The adoption of transcatheter aortic valve replacement (TAVR) for severe aortic stenosis outpaced available data for younger, low-risk patients.1,2 In younger patients with long life expectancy, reintervention is inevitable due to expected structural valve deterioration (SVD). Although some patients are anatomically feasible for redo TAVR,3 many patients will require surgical removal (TAVR-explant). TAVR-explant is currently associated with excessive risk of morbidity and mortality.4 The Heart Valve Collaboratory is a multistakeholder collaborative community established to identify knowledge gaps, build consensus, support the development of evidence to inform health care policy, and advance innovation in the evaluation and management of valvular disease. A recent virtual workshop organized by the Heart Valve Collaboratory was convened to improve surgical techniques and patient selection, with the expected

CENTRAL MESSAGE

We present preoperative, intraoperative strategies for TAVR-explant that will standardize techniques and improve outcomes.

See Commentary on page XXX.
<table>
<thead>
<tr>
<th>Study</th>
<th>Study period</th>
<th>Database</th>
<th>N</th>
<th>Age at TAVR explant</th>
<th>STS-PROM at TAVR explant (%)</th>
<th>Indications for TAVR explant</th>
<th>Concomitant cardiac surgery (%)</th>
<th>In-hospital mortality (%)</th>
<th>30-d mortality (%)</th>
<th>1-y mortality (%)</th>
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<tbody>
<tr>
<td>Fukuhara and colleagues (2020)</td>
<td>2011-2018</td>
<td>STS</td>
<td>782</td>
<td>74.0 (67-81)</td>
<td>8.5 ± 8.9</td>
<td>SVD (6.5%) Stenosis (20.2%) PVL (21.5%) Endocarditis (17.7%) Procedural-related failure (27%)</td>
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<td>NA</td>
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<td>Hirji and colleagues (2020)</td>
<td>2012-2017</td>
<td>CMS</td>
<td>227</td>
<td>73.7 ± 8.9</td>
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<td>THV failure (79.3%) Endocarditis (20.7%)</td>
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<td>22.9</td>
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<td>Jawitz and colleagues (2020)</td>
<td>2011-2015</td>
<td>STS</td>
<td>123</td>
<td>77.0 (67-84)</td>
<td>Low risk 2.6 (17.1%) Intermediate risk 6.0 (24.4%) High risk 17.9 (58.5%)</td>
<td>SVD (11.4%) PVL (15.5%) Endocarditis (9.8%) THV thrombosis (1.6) Failed repair (10.6%) Sizing/position issues (10.6%)</td>
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<td>17.1</td>
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<td>Bapat and colleagues (2021)</td>
<td>2009-2020</td>
<td>Explant-TAVR Registry</td>
<td>269</td>
<td>72.7 ± 10.4</td>
<td>5.6 (3.2-9.6)</td>
<td>SVD (20.1%) PVL (18.2%) PPM (10.8%) Endocarditis (43.1%)</td>
<td>54.6</td>
<td>11.9</td>
<td>13.1</td>
<td>28.5</td>
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<td>Brescia and colleagues (2021)</td>
<td>2012-2020</td>
<td>STS-Michigan State</td>
<td>46</td>
<td>73.0 ± 8.0</td>
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<td>STS</td>
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<td>2011-2022</td>
<td>STS*</td>
<td>531</td>
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<td>7.0 ± 7.3</td>
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<td>&gt;50</td>
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<td>NA</td>
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<td>Tang and colleagues (2023)</td>
<td>2009-2022</td>
<td>Explant or redo-TAVR Registry</td>
<td>181</td>
<td>72.1 ± 9.0</td>
<td>3.9 (2.5-6.6)</td>
<td>SVD (51.9%) PVL (28.7%) PPM (17.1%) THV thrombosis (1.7%) Delayed THV migration (3.3%)</td>
<td>55.8</td>
<td>11.6</td>
<td>13.6</td>
<td>32.4</td>
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</tbody>
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(Continued)
One concern raised during the workshop was the lack of knowledge and dissemination of optimal techniques due to the limited experience of individual surgeons. Herein, under the auspices of the Heart Valve Collaboratory, we review the current state of TAVR-explant with a specific focus on technical considerations, preoperative planning, and future directions in the field.

