Audit of homograft valve bank

Shiv Kumar Choudhary¹ · Nikhil Bansal¹ · Indeever Kumar¹ · Rajashekhar Palletti¹ · Milind Hote¹ · Sachin Talwar¹ · Devagourou Velaoudham¹ · Sanjeev Lalwani²

Received: 10 January 2019 / Revised: 24 March 2019 / Accepted: 27 March 2019 / Published online: 30 April 2019
© Indian Association of Cardiovascular-Thoracic Surgeons 2019

Abstract

Introduction Even today, the search for the ideal cardiac valve continues. With advantages of having superior flow dynamics, avoidance of anticoagulation, and resistance to infection, homograft has been shown to have an edge over conventional prosthetic and bioprosthetic valves. But they suffer from disadvantages of limited availability and durability. Our center operates one of the oldest functioning valve banks in the country. We present our experience with homograft valve banking with antibiotic and cryopreserved homografts spread over a quarter century.

Methods For donor selection, procurement, sterilization, and preservation, the recommendations of the American Association of Tissue Banks are being followed in accordance with statutory provisions of the Transplantation of Human Organs Act, 1994.

Results During 25-year period (1993–2017), 777 hearts were procured. Age of the donors ranged from 2 to 60 years and hearts were procured within 24 h of death. A total of 1646 homografts (774 pulmonary, 774 aortic, 60 mitral valves, 20 descending thoracic aortae, and 18 monocusps) were harvested. A total of 546 (32%) homografts were rejected for various reasons. Nine hundred sixty-seven (56.7%) homografts were used in different procedures. Of these, 478 were pulmonary homografts, 425 were aortic homografts, 39 mitral homografts, 18 monocusps, and 7 descending thoracic aorta homografts. One hundred fifty-four (16%) homografts were antibiotic preserved and the rest 813 (84%) were cryopreserved.

Conclusions It is possible to run a homograft valve bank with minimum costs. Though, cryopreservation is more expensive, it provides an opportunity to store the valves for an indefinite period and maintain an uninterrupted supply of homografts.

Keywords Homograft · Valve bank · Cryopreservation

Introduction

Even today, there is a never-ending search of the ideal cardiac valve. With the advantages of having superior flow dynamics, avoidance of anticoagulation, and resistance to infection, homograft has been shown to have an edge over conventional prosthetic and bioprosthetic valves. But they suffer from the disadvantage of having a limited availability and durability. Durability in one hand depends to a certain extent on the method of sterilization and preservation; availability on the other depends on maintaining a valve bank. There has been

a constant evolution in recovery, processing and storage techniques of homograft to improve their quality and safety so that suitable homograft is available when required for implantation. Our center operates one of the oldest functioning valve banks in the country. We presented our early experience with homograft valve banking in 1997 [1]. Now, we present our experience with antibiotic and cryopreserved homografts spread over a quarter century.

Methods

Donor selection

For technical considerations in donor selection, procurement, sterilization, and preservation, the recommendations of the American Association of Tissue Banks are being followed [2] in accordance with statutory provisions of the Transplantation of Human Organs Act, 1994 [3]. The details were provided earlier [1]. In brief,

✉ Shiv Kumar Choudhary
shivchoudhary@hotmail.com

¹ Department of Cardiothoracic and Vascular Surgery, All India Institute of Medical Sciences, New Delhi, India

² Department of Forensic Medicine and Toxicology, All India Institute of Medical Sciences, New Delhi, India

hearts were obtained from cadaver donors, beating heart donors and from heart transplant recipients. For donor selection, the following general guidelines are being followed: no sepsis, infectious, or communicable disease; no neoplasm other than carcinoma of skin, in situ carcinoma of the uterus, or an intracranial neoplasm; no evidence of serious illness of unknown etiology; and no drug abuse, poisoning, prolonged steroid treatment, systemic viremia, or fungemia and Chagas disease. From cardiothoracic point of view, hypertension, rheumatic fever, bacterial endocarditis, previous cardiac surgery, valvular disease, cardiomyopathy of idiopathic or viral etiology or untreated active pulmonary disease, and cardiac or chest wall trauma with prolonged closed-chest resuscitation or defibrillation are also ruled out. Upper age limit of 60 years and a time limit of 24 h after death for procuring the tissue are being followed.

