Structural Heart 8 (2024) 100276

Articles and Issues Available at ScienceDirect

Structural Heart

journal homepage: www.structuralheartjournal.org

Original Research

New Insights and Perspective on Bioprosthetic Valve Fracture From Bench Testing and Computed Tomography Analysis

Go Hashimoto, MD[a], Santiago Garcia, MD[b], Hirotomo Sato, MD, PhD[c], Miho Fukui, MD, PhD[a], Muhammad Hammadah, MD[d], Robert Steffen, MD[c,d], Joao L. Cavalcante, MD[a,c,d], Vinayak N. Bapat, MD[c,d,*]

[a] Cardiovascular Imaging Research Center and Core Lab, Minneapolis Heart Institute Foundation, Minneapolis, Minnesota, USA
[b] Division of Cardiology, The Christ Hospital, Cincinnati, Ohio, USA
[c] Valve Science Center, Minneapolis Heart Institute Foundation, Minneapolis, Minnesota, USA
[d] Minneapolis Heart Institute, Abbott Northwestern Hospital, Minneapolis, Minnesota, USA

ARTICLE INFO

Article history:
Submitted 27 June 2023
Revised 1 December 2023
Accepted 21 December 2023
Available online 5 February 2024

Keywords:
Bioprosthetic valve fracture (BVF)
Computed tomography angiography (CTA)
Surgical heart valve (SHV)
THV (transcatheter heart valve)
Valve-in-Valve TAVR (transcatheter aortic valve replacement)

ABSTRACT

Background: Bioprosthetic valve fracture (BVF) during valve-in-valve TAVR (transcatheter aortic valve replacement) is a procedural adjunct designed to optimize the expansion of the transcatheter heart valve and reduce patient-prosthesis mismatch by using a high-pressure balloon to intentionally fracture the surgical heart valve (SHV).
Methods: We performed bench testing on 15 bioprosthetic SHV to examine the optimal balloon size and pressure for BVF. We assessed morphological changes and expansion of SHV by computed tomography angiography. Successful BVF was defined as balloon waist disappearance on fluoroscopy and/or sudden pressure drop during balloon inflation.
Results: Nine valves met the definition of BVF, 3 of which were confirmed by disruption of the stent frame. We classified surgical valves into 3 subsets: 1) fracturable with metal stent frame (MSF), 2) fracturable with polymer stent frame (PSF) and 3) nonfracturable. In general, valves with MSF were fractured using a balloon size = true internal diameter plus 3-5 mm inflated at high pressure (16-20 ATM) whereas valves with PSF could be fractured with a balloon size = true internal diameter plus 3-5 mm and lower balloon pressure (6-14 ATM). Gains in computed tomography angiography derived inflow area after BVF were 12.3% for MSF and 3.6% for PSF SHV.
Conclusions: Gains in CT-determined valve area after BVF depend on the physical properties of the SHV, which in turn influences pressure thresholds and balloon sizing strategy for optimal BVF. Elastic recoil of PSF valves limits the gains in inflow area after BVF.

ABBREVIATIONS

BVF, Bioprosthetic Valve Fracture; CTA, Computed Tomography Angiography; HPB, High Pressure Balloon; ID, Internal Diameter; SAVR, Surgical Aortic Valve Replacement; SHV, Surgical heart valve; TAVR, Transcatheter Aortic Valve Replacement; THV, Transcatheter Heart Valve.

Introduction

Most surgical aortic valve replacement procedures in the U.S. are performed with bioprosthetic valves, a trend that has increased in recent years.[1,2] While bioprosthetic valves avoid the long-term risks of anti-coagulation, including bleeding and hemorrhagic stroke, they are susceptible to structural valve deterioration.[3]

Valve-in valve (VIV) transcatheter aortic valve replacement (TAVR) has emerged as an alternative to redo surgical aortic valve replacement[4,5] for the treatment of bioprosthetic valve failure, which is associated with

* Address correspondence to: Vinayak N. Bapat, MD, Cardiothoracic Surgery, Minneapolis Heart Institute, Abbott Northwestern Hospital, Valve Science Center, Minneapolis Heart Institute Foundation, 800 E 28th Street, Suite 300, Minneapolis, MN 55407.
E-mail address: vnbapat@yahoo.com (V.N. Bapat).
Twitter Handle: @bapat_savrtavr (V.N. Bapat)

https://doi.org/10.1016/j.shj.2023.100276

significant risks.[6] However, high postprocedure transvalvular gradients are common after VIV TAVR in small surgical valves (< 21 mm) and are associated with poor clinical outcomes.[5,7] Bioprosthetic valve fracture (BVF) is a technique that intentionally disrupts the stent frame of the surgical heart valve (SHV) to optimize expansion of the transcatheter heart valve (THV), improving residual gradients and effective orifice area after VIV TAVR.[8-11]

The principle of BVF is to mechanically disrupt the integrity of the SHV to allow full expansion of the THV. Many surgical valves can be fractured using high-pressure, noncompliant balloon inflations in benchtop models, allowing for a significant reduction in postprocedure gradients.[9,10] Bench testing, conducted in a selected group of SHV, demonstrated feasibility of BVF, which resulted in clinical adoption in small scale observational studies.[9-12] However, important questions remain regarding optimal BVF technique including balloon sizing strategy, intraprocedural feedback to confirm effective BVF, balloon pressure thresholds and expected gains in effective orifice areas as determined by computed tomography angiography (CTA).