CURRENT DATA ON TAVR-EXPLANT

The reported incidence of TAVR-explant is approximately 0.5% to 2%, although this number is expected to grow exponentially. This is because of the increase in TAVR use in low-risk patients and most patients in the current published series were high/extreme-risk patients and did not outlive the valve durability. Table 1 provides an overview of the patient population, surgical indications, and outcomes of TAVR-explant studies published to date. TAVR-explant risks are substantial, as evidenced by significant mortality and morbidity, with reported median 30-day mortality between 15% and 20%. This contrasts the outcomes after redo surgical AVR (SAVR), where the 30-day mortality was 4.6% from the Society of Thoracic Surgeons (STS) database. In several studies that compared the TAVR-explant outcomes to redo TAVR, TAVR-explant had higher mortality at 30 days. However, the EXPLANTORREDOTAVR registry showed that the mortality after 1 month was similar between TAVR-explant and redo TAVR. Further analysis showed that TAVR-explant was consistently associated with a high observed-to-expected mortality ratio of 1.5:3.5. The underestimation of risk score could be attributed to the sicker patient population, high clinical acuity, and procedural complexity and should be carefully considered during TAVR-explant evaluation. In the EXPLANT-TAVR registry, mortality after TAVR-explant was associated with longer cardiopulmonary bypass and crossclamp times and concomitant mitral or tricuspid valve surgery.
CURRENT CHALLENGES IN TAVR-EXPLANT

The unique challenges of TAVR-explant are based on the distinctive designs and implantation techniques. Explanting TAVR valves is more complex than surgical valves due to potential iatrogenic injury to the sinotubular junction, aorta, mitral valve, or membranous septum. The complexity increases in patients with concomitant diseases requiring combined surgeries. In the EXPLANT-TAVR registry, 54.6% needed concomitant procedures (32.0% mitral repair/replacement, and 24.5% coronary artery bypass graft), which was associated with increased mortality. A lack of expertise compounds this; in the STS database from 2011 to 2018, the median number of TAVR-explants per surgeon was 1, and per institution was also 1.

COMPUTED TOMOGRAPHY PLANNING IN TAVR-EXPLANT

A preoperative multidetector computed tomography (CT) scan with contrast is required to ensure a safe TAVR-explant. Several features suggest a more careful approach is warranted: degree of TAVR incorporation into the surrounding structures (eg, sinotubular junction, mitral valve anterior leaflet, or membranous septum), TAV location in relation to the anatomic landmarks, and characteristics of the aortic root (eg, size and calcifications). Device incorporation into the surrounding tissues is highly variable but is commonly present in a small aortic root. Patients with significant adhesions should be prepared to undergo concomitant procedures: aortic root/ascending replacement for sinotubular junction involvement, mitral valve repair/replacement if the anterior mitral leaflet is impinged, or ventricular septal defect repair if it appears the membranous septum could be injured at the time of TAVR-explant.

TECHNICAL PEARLS FOR TAVR-EXPLANT

Cannulation, Cardioplegia, and Aortotomy

The cannulation strategy must reflect the specific TAV and preoperative CT findings. For supra-annular valves with frame extending into the ascending aorta (such as CoreValve/Evolut [Medtronic] and Portico/Navitor [Abbott]), cannulation must be high in the aortic arch to ensure adequate room for aortic crossclamping. Peripheral femoral or axillary cannulation should be considered if the ascending aorta is insufficient.