Procurement

Informed consent is obtained from the relatives of the deceased in all cases. From cadaveric donor, the heart is obtained at autopsy in the Department of Forensic Medicine using a sterile technique. The dead body is immediately preserved in cold storage conditions in walk-in cold room with temperature of 2 to 4 °C to prevent putrefaction. For suitable donor, autopsy is performed within 24 h. The chest cavity is entered through a sternal incision. The pericardium is opened in the midline. The ascending aorta, aortic arch, and the proximal 2 to 3 cm of the arch vessels are dissected free. The superior vena cava and inferior vena cava are dissected and transected. Pulmonary veins are divided after everting the heart. The right and left pulmonary arteries are transected after dissecting them as far as possible. Finally, the aorta is transected distally as far as possible.

Transporting the cadaveric heart to the valve bank

The heart is removed and cleaned of all blood by rinsing in cold saline. Subsequently, the heart is packaged in 500 mL of cold saline at 4 °C in a sterile double bag and transported to the valve bank in operation room complex. Blood samples are collected from the donor heart at the time of harvesting and tested for blood group (ABO and Rh), human immunodeficiency virus, hepatitis B, hepatitis C, and syphilis. Blood culture and sensitivity testing are also done for donor blood.

Dissection of the heart (Fig. 1)

Dissection is carried out within the confines of a laminar flow hood in a sterile area using an aseptic technique. After carefully taking the heart out from the transport solution, it is

placed in a sterile basin containing 1.5 L saline solution at 4 °C. The aorta is separated from the pulmonary artery. The right ventricular cavity is entered anteriorly and by circumferential dissection, the pulmonary valve and pulmonary artery are separated from the right ventricle. The roof of the left atrium is opened. The chordal attachments of the anterior mitral leaflet are divided. The aorto-mitral curtain and the anterior mitral leaflet are left with aortic homograft. The left ventricular outflow tract and other attached tissues are divided circumferentially keeping a distance of about 1 cm from the aortic valve. Once the homograft block is removed from the donor heart, excess tissue including muscle and left atrial wall are removed. The aortic and pulmonary homografts are labeled after sizing with a conical sizer. The pericardium and thoracic aorta, if harvested initially, are also kept ready for storage after cleaning them thoroughly with saline.

Sterilization

Antibiotic solution is being used for sterilization. To 1 l of sterile filtered nutrient tissue culture medium (Hanks' balanced salt solution, 9.6 g/L), the following were added: Cefotaxime (500 mg), Lincomycin (1million units), Polymyxin B (1million units), Vancomycin (500 mg), and Amphotericin B (50 mg). Sodium bicarbonate is added to maintain the pH between 6.6 and 7.0. Each homograft is stored at 4 °C with 100 ml of antibiotic solution. In the initial period, antibiotic preserved homografts were used up to a period of 40 days.

Microbiological surveillance

Microbiological surveillance is performed as described by Angell [4] and colleagues. A sample is taken from the donor blood and the cold saline used to transport the heart for culture and sensitivity. Donor tricuspid valve tissue is obtained after antibiotic treatment and sent for fungal and bacterial cultures. The antibiotic solution used to preserve the homograft is also filtered through a 0.45-µm filter using an aseptic technique. The filter paper is incubated in thioglycolate broth at 37 °C for 7 days and then plated aerobically onto trypticase soy agar. The growth plates are read after 2 days of incubation at 37 °C. Fungal cultures are evaluated after intervals of 1 week and 3 weeks. The eventual use of the homograft is based on confirmation of tissue sterility. When the results are negative for donor human immunodeficiency virus, hepatitis B, hepatitis C, syphilis, and culture and sensitivity, the graft is deemed fit for clinical use. Its details are entered in a register. This register is always kept up to date and is referred to when the need for a homograft arises.

Fig. 1 Steps and technique of homograft harvesting from cadaveric heart. **a** The cadaveric heart. **b** The aorta (Ao) and the pulmonary artery (PA) are separated by sharp dissection. **c** The pulmonary artery (PA) is dissected posteriorly and mobilized. **d** A curved right-angled clamp is passed from the distal cut-end of the pulmonary artery (PA) into the right ventricular outflow tract (RVOT). An incision is made about a centimeter below the level of the pulmonary valve (PV). **e** The right ventricular outflow tract (RVOT) incision is enlarged circumferentially keeping a safe distance from the pulmonary valve (PV). Finally, the pulmonary homograft separates out (Ao, aorta; PA, pulmonary artery). **f** Length of the homograft (H)

is measured using a straight metallic ruler. **g** Size (diameter) of the homograft is measured using a graduated conical sizer. **h** The aorta (Ao) is held vertically and an incision is made in the roof of the left atrium (LA) near the base of the left atrial appendage (LAA) (RV, right ventricle). **i** The left atrium (LA) is opened wide. **j** Chordal attachments to the anterior mitral leaflet (AML) are divided and incision is extended circumferentially in the left ventricle (LV) maintaining a distance of about one centimeter from the aortic valve (Ao, aorta; AMC, aorto-mitral curtain). **k** The aortic homograft along with attached anterior mitral leaflet (AML) is ready to be separated from the left ventricle (LV)

