1 illustrates the TAV-in-TAV deformed configurations for the four scenarios with different implantation depth or device overexpansion.

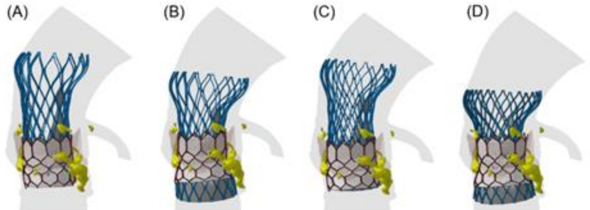

Figure 1 (A) reference TAV-in-TAV as done clinically, (B) low redo-TAVI, (C) high redo-TAVI and (D) TAV-in-TAV overexpansion.

Discussion

To the best of our knowledge, this is the first computational study evaluating the structural mechanics of TAV-in-TAV. We first simulated the TAV-in-TAV according to the implantation depth and device size indicated by the Heart Team, and then carried out a parametric analysis varying these device parameters.

Future computational flow studies will be undertaken to explore whether the parametrically-derived TAV-in-TAV shapes may lead to coronary flow obstruction and thus adverse events.

Moreover, simulations were used to explore the efficacy and safety of TAVI in young and high-risk patients, which are not conventionally treated with TAVs.

References

1. Gallo M et al, European Journal of Cardio-Thoracic Surgery, 61(5): 967-76, 2022.
2. Pasta S et al, Artif Organs, 41(9): E92-E102, 2017.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017523.