Cardioplegia delivery and aortotomy also require understanding the TAV frame and relationship to coronary arteries to allow for expeditious cardioplegic arrest and exposure for TAVR-explants. Standard antegrade cardioplegia is typically sufficient for intra-annular valves (such as Sapien; Edwards Lifesciences), in which the short stent frame is below the location for antegrade cardioplegia. With supra-annular valves, antegrade cardioplegia cannulation must avoid the tall prosthesis, typically palpable through the aorta. Retrograde cardioplegia is almost always used in TAVR-explants and is typically required for initial cardiac arrest in those with aortic regurgitation (paravalvular or central). Direct coronary ostial cardioplegia may be administered after the aortotomy and TAVR-explant. Access to the coronary ostia before valve removal is typically difficult due to the small cell opening of the stent frame.

The aortotomy location for intra-annular valves is in the standard location with a transverse or oblique incision. In contrast, the aortotomy with supra-annular valves can be performed at the top of or within the frame (Video 3).
the frame is nonpalpable, an epi-aortic ultrasound can be employed. Occasionally, transection of the aorta is necessary and may be required for root enlargement or repair of an aortic injury.

**Explant of Short Stent Frame Valves (Balloon Expandable Valves)**

**Double Kocher technique.** The fundamental technique for balloon expandable valve (BEV) explant is inwardly deforming the stent frame of the valve (Video 4). The first step is separating the aortic wall from the distal stent frame (Figure 3, A). Typically, endarterectomy spatulas are used, but in cases with significant adhesions a No. 15 scalpel can facilitate safe dissection (Figure 3, B). Once this is achieved circumferentially down to the halfway point of the frame, the stent is grasped with 2 long Kocher clamps (Figure 3, C). Perpendicular clamp application mobilizes the sharp edge of the BEV and serves as a handle for the valve explantation maneuver. As more frame is liberated, the clamps are repositioned deeper toward the base of the valve. The edges of the BEV valve may injure the aorta if not handled carefully. It is critical to enter the plane between the native valve leaflets and the TA VR cuff. Contrary to redo SA VR, native aortic valve leaflet still exist in TAVR-explant, making this dissection easier if the correct plane is entered. Care must be taken for the mitral valve, left ventricular outflow tract, and membranous septum in cases with deep device implantation during the index TAVR.

**FIGURE 2.** Ideal aortotomy locations for balloon-expandable valve (BEV) and self-expandable valve (SEV). Examples of ideal aortotomy locations for (A) BEV (Sapien 3 Ultra; Edwards Lifesciences) and (B) SEV (Evolut FX; Medtronic). A high implant of the SEV may complicate crossclamp placement and necessitate circulatory arrest. TAVR, Transcatheter aortic valve replacement.

**VIDEO 3A.** Aortotomy for a BEV valve is anteriorly above the sinotubular junction and provides excellent exposure for transcatheter aortic valve replacement removal. Video available at: https://www.jtcvs.org/article/S0022-5223(24)00369-6/fulltext.

**VIDEO 3B.** Aortotomy for a self-expanding valve is made mid-transcatheter aortic valve replacement, and the transcatheter aortic valve replacement is then circumferentially removed superiorly and inferiorly. Video available at: https://www.jtcvs.org/article/S0022-5223(24)00369-6/fulltext.
Roll technique. Another technique for BEV explant is the roll technique (Video 5). First, grasp the valve at the top of the commissures with a Tonsil or long clamp (Figure 4, A). Then, use a freer elevator and bluntly dissect the plane between the native valve and TAVR until reaching the cuff. The explant will be easier if more of the sealing cuff is freed from the aorta/aortic valve. Then, place 2 clamps 180° apart, with 1 jaw on the inside of BEV, ideally to the bottom of the cuff, and the other in the plane between the native valve and BEV (Figure 4, B). Roll both clamps inward simultaneously, with a complete 360° turn on both (Figure 4, C). This collapses the valve to the smallest diameter, allowing easy prosthesis removal. The roll technique offers several advantages: Due to the metal properties, rolling it radially requires less force than trying to fold it along its diameter so the resulting profile is much smaller along the entire length of the valve, such that when you extract it from the native valve it is less likely to damage the root or the aorta. The benefit of the roll technique is to minimize the dissection around the annulus and ascending aorta, hence decreasing the risk of injury.