Cryopreservation

At commencement, antibiotic preservation was used. These valves were used within a period of 40 days. Subsequently, cryopreservation is the preferred method of preservation. Cryopreservation is started immediately after an antibiotic incubation period of 48 h. Homografts obtained from transplant recipients are cryopreserved directly without antibiotic treatment. The homograft is removed from the antibiotic container in a sterile manner and packaged in a sterile plastic bag with the freezing solution to produce a total volume of 100 mL. The freezing medium was similar to that used by Kirklin and

colleagues [5] and consisted of RPMI 1640 tissue culture medium (Rose Park Memorial Institute tissue culture medium no. 1640) with 10% fetal calf serum amended with dimethyl sulfoxide to a 10% concentration. Cultures were obtained from all the solutions at the time of packaging. The air was evacuated, and the plastic bag was heat sealed. This plastic bag is transferred into an aluminum pouch which was heat sealed again. This aluminum pouch is transferred to a controlled rate freezer (Kryo 10, Planer Products Ltd., Minnesota Valley Engineering Inc., Bloomington, MN, USA), and is cooled at a rate of 1.5 °C per minute to a temperature of –40 °C, then rapidly cooled to –150 °C. The frozen homograft in an aluminum

pouch is then transferred for permanent storage in vapor phase liquid nitrogen between -150 and -190 °C in an XCL-500 vacuum insulated Dewar flask (Minnesota Valley Engineering Inc., Bloomington, MN, USA).

Thawing

An appropriate homograft is selected. Before implantation, the cryopreserved homografts are thawed for approximately 20 min in a water bath at a temperature of 37 to 42 °C. Caution is observed as not to crush the cryopreserved homograft. After thawing, the homograft is soaked twice for 3 min in a solution of RPMI tissue culture medium and 10% fetal calf serum to remove the cryopreservative and to restore osmotic isotonicity. Subsequently, the homograft was transferred to 50 mL of the recipient's heparinized blood where it was maintained until implantation.

Results

During this 25-year period (1993–2017), 777 hearts were procured. Fifty-six hearts were obtained from patients undergoing orthotopic cardiac transplantation, 27 hearts from beating heart donors, and the rest from autopsies. The predominant cause of death in cadaveric donors was road traffic accident (50.6%). The age of the donors ranged from 2 to 60 years and the hearts were procured within 24 h of death. A total of 1646 homografts (774 pulmonary, 774 aortic, 60 mitral valves, 20 descending thoracic aorta, 18 monocusps) were harvested. Six pulmonary and 14 aortic valves were damaged during dissection.

Seventy-four donors were found to be hepatitis B positive, 7 were found to be positive for hepatitis C, 10 were found to be positive for human immunodeficiency virus, and 1 was positive for syphilis. Table 1 shows the results of microbial surveillance. Blood culture of the donor was positive in 31 hearts, *Klebsiella* was the most common organism isolated (9/31). Fungal cultures were positive in 31 hearts; *Aspergillus* was the most commonly isolated organism (26/31). Bacterial cultures were positive in 28 hearts; *Pseudomonas* was the most commonly isolated (10/28) organism.

A total of 546 (32%) homografts were rejected for various reasons (Table 2). Homografts obtained from 135 hearts were discarded because of positive serology or positive blood/tissue culture. Other causes included interruption of cryopreservation ($n = 36$), improper selection of the homograft at the time of surgery ($n = 24$), or cracking of the homograft as a result of too rapid thawing ($n = 26$). Twenty-seven homografts had to be discarded because of the expiration of the antibiotic preservation period of 40 days prior to the introduction of cryopreservation in our bank.