We hypothesized that the procedural strategy and gains in valve area after BVF would depend on the structure of the SHVs.

Methods

Bioprosthetic Valve Fracture Procedure

We performed BVF using the high-pressure balloons [True Dilatation balloon catheter (BD, Tempe, Arizona] of various diameters (20, 22, 24, 26, and 28 mm). BVF was deemed successful if sudden balloon waist disappearance was seen on fluoroscopy (Supplemental Video 1) and/or a sudden pressure drop in the indeflator device was observed. The technique for BVF was performed using 2 inflation devices as previously reported.[9,10,13] For the first BVF attempt, we used a balloon size with at least the true internal diameter (ID) plus 3 mm (i.e., for a true ID of 19 mm the first balloon size had a diameter of 22 mm), and if unsuccessful the balloon was upsized by 2 mm. The balloon size and pressure of the inflation device when BVF occurred were recorded.

CTA Acquisition and Analysis

CTA examinations were performed at baseline and after BVF. The acquisition was performed using dual-source scanners (Siemens Healthineers, Germany) with third-generation (Siemens SOMATOM Definition Force 2 × 192 × 0.6 mm; TR 66 ms). Images reconstructed at 0.6 mm were provided to the Cardiovascular Imaging Research Center and Core Lab at Minneapolis Heart Institute Foundation (Minneapolis, MN). For this dedicated CTA analysis, all datasets were transferred to a dedicated postprocessing workstation equipped with Vitrea (7.10.1, Vital Images, Minnetonka, MN). The analysis was performed by an experienced cardiologist (G.H.) with 2 years of experience in structural imaging under the supervision of the Core Lab director (J.L.C). As shown in Figure 1, we measured both inflow and outflow areas of the SHV and compared pre-BVF and post-BVF values.

Statistical Analysis

Five surgical valves (Magna, Mosaic, Mitroflow, Trifecta, and Hancock II) were chosen to determine intraobserver and interobserver variability of THV area measurements (total number of samples was 10) at baseline and after BVF in both inflow and outflow level using intraclass correlation (ICC) in bench testing. The interobserver variability was assessed between G.H and M.H. A two-sided $p < 0.05$ was considered statistically significant. The analyses were performed using SPSS statistics version 25 software (IBM, Armonk, New York).

Results

Characteristics of Fractured SHVs in Bench Testing

Of the 15 types of SHV tested, 9 SHVs met the definition of BVF. In addition, Perimount 2800, Magna 3000, Magna Ease 3300 had visible disruption of basal ring of the stent frame on fluoroscopy (Table 1 and Figure 2). In contrast, Mosaic, Biocor Standard, Biocor Supra, Mitroflow, CROWN, and Labcor were fractured but without visible disruption of the