Explant of Tall Stent Frame Valves (Self-Expanding Valves)

Tourniquet technique. As seen in Video 6, most self-expanding valves (SEVs) are made of nitinol and have a tall supra-annular hourglass shape, which makes dissection around the frame difficult. The tourniquet technique can make this process safer and faster. Following the aortotomy just above the frame, a freer elevator is carefully used to lift the neointima and frame from the aortic wall (Figure 5, A). Silk ties are passed through the top cells of the frame at opposite ends (Figure 5, B). Next, snare the silk ties through a three-eighths inch pump tubing piece (Figure 5, C). The tubing is advanced to create a tourniquet and recapture the valve, making the hourglass-shaped valve a smaller profile, allowing easier removal of the TAV and avoiding injury to the aorta from the top of the frame.

Handlebar and mustache. Radial infolding of SEVs has also been described, the so-called handlebar mustache technique, wherein the valve is divided in half transversely to remove the crown, and then cut longitudinally. The
valve is then grasped at the cut edges and infolded. Although the concerns regarding the sharp edges of the metal frame are present, it is an alternative to the tourniquet technique.

**Early Versus Late TAVR-Explant**

The early TAVR-explant will have minimal adhesions, which makes the dissection of the stent frame easier. The early TAVR-explant will occur in patients with endocarditis, significant paravalvular regurgitation, or early SVD. The late TAVR-explant will have significant endothelization covering the TAVR valve, which will make dissection difficult. The complete endothelization could be seen as early as 12 months. As the TAVR-explant population move to low-risk young patients, anticipations are that we will see explants after late SVD around 10 years. The data published only looks at TAVR-explant after 12 months and the data on true late TAVR-explant is lacking. Technically, meticulous dissection using a scalpel may be needed to avoid injury to the aortic root structures is needed to avoid unnecessary aortic root replacement.

**Explant of Other TAVs**

The following valves represent the less utilized TAVR devices with unique design features that can influence explant.

- **ACURATE (Boston Scientific).** This SEV received CE mark in 2024 and is currently pending US Food and Drug Administration approval. The valve has stabilization arches at the outflow and a lower crown of the inflow and behaves similarly to other SEV devices. However, the upper crown in the midportion is 5-mm larger than the main body of the valve, and due to its flared nature, the tourniquet technique cannot be used. Extra care is required to prevent injury to the aorta during its removal once it is entirely freed from the annulus and removed sideways (Figure 6, A).

- **Lotus (Boston Scientific).** This valve is no longer manufactured; however, it was used in clinical trials and briefly commercially in the United States and Europe. The valve has a short intra-annular profile made of a single nitinol wire. The commissural posts had a seat buckle mechanism, which, once locked, stabilizes the commissures. Manual unbuckling of these commissural posts can be accomplished by pressing the buckle, which facilitates removal and allows the valve to stretch (Figure 6, B). The double Kocher or roll technique can be used if accessing the buckle is impossible due to tissue ingrowth. The valve height is 19 mm across all sizes. Small valve sizes tend to sit higher in the native anatomy, can be above the sinotubular junction, and are challenging to remove.

- **DirectFlow.** This valve is no longer manufactured. The valve has a unique structure with 2 polymer rings, 1 below the annulus and the second above. The rings are extremely rigid and cannot collapse inward. A bone rongeur or similar instrument is used to nibble the rings to remove the valve (Figure 6, C). Care must be taken not to damage surrounding tissue and prevent embolization into the coronary ostia.
Concomitant Surgery

Aortic root enlargement. If a small TAV was placed or the failure mode was prosthesis-patient mismatch, an aortic root enlargement may be necessary. A preoperative CT scan can predict the need for aortic root enlargement before surgery (Video 6). Following the TAVR-explant, the aortotomy is extended posteriorly and down through the left noncommissure to the annulus, and a patch is placed. Different aortic enlargement techniques can be utilized. The video demonstrates the Y-technique. The incision continues along the left-sided annulus, stopping short of the left main, and under the noncoronary cusp, stopping short of the membranous septum. A polyethylene terephthalate graft is sutured to the aorta, annulus, and aortomitral curtain using polypropylene sutures, and a larger valve is implanted. To facilitate future valve-in-valve TAVR, the sinotubular junction should be large enough to allow coronary flow with future valve-in-valve TAVR, and a patch augmentation may be necessary.