Table 1 Culture positivity for donor blood/tissue for bacteria/fungi

S. no	Organism isolated	Number
A. Blood culture positivity of the donor		
1.	<i>Klebsiella</i>	9
2.	Multiple Gram-negative bacilli	6
3.	<i>Pseudomonas</i>	5
4.	<i>E. coli</i>	5
5.	<i>Acinetobacter</i>	3
6.	<i>Enterobacter</i>	2
7.	<i>Proteus</i>	1
Total		31
B. Fungal culture positivity of the donor tissue sample		
1.	<i>Aspergillus</i>	26
2.	<i>Candida</i>	4
3.	<i>Penicillium</i>	1
Total		31
C. Bacterial culture positivity of the donor tissue sample		
1.	<i>Pseudomonas</i>	10
2.	Multiple Gram-negative bacilli	8
3.	<i>E. coli</i>	5
4.	<i>Acinetobacter</i>	3
5.	<i>Klebsiella</i>	2
Total		28

Nine hundred sixty-seven (56.7%) homografts were used in different procedures. Of these, 478 were pulmonary homografts, 425 were aortic homografts, 39 mitral homografts, 18 monocusps, and 7 descending thoracic aorta homografts. Indications for the use of homografts for various adult and congenital conditions are shown in Tables 3 and 4. One hundred fifty-four (16%) homografts were preserved using antibiotic and the rest 813 (84%) were cryopreserved. Average time interval between preparation (cryopreservation) and use was 52 days.

Discussion

After being introduced in 1960s, homograft valves have always had the advantage of being virtually free from risk of thromboembolism and hemorrhage related to anticoagulation [6–10]. They also have an advantage when used in presence of active infection, as they have been shown to be associated with low risk of early and late endocarditis [11–13]. However, reoperation due to structural deterioration remains a constant threat.

Homograft use is primarily limited by their availability. In the past, their primary source has been multi-organ donors, but currently, postmortem retrieval and excised hearts of transplant recipients have contributed to their supply. Historically,

Table 2 Reasons for discarding homografts

SN	Reason	Number of homografts
1	Positive serology (donor blood)	246
2	Positive bacterial/fungal culture	118
3	Expiration of antibiotic preservation period of 40 days	27
4	Interruption of cryopreservation	36
5	Physical damage while harvesting	20
6	Wrong size selection	24
7	Crack in homograft because of rapid thawing	26
8	Others	49
Total		546

the use of chemicals, irradiation and other harsh methods of sterilization, and inferior methods of storage [14] have led to poor durability [15]. In 1969, Yacoub and Barratt-Boyes introduced the antibiotic decontamination of homografts [16, 17]. Since then, different tissue establishments [16–20] have adopted different protocols using varying combinations of antibiotics, duration of incubation, and temperature conditions with relatively good results.

We used an antibiotic cocktail containing five antibiotics including an antifungal. These antibiotics cover an entire spectrum including Gram-positive, Gram-negative, aerobic and anaerobic bacteria, with low toxicity. The inherent risk of microbial contamination from the respiratory and gastrointestinal systems after death and from the mortuary atmosphere has been overcome without risk of damaging the valve. Though O'Brien and colleagues [6] follow low-intensity antibiotic sterilization, others [21, 22] have supported an intense protocol. Considering the excessive contamination in Indian circumstances, we feel that our current protocol is justified.

We currently incubate homografts in antibiotic containing solution at 4 °C. It is hypothesized that lower temperatures allow for the antibiotic to function while maintaining tissue integrity [20]. A recent study showed a greater reduction in bioburden by incubation at 37 °C [23]. However, disinfecting

Table 3 Use of homograft in acquired heart diseases

SN	Operation	Number
1	Homograft aortic valve replacement	163
2	Homograft mitral valve replacement	39
3	Ross procedure	189
4	Homograft aortic valve replacement + mitral valve repair	56
5	Pulmonary valve replacement	6
6	Ascending aortic aneurysm	8
7	Aortic root abscess	16
Total		477

Table 4 Use of homograft in congenital heart diseases

SN	Operation	Number
1	Tetralogy of Fallot and its variants	52
2	Pulmonary atresia and its variants	214
3	Truncus arteriosus	115
4	Single ventricle physiology	34
5	Transposition physiology	35
6	Coarctation/interruption	8
7	Others	32
Total		490

tissues at lower temperature has unequivocally shown to prevent warm ischemic damage to the tissue [24]. Decontamination success rates as reported remain between 60 and 70% for different homograft valve banks, despite the extensive variation in antibiotic regimens [24]. In our experience, out of 777 hearts, only 59 hearts showed positive tissue culture (31 fungal and 28 bacterial, Table 1) yielding a decontamination rate of 92.5%.

