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Gradient and pressure recovery of a self-expandable transcatheter aortic valve depends on ascending aorta size: In vitro study

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Gradient and pressure recovery of a self-expandable transcatheter aortic valve depends on ascending aorta size: In vitro study

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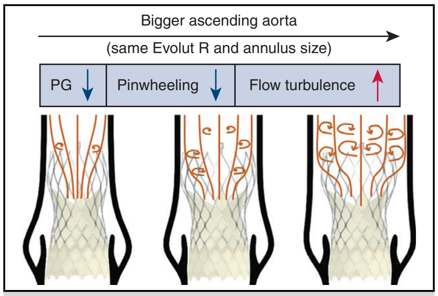
ABSTRACT

Objective: In this study we aimed to understand the role of interaction of the Medtronic Evolut R transcatheter aortic valve with the ascending aorta (AA) by evaluating the performance of the valve and the pressure recovery in different AA diameters with the same aortic annulus size.

Methods: A 26-mm Medtronic Evolut R valve was tested using a left heart simulator in aortic root models of different AA diameter (D): small (D = 23 mm), medium (D = 28 mm), and large (D = 34 mm) under physiological conditions. Measurements of pressure from upstream to downstream of the valve were performed using a catheter at small intervals to comprehensively assess pressure gradient and pressure recovery.

Results: In the small AA, the measured peak and mean pressure gradient at vena contracta were 11.5 ± 0.5 mm Hg and 7.8 ± 0.4 mm Hg, respectively, which was higher (*P* < .01) compared with the medium (8.1 ± 0.4 mm Hg and 5.2 ± 0.4 mm Hg) and large AAs (7.4 ± 1.0 mm Hg and 5.4 ± 0.6 mm Hg). The net pressure gradient was lower for the case with the medium AA (4.1 ± 1.2 mm Hg) compared with the small AA (4.7 ± 0.8 mm Hg) and large AA (6.1 ± 1.4 mm Hg; *P* < .01).

Conclusions: We have shown that small and large AAs can increase net pressure gradient, because of the direct interaction of the Medtronic Evolut R stent with the AA (in small AA) and introducing higher level of turbulence (in large AA). AA size might need to be considered in the selection of an appropriate device for transcatheter aortic valve replacement. (JTCVS Open 2022;9:28-38)



For the same Evolut R (Medtronic) and annulus size, gradients strongly depend on the ascending aorta size.

CENTRAL MESSAGE

The size of ascending aorta might be an important parameter for the self-expandable transcatheter heart valve sizing and valve choice.

PERSPECTIVE

For the first time, we have examined the influence of the varying AA diameters within an acceptable range on the Medtronic Evolut R TAVR device's performance and pressure recovery. We demonstrated that for the same Evolut R and annulus size, pressure gradients strongly depend on the AA size.

See Commentaries on pages 39 and 41.

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Abbreviations and Acronyms

AA = ascending aorta
AS = aortic stenosis
BE = balloon-expandable
Echo = Doppler echocardiography
LV = left ventricle
LVOT = left ventricular outflow tract
PG = pressure gradient
PI = pinwheeling index
PR = pressure recovery
SE = self-expandable
T = instantaneous time during cardiac cycle
TAVR = transcatheter aortic valve replacement
THV = transcatheter heart valve
VC = vena contracta

▶ Video clip is available online.

Transcatheter aortic valve replacement (TAVR) has emerged as a minimally invasive alternative to the highly invasive surgical aortic valve replacement for severe, symptomatic aortic stenosis (AS); however, surgical aortic valve replacement is still the gold standard. For patients who are candidates for bioprosthetic valve replacement, recent societal guidelines give a class I indication to consideration for TAVR, depending on a balance of life expectancy and valve durability.[1] Recent studies suggest mortality rates might differ for the 2 commercially available transcatheter heart valves (THVs), favoring the balloon-expandable (BE) valve[2,3] despite reports suggesting higher post-TAVR gradients compared with the self-expandable (SE) valve.[4] The 2 key hemodynamic parameters for evaluation of aortic valve performance are mean and peak transvalvular pressure gradients (PGs).[1,5-7] Peak gradient occurs at the vena contracta (VC); beyond the point of the VC (within the ascending aorta [AA]), the blood flow decelerates and kinetic energy (velocity) is consequently converted back to potential energy (pressure). This phenomenon is called pressure recovery (PR) and might significantly affect the calculation of aortic valve effective orifice area[8,9]; however, PR is not typically quantified using standard noninvasive measurements.

A standard noninvasive approach to assessing transvalvular PG after prosthetic aortic valve replacement is Doppler echocardiography (Echo)[10,11] to measure the transvalvular peak velocity at the VC and then calculating peak PG using the simplified Bernoulli equation. There is also an invasive approach to evaluate PG using percutaneous cardiac catheterization.[12] This technique usually requires the use of a side-hole catheter within the AA, thus measuring pressures beyond the VC. PGs on the basis of Echo and catheter represent valuable information about valve performance but have frequently been reported to be discordant with Echo, with overestimation of invasive measurements, and with other imaging modalities.[6,13] A significant clinical knowledge gap exists in measurements for these 2 distinct modalities.

The process of selecting the appropriate THV relies on computed tomography measurements of the annulus size.[14,15] In a recent study from our group,[16] an in vitro PR comparison was performed for a BE and SE THV. This study highlighted the influence of the taller SE stent frame on the efficiency of PR[16,17] through interaction with the downstream flow in the AA and causing disturbances in the flow field. The fluttering of the THV leaflets also helped in increasing the level of turbulence. In that study, it was also shown that the SE THV has a lower PR and lower PG at the VC (PG_{max}) compared with the BE THV.[16] The lower PR with the SE THV compared with the BE THV was not observed in a study by Stanova and colleagues.[18] In their study, the 2 THV types had similar PR (approximately 45%). They also reported that the SE THV had a lower mean gradient compared with the BE THV and argued that it is because the stent was not compressed by the aortic walls. However, other studies have shown that pre-valve, in-stent increases in gradient (thus not related to valve function) are seen with the BE THV and might account for these measured differences.[16,19] As a result, it is important to assess the hemodynamics of the SE THV when it interacts with different AA sizes. The objective of this study was to examine the influence of the AA size on the performance of an implanted SE transcatheter aortic valve. To achieve this goal, 3 sets of aortic chambers with the same geometrical features except AA size were used.