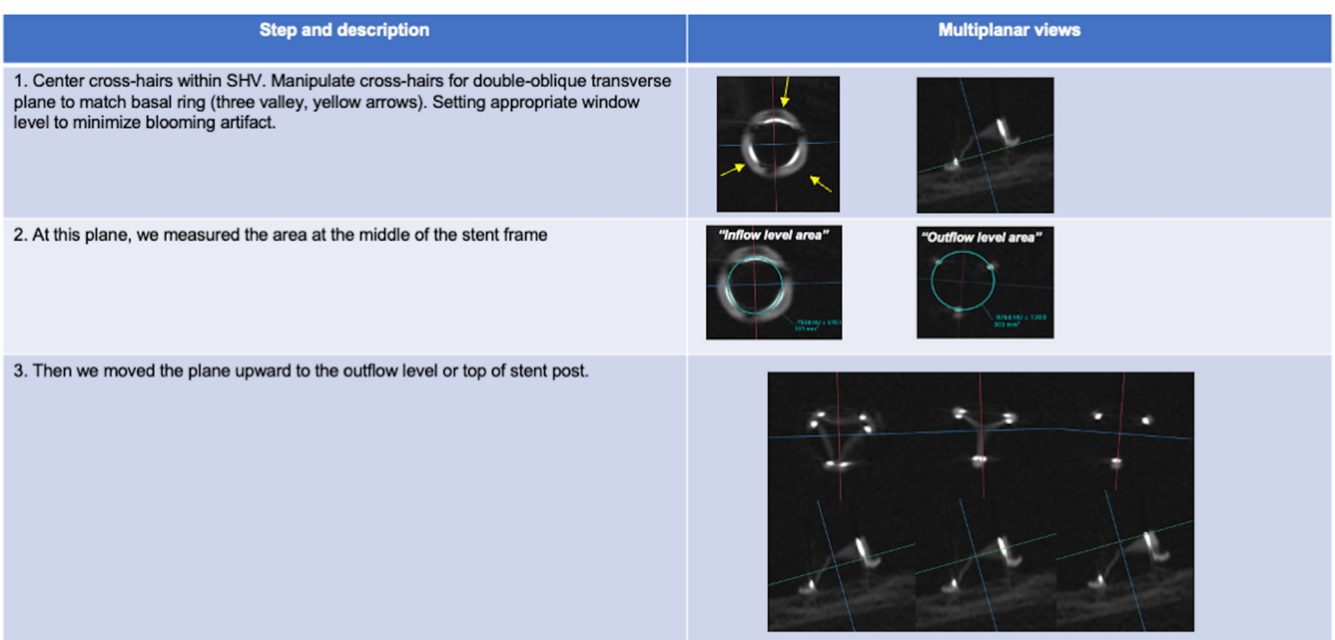


Figure 1. Methodology of Measuring of Surgical Heart Valve Area by CTA (Bench testing part, Perimount 2700).
Abbreviations: CTA, computed tomography angiography; SHV, surgical heart valve.

Table 1
Size and composition of 15 surgical valves tested in in bench experiments

Valve type	Labeled size (mm)	Composition of stent frame	Stent frame (stent post and base)	Manufacturer	Confirmation of BVF on fluoroscopy	Confirmation of BVF by sudden drop in pressure/waist disappearance	Gains in inflow area (CTA)	Leaflets
Perimount 2700 (old)§	21	Cobalt-chromium	Together	Edwards Lifesciences	**No**	**No**	**9%**	Pericardial
Perimount 2800 (new)§	21	Cobalt-chromium	Separate		**Yes**	**Yes**	**12%**	Pericardial
Magna 3000§	21	Cobalt-chromium	Separate		**Yes**	**Yes**	**15.8%**	Pericardial
Magna Ease 3300§	21	Cobalt-chromium	Separate		**Yes**	**Yes**	**8.7%**	Pericardial
Mosaic‡	21	Acetyl homopolymer	Together	Medtronic	**No**	**Yes**	**3.2%**	Porcine
Hancock II†	21	Acetyl homopolymer	Together		**No**	**No**	**10%**	Porcine
Biocor‖	21	Flexible Acetyl copolymer		St.Jude Medical	**No**	**Yes**	**13%**	Porcine
Biocor Supra‖	21	Flexible Acetyl copolymer			**No**	**Yes**	**1.6%**	Porcine
Trifecta†	21	Titanium			**No**	**No**	**0%**	Pericardial
Mitroflow‖	21	Acetyl homopolymer	Together	Sorin	**No**	**Yes**	**0%**	Pericardial
Crown	21	Acetyl homopolymer			**No**	**Yes**	**2.2%**	
Soprano‖	24				**No**	**No**	**0%**	Pericardial
Dokimos*	23	Copolymer stent		Labcor	**No**	**No**	**4.3%**	Pericardial
Labcor*	23	Copolymer stent			**No**	**Yes**	**1.5%**	Porcine
Aspire*	21		Together	Vascutek	**No**	**No**	**0%**	Porcine

Bold values indicate some of the results more relevant than others.
Abbreviations: BVF, bioprosthetic valve fracture; CTA, computed tomography angiography.
* No fluoroscopic markers.
† Fluoroscopic markers located in the sewing ring and stent post.
‡ Fluoroscopic markers located in the stent post tip.
§ Fluoroscopic markers located in the stent post.
‖ Fluoroscopic markers in the sewing ring.

basal ring on fluoroscopy (Table 1 and Figure 2). The remaining 6 SHVs could not be fractured.

We classified the SHV in 3 groups (Figures 3 and 4)

1) **Fracturable with Metal Stent Frame (MSF):** Perimount 2800 (Supplemental Video 1), Magna 3000, Magna Ease 3300 consist of cobalt-chromium stent post and basal ring with bovine pericardium leaflets sewn inside the stent frame. A relatively high balloon pressure was required to achieve BVF of these valves, regardless of the size of the SHVs. Balloon size at fracturing was True ID plus 3 mm or 5 mm.

2) **Fracturable with Polymer Stent Frame (PSF):** Mosaic (Supplemental Video 2), Biocor Standard, Biocor Supra, and Labcor Supra were included in this category. Mosaic and Labcor Supra consist of a PSF and porcine leaflets sewn inside the stent. Biocor and Biocor Supra consist of a PSF with a thin stainless-steel wire within the sewing ring and porcine leaflets sewn inside the stent. A relatively low balloon pressure was required to achieve BVF, regardless of the size of the SHVs. Balloon size at fracturing was True ID plus 5 mm or 7 mm for Mosaic and Biocor, True ID plus 3 mm in Biocor Supra, and Labcor Supra. Mitroflow and Crown consists of Acetyle PSF, and