Advances in the methods of preservation and storage have led to the development of heart valve banks worldwide. There is a relative standardization of the processing aspects [25, 26]. These include (i) the use of sterile culture media, (ii) the use of dimethyl sulphoxide as a cryoprotectant, (iii) antibiotic disinfection, (iv) controlled rate freezing for cryopreservation, and (v) storage at ultralow temperatures below – 135 °C.

With the introduction of cryopreservation in our bank, there is greater availability and flexibility to use homograft in various conditions. Besides the obvious advantages to the patient, the use of a homograft significantly reduces the cost of surgery [1, 27]. The commercially available xenograft conduits are expensive and less durable. After the initial

Table 5 Initial equipment and cost of setting up valve bank with cryopreservation unit

SN	Equipment	Approximate cost in \$
1	Liquid nitrogen storage tank	10,000
2	Liquid nitrogen cylinder (230 L) (2 numbers)	13,000
3	Liquid nitrogen dewar (50 L)	2000
4	Controlled rate freezer	17,000
5	Refrigerator	400
6	Laminar flow cabinet	900
7	Water bath	300
8	Sealing machine	200
9	Vacuum filtrations assembly	800
10	Instrument set for dissection	500
Total		45,100

Table 6 Average recurring monthly expenditure (excluding expenditure on microbiological and serological testing) on consumable items for valve bank with cryopreservation unit (these are prices in the Indian market)

SN	Item	Monthly consumption	Average monthly expenditure in \$
1	Liquid nitrogen	540 L	350
2	Hank solution	One pouch	15
3	RPMI-1640 [#]	One pouch	35
4	Polymyxin B	One vial	50
5	Lincomycin	One vial	40
6	Fetal calf serum	200 ml	50
7	Cefotaxime	One vial	1
8	Amphotericin B	One vial	5
9	Vancomycin	One vial	4
10	Dimethyl sulfoxide	150 ml	10
11	Plastic bag, aluminum pouch	10 each	10
Total			570

[#] Roswell Park Memorial Institute Culture Medium 1640

investment to set up a valve bank ($\approx 45,000\$$) (Table 5), the recurring expenditure on monthly basis ($\approx 600\$$) (Table 6) is negligible as compared to the expenses involved in case all those patients had mechanical/bioprosthetic valves or conduits. In spite of this, it is not possible to offer the benefits of homografts to all patients because of the limited supply. Lack of public awareness and legislative support are the major factors responsible for the limited supply of homograft [1]. Despite limitations, homograft valve bank is feasible in high volume centers having access to medicolegal autopsies.

Conclusion

Our experience and good results with valve banking have been encouraging. It is possible to run a homograft valve bank with minimum costs. Though cryopreservation is more expensive, it provides an opportunity to store the valves for an indefinite period and maintain an uninterrupted supply of homografts.

Acknowledgments The homograft valve bank at our center was established and nurtured by Professor A. Sampath Kumar for 15 years. Authors are thankful to him.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Research involving human participants and/or animals All procedures performed in studies involving human participants were in accordance

with the ethical standards of the institutional ethics committee. Ethical approval was obtained from institutional ethics committee.

This article does not contain any studies with animals performed by any of the authors.

Informed consent It is a retrospective study and informed consent from individual patients was waived off by institutional ethics committee.