METHODS

Left Heart Simulator

An in vitro experimental setup was developed to investigate the role of the AA size on the performance of a 26-mm Evolut R (Medtronic) valve. A left heart simulator was used to subject pulsatile flow on a 26-mm Evolut R THV at 3 different AA sizes. Although sinus size is also a function of the aortic annulus, this parameter was set constant for the 3 different AA sizes. The selected AA sizes were derived from the patient statistical distribution and span the distribution of the normal value of AA sizes.[14] The size and label of the aortic chambers used are tabulated in Table 1. The small, medium, and large AAs were selected on the basis of the 5th, 50th, and 95th percentile of the distribution, respectively.

The flow loop consists of a reservoir, a bioprosthetic mitral valve, a bladder pump (acting as the left ventricle [LV]) controlled by a custom LabVIEW program and driven by compressed air, an aortic chamber model in which a 26-mm Medtronic Evolut R valve was placed, and a compliance chamber and resistance valve to control the aortic pulse pressure. The schematic of this pulse duplicator left heart simulator is shown and described in previous studies.[20,21] The loop was filled with a water-glycerin mixture (40% glycerin by volume) to mimic the blood properties (kinematic

TABLE 1. Dimensions of all 3 aortic chambers with different AA sizes

Label	Small AA	Medium AA	Large AA
AA diameter (mm)	23	28	34
AA/annulus ratio	1.05	1.27	1.55

In all 3 chambers, the size of the aortic annulus is $D_0 = 22$ mm. *AA*, Ascending aorta; D_0, aortic annulus size.

viscosity = 3.3 mm^2/s; density = 1080 kg/m^3) at room temperature (25°C). The aortic chamber model is as shown in Figure 1. The aortic valve annulus is located at X = 0 cm, and the Evolut was deployed as recommended in the report by Giannini and colleagues.[22]

Experimental Protocols

The flow loop imposed physiological hemodynamics (peak aortic flow = 24.2 ± 0.2 L/min; heart rate = 60 beats per minute; systolic/diastolic aortic pressure = 120/80 ± 1 mm Hg) in all 3 sets of experiments. The aortic annulus size (D_0) was kept constant ($D_0 = 22$ mm, the appropriate annular dimensions for a 26-mm Evolut R THV[23,24]) in all experiments, and the only variable parameter was the size of the AA as shown in Figure 1. The inflow diameter of the 26-mm Evolut R valve is 26 mm, with a frame height of 45 mm, skirt height of 13 mm, and stent top diameter of 32 mm.[25] Thus, the distal (aortic) edge of the fully-opened leaflet is located at X = 2.4 cm as shown in Figure 1.

Data Acquisitions

Flow data were acquired using a clamp-on ultrasonic flowmeter (Transonic Systems Inc). Pressure measurements were performed along the axial center line of the aortic root from upstream to downstream of the valve using a Millar catheter (ADInstruments Inc) with intervals of 1 mm inside the valve and 5 mm downstream of the valve. Pressure measurement was performed on a total length of 10 cm (Figure 1). X = 0 cm corresponds to the first measurement location, which is the ventricular pressure (upstream of the valve annulus). X = 10 cm

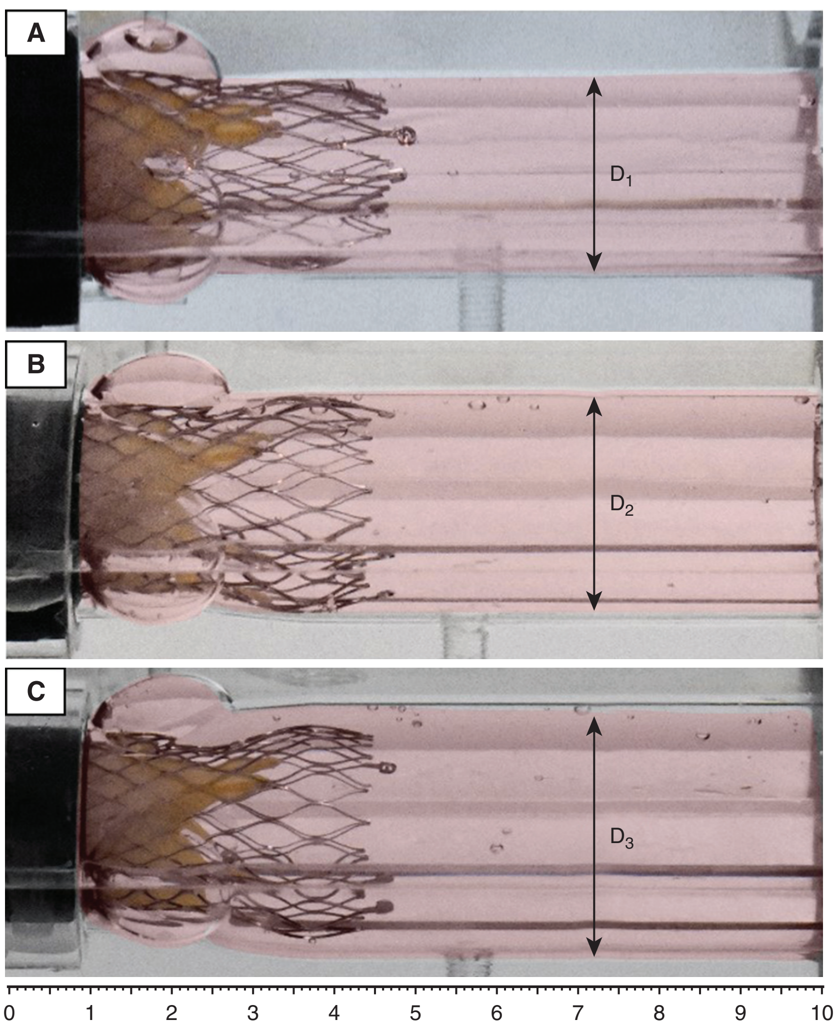


FIGURE 1. The experimental setup of a deployed Evolut R (Medtronic) transcatheter aortic valve in aortic root chambers of the left heart simulator. X = 0 denotes the annulus. The Evolut R valve is deployed in chambers with different ascending aorta (AA) size: (A) small AA ($D_1 = 23$ mm), (B) medium AA ($D_2 = 28$ mm), and (C) large AA ($D_3 = 34$ mm). The diameter of the aortic annulus is $D_0 = 22$ mm in (A), (B), and (C). D_0, aortic annulus size; D_1, small AA size; D_2, medium AA size; D_3, large AA size.

