The Cardiothoracic Surgeon

REVIEW

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A novel approach, AngioVac use in right-sided infective endocarditis: a scoping review

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Abstract

Background Infective endocarditis is an infection of microbial origin affecting the endocardial layer of the heart, mostly impacting the heart valves. Right-sided infective endocarditis mainly affects the tricuspid valve. In some cases where surgical management is indicated the patients might not be good candidates for surgery. The AngioVac drainage cannula (AngioDynamics, Latham, NY, USA) is a novel device used in debulking and suction of intravascular material. It has been reported in the literature as a novel treatment for patients with right-sided tricuspid valve endocarditis vegetations, where their size is reduced and the efficacy of antibiotics in clearing the bloodstream infection is enhanced.

Methods and results We conducted a thorough literature review to assess the uses of the AngioVac drainage cannula in the management of right-sided infective endocarditis vegetations and lesions. We collected all reported cases where the system was used for the management of right-sided infective endocarditis and performed an encompassing review of the literature. In the review, we found 65 cases reported using the AngioVac drainage cannula for the removal of right-sided infective endocarditis vegetations. Majority of the cases were successful with no complications (87.6%); 7 (10.7%) cases were successful but there were complications: 2 reported mortalities, 1 patient had worsening TR during follow-up, 3 had recurrence of the vegetation, and 1 patient remained bacteremic. There was only 1 reported failure. Four (6.1%) patients required postprocedural valvular surgery with 3 repairs and a single valve replacement.

Conclusions The AngioVac system is a possible bailout option for surgeons managing patients with right-sided infective endocarditis vegetations who are not ideal candidates for surgery. With increased reports on its use, it could be effective at reducing the microbiological burden with minimal complications.

Keywords AngioVac, Right-sided infective endocarditis, Tricuspid valve vegetation, Percutaneous debulking, Percutaneous vegetectomy

Background

Infective endocarditis (IE) is an infection of microbial origin affecting the endocardial layer of the heart, mostly impacting the heart valves. Right-sided infective endocarditis (RSIE) is much less common than left-sided endocarditis and mainly affects the tricuspid valve. The underlying causes of infection mainly arise from congenital or acquired valve disease, indwelling catheters such as a tunneled dialysis catheter or central lines, hematological spread of bacterial oral flora from dental procedures,

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intravenous drug abuse (IVDA), prosthetic valves, and implanted cardiac devices [1, 2]. Approximately 90% of the organisms causing IE are *Staphylococcus* species, *Streptococcus* species, and *Enterococcus* species, with *Staphylococcus aureus* being the most common microorganism associated with IE [3].

IE leads to heart valve vegetations that break from the valve causing emboli that affect multiple organs, leading to a plethora of symptoms including fever, shortness of breath, chest pain, lower limb edema, painful fingertip nodules (Osler nodes), hand and feet painless lesions (Janeway lesions), retinal hemorrhages (Roth spots), and flu-like symptoms. Severe IE can also lead to life-threatening complications such as acute heart failure, pulmonary septic embolism, and stroke, if not treated effectively [3].

The treatment of infective endocarditis stands on two pillars: (1) the eradication of the organisms by appropriate antibiotic coverage, (2) surgical removal of the vegetation, if indicated, to decrease the microbiological burden. In some cases where surgical management is indicated, some patients have an increased risk for morbidity and mortality if they undergo surgery, due to multiple causes, such as frailty status that may not tolerate surgery or a critically ill patient. The AngioVac (AngioDynamics, Latham, NY, USA) is a minimally invasive percutaneous aspiration system that can be used to debulk tricuspid valve vegetations in patients with a high operative risk. The concept of debulking tricuspid valve vegetations aims to reduce bacterial load in order to allow antimicrobial therapy to cure the infection or to stabilize the patient as a bridge to surgery [3].

The primary objectives of this study were (1) to identify the outcomes of the use of the AngioVac system in the setting of RSIE and (2) to review the relevant literature on this topic.

Methods

Data sources and search strategy

F.M.S and A.S.S comprehensively searched PubMed, Embase, Cochrane Library, and Web of Science up to January 2024. The following keywords were used: AngioVac, Percutaneous debulking, Percutaneous suction, Percutaneous vegetectomy, and Endocarditis. The search process involved no limitations. We also screened the selected reports' reference lists for other relevant reports. The detailed search strategy and results can be found in supplementary Table S1.

Eligibility criteria

We included case reports and case series articles that reported the use of the AngioVac cannula in the setting of RSIE. Our inclusion criteria were limited to articles published in peer-reviewed international journals. We excluded articles that did not align with our predefined eligibility criteria.

Study selection

All identified studies were imported into Covidence from online databases, and duplicates were automatically removed. Two authors (F.M.S and A.S.S) independently screened the title and abstract with any conflicts arising resolved by the authors (A.H.B and M.A.F). Full-text screening was performed by the authors F.M.S and A.S.S, and the conflicts were settled by the authors A.H.B and M.A.F. The study selection process is illustrated in a PRISMA flow chart (Fig. 1).

Data extraction

Two authors (F.M.S and A.S.S) independently extracted the following data: age, sex, risk factor for developing infective endocarditis, preprocedural vegetation size, vegetation location, preprocedural tricuspid valve regurgitation severity, isolated organism, contraindication for surgery, cannulation sites, postprocedural vegetation size, postprocedural tricuspid valve regurgitation severity, patient outcome, and the need for surgery. Any conflict was handled by the authors A.H.B and M.A.F.

Results

Search results and study selection

A total of 1722 records were identified after searching electronic databases. After eliminating 151 duplicated articles, 1571 studies were eligible for title and abstract screening. Nine hundred eighty-nine studies were excluded due to their lack of relevance to the research objectives. Five hundred eighty-two articles proceeded to full-text screening with 534 being excluded. In this review, a total of 48 publications were included with a total of 65 patients reported to undergo the usage of AngioVac in the setting of RSIE. Detailed patient characteristics and data are included in Table 1.

Patient demographics

The median age of the patient was 40 years old (IQR,15–82) with the majority being males with 36 (55.3%) patients, and of note, 3 of the female patients were pregnant (Table 2).

Risk factors for developing RSIE

The most common risk factor was the abuse of intravenous drugs reported in 25 (38.4%) patients, followed by cardiac implantable electronic devices (CIED) in 22 (33.7%) patients, 5 (7.6%) patients were reported to have a bioprosthetic valve. Also, another 5 (7.6%) patients had tunneled dialysis catheters. Only 2 (3.07%) patients had a

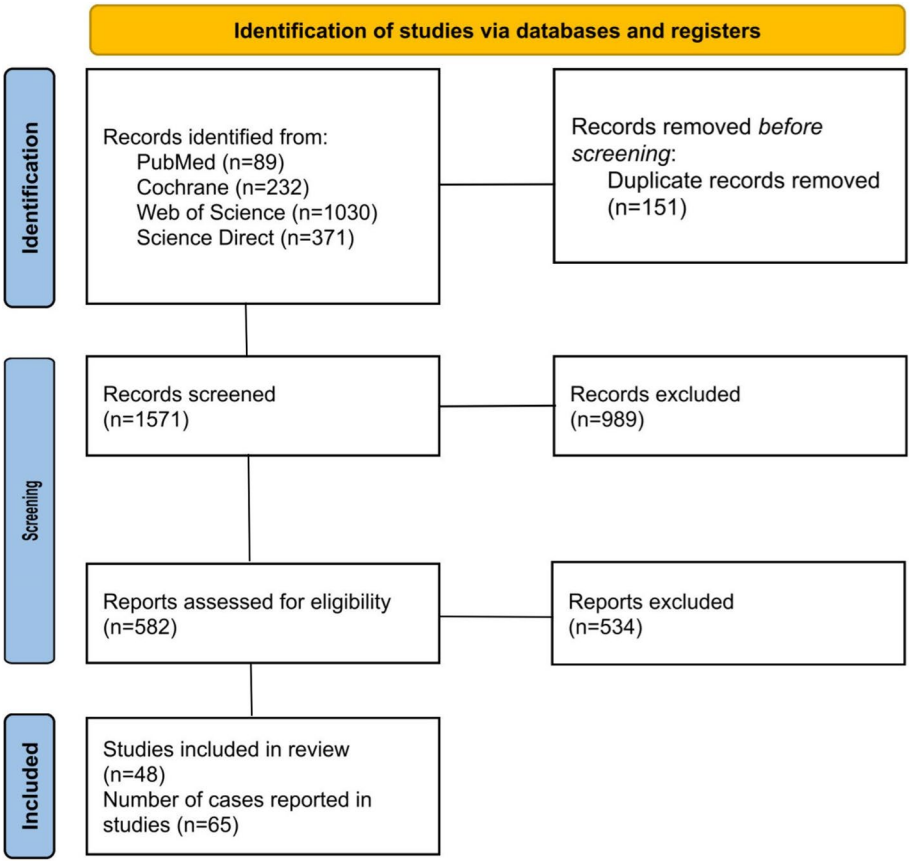

Fig. 1 PRISMA flowchart

distant infection with both of them having osteomyelitis. Two (3.07%) patients had a combination of risk factors (Table 2).