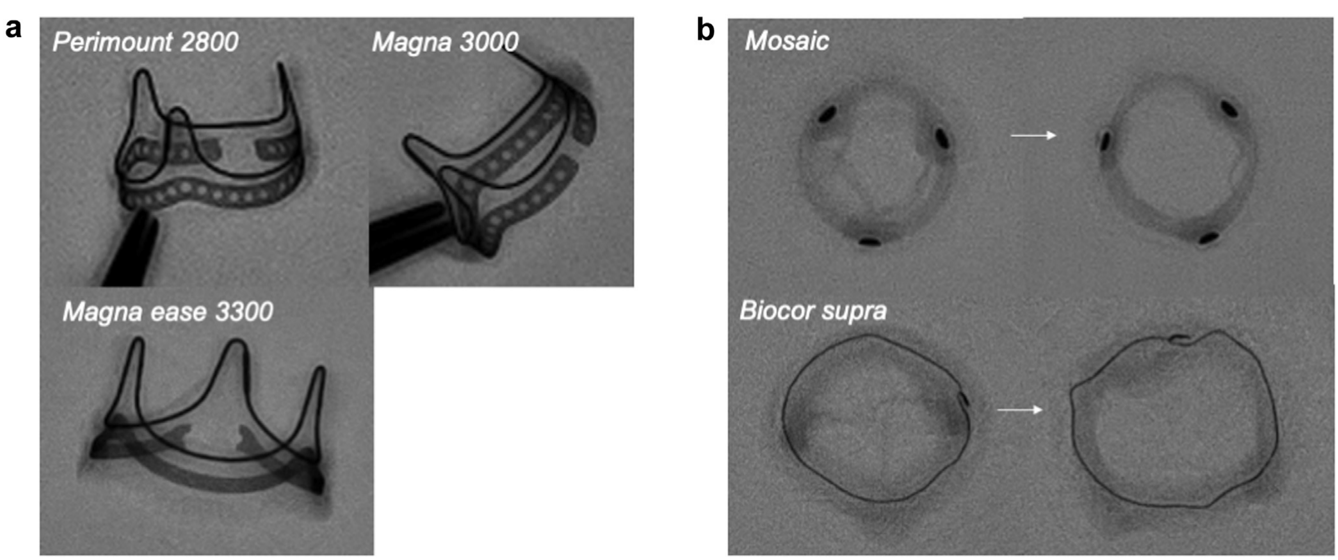
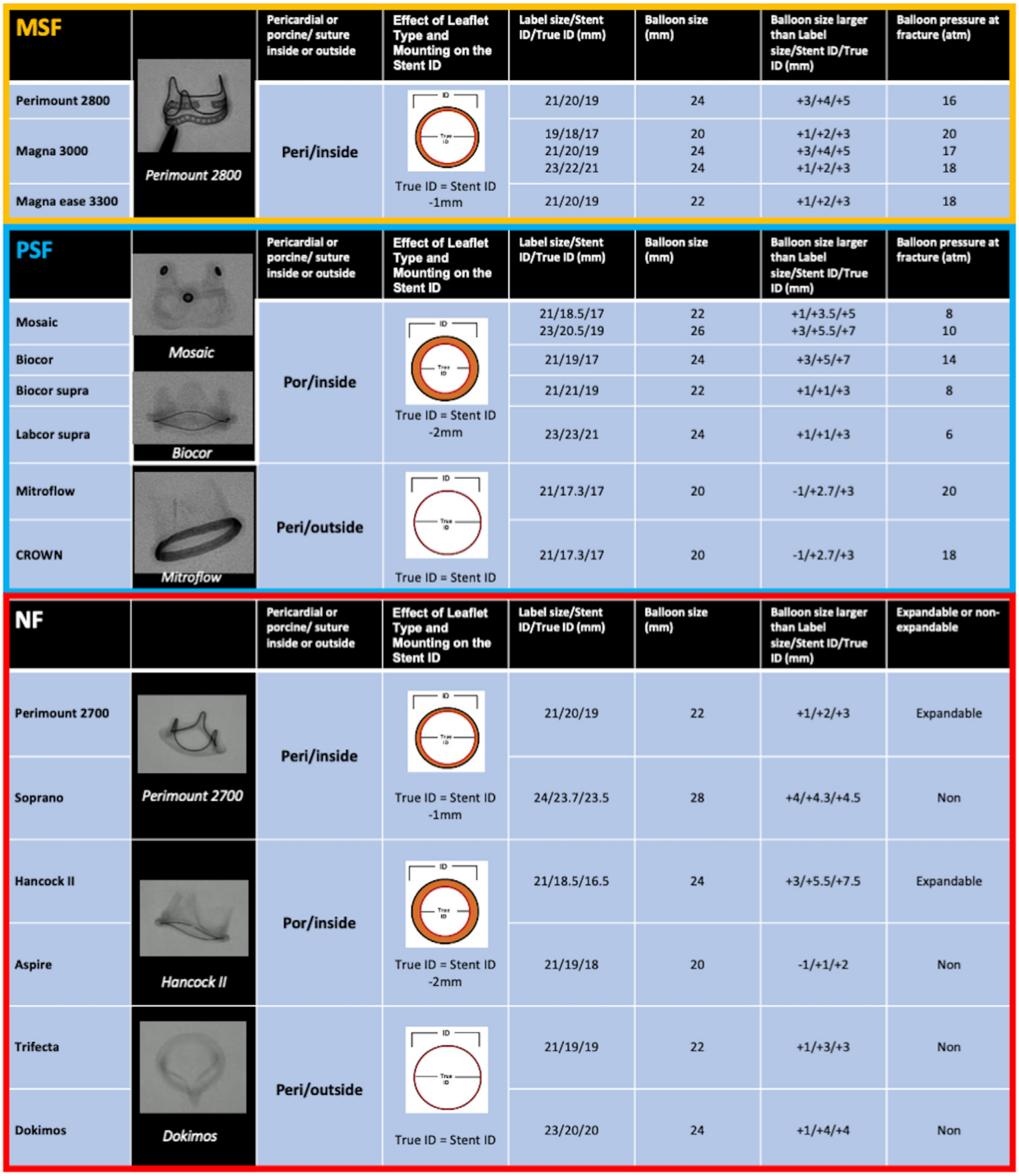