corresponds to the last measurement location, which is the furthermost downstream location (Figure 1). Physiological hemodynamics imposed include physiological LV pressures observed at 0 cm upstream of the aortic valve annulus and physiological aorta pressures observed 5.5 cm downstream of the aortic valve annulus. Data were acquired for 200 consecutive cardiac cycles at a sampling rate of 100 Hz for each axial location.

En-face images were recorded using a high-speed camera at a frame rate of 1 kHz. Using the en-face image in diastole, pinwheeling index (PI) was calculated, similar to previous publications,[20,26,27] as follows:

$$PI = \frac{L_{actual} - L_{ideal}}{L_{ideal}} \times 100$$

Where L_{actual} and L_{ideal} represent the deflected and unconstrained free edge of the leaflet, respectively. The PI indicates leaflet durability[28,29] and quantifies the amount of leaflet twisting. Pinwheeling is correlated with premature tissue degradation[26] and should be minimized in the leaflet postdeployment.

Data Postprocessing

The mean pressure and SD were calculated at a given time and axial location across the 200 cycles. The PG was defined as the difference between the upstream pressure at the first location of X = 0 (ventricular pressure) and the pressure value at each location. We report on 2 PGs: peak flow PG and mean PG. Peak flow PG is considered as the PG at the peak flow time point (note this differs from peak PG, which occurs earlier than the peak flow time[16]). Mean PG is the mean value of PG at each location, calculated by averaging the positive values of PG during the forward flow at the given location. PG_{max}, PG at recovery zone (PG_{net}), and PR ($PR = PG_{max} - PG_{net}$) were calculated (Figure 2). The PR zone was defined as the measured pressure at the end of the aortic root chamber (the typical pullback range is 5-8 cm from the aortic annulus as shown in Figure 3). We calculated PG_{net} on the basis of the PG at X = 7 cm. PR percentages were calculated as follows:

$$PR\ \ percentage = 100 \times \frac{PG_{max} - PG_{net}}{PG_{max}}$$

Statistical Analysis

The pressure data were analyzed using JMP Pro 15 (SAS Institute) to evaluate PGs at the VC and recovery zone within the 3 sizes of aortic chambers. The non-normality of the data was confirmed using the Kolmogorov–Smirnov test with $P < .15$. The Wilcoxon method was used for nonparametric comparison of PGs at the VC and recovery zone pairwise for the AA sizes.

Patient Data Collection

One hundred fifty-six patients who underwent TAVR with a self-expanding CoreValve prosthesis (Medtronic Inc) between January 2015 and November 2019 at Ohio State University Wexner Medical Center were retrospectively analyzed with institutional review board approval (protocol title: OSU: Developing Precision Medicine Guidelines for Trans-Catheter Aortic Valve Replacement; principal investigator: Lakshmi Prasad Dasi; protocol number: H20010; Approval date: February 27, 2020). After deployment, the invasive PGs were measured via catheterization. Transducers were zeroed immediately before measurement, and the pressure was measured 3 cm above the annulus and averaged over 5 cardiac cycles. Echo was performed within 24 hours of the procedure, and Doppler PGs were measured across the valve. The PR was then calculated in each patient as the difference between the Echo PG and the catheter-derived gradient. This is because the catheter-derived gradient is measured between the valve and AA, thus factoring the PR.

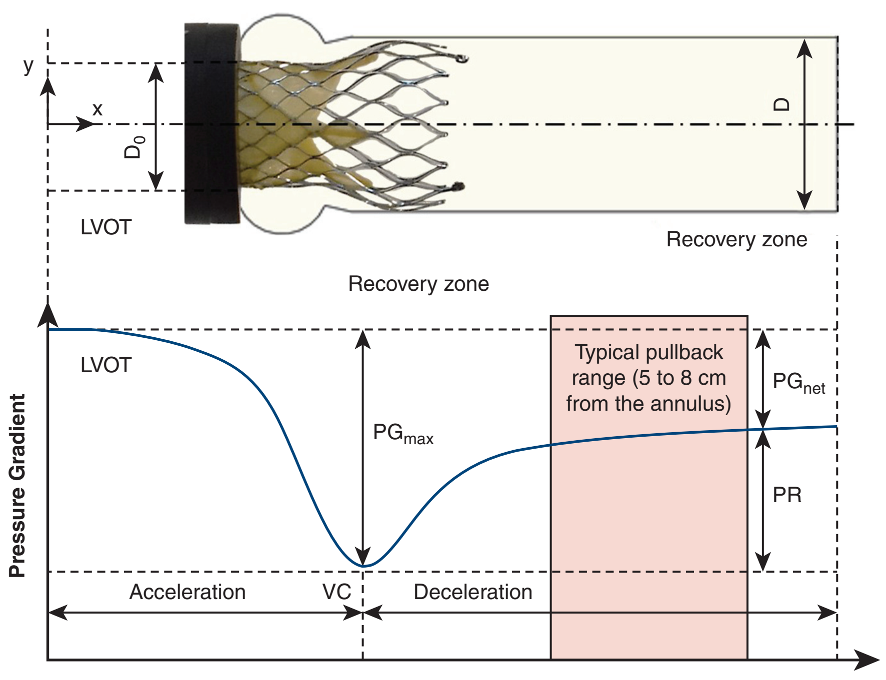


FIGURE 2. Peak and net gradients. Upstream and downstream of the valve represent left ventricular outflow tract (*LVOT*) and the recovery zone, respectively. By crossing blood flow through the aortic valve, pressure does not recover to the LVOT pressure values, because of energy losses. The amount of pressure recovered at the recovery zone (difference between peak pressure and net pressure) is called pressure recovery (*PR*). The typical pullback range is 5 to 8 cm from the annulus. D_o, aortic annulus size; *D*, diameter; PG_{max}, PG at VC; PG_{net}, PG at recovery zone; *VC*, vena contracta.