Causative organism

The most common isolated organism was methicillin-sensitive *Staphylococcus aureus* (MSSA) in 23 (35.3%) patients, followed by methicillin-sensitive *Staphylococcus aureus* (MRSA) in 17 (26.1%) patients, *Candida* spp. in 5 (7.6%) patients, *Streptococcus* spp. in 4 (6.1%) patients. *Staphylococcus aureus*, *Staphylococcus hominis*, *Enterococcus faecalis*, and *Enterobacter* spp. were all individually reported in 2 (3.07%) patients. *Klebsiella oxytoca*, *Pseudomonas aeruginosa*, *Serratia marcescens*, and *Haemophilus parainfluenzae* were each reported only once (1.5%). Three (4.6%) patients had a polymicrobial infection (Table 2).

Indications for AngioVac system

The main cause was lack of surgical candidacy in 23 (35.3%) patients who had multiple comorbid conditions with 8 (12.3%) of them having severely depressed cardiac function with cardiomyopathy. The other most common cause was hemodynamic instability in 23 (35.3%) patients as well. Three (4.6%) patients had prior cardiac surgery. Also, another 3 (4.6%) patients had extensive septic pulmonary emboli. Recurrent intravenous drug abuse was a contraindication for surgery in 2 (3.07%) patients. One (1.5%) patient had a pulmonary artery aneurysm, and 1 (1.5%) patient was reported to refuse offered surgery (Table 2).

Location of the vegetation

The most common site was the tricuspid valve in 36 (55.3%) patients, followed by the vegetations forming on a lead of a CIED in 12 (18.4%) patients; 5 (7.6%) cases were reported to be on a bioprosthetic valve, 2 (3.07%) cases in the right atrium. The right ventricle, superior vena cava, chiari network, pulmonary valve, and tricuspid valve annuloplasty were each reported only once (1.5%). Six (9.2%) patients had multiple vegetations (Table 3).

Preprocedural echocardiographic findings

The median size of the vegetations reported was 24 mm (IQR, 6–61). Preprocedural tricuspid regurgitation (TR) was reported to be mild in 8 (12.3%) cases, moderate in

Table 1 Reported cases of right-sided infective endocarditis treated by the AngioVac system

	Author, year	Type of publication	Age/Sex	Risk factor	Organism	Pre-AngioVac vegetation size	Pre-AngioVac Tricuspid regurgitation	Location	Contraindication to surgery	Post-AngioVac vegetation size	Post-AngioVac Tricuspid regurgitation	AngioVac Access sites	Need for operation for tricuspid valve	Outcome of AngioVac
1	Dalia et al., 2017	Case report	26/Female	IVDA	MRSA	16×8 mm	Not reported	Tricuspid valve	Pulmonary artery aneurysm	Not reported	Not reported	Bilateral femoral	No-Pulmonary artery aneurysm repair	Successful
2	Vaidya et al., 2018	Case report	50/Female	ICD	MRSA	30×13 mm	Not reported	Right ventricle on the ICD lead	Myomectomy	Not reported (80% reduction)	Not reported	AngioVac: right internal jugular Return cannula: right common femoral vein	No-ICD insertion	Successful
3	Prabhudas-Strynckera et al., 2020	Case report	42/Female	Dialysis catheter	Candida tropicalis	20 mm	Not reported	SVC and right atrium	Chronic kidney disease and multiple comorbidities	Not reported (75% reduction)	Not reported	Not reported	No	Successful
4	Mercado-alamo et al., 2021	Case report	27/Female	IVDA	MRSA	26×10 mm	Moderate	Tricuspid valve	Multiple comorbid conditions	Not reported (significant reduction)	Severe	AngioVac: right internal jugular vein	No (left against medical advice)	Successful
5	Koney et al., 2019	Case report	15/Male	Not reported	*Staphylococcus hominis*	20 mm	Interval development (mild)	Tricuspid valve	Hemodynamically unstable for surgery	Complete removal (100% reduction)	Complete resolution	AngioVac: right internal jugular vein	No	Successful
6	Thiagaraj et al., 2017	Case series	35/Male	Permacath dialysis catheter	MSSA	45 mm	Not reported	SVC	Hemodynamically unstable for surgery	Complete removal (100% reduction)	Not reported	Not reported	No	Successful
			28/Female	IVDA	MRSA	22×17 mm	Moderate	Tricuspid valve	Hemodynamically unstable for surgery	Complete removal (100% reduction)	Not reported	Not reported	No	Successful. Patient died after due to cardiac arrest 5 days after AngioVac
			53/Female	ICD, IVDA, bioprosthetic valve	*Enterococcus faecalis*	32 mm	Moderate	Bioprosthetic tricuspid valve	Septic emboli	removal (25–50% reduction)	Mild	Not reported	No	Successful but trace worsening of tricuspid Regurgitation during follow-up

Table 1 (continued)

	Author, year	Type of publication	Age/Sex	Risk factor	Organism	Pre-AngioVac vegetation size	Pre-AngioVac Tricuspid regurgitation	Location	Contraindication to surgery	Post-AngioVac vegetation size	Post-AngioVac Tricuspid regurgitation	AngioVac Access sites	Need for operation for tricuspid valve	Outcome of AngioVac
7	Starck et al., 2019	Case report	57/Male	Bioprosthetic tricuspid valve	MSSA	12×17 mm	Mild	Tricuspid valve	Hemodynamically unstable for surgery	Not reported (significant reduction)	Worsening	AngioVac: right internal jugular Return cannula: right common femoral vein	Yes (repair)	Successful but recurrence of vegetation
8	Ahmed et al., 2018	Case report	56/Female	ICD	MSSA	24×21 mm	Not reported	ICD lead	Hemodynamically unstable for surgery	Complete removal (100% reduction)	Not reported	Not reported	No	Successful
9	Divekar et al., 2013	Case report	17/Male	Bioprosthetic pulmonary valve	MSSA	35×15 mm	Not reported	Bioprosthetic pulmonary valve	Hemodynamically unstable for surgery	Not reported (significant reduction)	Not reported	Bilateral femoral	No	Successful
10	Leso et al., 2021	Case report	34/Male	IVDA	*Klebsiella oxytoca*	35 mm	Severe	Tricuspid valve	Hemodynamically unstable for surgery	<10 mm (75% reduction)	Not reported	Not reported	No(but cardiac surgery offered after AngioVac)	Successful
11	Tarzia et al., 2021	Case report	42/Male	ICD	MSSA	40×11 mm	Not reported	ICD lead (ventricular)	Previous pulmonary atresia and ventricular septal defect repair with aortic adhesion to the sternum	Complete removal (100% reduction)	Not reported	Bilateral femoral	No	Successful
12	Talebi et al., 2017	Case report	57/Female	Permacath dialysis catheter	*Candida parapsilosis*	20×30 mm	Mild	Right atrial above the tricuspid valve annulus	Multiple comorbid conditions	Not reported	Moderate	Not reported	No	Successful
13	Bangalore et al., 2021	Case report	36/Male	IVDA	MSSA	27×8 mm	Severe	Tricuspid valve	Not reported	Complete removal (100% reduction)	severe	AngioVac: right internal jugular Return cannula: right common femoral vein	No	Successful

Table 1 (continued)