Figure 2. **Appearance of Fractured SHVs on Fluoroscopy.** (Panel a) Visible disruptions in the stent frame after BVF in Perimount 2800, Magna 3000, and Magna Ease 3300. (Panel b) BVF not appreciated on fluoroscopy in Mosaic (markers are at top of stent post). The thin metal ring was deformed after BVF in Biocor Supra. Abbreviations: BVF, bioprosthetic valve fracture; SHV, surgical heart valve.



MSF	Image	Pericardial or porcine/ suture inside or outside	Effect of Leaflet Type and Mounting on the Stent ID	Label size/Stent ID/True ID (mm)	Balloon size (mm)	Balloon size larger than Label size/Stent ID/True ID (mm)	Balloon pressure at fracture (atm)
Perimount 2800	Perimount 2800	Peri/inside	True ID = Stent ID -1mm	21/20/19	24	+3/+4/+5	16
Magna 3000				19/18/17 21/20/19 23/22/21	20 24 24	+1/+2/+3 +3/+4/+5 +1/+2/+3	20 17 18
Magna ease 3300				21/20/19	22	+1/+2/+3	18

PSF	Image	Pericardial or porcine/ suture inside or outside	Effect of Leaflet Type and Mounting on the Stent ID	Label size/Stent ID/True ID (mm)	Balloon size (mm)	Balloon size larger than Label size/Stent ID/True ID (mm)	Balloon pressure at fracture (atm)
Mosaic	Mosaic	Por/inside	True ID = Stent ID -2mm	21/18.5/17 23/20.5/19	22 26	+1/+3.5/+5 +3/+5.5/+7	8 10
Biocor				21/19/17	24	+3/+5/+7	14
Biocor supra	Biocor			21/21/19	22	+1/+1/+3	8
Labcor supra				23/23/21	24	+1/+1/+3	6
Mitroflow	Mitroflow	Peri/outside	True ID = Stent ID	21/17.3/17	20	-1/+2.7/+3	20
CROWN				21/17.3/17	20	-1/+2.7/+3	18

NF	Image	Pericardial or porcine/ suture inside or outside	Effect of Leaflet Type and Mounting on the Stent ID	Label size/Stent ID/True ID (mm)	Balloon size (mm)	Balloon size larger than Label size/Stent ID/True ID (mm)	Expandable or non-expandable
Perimount 2700	Perimount 2700	Peri/inside	True ID = Stent ID -1mm	21/20/19	22	+1/+2/+3	Expandable
Soprano				24/23.7/23.5	28	+4/+4.3/+4.5	Non
Hancock II	Hancock II	Por/inside	True ID = Stent ID -2mm	21/18.5/16.5	24	+3/+5.5/+7.5	Expandable
Aspire				21/19/18	20	-1/+1/+2	Non
Trifecta	Dokimos	Peri/outside	True ID = Stent ID	21/19/19	22	+1/+3/+3	Non
Dokimos				23/20/20	24	+1/+4/+4	Non

Figure 3. Classification of Fractured SHVs according to the physical properties of the stent frame. Upper row (Metal band): SHVs that required high balloon pressure (Perimount 2800, Magna 3000, and Magna Ease 3300). Middle row (Polymer stent, low balloon pressure): Subset of SHVs that required low balloon pressure for BVF (Mosaic, Biocor, Biocor Supra, and Labcor Supra). Lower row (Polymer stent, high balloon pressure): Subset of SHV with intermediate to high balloon pressure required for BVF (Mitroflow and Crown).
Abbreviations: BVF, bioprosthetic valve fracture; MSF, metal stent frame; NF, nonfracturable; PSF, polymer stent frame; SHV, surgical heart valve.

bovine pericardial leaflets sewn outside the stent. Balloon size at fracturing was True ID plus 3 mm and required high pressure (18 or 20 atm).

3) **Nonfracturable (NF):** Valves in this group can have a MSF (Perimount 2700 and Trifecta) or a PSF (Hancock II, Soprano, Dokimos and Aspire).

SHV Area Change Assessed by CTA During Bench Testing

The changes in SHV area assessed by CTA are summarized in Figure 4.

Fracturable With MSF

Three SHVs with confirmed BVF on fluoroscopy (red translucent box), had significant increases in the SHV area after BVF both at the inflow (average 12.3%) and outflow (10.6%) level.