References

- Choudhary SK, Srivastava S, Chander H, et al. Early experience with homograft valve banking. *Asian Cardiovasc Thorac Ann.* 1997;5:137–40.
- The American Association of Tissue Banks. Technical manual for tissue banking. Arlington: AATB; 1993.
- Transplantation of Human Organs Act 1994. Central Act 42/1994.
- Angell WW, Angell JD, Oury JH, Lamberti JJ, Grehl TM. Long-term follow-up of viable frozen aortic homografts. A viable homograft valve bank. *J Thorac Cardiovasc Surg.* 1987;93:815–22.
- Kirklin JW, Blackstone EH, Maehara T, et al. Intermediate-term fate of cryopreserved allograft and xenograft valved conduits. *Ann Thorac Surg.* 1987;44:598–606.
- O'Brien MF, McGiffin DC, Stafford EG, et al. Allograft aortic valve replacement: long-term comparative clinical analysis of the viable cryopreserved and antibiotic 4° C stored valves. *J Card Surg.* 1991;6:534–43.
- Bodnar E, Matsuki O, Parker R, Ross DN. Viable and nonviable aortic homografts in the subcoronary position: a comparative study. *Ann Thorac Surg.* 1989;47:799–805.
- O'Brien MF, Stafford EG, Gardner MA, Pohlner PG, McGiffin DC. A comparison of aortic valve replacement with viable cryopreserved and fresh allograft valves, with a note on chromosomal studies. *J Thorac Cardiovasc Surg.* 1987;94:812–23.
- Jamieson WR. Modern cardiac valve devices—bioprostheses and mechanical prostheses: state of the art. *J Card Surg.* 1993;8:89–98.
- Bloomfield P, Wheatley DJ, Prescott RJ, Miller HC. Twelve-year comparison of a Björk–Shiley mechanical heart valve with porcine bioprostheses. *N Engl J Med.* 1991;324:573–9.
- Haydock D, Barratt-Boyes B, Macedo T, Kirklin JW, Blackstone E. Aortic valve replacement for active infectious endocarditis in 108 patients. A comparison of freehand allograft valves with mechanical prostheses and bioprostheses. *J Thorac Cardiovasc Surg.* 1992;103:130–9.
- McGiffin DC, Galbraith AJ, McLachlan GJ, et al. Aortic valve infection. Risk factors for death and recurrent endocarditis after aortic valve replacement. *J Thorac Cardiovasc Surg.* 1992;104:511–20.
- Glazier JJ, Verwilghen JO, Donaldson RM, Ross DN. Treatment of complicated prosthetic aortic valve endocarditis with annular abscess formation by homograft aortic root replacement. *J Am Coll Cardiol.* 1991;17:1177–82.
- Longmore DB, Lockey E, Ross DN, Pickering BN. The preparation of aortic-valve homografts. *Lancet.* 1966;288:463–4.
- Smith JC. The pathology of human aortic valve homografts. *Thorax.* 1967;22:114–38.
- Yacoub M, Kittle CF. Sterilization of valve homografts by antibiotic solutions. *Circulation.* 1970;41:II-29-II-32.
- Barratt-Boyes BG, Roche AH, Brandt PW, Smith JC, Lowe JB. Aortic homograft valve replacement: a long-term follow-up of an initial series of 101 patients. *Circulation.* 1969;40:763–75.
- Gall K, Smith S, Willmette C, Wong M, O'Brien M. Allograft heart valve sterilization: a six-year in-depth analysis of a twenty-five–

- year experience with low-dose antibiotics. *J Thorac Cardiovasc Surg.* 1995;110:680–7.
19. Strickett MG, Barratt-Boyes BG, MacCulloch D. Disinfection of human heart valve allografts with antibiotics in low concentration. *Pathology.* 1983;15:457–62.
 20. Wain WH, Pearce HM, Riddell RW, Ross DN. A re-evaluation of antibiotic sterilization of heart valve allografts. *Thorax.* 1977;32:740–2.
 21. Villalba R, Mirabet V, Rendal E, et al. Microbiological analysis of cryopreserved human heart valves after storage: a survey of 3 banks in Spain. *Cell Tissue Bank.* 2009;10:345–9.
 22. Jashari R, Tabaku M, Van Hoeck B, Cochéz C, Callant M, Vanderkelen A. Decontamination of heart valve and arterial allografts in the European Homograft Bank (EHB): comparison of two different antibiotic cocktails in low temperature conditions. *Cell Tissue Bank.* 2007;8:247–55.
 23. Germain M, Thibault L, Jacques A, Tremblay J, Bourgeois R. Heart valve allograft decontamination with antibiotics: impact of the temperature of incubation on efficacy. *Cell Tissue Bank.* 2010;11:197–204.
 24. Fan YD, Van Hoeck B, Holovska V, Jashari R. Evaluation of decontamination process of heart valve and artery tissues in European Homograft Bank (EHB): a retrospective study of 1,055 cases. *Cell Tissue Bank.* 2012;13:297–304.
 25. Verghese S, Padmaja P, Sindhu B, Elizabeth SJ, Lesley N, Cherian KM. Homograft valve bank: our experience in valve banking. *Indian Heart J.* 2004;56:299–306.
 26. Heng WL, Albrecht H, Chiappini P, Lim YP, Manning L. International heart valve bank survey: a review of processing practices and activity outcomes. *J Transplant.* 2013. <https://doi.org/10.1155/2013/163150>.
 27. Choudhary SK, Mathur A, Chander H, et al. Aortic valve replacement with biological substitute. *J Card Surg.* 1998;13:1–8.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.