	Author, year	Type of publication	Age/Sex	Risk factor	Organism	Pre-AngioVac vegetation size	Pre-AngioVac Tricuspid regurgitation	Location	Contraindication to surgery	Post-AngioVac vegetation size	Post-AngioVac Tricuspid regurgitation	AngioVac Access sites	Need for operation for tricuspid valve	Outcome of AngioVac
14	Jones et al., 2017	Case report	25/Female	ICD	*Candida albicans*	First Vegetation: 61 mm × 16 mm Second vegetation: 21 × 16 mm	Not reported	First vegetation: SVC to right atrium Second vegetation: above the tricuspid valve	Unfit for surgery / EF of 10%	Not reported	Not reported	Bilateral femoral	No	Successful
15	Ababukar et al., 2017	Case report	33/Female	IVDA	*Streptococcus pyogenes*	30 × 15 mm	Moderate	Tricuspid valve	Hemodynamically unstable for surgery and poor nutritional status	Decreased 21 mm from its original size (50–60% reduction)	Not reported	AngioVac: right internal jugular Return cannula: left common femoral vein	No	Successful
16	Winkle et al., 2020	Case report	27/Female	IVDA	Polymicrobial: MSSA, *Serratia marcescens*	Anterior leaflet: 34 × 20 mm Posterior leaflet: 32 × 11 mm	Not reported	Tricuspid valve	Hemodynamically unstable	Not reported (reduction in size)	Not reported	Not reported	No	Successful
17	Yoruk et al., 2020	Case report	35/Male	IVDA, ICD	MSSA	25 mm	Not reported	ICD lead	Multiple comorbid conditions	Complete removal (100% reduction)	Not reported	Not reported	No	Successful
18	Souka et al., 2021	Case report	27/Male	Bioprosthetic valve, IVDA	Not reported	26 × 17 mm	Not reported	Bioprosthetic valve	Hemodynamically unstable	Not reported (Significant reduction in size)	Mild	AngioVac: right internal jugular Return cannula: left common femoral vein	No	Successful
19	Hamilton et al., 2021	Case report	35/Male	IVDA	MRSA	20 mm	Severe	Tricuspid valve	Recurrent IVDA	Not reported	Not reported	Not reported	No	Successful

Table 1 (continued)

	Author, year	Type of publication	Age/Sex	Risk factor	Organism	Pre-AngioVac vegetation size	Pre-AngioVac Tricuspid regurgitation	Location	Contraindication to surgery	Post-AngioVac vegetation size	Post-AngioVac Tricuspid regurgitation	AngioVac Access sites	Need for operation for tricuspid valve	Outcome of AngioVac
20	Kashyap et al., 2021	Case report	39/Female	IVDA	MRSA	Septal leaflet: 6×4 mm Anterior leaflet: 14×4 mm	Moderate	Tricuspid valve	Hemodynamically unstable	Not reported	Not reported	Not reported	No	Successful
21	ELjack et al., 2021	Case report	24/Female	IVDA	*Staphylococcus aureus*	Not reported	Moderate	On tricuspid valve annuloplasty ring	Recurrent IVDA	Not reported (small residual vegetation left)	Slightly worsening	Not reported	No	Successful
21	Chang et al., 2021	Case series	22/Male	Not reported	MSSA	Not reported	Not reported	Tricuspid valve	Not reported	Not reported	Not reported	Not reported	No	Successful
			38/Male	Not reported	MSSA	Not reported	Not reported	Tricuspid valve	Not reported	Not reported	Not reported	Not reported	No	Successful
			34/Female	Not reported	MRSA	Not reported	Not reported	Tricuspid valve	Not reported	Not reported	Not reported	Not reported	No	Successful
23	Moriarty et al., 2014	Case report	62/Male	ICD	*Enterococcus faecalis*	47×21 mm	Not reported	Tricuspid valve	Unfit for surgery / EF of 20%	Decreased to 14×21 mm (71% reduction in size)	Not reported	Not reported	No	Successful
24	Ayzenbart et al., 2021	Case report	27/Female (pregnant)	IVDA	MRSA	First Vegetation: 24×12 mm Second Vegetation: 14×7 mm	severe	Tricuspid valve	Hemodynamically unstable / pregnant	Recurrence of vegetation	Not reported	Not reported	No	The first AngioVac was done with recurrence of the vegetation; a second one was performed, and it was successful
25	Hosoba et al., 2015	Case series	67/Male	Osteomyelitis	MRSA	15×15 mm	Not reported	Right atrium	Not reported	Not reported	Not reported	Not reported	No	Successful
			33/Female	ICD	*Enterobacter cloacae*	22×6 mm	Not reported	Chiari network	Multiple comorbid conditions	Not reported	Not reported	Not reported	No	Successful
			70/Male	ICD	MSSA	34×13 mm	Not reported	Right atrium	Prior coronary artery bypass grafting	Not reported	Not reported	Not reported	No	Successful
26	Kumar et al., 2017	Case report	62/Male	CRT-D	MSSA	20×20 mm	Not reported	CRT-D atrial lead	Hemodynamically unstable	Not reported (majority of the vegetation removed)	Not reported	Not reported	No	Successful

Table 1 (continued)

	Author, year	Type of publication	Age/Sex	Risk factor	Organism	Pre-AngioVac vegetation size	Pre-AngioVac Tricuspid regurgitation	Location	Contraindication to surgery	Post-AngioVac vegetation size	Post-AngioVac Tricuspid regurgitation	AngioVac Access sites	Need for operation for tricuspid valve	Outcome of AngioVac
27	Gjeka et al., 2019	Case report	45/Male	IVDA	MSSA	55 mm	Not reported	Tricuspid valve	Poor surgical candidate with multiple septic pulmonary emboli	Not reported (75–80% reduction in vegetation)	Not reported	Not reported	No	Successful
28	Green et al., 2020	Case report	55/Male	ICD	*Staphylococcus hominis*	50 × 20 mm	Not reported	Tricuspid valve	Ischemic cardiomyopathy	Not reported (75–80% reduction in vegetation)	Not reported	AngioVac: right internal jugular Return cannula: right common femoral vein	Yes (repair)	The AngioVac was done and removed the Vegetation with recurrence of the vegetation
29	Xiao et al., 2023	Case report	45/Male	IVDA	*Streptococcus mitis*	43 × 43 mm	Severe	Tricuspid valve	Multiple comorbid conditions / Acute kidney injury / pancytopenia	37 × 23 mm (54% reduction in size)	severe	Not reported	No	Successful (patient left against medical advice)
30	Eichelberger et al., 2022	Case report	40/Male	IVDA	MSSA	27 × 11 mm	Severe	Tricuspid valve	Hemodynamically unstable	Not reported	Not reported	Not reported	No	Successful
31	Khan et al., 2022	Case report	36/Female	IVDA	MRSA	24 × 12 mm	Severe	Tricuspid valve	Hemodynamically unstable	Not reported	Not reported	AngioVac: right internal jugular Return cannula: right common femoral vein	No	Successful

Table 1 (continued)

	Author, year	Type of publication	Age/Sex	Risk factor	Organism	Pre-AngioVac vegetation size	Pre-AngioVac Tricuspid regurgitation	Location	Contraindication to surgery	Post-AngioVac vegetation size	Post-AngioVac Tricuspid regurgitation	AngioVac Access sites	Need for operation for tricuspid valve	Outcome of AngioVac
32	Mittal et al., 2022	Case series	56/Male	ICD	*Pseudomonas aeruginosa*	30×15 mm	No regurgitation	Tricuspid valve	Multiple comorbid conditions	Not reported (80% reduction in vegetation)	mild	AngioVac: right internal jugular Return cannula: right common femoral vein	No	Successful
			39/Female	IVDA	MRSA	Septal leaflet: 8×4 mm Anterior leaflet: 15×9 mm	Severe	Tricuspid valve	Hemodynamically unstable	Not reported (80% reduction in vegetation)	Not reported	AngioVac: right internal jugular Return cannula: right common femoral vein	No	Successful
			70/Female	ICD, dialysis catheter	MSSA	SVC: 27×10 mm ICD lead: 9×1 mm	Not reported	SVC, ICD lead, tip of tunneled catheter	Multiple comorbid conditions	Not reported (70% reduction in vegetation)	Mild to moderate	AngioVac: right internal jugular Return cannula: right common femoral vein	No	Successful
33	Riasat et al., 2023	Case report	54/Male	CRT-D	Polymicrobial: MSSA, *Enterococcus faecalis*	26×21 mm	Moderate	Right lead of the CRT-D	Low EF of 20%	Complete removal (100% reduction)	Moderate	Not reported	No	Successful
34	Pasley et al., 2023	Case series	28/Female	IVDA	MRSA	21×13 mm	Not reported	Tricuspid valve	Multiple comorbid conditions / IVDA	Complete removal (100% reduction)	Not reported	Not reported	No	Successful
			68/Male	Dialysis	MSSA	1.3×21 mm	Severe	Pulmonary valve	Multiple comorbid conditions / Low EF of 20%	Not reported	Not reported	Not reported	No	Successful