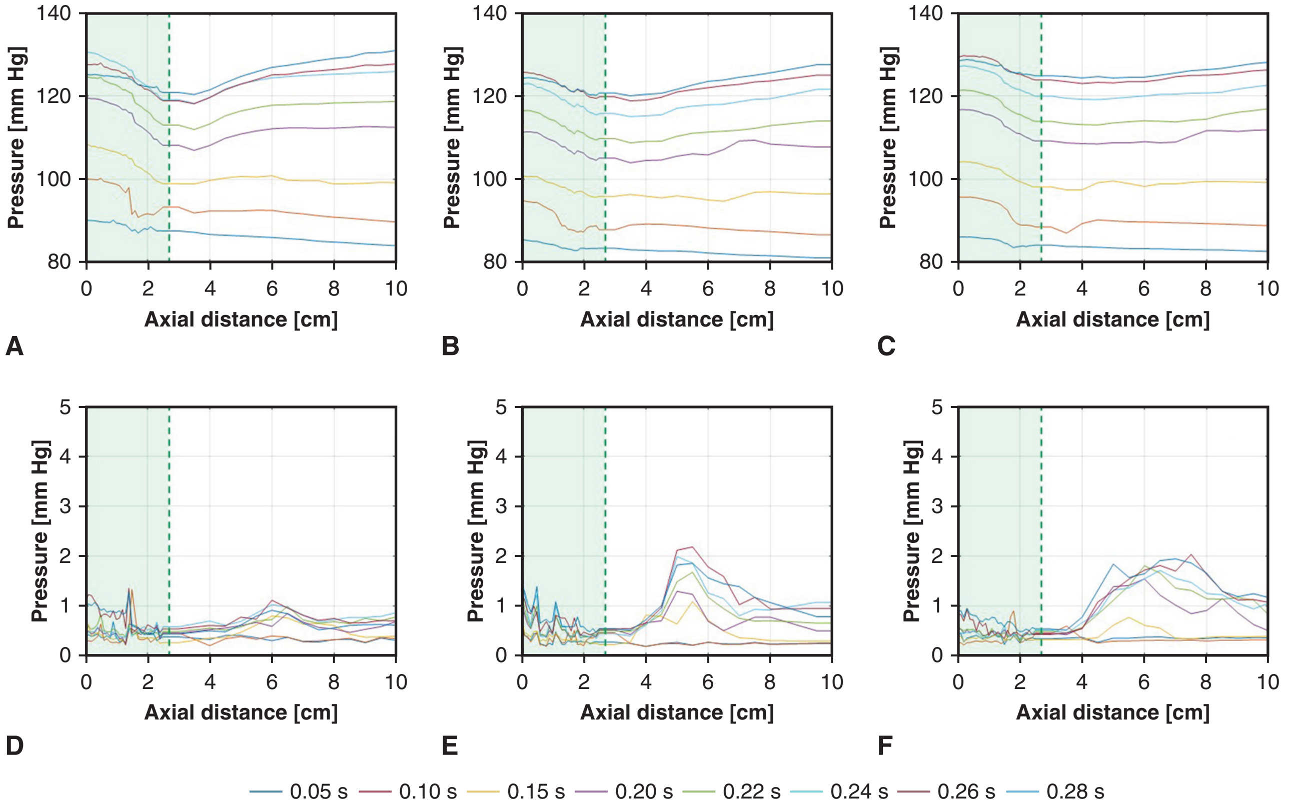
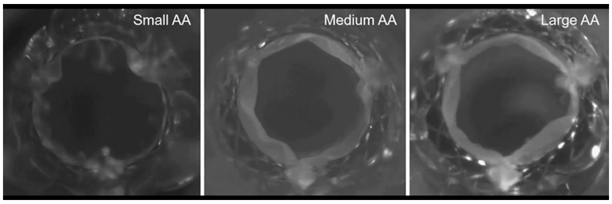


FIGURE 3. Averaged and standard deviation of the measured pressures as a function of axial length. Each curve is an average of 200 consecutive cardiac cycles. Averaged pressures at 8 different time points during systole from aortic flow acceleration to deceleration are plotted at (A) small ascending aorta (AA), (B) medium AA, and (C) large AA. The *horizontal axis* represents the longitudinal direction along the aortic chamber center line. Pressure standard deviation at 8 different time points during systole from aortic flow acceleration to deceleration are plotted at (D) small AA, (E) medium AA, and (F) large AA. The maximum flow rate occurs at T = 0.26 seconds (*magenta line*). The *green shaded area* represents the region of the valve from the inflow entrance to the edge of the fully-opened leaflet (*dashed line*).

The diameter of the AA was measured from Echo, and the size of the THV was recorded for each patient. The ratio of the AA diameter to the THV size was calculated and used to split the patient population into 2 groups. The large AA group was classified as being above the average AA diameter to THV size ratio and the small AA group was classified as being below this average ratio. The PR was then compared between the 2 groups.

RESULTS

The opening and closing of the valve leaflets for different AA sizes are shown in Video 1. These videos are recorded during systole plus 100 ms after valve closure for visualizing and measuring the PI. The highest PI value was observed in the small AA case (17.1% ± 2.9%), followed by medium AA (8.9% ± 1.5%) and large AA (3.3% ± 0.6%). Cycle-averaged pressure and pressure SD curves are plotted as a function of axial distance in Figure 3. The green shaded region shows the valve region, and the dashed line represents the fully opened leaflet at X = 2.6 cm. As a general trend in Figure 3, pressure values start dropping in the left ventricular outflow tract (LVOT) region from X = 0 to the lowest value at the VC. Peak flow occurs at T = 0.26 s (flow curves are presented in Figure 4, *A*).