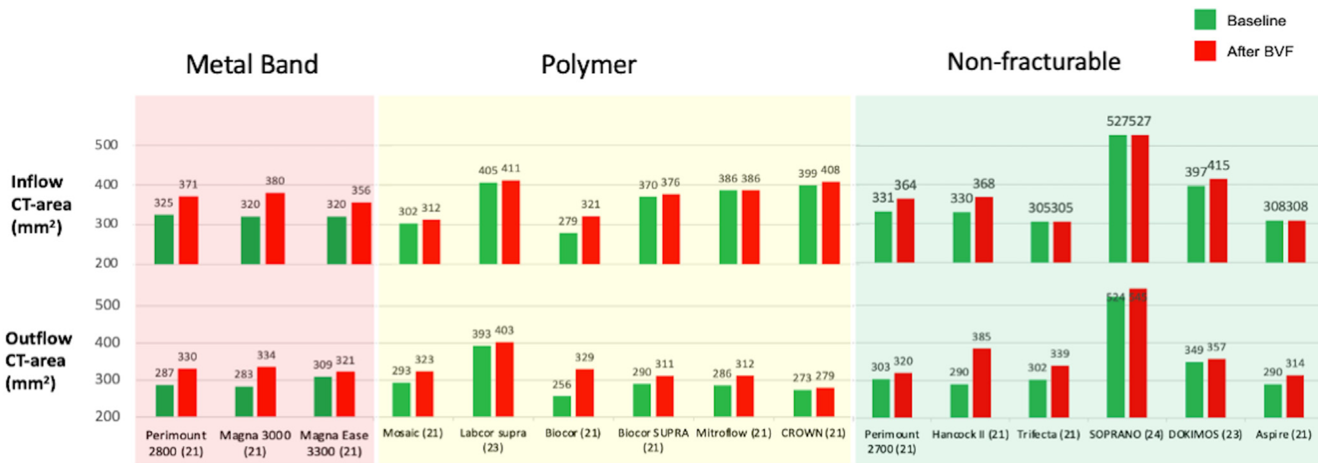
Fracturable With PSF

For the Mosaic, Labcor, Biocor Supra, Mitroflow, and Crown SHV which were fractured without visible disruption of the basal ring on fluoroscopy (yellow translucent box), increases in the inflow SHV area were less pronounced (average < 3.6%).

At the outflow level, increase in SHV area was moderate (8.5%) with the exception of Biocor that had a marked (22%) expansion at the outflow but it required a large balloon (True ID plus 7 mm).

NF

Among NF SHVs (Trifecta, Hancock II, Perimount 2700, Soprano, Dokimos, and Aspire), no significant changes in inflow SHV area were seen for Trifecta, Soprano, and Aspire (0%). Overall, gains at the inflow level for this group were 3.8% but this was driven primarily by expansion of 2 valves, Perimount 2700 and Hancock II, both of which



		Perimount 2800 (21)	Magna 3000 (21)	Magna Ease 3300 (21)	Mosaic (21)	Labcor supra (23)	Biocor (21)	Biocor SUPRA (21)	Mitroflow (21)	CROWN (21)	Perimount 2700 (21)	Hancock II (21)	Trifecta (21)	SOPRANO (24)	DOKIMOS (23)	Aspire (21)
SHV Area increasing rate (%)	Inflow	+12.4	+15.8	+8.7	+3.2	+1.5	+13.1	+1.6	±0	+2.2	+9.1	+10.3	±0	±0	+4.3	±0
	Outflow	+13.0	15.3	+3.7	+9.2	+2.5	+22.2	+6.8	+8.3	+2.2	+5.3	+24.7	+10.9	+3.9	+2.2	+7.6
Balloon size at fracture (mm)		24	24	22	22	24	24	22	20	20	-	-	-	-	-	-
Balloon pressure at fracture (atm)		16	17	18	8	6	14	8	20	18	-	-	-	-	-	-
Maximum Balloon size		-	-	-	-	-	-	-	-	-	22	24	22	28	24	20
Balloon size larger than true ID (mm)		+5	+5	+3	+5	+3	+7	+3	+3	+3	+3	+7	+3	+4.5	+4	+2

Figure 4. Changes on structural heart valve area at the inflow and outflow level after bioprosthetic valve fracture (BVF).
Abbreviation: CT, computed tomography.

showed 10% gains at the inflow. Gains at the outflow were moderate (9.1%).

Intraobserver repeatability for *baseline* and post-BVF *inflow* (ICC = 0.978, 95% CI: 0.917-0.994), and *outflow* SHV area (ICC = 0.991, 95% CI: 0.960-0.998) was excellent.

Discussion

We conducted a series of bench experiments on a wider variety of bioprosthetic valves to refine our understanding of the emerging field of BVF. There are several important findings. First, surgical valves contain different materials and physical properties, which in turn determine the size and pressure required for disruption of the basal ring or inflow as well as predicted gains in SHV area. We propose a classification based on the type and structure of each bioprosthetic valve (fracturable with MSF, fracturable with PSF, or nonfracturable) to facilitate and standardize balloon selection, pressure thresholds, and fluoroscopic appearance for optimal BVF. Second, we quantified changes in surgical valve areas at the inflow and outflow level with CTA and demonstrated influence of stent frame material on recoil. MSFs valves have greater expansion after BVF whereas PSF valves, despite using similar size balloons, have more elastic recoil as assessed by reduced expansion on CT. Third, we demonstrated significant inflow dimension changes in Hancock II valve, which was thought to be nonfracturable.