Table 1 (continued)

	Author, year	Type of publication	Age/Sex	Risk factor	Organism	Pre-AngioVac vegetation size	Pre-AngioVac Tricuspid regurgitation	Location	Contraindication to surgery	Post-AngioVac vegetation size	Post-AngioVac Tricuspid regurgitation	AngioVac Access sites	Need for operation for tricuspid valve	Outcome of AngioVac
35	Abdelhabib et al., 2021	Case report	26/Female	IVDA	MSSA	20 × 20 mm	Not reported	Tricuspid valve	Hemodynamically unstable (respiratory failure and septic shock)	Not reported	Not reported	Not reported	No	Successful
36	Hritani et al., 2022	Case report	51/Male	Osteomyelitis	*Serratia marcescens*	21 × 24 mm	Mild	Tricuspid valve	Multiple comorbid conditions	Not reported (90% reduction in vegetation)	Severe	Not reported	No	Successful
37	Pargaonkar et al., 2023	Case report	25/Male	Dialysis catheter	MSSA	SVC: 25 × 9 mm Tricuspid: 16 × 18 mm	Mild	SVC and Tricuspid valve	Hemodynamically unstable (Respiratory failure and septic shock)	Complete removal (100% reduction)	Severe	Not reported	No	Successful
38	Ali et al., 2023	Case report	24/Female (pregnant)	IVDA	MRSA	47 × 20 mm	severe	Tricuspid valve	Hemodynamically unstable (Respiratory failure) / pregnant	Not reported	Not reported	Not reported	No	Successful
39	Stephens et al., 2022	Case report	31/Male	IVDA	MRSA	15 × 10	Moderate	Tricuspid valve	Multiple comorbid conditions	Not reported	Not reported	Not reported	No	Successful
40	Beshai et al., 2022	Case report	31/Female	Bioprosthetic tricuspid valve, IVDA	Polymicrobial: MRSA, *Candida glabrata*, *Escherichia coli*, *Klebsiella*, *Enterococcus*, and *Pseudomonas*	Not reported	Not reported	Bioprosthetic tricuspid valve	Multiple comorbid conditions	Failed no removal	Not reported	Bilateral femoral	No	Failed after multiple attempts
41	Báez et al., 2023	Case report	61/Male	ICD	*Candida parapsilosis*	23 mm	Moderate	Tricuspid valve	Multiple comorbid conditions / Low EF of 20% / ischemic cardiomyopathy	Complete removal (100% reduction)	Not reported	Not reported	No	Successful
42	Nguyen et al., 2022	Case report	71/Male	ICD	MRSA	10 mm	Not reported	Right ventricle adjacent to the leadless pacemaker	Multiple comorbid conditions	Complete removal (100% reduction)	Not reported	Bilateral femoral	No	Successful

Table 1 (continued)

	Author, year	Type of publication	Age/Sex	Risk factor	Organism	Pre-AngioVac vegetation size	Pre-AngioVac Tricuspid regurgitation	Location	Contraindication to surgery	Post-AngioVac vegetation size	Post-AngioVac Tricuspid regurgitation	AngioVac Access sites	Need for operation for tricuspid valve	Outcome of AngioVac
43	Poliwoda et al., 2023	Case series	37/Male	IVDA	MSSA	10 × 9 mm	Not reported	Tricuspid valve	Not reported	Not reported	Not reported	AngioVac: right internal jugular Return cannula: left common femoral vein	No	Successful
			43/Female	IVDA	MSSA	15 × 11 mm	Moderate to severe	Tricuspid valve	Not reported	Not reported	Not reported	AngioVac: right internal jugular Return cannula: left common femoral vein	No	Successful
			26/Female	IVDA	MRSA	10 × 15 mm	Moderate	Tricuspid valve	Not reported	Not reported	Not reported	AngioVac: right internal jugular Return cannula: left common femoral vein	No	Successful
44	Middleton et al., 2023	Case report	70/Female	ICD	*Streptococcus pneumoniae*	10 × 20 mm	Moderate	Tricuspid valve	Multiple comorbid conditions	Not reported (near complete reduction in vegetation)	Not reported	AngioVac: right internal jugular Return cannula: right common femoral vein	No	Successful

Table 1 (continued)

	Author, year	Type of publication	Age/Sex	Risk factor	Organism	Pre-AngioVac vegetation size	Pre-AngioVac Tricuspid regurgitation	Location	Contraindication to surgery	Post-AngioVac vegetation size	Post-AngioVac Tricuspid regurgitation	AngioVac Access sites	Need for operation for tricuspid valve	Outcome of AngioVac
45	Stroker et al., 2022	Case report	43/Male	IVDA	MSSA	32 × 26 mm	Mild	Tricuspid valve	Patient refused surgery	Not reported (Satisfactory reduction in vegetation)	Moderate	AngioVac: right internal jugular Return cannula: right common femoral vein	No	Successful
46	Boudova et al., 2023	Case report	22/ Female(pregnant)	IVDA	MSSA	20 × 10 mm	severe	Tricuspid valve	Hemodynamically unstable / pregnant	Complete removal (80% reduction)	severe	AngioVac: right internal jugular Return cannula: right common femoral vein	Yes (replacement)	Successful
47	Patel et al., 2018	Case series	46/Male	ICD	*Candida albicans*	20 mm	Not reported	Right atrial lead	Poor surgical candidate with multiple septic pulmonary emboli	Complete removal (100% reduction)	Not reported	AngioVac: right common femoral vein Return cannula: left common femoral vein	No	Successful
			50/Male	CRT-D	MSSA	32 × 13 mm	Not reported	Right atrial lead	Multiple comorbid conditions with cardiomyopathy and heart failure	Complete removal (100% reduction)	Not reported	AngioVac: right internal jugular Return cannula: left common femoral vein	No	Successful

Table 1 (continued)

Author, year	Type of publication	Age/Sex	Risk factor	Organism	Pre-AngioVac vegetation size	Pre-AngioVac Tricuspid regurgitation	Location	Contraindication to surgery	Post-AngioVac vegetation size	Post-AngioVac Tricuspid regurgitation	AngioVac Access sites	Need for operation for tricuspid valve	Outcome of AngioVac
		68/Male	Pacemaker	*Haemophilus parainfluenza*	Not reported	Not reported	Tricuspid, mitral, and right atrium	Hemodynamically unstable	Complete removal of tricuspid valve vegetation(100% reduction)	Not reported	AngioVac: right internal jugular Return cannula: left common femoral vein	No	Successful
		45/Female	ICD	*Enterobacter faecalis*	39 × 13 mm	Not reported	Tricuspid valve	Multiple comorbid conditions	Complete removal (100% reduction)	Not reported	AngioVac: right internal jugular Return cannula: left common femoral vein	No	Successful
		68/Female	Pacemaker	MSSA	15 × 10 mm	Not reported	Tricuspid valve, right atrial, and ventricular lead	Hemodynamically unstable (respiratory failure and septic shock)	Not reported (significant reduction in vegetation)	Not reported	AngioVac: right internal jugular Return cannula: left common femoral vein	No	Successful (patient passed away due to deterioration)l

Table 1 (continued)

	Author, year	Type of publication	Age/Sex	Risk factor	Organism	Pre-AngioVac vegetation size	Pre-AngioVac Tricuspid regurgitation	Location	Contraindication to surgery	Post-AngioVac vegetation size	Post-AngioVac Tricuspid regurgitation	AngioVac Access sites	Need for operation for tricuspid valve	Outcome of AngioVac
48	Patel et al., 2013	Case series	59/Male	ICD	*Staphylococcus aureus*	30 × 20 mm	Mild	Right ventricular lead	Multiple comorbid conditions / Low EF of 20% / ischemic cardiomyopathy	50 × 20 × 10 mm vegetation was removed (significant reduction)	Significant improvements	AngioVac: right internal jugular Return cannula: left common femoral vein	No	Successful
			82/Male	Pacemaker	Group B *Streptococcus*	Right ventricular lead: 15 × 40 mm Tricuspid valve: 5 × 11 mm	Not reported	Right ventricular lead and tricuspid valve	Not reported (old age)	Not reported (significant reduction in vegetation)	Not reported	AngioVac: right internal jugular Return cannula: left common femoral vein	No	Successful
			56/Male	Pacemaker	MRSA	35 × 17 mm	Mild	Atrial lead	Hemodynamically unstable (septic shock)	30 × 25 × 10 mm vegetation was removed (Significant reduction)	Severe	AngioVac: right internal jugular Return cannula: left common femoral vein	Yes(repair)	Successful (but the bacteremia did not resolve after debulking)