VIDEO 1. En-face imaging views of the Evolut R (Medtronic) at 3 different aortic chamber arrangements throughout systole. Video available at: https://www.jtcvs.org/article/S2666-2736(22)00009-2/fulltext.

SD pressures are plotted versus axial distance during systole at different time points in Figure 4, *D-F*. The magnitude of SD downstream from the stent frame is higher than the valve region and LVOT. Also, higher fluctuations in pressure were observed with larger AAs, with a maximum value of fluctuation in the large and medium AAs of 2.1 mm Hg.

Flow rate curves are plotted in Figure 4, *A*. The peak flow rate is shown by a vertical black dashed line in Figure 4, *A*, and horizontal dashed lines in Figure 4, *B-G*. The values of

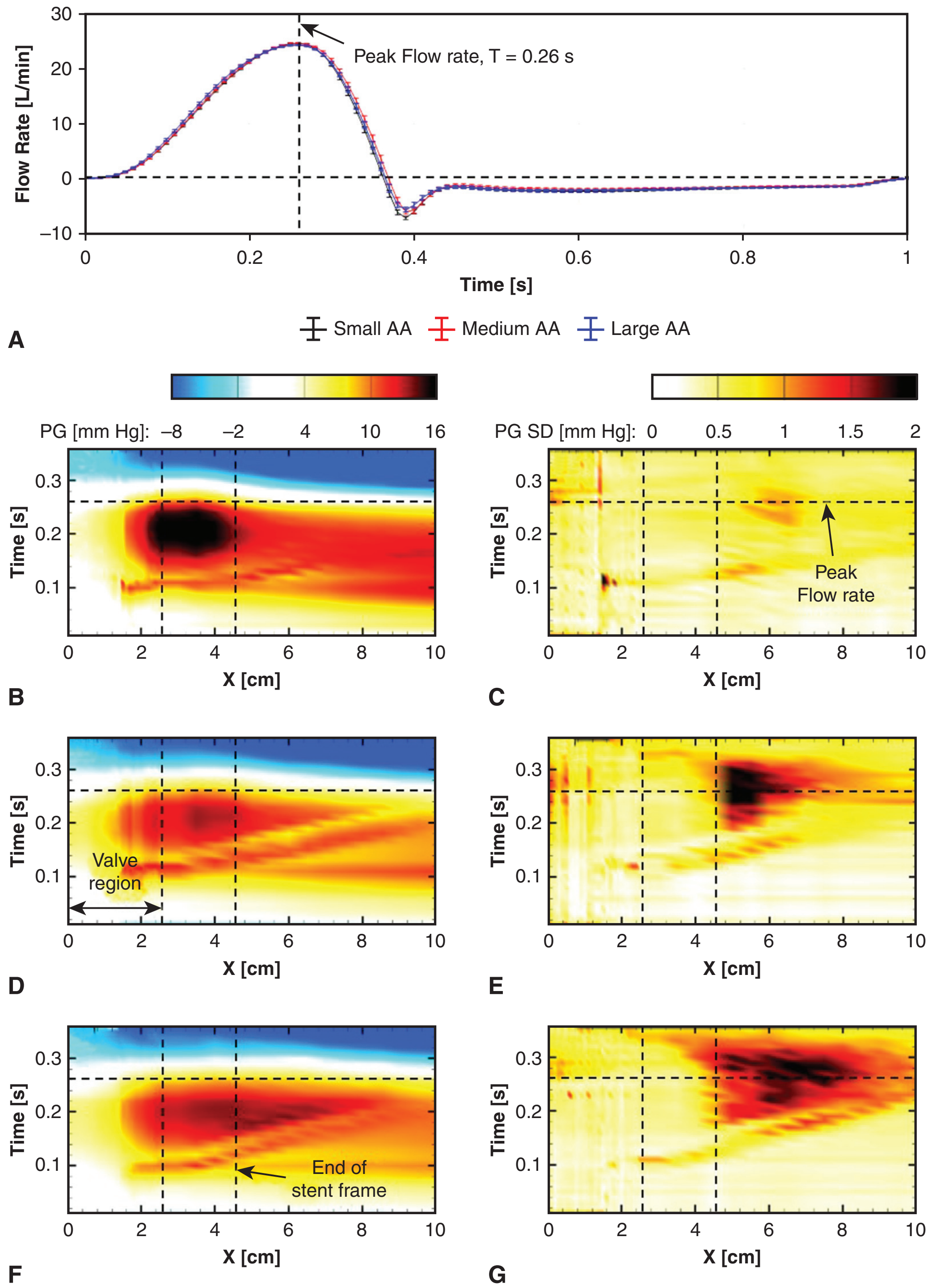


FIGURE 4. Measured aortic flow rates and calculated pressure gradients (*PG*) and corresponding standard deviations (*SD*) at different ascending aorta (*AA*) sizes. A, Averaged 200 consecutive cardiac cycles of aortic flow rate in different sizes of AA. *Error bars* represent standard deviations. Pressure gradient contours at continuous time points (T) from the start of systole (T = 0 seconds) to approximately the end of systole (T = 0.36 seconds) at different AA sizes: (B) small AA, (C) medium AA, and (D) large AA. The *horizontal axis* in (B-G) represents the longitudinal direction along the aortic chamber center line. Pressure gradient standard deviation contours at continuous time points from the start of systole (T = 0 seconds) to the end of systole (T = 0.36 seconds) at different AA sizes: (E) small AA, (F) medium AA, and (G) large AA. The *vertical dashed line* in (A) and also the *horizontal line* in (B-G) shows the peak flow rate (T = 0.26 seconds). The *vertical dashed lines* in (B-G) represent the region of the valve from the inflow entrance to the edge of the fully-opened leaflet and the rightmost one shows the end of the stent frame.