Author's Recommendations for Optimal Balloon Sizing for BVF

Fracturable MSF SHV

We recommend using the ***true ID plus 5-mm*** balloon to fracture SHV with a metal frame. Although fracture may also be achieved with true ID plus 3-mm balloons, it requires higher pressure, may not be evident on fluoroscopy and may not result in significant gain in inflow dimensions. The use of a larger balloon that is true ID plus 5-mm fractures the basal ring reliably at lower pressures.

Fracturable PSF SHV

Although all polymer valves are made of Acetal homopolymer such as Delrin, the construct and thickness may determine the pressure at which a SHV can be fractured and also result in recoil of variable degrees, as observed in our study.

Thus, 3 valves (Biocor Supra, Mosaic and Labcor) were fractured at relatively low balloon pressure but despite a successful BVF procedure the inflow level area did not significantly change when measured on CTA, which suggests recoil of the polymer. This may have practical implications on midterm and long-term results. In these 3 valves, we recommend using ***true ID plus 3-mm*** balloon for BVF. Although Biocor Supra (true ID plus 3 mm) and Biocor Standard (true ID plus 7 mm) required different balloon sizes to achieve BVF, the construct of the basal ring is similar so it seems prudent to start with a smaller balloon and upsize if necessary.

On the other hand, Mitroflow and Crown have a PSF as well, using a balloon size equal to true ID plus 3 mm achieved BVF but required relatively high pressure (18-20 mm). Interestingly, the valve area at the inflow level measured by CTA did not change. This may reflect the strength of the polymer as stronger material requires higher pressure but can also lead to more recoil. This is further supported by the fact that in previous series, a balloon size of true ID plus 5 mm was required to achieve BVF. In these cases, the reported pressure was nearly half of that observed in our experiments on the bench with smaller balloon. Hence, it could be recommended to use a ***true ID plus 5-mm*** balloon for these valves. This will help achieve a reliable fracture and help prevent leaflet injury with higher balloon pressure observed with smaller size balloon.

Of note, in Mitroflow or Crown, the polymer within the sewing ring is not fluoroscopically visible. The radiopaque cloth strip outside the polymer remains intact after valve fracture and prevents fluoroscopy from documenting valve fracture. Fracture/disruption of the fluoroscopic marker in Mitroflow or Crown will signify disruption of the sewing ring and can cause significant complications such as ventricular septal defect of conduction disorder as previously reported when a true ID plus 7-mm balloon was used.[14] Therefore, using disruption of the fluoroscopic marker to assess efficacy of BVF is not advised for these 2 SHVs. As previously noted, the polymer used in Mosaic SHV was changed from Delrin to PEEK in 2016; hence Mosaic valves implanted after 2016 may not be fracturable.

Expandable (NF) SHV: Perimount 2700 and Hancock II did not meet the definition of BVF, but interestingly, the area measured by CT was significantly higher and consistent with meaningful expansion of both inflow and outflow of the SHV. BVF should be considered when clinically indicated.

Finally, recent analyses from the TVT registry showed that the timing of BVF in relationship to THV implant is an important determinant of the safety and efficacy of the procedure. BVF performed before THV implant was associated with increased mortality and insignificant gains in valve area. These observations suggest that, when clinically indicated, BVF should be performed after, rather than before, THV implantation.[15]

Limitations

Our study has important limitations. First, we examined the balloon size and pressure required for BVF and changes in SHV and THV areas after BVF using different techniques, but we did not examine hemodynamic parameters, which is arguably the most important goal of BVF. Although PPM and residual pressure gradients are affected by the implantation depth and type of THV device, the inflow SHV area regulates the amount of blood flow into the aorta from the left ventricle, so the assessment of the SHV area in this study could be used as an imperfect surrogate marker for PPM. Second, structure of the surgical valve as determined by CTA was only studied once (i.e., after BVF was confirmed). For valves that required multiple balloon dilations, it is possible that the structure of the valve might have been affected by serial dilations below the threshold required to fracture. Third, further research is needed on the effectiveness of the new classification that determines the balloon size for BVF and whether SHV remodeling without fracture can improve hemodynamics in clinical cases. Finally, quantification of acute recoil in PSF valves requires further study.

Conclusions

Gains in CT-determined valve area after BVF depend on the physical properties of the surgical valve, which in turn influences pressure thresholds and balloon sizing strategy for optimal BVF. Elastic recoil of PSF valves limits the gains in inflow area after BVF.

ORCIDs

Go Hashimoto https://orcid.org/0000-0001-5067-2786
Santiago Garcia https://orcid.org/0000-0002-1806-6783
Miho Fukui https://orcid.org/0000-0002-7235-5551

Funding

The authors have no funding to report.