MRSA methicillin-resistant *Staphylococcus aureus*, *MSSA* methicillin-sensitive *Staphylococcus aureus*, *ICD* implantable cardioverter defibrillator, *IVDA* intravenous drug abuse, *SVC* superior vena cava, *CRT-D* cardiac resynchronization therapy–defibrillator, *EF* ejection fraction

Table 2 Preprocedural characteristics

Characteristic	*N* = 65
Age in years, **(median (IQR))**	40 (15–82)
Gender, *n* (%)	
Male	36 (55.3%)
Female	29 (44.6%)
Pregnant	3 (4.6%)
Risk factors, *n* (%)	
IVDA	25 (38.4%)
ICD	15 (23.07%)
Pacemaker	4 (6.1%)
CRT-D	3 (4.6%)
Dialysis catheters	5 (7.6%)
Right-sided bioprosthetic valve	5 (7.6%)
Osteomyelitis	2 (3.07%)
Multiple risk factors	2 (3.07%)
Not reported	4 (6.1%)
Isolated organism, *n* (%)	
MSSA	23 (35.3%)
MRSA	17 (26.1%)
Candida spp.	5 (7.6%)
Streptococcus spp.	4 (6.1%)
Staphylococcus aureus	2 (3.07%)
Staphylococcus hominis	2 (3.07%)
Enterococcus faecalis	2 (3.07%)
Enterobacter spp.	2 (3.07%)
Klebsiella oxytoca	1 (1.5%)
Pseudomonas aeruginosa	1 (1.5%)
Serratia marcescens	1 (1.5%)
Haemophilus parainfluenzae	1 (1.5%)
Polymicrobial	3 (4.6%)
Not reported	1 (1.5%)
Indications for AngioVac usage, *n* (%)	
Multiple comorbid conditions	23 (35.3%)
Reduced EF and cardiomyopathy	8 (12.3%)
Hemodynamic instability	23 (35.3%)
Prior cardiac surgery	3 (4.6%)
CABG	1 (1.5%)
Myectomy	1 (1.5%)
Pulmonary atresia with VSD closure	1 (1.5%)
Extensive pulmonary septic emboli	3 (4.6%)
Recurrent IVDA	2 (3.07%)
Pulmonary artery aneurysm	1 (1.5%)
Refused surgery	1 (1.5%)
Not reported	9 (13.8%)

IVDA intravenous drug abuse, *ICD* implantable cardioverter, *CRT-D* cardiac resynchronization therapy–defibrillator, *MSSA* methicillin-sensitive *Staphylococcus aureus*, *MRSA* methicillin-resistant *Staphylococcus aureus*, *EF* ejection fraction, *CABG* coronary artery bypass grafting, *VSD* ventricular septal defect

Table 3 Preprocedural echocardiographic findings

Characteristic	*N* = 65
Location of the vegetation, *n* (%)	
Tricuspid valve	36 (55.3%)
CIED leads	12 (18.4%)
Bioprosthetic valve	5 (7.6%)
Right atrium	2 (3.07%)
Right ventricle	1 (1.5%)
Superior vena cava	1 (1.5%)
Chiari network	1 (1.5%)
Native pulmonary valve	1 (1.5%)
Tricuspid valve annuloplasty ring	1 (1.5%)
Large vegetations in multiple locations	6 (9.2%)
Vegetation size in mm, **median (IQR)**	24 (6–61)
Degree of preprocedural TR, *n* (%)	
No TR	1 (1.5%)
Mild	8 (12.3%)
Moderate	12 (18.4%)
Severe	11 (16.9%)
Not reported	33 (50.7%)

CIED cardiac implantable electronic devices, *TR* tricuspid regurgitation

12 (18.4%), and severe in 11 (16.9%). One (1.5%) case reported no preprocedural TR (Table 3).

Postprocedural echocardiographic findings

Sixteen (24.6%) cases reported complete reduction (100%) of the vegetation, 22 (33.8%) reported satisfactory reduction (>70%), and only 3 (4.6%) cases reported unsatisfactory reduction (<70%). It is to be noted that 3 (4.6%) cases were reported by the authors to have satisfactory reduction but no postprocedural size or percentage of reduction being reported. As for the postprocedural TR, 9 (13.8%) cases reported worsening, 3 (4.6%) cases reported improvement, and 4 (6.1%) cases reported the same degree of TR with 3 of 4 cases were reported as severe TR preprocedural and remained at the same degree. Unfortunately, the majority of the studies did not report the degree of postprocedural TR (Table 4).

Postprocedural outcomes

Majority of the cases were successful with no complications (87.6%); 7 (10.7%) cases were successful but there were complications: 2 reported mortalities, 1 patient had worsening TR during follow-up, 3 had recurrence of the vegetation, and 1 patient remained bacteremic. There

Table 4 Postprocedural outcomes

Characteristic	*N* = 65
Percentage of vegetation size reduction, *n* (%)	
Complete reduction (100% reduction)	16 (24.6%)
Satisfactory reduction (> 70% reduction)	22 (33.8%)
Unsatisfactory reduction (< 70% reduction)	3 (4.6%)
Reported satisfactory removal (no reported postoperative sizes or percentages of difference)	3 (4.6%)
Not reported	21 (32.3%)
Postoperative TR, *n* (%)	
Improvement	3 (4.6%)
Worsening	9 (13.8%)
Same	4 (6.1%)
Severe	3 (4.6%)
Moderate	1 (1.5%)
Not reported	49 (75.3%)
Outcomes, n(%)	
Successful with no complications	57 (87.6%)
Successful removal with complications	7 (10.7%)
Mortality	2 (3.07%)
Worsening of tricuspid valve Regurgitation during follow-up	1 (1.5%)
Recurrence of the vegetation	3 (4.6%)
Bacteremia did not resolve	1 (1.5%)
Failure	1 (1.5%)
Need for tricuspid valve surgery	4 (6.1%)
Repair	3 (4.6%)
Replacement	1 (1.5%)

TR tricuspid regurgitation

was only 1 reported failure. Four (6.1%) patients required postprocedural valvular surgery with 3 repairs and a single valve replacement (Table 4).

Discussion

RSIE accounts for 10% of all IE cases and continues to rise, with an aging multi-morbid population. Nearly 90% of all RSIE occurs in patients who use injectable drugs, 9% in patients with CIED or intravascular devices, and 1% in those with congenital heart disease (CHD) [4, 5].

Disease development in individuals who abuse intravenous drugs is caused by direct endothelial damage as well as the introduction of organisms through injection sites from the skin or as a contaminant in the drug. For individuals with intravascular or cardiac implantable electronic devices, contamination is frequently initiated during handling or implantation. Most RSIE (60–90%) is by infection with *Staphylococcus aureus*, thereafter streptococcal, gram-negative, or HACEK bacteria. While RSIE involving intravascular catheters or prosthetic valves is caused by MSSA, MRSA and fungal organisms are the cause in the presence of immunosuppression, cardiac implanted devices, and intravenous drug abuse [6].

The diagnosis of IE can be determined using the modified Duke criteria. This includes a list of major and minor criteria, that, when fulfilled, most likely suggest IE. The major modified Duke criteria are blood culture positive for IE causative organisms and evidence of endocardial involvement. The minor criteria include a predisposing heart condition, intravenous venous drug use, fever of 38 °C, vascular phenomena, including major arterial emboli, septic pulmonary infarcts, mycotic aneurysm, intracranial hemorrhage, conjunctival hemorrhages and Janeway lesions, immunological phenomena such as Osler nodes, glomerulonephritis, Roth spots, rheumatoid factor, and microbiological evidence. The criteria are fulfilled when one major and one minor or three minor criteria are met [6].