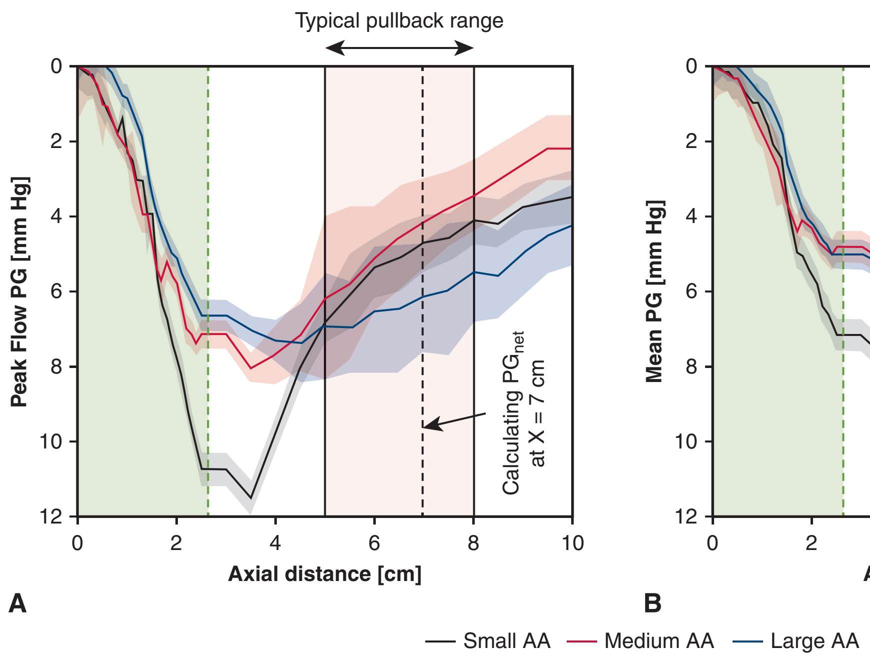


FIGURE 5. Pressure gradient (*PG*) curves as a function of axial distance at different ascending aorta (*AA*) size. A, Peak PG and (B) Mean PG. *Shaded curves* indicate standard deviations. The *horizontal axis* represents the longitudinal direction along the aortic chamber center line. The *green shaded area* represents the region of the valve from the inflow entrance to the edge of the fully-opened leaflet (*dashed line*). The *orange shaded region* shows the typical pullback traces of the pressure catheter perform by surgeons. The *vertical dashed black line* shows X = 7 cm, where we calculated PG at recovery zone (PG_{net}).

PG and corresponding pressure SD contours for all 3 cases are plotted as a function of systolic time and axial distance in Figure 5. As clearly visible in Figure 4, *B-D*, the peak PG occurs during the flow acceleration (T = approximately 0.2 s), which is approximately 60 ms before the peak flow rate (at T = 0.26 s) in the cardiac cycle. The valve leaflet range is depicted between X = 0 and the first vertical dashed line (at X = 2.5 cm). The rightmost vertical dashed line (at X = 4.5 cm) depicts the end of the stent frame (Figure 4, *B-G*). As visible in the SD contours in Figure 4, *E-G*, flows distal to the stent frame (at X = 4.5 cm) are more fluctuated.

Peak flow PG and mean PG curves for all 3 AA sizes are presented in Figure 5, *A* and Figure 5, *B*, respectively. The small AA has the highest PG_{max} (11.5 ± 0.5 mm Hg; $P < .01$) compared with the medium AA (8.1 ± 0.4 mm Hg) and large AA (7.4 ± 1.0 mm Hg). The net PG is lower

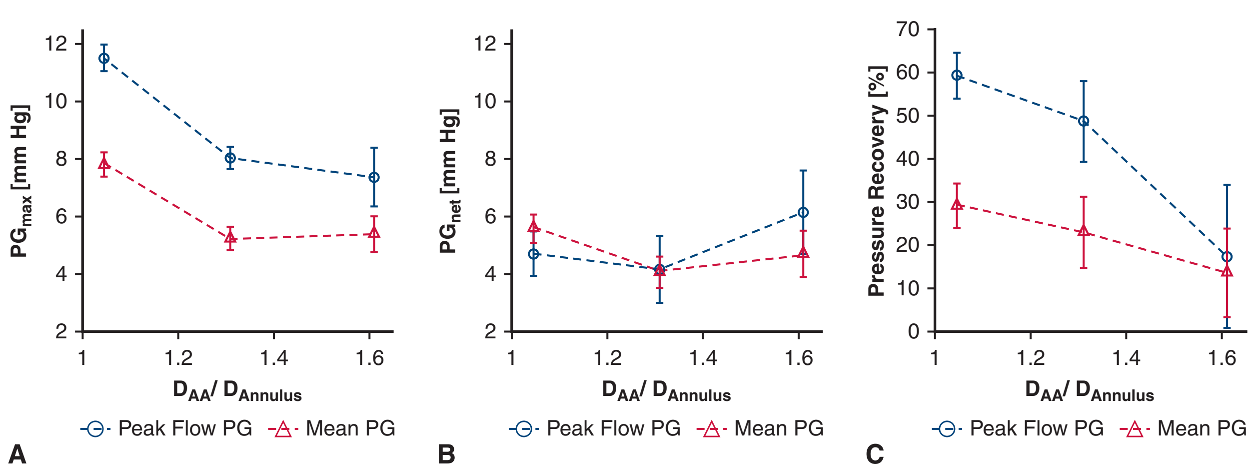


FIGURE 6. Pressure gradient (*PG*) and pressure recovery at 3 different ascending aorta (AA) sizes. Each data point is an average of 200 consecutive cardiac cycles. Pressure gradient at peak flow and mean pressure gradient are summarized as a function of the diameter of AA to the diameter of the annulus ratio at (A) vena contracta and (B) recovery zone. C, Pressure recovery percentage, which is defined as the difference between peak gradient and net gradient divided by peak gradient. *Error bars* denote standard deviations. PG_{max}, PG at VC; D_{AA}, AA diameter; $D_{Annulus}$, aortic annulus diameter; PG_{net}, PG at recovery zone.

with medium AA (4.1 ± 1.2 mm Hg; $P < .01$) compared with the small AA (4.7 ± 0.8 mm Hg) and large AA (6.1 ± 1.4 mm Hg).