Aortic root replacement. Aortic root replacement may be used as the definitive solution for all pathologies requiring TAVR-explant. In the STS database, roughly 20% required aortic root replacement, regardless of the explanted TAVR valve type. Root replacement is most frequently used during TAVR-explant in the setting of endocarditis, particularly when associated with a periannular abscess. It may also be required when explanting a TAVR valve that has deeply endothelialized into the native aortic wall, causing damage to the proximal ascending aorta or sinuses at the time of explant. Less often, root replacement is needed to address a root aneurysm, aortic dissection, pseudoaneurysm, or TAV degeneration in a small aortic root. In the small root, root replacement is also an excellent strategy as it allows for both the placement of a larger supra-annular prosthesis and the movement of the coronary arteries away from the prosthesis. Despite added complexity, in experienced hands root replacement can be performed with similar peri-procedural outcomes as SAVR for TAVR-explant. The choice of prosthesis is primarily a bioprosthetic valve, but in specific pathologies and patient populations, homograft, mechanical valve, or Ross procedure could be considered. Nevertheless, in the case of small aortic root, we believe aortic root enlargement may be considered first, especially for the nonaortic surgeons.

Mitral valve surgery with previous TAVR. Mitral valve surgery (MVS) after TAVR is frequently required, 21% to 23% during TAVR explant. There are 2 scenarios: concomitant MVS during TAVR-explant and MVS while leaving the TAVR intact.

For concomitant MVS during TAVR-explant, the technical steps follow standard TAVR-explant. After the explant, MVS is carried out in standard fashion. A deeply
implanted TAVR valve may be encased with the mitral valve anterior leaflet and require careful dissection to avoid injury to the aortomitral curtain. For endocarditis extending into the aortomitral curtain, extensive reconstruction or a Commando operation may be necessary.

For MVS with TAV intact, operative strategy (sternotomy vs right thoracotomy, aortic crossclamp location, and cardioplegia delivery) must be carefully considered preoperatively. BEV deformation during left atrial retraction can occur and may require balloon postdilatation to restore the nominal geometry or necessitate TAVR-explant. For deeply implanted valves, the frame in the outflow tract makes visualization of the lateral trigone difficult. The right thoracotomy or transseptal approach may help with visualization in these cases (Video 7).

Alternative Technique (Surgical Resection of Prosthetic Valve Leaflets Under Direct Vision)

Surgical Resection of Prosthetic Valve Leaflets Under Direct Vision (SURPLUS) is a hybrid technique combining the surgical resection of the TAVR leaflets and the direct implantation of a BEV under direct vision and fluoroscopic guidance. After initiation of cardiopulmonary bypass, aortic crossclamp, and cardioplegia, an oblique aortotomy is performed above the frame. The TAV leaflets are resected, whereas the frame is left intact. Under direct vision, a BEV is positioned over a guidewire, and the valve commissures are aligned. Using fluoroscopic guidance, the valve is deployed slowly at its intended position (Figure 7 and Video 8).

SURPLUS avoids tissue dissection during TAVR-explant, preventing aortic or other structural injuries. It also shortens the cardiopulmonary bypass and aortic crossclamp times, which may be critical for high-risk patients. It is beneficial in patients needing SEV explant due to the risk of coronary obstruction with redo TAVR. SURPLUS should not be used for endocarditis treatment and will not prevent prosthesis-patient mismatch.