The mainstay of treatment for RSIE is intravenous antibiotic therapy of the underlying infection and the removal of the underlying source of infection by either the removal of causative intravascular devices or surgical removal of the infected prosthetic valve or valvular vegetation [4–6].

As patients can rapidly decompensate, necessitating surgical intervention, ideally, they should be managed by a multidisciplinary team consisting of microbiologists, valve disease specialists, and cardiac surgeons.

The recent European guidelines by the European Society of Cardiology indicate surgery if the patient has the following: (1) persistent fungi or bacteremia for more than 7 days, despite adequate antibiotic therapy, (2) persistent tricuspid valve vegetations, greater than 20 mm in size, causing recurrent pulmonary embolism with or without right-sided heart failure, (3) right-sided heart failure caused by severe TR, not responsive to diuretic therapy, (4) if percutaneous removal of a CIED was incomplete, or not possible, or associated with severely destroyed tricuspid valve, and (5) if the CIED has large vegetations greater than 20 mm in size [7].

Recently, the American Heart Association guidelines stated that surgery is indicated for certain complications: (1) resistant infections caused by fungi or drug-resistant bacteria, (2) tricuspid valve vegetations more than 20 mm in size, (3) right-sided heart failure due to severe TR, without response to diuretic therapy, (4) recurrent pulmonary embolism despite appropriate antibiotic therapy and coverage. Also, valvular repair is preferred rather than replacement, when feasible, with an individualized prosthesis for every patient if valve replacement was performed, and avoiding surgery is recommended, when possible, in patients with a history of IVDA [8].

In cases where surgery is recommended, operative risk assessment is important to decide whether the

risk–benefit analysis supports surgery being performed. In recent years, several case reports and case series have introduced a novel, minimally invasive, technique using a percutaneous aspiration system to debulk tricuspid valve vegetations in patients with a high operative risk. This concept of debulking tricuspid valve vegetations aims to reduce bacterial load to allow antimicrobial therapy to cure the infection or to stabilize the patient as a bridge to surgery [9–57].

This device is the AngioVAC system. The United States Food and Drug Administration (FDA) approved the AngioVac system for the removal of unwanted intravascular materials (thrombi and emboli) in 2014. Currently, the device is not approved to be used in the setting of RSIE vegetation removal, but recently, the device received the FDA breakthrough device designation to expand its use in RSIE. This designation will accelerate assessments and review processes to allow its approval in the near future [58].

The device comprises a venous drainage cannula and a reinfusion (venous return) cannula, which are connected to an extracorporeal circuit and a commercially available pump head and bubble trap. The venous drainage component is a 22-Fr cannula with a funnel-shaped distal tip that can be advanced through a 26-Fr sheath over a guidewire, percutaneously, into the venous system. When the pump is started, a suction force is created that facilitates aspiration of blood and thrombotic materials into the tip of the AngioVac cannula, circulating the blood through a filter. After filtration, the drained blood is returned to the patient via a second percutaneously placed reinfusion venous cannula, through the internal jugular or femoral vein. The recirculation of venous blood minimizes intra-procedural blood loss and the requirement for blood transfusion (Fig. 2) [59].

The venovenous extracorporeal circuit step used in our institute for the percutaneous aspiration consists of the 22 F AngioVac (Gen 3) 20° suction cannula for venous drainage, a CAPIOX® BT15 bubble trap (Terumo Cardiovascular, Ann Arbor, MI, USA) as a filter for aspirated thrombotic material, an Affinity™ centrifugal pump (Medtronic, Minneapolis, Minnesota, USA), and a 18-F Bio-Medicus™ NextGen Femoral cannula (Medtronic, Minneapolis, Minnesota, USA) for venous return. During the procedure, heparin is used for anticoagulation with a target-activated clotting time of 250 to 300 s. The setup used is shown in Fig. 3.

As a first step, we percutaneously cannulate the left common femoral vein. After systemic heparin administration, an 18-F Bio-Medicus™ NextGen Femoral cannula is introduced into the left femoral vein for venous return using Seldinger's technique and advanced until it reached the left iliac vein. The right common femoral vein was accessed by the same method. As a final step, prior to initiation of the extracorporeal circuit, the 22-F AngioVac (Gen 3) 20° angled tip cannula is introduced via the sheath. Under continuous fluoroscopy and transesophageal echocardiography guidance, the cannula is advanced from the right common femoral vein to the right iliac vein, to the inferior vena cava, to the right atrium, and both the return cannula, and the AngioVac suction cannula were connected to the extracorporeal circuit.

There are a limited number of case reports describing the use of the AngioVac device in the management of RSIE vegetations [9–57].

In a single-center study performed by George et al., 33 patients were analyzed (72.7% injection drug use, 3% a bioprosthetic valve, and 6.1% pacemaker or defibrillator device present). The patients all had large tricuspid valve vegetations (mean 2.1 ± 0.7 cm), 18% had severe preprocedural TR, and they underwent the vacuum-assisted procedure for reduction of vegetation size and burden by the AngioVac device. It was reported that

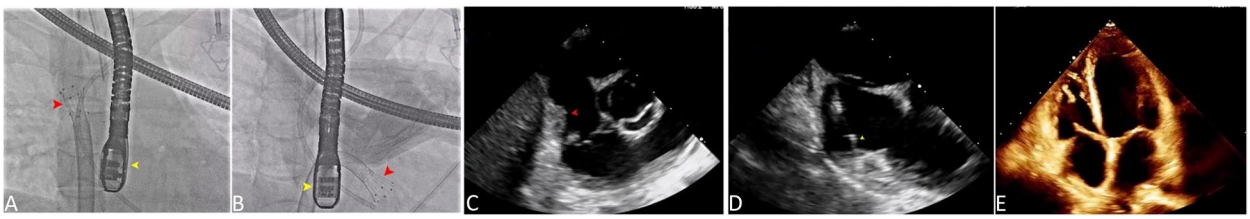

Fig. 2 AngioVac guidance using intra-procedural imaging. A Introduction and deployment of the AngioVac cannula to the right atrium (yellow arrowhead indicating transesophageal echocardiography (TEE) probe, red arrowhead indicating the funnel tip of the AngioVac cannula. **B** Angulation of the AngioVac cannula to face the tricuspid valve (yellow arrowhead indicating transesophageal echocardiography (TEE) probe, red arrowhead indicating the funnel tip of the AngioVac cannula). **C** TEE—midesophageal 4 chamber view: revealing a 34 × 35 mm vegetation in the right atrium indicated by the red arrowhead. **D** TEE -midesophageal 4 chamber view: showing the engagement of the AngioVac cannula to the right atrial vegetation. **E** Transthoracic echocardiography 4 chamber view at 3 months follow-up revealing complete removal of the vegetation (see supplementary video 1))

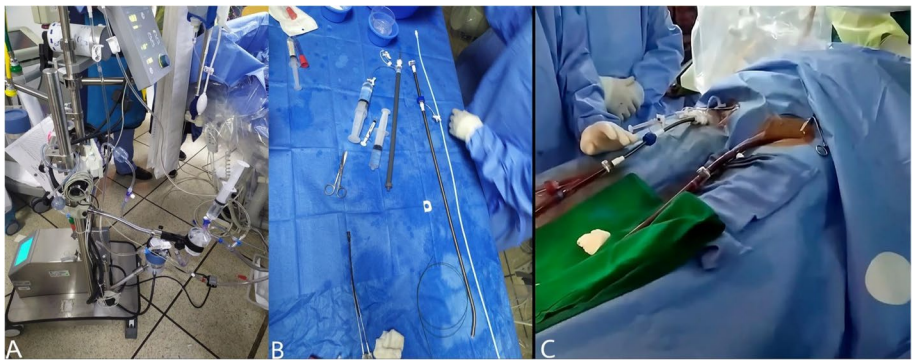

Fig. 3 AngioVac setup (showing our institute setup): **A** venovenous extracorporeal circuit consists of the 22-F AngioVac (Gen 3) 20° suction cannula (AngioDynamics, Latham, NY, USA) for venous drainage, a CAPIOX® BT15 bubble trap (Terumo Cardiovascular, Ann Arbor, MI, USA) as a filter for aspirated thrombotic material, an Affinity™ centrifugal pump (Medtronic, Minneapolis, Minnesota, USA), and a 18-F Bio-Medicus™ NextGen Femoral cannula (Medtronic, Minneapolis, Minnesota, USA) for venous return. **B** The AngioVac cannula. **C** The cannulation Strategy a BI-femoral approach with the suction cannula placed in the right common femoral vein with the reperfusion cannula placed in the left common femoral vein

there was a 61% reduction in vegetation size with the use of the AngioVac system, with only three patients requiring tricuspid valve surgery due to worsening of their TR. There were no patient deaths from the procedure, with a hospital survivability of 90.0% [60].