Disclosure Statement

Dr Bapat is a consultant for Medtronic, Edwards Lifesciences, Boston Scientific, and Abbot Vascular. Dr Garcia is a consultant for Medtronic, Edwards Lifesciences, BSCI, and Abbott Vascular. Institutional research grants from Edwards Lifesciences, Abbott vascular, Gore, and BSCI. Proctor for Edwards Lifesciences. Dr Cavalcante has received consulting fees from Boston Scientific and Abbott Vascular, and from research grant support from Circle Cardiovascular Imaging, Edwards Lifesciences, Medtronic, Boston Scientific, and Abbott Vascular; and has been a speaker for Medtronic, Circle Cardiovascular Imaging, and Siemens Healthineers. The other authors had no conflicts to declare.

Supplementary Material

Supplemental data for this article can be accessed on the publisher's website.

References

1 Isaacs AJ, Shuhaiber J, Salemi A, Isom OW, Sedrakyan A. National trends in utilization and in-hospital outcomes of mechanical versus bioprosthetic aortic valve replacements. *J Thorac Cardiovasc Surg*. 2015;149(5):1262-1269.e3. https://doi.org/10.1016/j.jtcvs.2015.01.052
2 Thourani VH, Suri RM, Gunter RL, et al. Contemporary real-world outcomes of surgical aortic valve replacement in 141,905 low-risk, intermediate-risk, and high-risk patients. *Ann Thorac Surg*. 2015;99(1):55-61. https://doi.org/10.1016/j.athoracsur.2014.06.050
3 Cartlidge TRG, Doris MK, Sellers SL, et al. Detection and prediction of bioprosthetic aortic valve degeneration. *J Am Coll Cardiol*. 2019;73(10):1107-1119. https://doi.org/10.1016/j.jacc.2018.12.056
4 Webb JG, Murdoch DJ, Alu MC, et al. 3-Year outcomes after valve-in-valve transcatheter aortic valve replacement for degenerated bioprostheses. *J Am Coll Cardiol*. 2019;73(21):2647-2655. https://doi.org/10.1016/j.jacc.2019.03.483
5 Dvir D, Webb JG, Bleiziffer S, et al. Transcatheter aortic valve implantation in failed bioprosthetic surgical valves. *JAMA*. 2014;312(2):162. https://doi.org/10.1001/jama.2014.7246
6 Goldstone AB, Chiu P, Baiocchi M, et al. Mechanical or biologic prostheses for aortic-valve and mitral-valve replacement. *N Engl J Med*. 2017;377(19):1847-1857. https://doi.org/10.1056/NEJMoa1613792
7 Faerber G, Schleger S, Diab M, et al. Valve-in-Valve transcatheter aortic valve implantation: the new playground for prosthesis-patient mismatch: VIV TAVI and PPM. *J Interv Cardiol*. 2014;27(3):287-292. https://doi.org/10.1111/joic.12108
8 Nielsen-Kudsk JE, Christiansen EH, Terkelsen CJ, et al. Fracturing the ring of small mitroflow bioprostheses by high-pressure balloon predilatation in transcatheter aortic valve-in-valve implantation. *Circ Cardiovasc Interv*. 2015;8(8):e002667. https://doi.org/10.1161/CIRCINTERVENTIONS.115.002667
9 Chhatriwalla AK, Allen KB, Saxon JT, et al. Bioprosthetic valve fracture improves the hemodynamic results of valve-in-valve transcatheter aortic valve replacement. *Circ Cardiovasc Interv*. 2017;10(7):e005216. https://doi.org/10.1161/CIRCINTERVENTIONS.117.005216
10 Allen KB, Chhatriwalla AK, Cohen DJ, et al. Bioprosthetic valve fracture to facilitate transcatheter valve-in-valve implantation. *Ann Thorac Surg*. 2017;104(5):1501-1508. https://doi.org/10.1016/j.athoracsur.2017.04.007
11 Allen KB, Chhatriwalla AK, Saxon JT, et al. Bioprosthetic valve fracture: technical insights from a multicenter study. *J Thorac Cardiovasc Surg*. 2019;158(5):1317-1328.e1. https://doi.org/10.1016/j.jtcvs.2019.01.073
12 Chhatriwalla AK, Sorajja P. Expanding indications for bioprosthetic valve fracture and bioprosthetic valve remodeling: who is most likely to benefit? *Circ Cardiovasc Interv*. 2018;11(8), e007017. https://doi.org/10.1161/CIRCINTERVENTIONS.118.007017
13 Saxon JT, Allen KB, Cohen DJ, Chhatriwalla AK, et al. Bioprosthetic valve fracture during valve-in-valve TAVR: bench to bedside. *Interv Cardiol*. 2018;13(1):20-26. https://doi.org/10.15420/icr.2017:29:1
14 Hashimoto G, Cavalcante JL, Mooney MR, Burns MR, Ukaigwe AC, Garcia S. Assessment of aortic bioprosthetic valve fracture by computed tomography angiography. *J Cardiovasc Comput Tomogr*. 2021;15(1):e7-e9. https://doi.org/10.1016/j.jcct.2020.09.002
15 Chhatriwalla AK, Allen KB, Depta JP, et al. Outcomes of bioprosthetic valve fracture in patients undergoing valve-in-valve TAVR. *JACC Cardiovasc Interv*. 2023;16(5):530-539. https://doi.org/10.1016/j.jcin.2022.12.019