The values of PG_{max} and PG_{net} at X = 7 cm are summarized in Figure 6 as a function of the ratio of the AA size to the annulus size. Also, PR percentages are plotted in Figure 6, *C*. PR percentage in peak flow PG is 59.2% ± 5.3%, 48.4% ± 9.6%, and 16.6% ± 16.8% in the small, medium, and large AA sizes, respectively. PR percentage in mean PG is 28.5% ± 5.2%, 22.3% ± 8.5%, and 12.8% ± 10.3% in the small, medium, and large AA sizes, respectively, as shown in Figure 6, *C*. Among the 3 AA sizes, differences in PG at peak flow and at mean PG measured at the VC and at the recovery zone were seen.

PR values in human studies were defined as the difference between Echo and catheter PGs and are plotted in Figure 7. The dataset was classified to 2 groups of AA sizes as large and small AA.

DISCUSSION

Patient-specific studies highlighted conflicting results when it comes to estimating PR in AS and TAVR patient cohorts.[30-32] Studies in native AS patients have suggested that PR can be estimated on the basis of the severity of AS and the size of the AA.[8] Recent studies showed that using the PR correction in a cohort of 697 patients resulted in the reclassification of nearly 25% of patients from severe AS to moderate AS. The reclassified moderate AS patients had a significantly better 4-year clinical event-free survival compared with patients who remained in the severe AS subgroup.[33] However, there is a paucity of data in the TAVR population. The SE THV is relatively less performed in patients with a dilated AA (>43 mm) or severely angulated aorta (aortoventricular angle >70°).[34,35] In this study, to our knowledge for the first time, we have examined the influence of AA diameter (within an acceptable range for the SE THV) on the performance and PR of the Medtronic Evolut R TAVR device. The Evolut R is characterized by a long, nitinol stent frame that gets compressed or expanded depending on the surrounding anatomy, in particular the diameter of the AA. Hence, it is important to quantify the effect of varying AA diameters on the valve's performance not only at the leaflet level but also in terms of the net gradient after taking into account PR effects.

The peak PG is the pressure at the VC subtracted from the LV pressure. Clinicians measure the peak velocity using Echo and use the simplified Bernoulli equation to calculate peak PG. Although the inappropriate assumptions of the simplified Bernoulli equation might explain some of the differences between Echo and invasive PG measurements,[13] other reasons for discordance have long been sought. In this study, we observed that the peak PG of an Evolut R valve is dependent on the AA diameter. PG_{max} decreases with increasing AA size. Because the stent structure of the Evolut R valve might be constrained in a small AA, leaflet excursion might be restricted, resulting in a higher pressure decrease at the VC. Despite the upper stent frame diameter of 32 mm, within the 28 and 34 mm AA, the stent structure shape looks nonconstrained, which results in a comparable jet velocity in these 2 cases and a corresponding close PG_{max}.

The net transvalvular PG is the pressure after the recovery has occurred subtracted from the LV pressure. The net gradient is a key parameter to assess the invasively derived valve effective orifice area.[1,8] We observed the net gradient is also dependent on the AA size. By crossing blood flow through the aortic valve, pressure does not recover to the LVOT pressure values due to energy losses. Hatoum and colleagues[16] showed that pressure fluctuations exist downstream of the SE THV stent, which results in energy losses and less PR. There is less turbulence distal to the stent frame in the small AA case compared with the medium and large AA cases. However, the turbulence in the large AA was high and leads to a higher net PG. Our results are in agreement with previous studies, in which they reported low PR and high energy loss in a dilated aorta.[8,36]

In this work, PR values at peak flow rate showed a significant difference between the small and large AA (4.9 mm Hg), which indicates the dependence of PR on AA size.

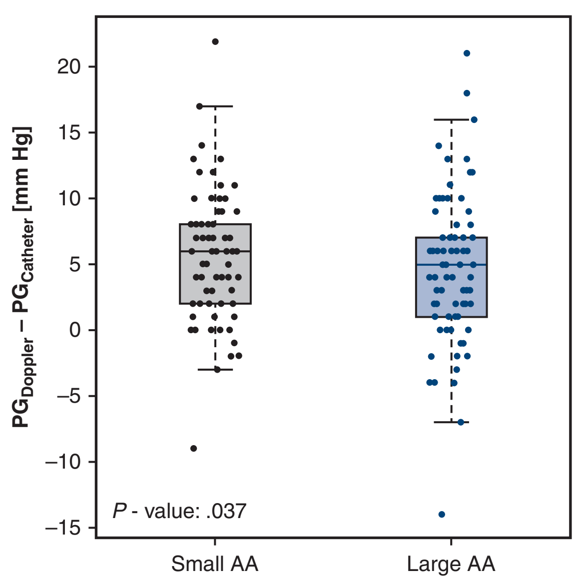


FIGURE 7. Pressure recovery comparison between small and large geometries. Pressure recovery plotted as the echocardiography pressure gradient subtracted by the catheter pressure gradient on the y-axis versus small and large geometries on the x-axis defined by the ratio of the ascending aorta (*AA*) diameter to the CoreValve (Medtronic) size with small being below the average and large being above the average. The *upper and lower borders* of the box represent the upper and lower quartiles. The *middle horizontal line* represents the median. The *upper and lower whiskers* represent the maximum and minimum values of nonoutliers. Extra *dots* outside the whiskers represent outliers. $PG_{Doppler}$, echocardiography pressure gradient; $PG_{Catheter}$, catheter pressure gradient.