Although the AngioVac system can be an excellent bailout option for patients with undesired surgical outcomes, there are complications. One of the most noticeable complications during our review was worsening of the TR, especially when the AngioVac was used on TV vegetations. This mainly occurs due to the high suction pressures on the tip of the cannula. To mitigate this compilation, proper visualization of the cannula should be of the utmost importance using continuous intra-procedural TEE to avoid damage to the TV and its structures. In our practice, we use a modified midesophageal 4-chamber view with an emphasis on the right-sided cardiac chambers and the use of continuous Doppler monitoring to assess the degree of the TR during the suction part of the procedure.

In a study performed by Worku et al., 56 patients underwent AngioVac procedures, and the success rate for removing thrombus in the right side of the heart was 82%. This same study reported a 12% complication rate that included hematoma and retroperitoneal hemorrhage. Another possible complication of an AngioVac procedure for vegetation removal on the tricuspid valve is worsening of tricuspid valve insufficiency, given the suctioning properties of the device [60].

In a review study of the Registry of AngioVac Procedures in Detail (RAPID) registry data performed by Moriarty et al., an analysis was conducted on adult patients who underwent AngioVAC removal of right heart thrombus. They reported that among the 47 patients, 42 (89.4%) of the thrombi were in the right atrium only, three (6.4%) were in the right ventricle, and two (4.3%) were in the right atrium and the right ventricle. Four (8.5%) patients had concomitant caval thrombi, three (6.4%) had catheter-related thrombi formation, and one patient had both caval- and catheter-related thrombi in combination with the right heart thrombi. With excellent outcomes stating that 70 to 100% removal of thrombus was achieved in 28 (59.6%) patients. One patient had hematoma at the site of the reinfusion catheter, and another patient developed pericardial effusion due to caval rupture that required drain insertion, and was discharged 2 days after the procedure. There was pulmonary embolization in three patients who were treated by anticoagulation with no requirement for an interventional procedure or mechanical support. There was one death, not related to the AngioVac, which occurred in a 43-year-old female who underwent a heart and liver transplant and subsequently developed a right ventricular thrombus and stroke, with her family electing to withdraw care [61].

A further analysis of the RAPID registry showed that the majority of the procedures were performed by either an interventional cardiologist or radiologist. So currently, cardiac surgeons are not the primary operators in most AngioVac cases. Even though our review showed that there was a lack of intra-procedural complications, this does not mean that unexpected adverse events cannot occur. So, even if a cardiac surgeon is not the main operator of the device, they should be present during such procedures to provide their unique skill set in the setting of an emergency. A multidisciplinary team approach is critical to provide the most optimum safety and outcomes.

Al Badri et al. described the percutaneous removal of right heart thrombus using vacuum aspiration in seven patients undergoing right atrial thrombectomy. Two of the patients in the series were diagnosed with submassive

pulmonary embolism. The procedure was successful for six (85.7%) patients, and treatment was ultimately successful for the remaining patients who developed cardiogenic shock requiring brief extracorporeal membrane oxygenation. The authors reported no device or procedure-related complications. Additionally, no patients experienced a postprocedural decrease in hematocrit or required a transfusion. Their conclusion was that patients with right-sided intracardiac thrombus, who were hemodynamically stable, but not candidates for surgery, would benefit from vacuum thrombectomy [62].

Donaldson et al. reported on 15 procedures performed with the use of the AngioVac system. Eleven (73.3%) were removed from the right atrium, and the other four were removed from the right ventricle. Complete removal of the mass was achieved in 11 (73.3%) patients. Eleven patients had a decrease in hematocrit, with six (54.5%) requiring transfusion, and they did not report the development of vascular complications [63].

In a review of the Manufacturer and User Facility Device Experience (MAUDE) database, which contains reports submitted to the FDA by mandatory reporters: manufacturers, importers, and device user facilities and voluntary reporters: healthcare professionals, patients, and consumers, they assessed 93 reported failures of the AngioVac device, with the most common points of failure being physical damage in 13 reports (14.0%), occlusion of the suction cannula in five reports (5.4%), and development of air bubbles in two reports (2.2%). Physical damages to the cannula were the following: (1) breaks in two reports, (2) deflation and inflation issues in three reports, (3) entrapment of the device in two reports, failure to advance in three reports, and (4) inadequate device training in three reports. Reported complications were the following: (1) Thirty-four (36.6%) reports of pulmonary embolism, (2) 16 (17.2%) perforation, (3) four (4.3%) reports of arrhythmia, (4) three (3.2%) reports of stroke, and (5) one (1.1%) report of hematoma [64].

The results of our review show promising outcomes of the AngioVac cannula in the setting of RSIE, but it mainly looks at individual case reports and series. Further larger studies on the topic should be done looking at outcomes in a broader manner including but not limited to (1) its effects on TR postprocedural and during long-term follow-up, (2) comparing local versus general anesthesia on postprocedural outcomes and pain management, (3) effects of prolonged extracorporeal circulation on patient's hemoglobin level and need for transfusion, (4) comparing its outcomes in different patient profiles including patients with IVDU, (5) comparing it to surgery, and (6) prolonged long-term outcomes.

Limitations

There are some limitations to this study that should be acknowledged. Firstly, our sample size of 65 patients is small which is expected due to the novelty of the device. Secondly, some case reports were lackluster in reporting all of the postprocedural outcomes, especially the degree of postprocedural TR, hematological complication, and hospital length of stay. Thirdly, there was a lack of long-term follow-up in the reports. Fourthly, due to the lack of literature on the topic with the majority of the new article on it being case reports by centers using the device for the first time and lack of new retrospective studies, we decided that to limit our review to case reports and series to provide insight on how new facilities manage patients using this novel device and their outcomes.

Conclusions

The AngioVac system is a possible bailout option for patients with right-sided infective endocarditis vegetations who are not ideal candidates for surgery. Increased reports on its use have shown that it could be effective in the reduction of microbiological burden with minimal complications. However, more studies should be performed to determine the long-term effects and complications, with comparisons to surgical management in patients who are candidates for surgery and are well-suited for the use of the AngioVac system.

Abbreviations

IE	Infective endocarditis
RSIE	Right-sided infective endocarditis
IVDU	Intravenous venous drug use
CIED	Cardiac implantable electronic devices
TV	Tricuspid valve
TR	Tricuspid regurgitation
MSSA	Methicillin-sensitive *Staphylococcus aureus*
MSRA	Methicillin-resistant *Staphylococcus aureus*
RAPID	Registry of AngioVac Procedures in Detail

Supplementary Information

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Supplementary Material 1.

Supplementary Material 2.

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None.

Authors' contributions

FMS conceived the idea, designed the methodology, searched the databases, screened the retrieved records, extracted the data, analyzed the data, and wrote and edited the manuscript. ASS searched the databases, screened the retrieved records, and extracted the data. AHB and MAF resolved the conflicts and supervised the study.

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Availability of data and materials
Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Declarations

Ethical approval and consent to participate
This is a review article of available literature with no patient information being shared, so ethical approval and participation consent are not applicable.

Consent for publication
This is a review article of available literature with no patient information being shared, so a consent to publish is not applicable.

Competing interests
The authors declare that they have no competing interests.