FUTURE DIRECTIONS OF TAVR-EXPLANT

TAVR-explant is currently the fastest-growing cardiac surgery procedure in the United States. With TAVR being applied to younger, low-risk patients, an exponential increase in TAVR-explants is expected. It is critical for
cardiac surgeons to remain influential in the heart team to discuss the lifetime management of these patients. If the low-risk patient is not a candidate for redo TAVR, this patient should undergo SAVR to avoid future TAVR-explant. When TAVR-explant is needed, surgeons should understand that each TAVR design and patient anatomy present unique challenges. Surgeons must be familiar with TAVR devices and understand potential interaction with the native anatomy. Meticulous CT preoperative planning will reduce the risk of iatrogenic injury and facilitate the least complicated procedure. Restricting TAVR-explant to centers of excellence may reduce morbidity and mortality. However, lower volume centers will likely perform TAVR-explant to preserve access to care and satisfy local politics. Standardization and dissemination of TAVR-explant techniques can reduce the learning curve. Careful follow-up after index TAVR and early referral to surgeons are crucial to avoiding operating on patients with more advanced pathology. Ideally, the goal for the cardiac surgeons is to reduce TAVR-explant mortality and morbidity to be equal to an isolated first-time or redo SAVR. Figure 8 depicts the current status on TAVR-explant, highlighting existing challenges and outlining future directions.

CONCLUSIONS

With the rise of TAVR, TAVR-explant will continue to increase. The reported poor outcomes after TAVR-explant may improve with lower-risk patient populations, careful patient monitoring, early referral, and, most importantly, meticulous preoperative planning, standardization, and dissemination of TAVR-explant techniques.

Conflict of Interest Statement

Dr Kaneko is on the advisory board for Edwards Lifesciences, Abbott, and Johnson and Johnson and serves as a consultant for Medtronic. Dr Bapat is a consultant for Medtronic, Edwards Lifesciences, 4C Medical, and Boston Scientific. Dr George is a consultant for WL Gore, Vdyne, CardioMech, MitreMedical, and Atricure. Dr Grubb is a consultant for Medtronic, Abbott, 4C Medical, Boston Scientific, OpSens, Ancora, and Edwards Lifesciences. Dr Desai has received institution research funding and speaker fees from Gore and Medtronic. Dr Modine is a physician proctor and consultant for Medtronic, Edwards Lifesciences, and Abbott. Dr Denti has received speakers’ honoraria from Abbott and Edwards Lifesciences and is a consultant for InnovHeart. Dr Kempfert has served as a proctor to Boston Scientific. Dr Ruge is a member of the advisory board of Edwards Lifesciences.
Abbott and a physician proctor for Abbott and Edwards Lifesciences. Dr Thourani has received grants from Edwards Lifesciences; consulting fees from Atricure, Abbott, Boston Scientific, Artivion, Shockwave, and Edwards Lifesciences; and holds equity in Dasi Simulations. Dr Bavaria is a consultant to Edwards Lifesciences and Abbott. Dr Reardon is a consultant for Medtronic, Boston Scientific, Abbott, and W. L. Gore & Associates. Dr Mack is coprimary investigator for the PARTNER trial for Edwards Lifesciences and the COAPT trial for Abbott and served as study chair for the APOLLO trial for Medtronic. Dr Borger receives speakers honoraria and or consulting fees on his behalf from Edwards Lifesciences, Medtronic, Abbott, and CryoLife. Dr Leon has received institutional grants for clinical research from Abbott, Boston Scientific, Edwards, JenaValve, and Medtronic and has received stock options (equity) for advisory board participation in Valve Medical, Picardia, and Venus MedTech. Dr Tang is a physician proctor, consultant, and advisory board member for Medtronic, a consultant and physician advisory board member for Abbott Structural Heart, and a physician advisory board member for Boston Scientific and JenaValve. Dr Fukuhara is a consultant for Terumo Aortic. This work was done under the auspices of the Heart Valve Collaboratory. All other authors reported no conflicts of interest.

The Journal policy requires editors and reviewers to disclose conflicts of interest and to decline handling 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: aortic valve, aortic valve replacement, transcatheter aortic valve replacement
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**Commentary:** Good information is the best medicine. Bhama JK. *J Thorac Cardiovasc Surg.* 2021;162(2):549-550.