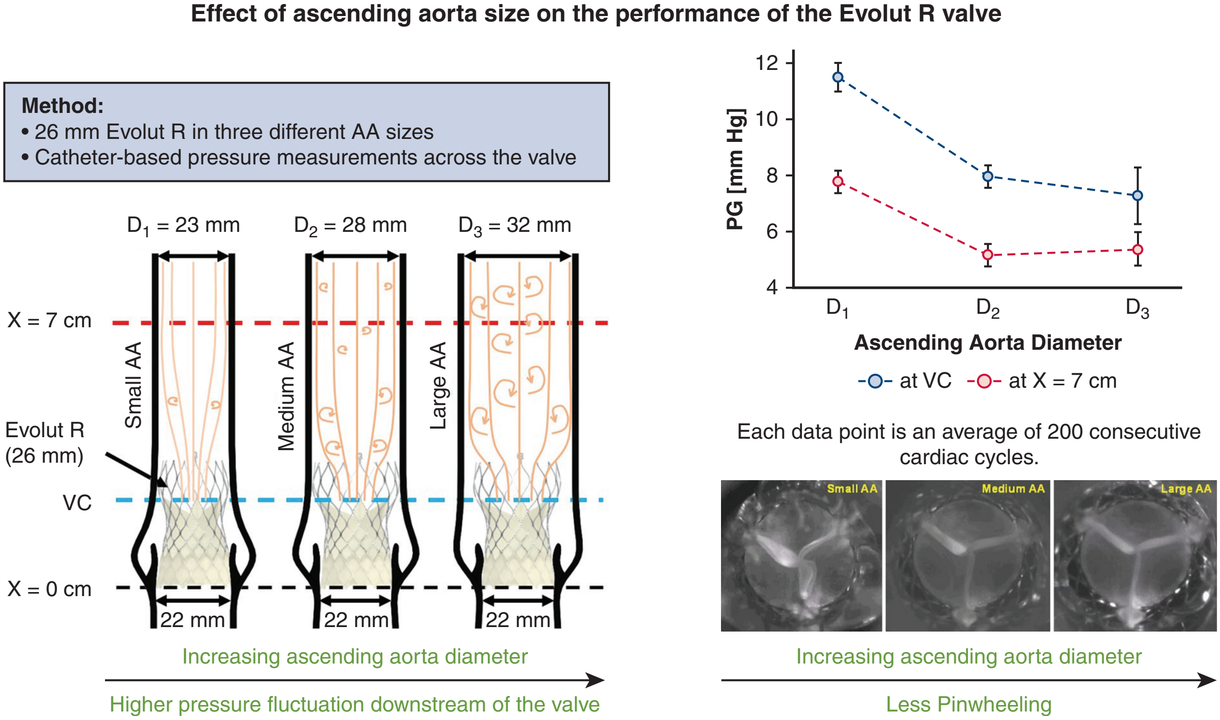


FIGURE 8. For the first time, the influence of the varying ascending aorta (*AA*) diameters within an acceptable range on an self-expandable transcatheter aortic valve (*TAV*) device's performance and pressure recovery have been examined. We studied gradients of the Evolut R (Medtronic) transcatheter aortic valve replacement (TAVR) device at 3 different AA sizes. We showed that for the same Evolut R and annulus size, peak and mean gradients strongly depend on the AA size. As a result, the size of AA might be an important parameter for the self-expandable transcatheter heart valve sizing and valve choice. D_1, small AA size; D_2, medium AA size; D_3, large AA size; *PG*, pressure gradient; *VC*, vena contracta.

The small AA showed the highest value of PR (59.2% ± 5.3%) compared with the larger AA sizes (16.6% ± 16.8%). This could be because of more significant ambient mixing that occurs with the larger diameter AA compared with the smaller one. Although the small AA shows the highest value of PR compared with the large and medium AAs, the performance of the valve was not the best in the small AA because the small AA shows the highest value of maximum PG compared with the other 2 AA diameters. In contrast, the medium AA shows a moderate PR and a low value of PG_{max}, which has the best valve performance among the 3 cases.

Recent studies by Tasca and colleagues[37] and Hatoum and colleagues[16] showed that different designs of bioprosthesis aortic valves can alter the position of the VC. Therefore, the interaction between the valve, the surrounding anatomy, and the flow play a tremendous role in dictating the spatial variation of pressure. Our study showed that by increasing the AA size, the position of the VC was slightly changed toward the AA downstream.

Limitation

The aortic chamber used in this experiment was rigid and straight, which is not anatomical. However, the main goal of this study was to compare PGs at 3 different AA sizes, and because the experimental conditions were not changed among 3 different conditions, we can rely on the results of this study. Future work involves performing similar experiments in patient-specific models with compliant material and a geometry that involves the intricate features in vivo. Another limitation in this study is the use of the Evolut R transcatheter aortic valve at room temperature.

CONCLUSIONS

The major finding of this study was that interactions between the Evolut R stent frame and AA affect the performance of the valve and downstream hemodynamics. As summarized in Figure 8, we showed that the 26-mm Evolut R THV will be constrained in a small AA, resulting in high peak and mean PG as well as net PG, despite high PR. Whereas the medium and large AA chambers allowed for a nonconstrained THV frame with similar PR, the medium AA chamber (AA to annulus diameter ratio = 1.32) minimized the ambient peripheral mixing by downstream turbulence compared with the large AA chamber. Thus, AA size might be an important parameter for SE THV sizing and valve choice.

Conflict of Interest Statement

Dr Dasi has reported patents on novel polymeric heart valves, 3D computational predictive modeling for TAVR, vortex generators on heart valves, and superhydrophobic/omniphobic surfaces. Dr Hahn reports speaker fees from Edwards Lifesciences and Philips Healthcare; consulting fees for Abbott Structural, Boston Scientific, Edwards Lifesciences, Gore & Associates, Medtronic, and Navigate; nonfinancial support from 3mensio; equity with Navigate; and is Chief Scientific Officer for the Echocardiography Core Laboratory at the Cardiovascular Research Foundation for multiple industry-sponsored trials, for which she receives no direct industry compensation. Dr Thourani is a consultant for Abbott Vascular, Boston Scientific, Cryolife, Edwards Lifesciences, Gore Vascular, Jenavalve, and Shockwave. The remaining authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: transcatheter aortic valve, ascending aorta, pressure recovery, pressure gradient, left heart simulator