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References

1. Rajani R, Klein JL. Infective endocarditis: a contemporary update. Clinical Medicine. 2020;20(1):31–5. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6964163/.
2. Vincent LL, Otto CM. Infective endocarditis: update on epidemiology, outcomes, and management. Curr Cardiol Rep. 2018;20(10). Available from: https://link.springer.com/article/10.1007%2Fs11886-018-1043-2.
3. Randhawa VK, Rajani R. Novel frontiers for managing tricuspid valve endocarditis. JACC: Case Reports. 2021;3(11):1350–3. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8414422/. Cited 2023 Dec 13.
4. Shmueli H, Thomas F, Flint N, Setia G, Janjic A, Siegel RJ. Right-sided infective endocarditis 2020: challenges and updates in diagnosis and treatment. J Ame Heart Assoc. 202023;9(15). Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7792231/.
5. Habib G, Lancellotti P, Antunes MJ, Bongiorni MG, Casalta JP, Del Zotti F, et al. 2015 ESC Guidelines for the management of infective endocarditis. Eur Heart J. 2015;36(44):3075–128. Available from: https://academic.oup.com/eurheartj/article/36/44/3075/2293384.
6. Baddour LM, Wilson WR, Bayer AS, Fowler VG, Tleyjeh IM, Rybak MJ, et al. Infective endocarditis in adults: diagnosis, antimicrobial therapy, and management of complications: a scientific statement for healthcare professionals from the American Heart Association. Circulation. 2015;132(15):1435–86. Available from: https://www.ncbi.nlm.nih.gov/pubmed/26373316.
7. Delgado V, Ajmone Marsan N, de Waha S, Bonaros N, Brida M, Burri H et al (2023) 2023 ESC Guidelines for the management of endocarditis. Eur Heart J 44(39). https://doi.org/10.1093/eurheartj/ehad193
8. Otto CM, Nishimura RA, Bonow RO, Carabello BA, Erwin JP, Gentile F, et al. 2020 ACC/AHA guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Joint Committee on clinical practice guidelines. Circulation. 2021;143(5). Available from: https://www.ahajournals.org/doi/10.1161/CIR.0000000000000923.
9. Dalia AA, Bamira D, Albaghdadi M, Essandoh M, Rosenfield K, Dudzinski DM (2018) Four-dimensional transesophageal echocardiography-guided AngioVac debulking of a tricuspid valve vegetation. J Cardiothorac Vasc Anesth 31(5):1713–6
10. Vaidya GN, Deam AG (2018Jul) Simultaneous suction debulking of lead vegetation prior to percutaneous lead extraction. J Cardiol Cases 18(1):17–19
11. Prabhudas-Strycker KK, Butt S, Reddy MT. Candida tropicalis endocarditis successfully treated with AngioVac and micafungin followed by long-term isavuconazole suppression. IDCases. 2020;21:e00889. Available from: https://pubmed.ncbi.nlm.nih.gov/32642436/. Cited 2023 Dec 13.
12. Mercado-Alamo A, Singh H, Rosman H, Mehta R, Lalonde T, Kaki A. Unmasking severe tricuspid valve regurgitation after percutaneous debulking of large tricuspid vegetation. JACC Case Reports. 2020;3(5):818–22. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8311153/. Cited 2023 Dec 13.
13. Koney N, Benmessaoud C, Cole KY, Bulut Y, Yang EH, Moriarty JM. Percutaneous removal of a cardiac mass in a patient with infective endocarditis: a case report. J Pediatric Intensive Care. 2019;8(2):103–7. Available from: https://pubmed.ncbi.nlm.nih.gov/31093464/. Cited 2023 Dec 13.
14. Thiagaraj AK, Malviya M, Htun WW, Telila T, Lerner SA, Elder MD et al (2017May) A novel approach in the management of right-sided endocarditis: percutaneous vegectomy using the AngioVac cannula. Future Cardiol 13(3):211–217
15. Starck CT, Dreizler T, Falk V. The AngioVac system as a bail-out option in infective valve endocarditis. Annals of Cardiothoracic Surgery. 2019;8(6):675–7. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6892725/. Cited 2021 Jun 16.
16. Ahmed M, Montford JH, Lau E. (2018)Vacuum-assisted right atrial infected clot extraction due to persistent bacteraemia: a percutaneous approach for the management of right-sided endocarditis. BMJ Case Reports. bcr-2018–226493.
17. Divekar AA, Scholz T, Fernandez JD. Novel percutaneous transcatheter intervention for refractory active endocarditis as a bridge to surgery-AngioVac aspiration system. Catheter Cardiovasc Interv. 2013;81(6):1008–12. Available from: https://pubmed.ncbi.nlm.nih.gov/22887769/. Cited 2023 Dec 13.
18. Leso J, Al-Ahmad M, Hand DO. Patient with systemic emboli in the setting of Klebsiella oxytoca tricuspid valve endocarditis and patent foramen ovale treated with NobleStitch and AngioVac. BMJ case reports. 2021;14(8):e243370. Available from: https://pubmed.ncbi.nlm.nih.gov/34417236/. Cited 2023 Dec 13.
19. Tarzia V, Tessari C, Bagozzi L, Migliore F, Pittarello D, Zanella F, et al. Totally peripheral approach for ICD lead vegetation removal in a GUCH patient. Journal of Cardiovascular Electrophysiology. 2021;32(6):1778–81. Available from: https://pubmed.ncbi.nlm.nih.gov/33825266/. Cited 2023 Dec 13.
20. Talebi S, Tan BEX, Gazali RM, Herzog E (2017) Last resort: successful AngioVac of fungal tricuspid valve vegetation. QJM: An Int J Med 110(10):673–4
21. Bangalore S, Alviar CL, Vlahakis S, Keller N (2021)Tricuspid valve vegetation debulking using the AngioVac system. Catheter Cardiovasc Interv. https://doi.org/10.1002/ccd.29519
22. Jones B, Wazni O, Rehm SJ, Shishehbor MH (2017) Fighting fungus with a laser and a hose: management of a giant Candida albicans implantable cardioverter-defibrillator lead vegetation with simultaneous AngioVac aspiration and laser sheath lead extraction. Catheter Cardiovasc Interv 91(2):318–21
23. Abubakar H, Rashed A, Subahi A, Yassin AS, Shokr M, Elder M. AngioVac system used for vegetation debulking in a patient with tricuspid valve endocarditis: a case report and review of the literature. Case Reports in Cardiology. 2017;2017:1923505. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5697122/. Cited 2022 Mar 18.
24. Winkle S, Salem Gaballa, Memon A, Miller JB, Curfiss R. Serratia marcescens tricuspid valve vegetation and successful use of the AngioVac® system. Cureus. 2020. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7515097/. Cited 2023 Dec 13.
25. Yoruk A, Tankut S, Riordan M, Ling F, Aktas M (2020Mar) Cleaning up the mess: AngioVac debulking in endocarditis patient with large, device-related vegetations. J Am Coll Cardiol 75(11):2312
26. Souka A, Sukhija R, Dimitri DS, Arif I (2021May) AngioVac Debulking Of Bioprosthetic Valve. J Am Coll Cardiol 77(18):2383
27. Hamilton S, Elkhouly A, Wolf A, Stivala C (2021May) Tricuspid valve vegetation debulking using AngioVac in an intravenous drug user. J Am Coll Cardiol 77(18):2825
28. Kashyap C, Patel D, Sethi P, Lahoti A (2021May) AngioVac success in management of tricuspid valve infective endocarditis. J Am Coll Cardiol 77(18):2877
29. ELJack AF, Bhattal G, Christensen J, Potluri S, Wang Z (2021) Successful AngioVac aspiration system in the management of high-risk patient with tricuspid valve vegetations. J Am Coll Cardiol 77(18):2900–0
30. Chang E (2021) Clinical outcomes of early infective endocarditis vegetation extraction with AngioVac system. Eur Heart J Acute Cardiovasc Care 10(Supplement_1). https://doi.org/10.1093/ehjacc/zuab020.183

31. Moriarty. Vacuum-assisted debulking of a prohibitively large tricuspid valve vegetation prior to percutaneous laser lead extraction . www.innovationsincrm.com. Available from: https://www.innovationsincrm.com/cardiac-rhythm-management/2014/march/569-vacuum-assisted-debulking-tricuspid-valve.
32. Ayzenbart V, Fuentes H, Fuentes F, Aziz S, Joseph M. AngioVac use in endocarditis during pregnancy: a novel approach for recurrent debulking of tricuspid infective vegetations in a 27-year-old woman in her 22nd and 26th weeks of pregnancy. 2021. Available from: https://journal.chestnet.org/article/S0012-3692(21)02193-0/fulltext.
33. Hosoba S, Mori M, Furtado AD, Lattouf OM. Extraction of right-sided vegetation with use of an aspiration catheter system. Innovations (Philadelphia, Pa). 2015;10(5):357–9. Available from: https://pubmed.ncbi.nlm.nih.gov/26575384/. Cited 2023 Dec 13.
34. Kumar V, Sheikh M, Yee J, Styš A (2017Mar 1) An alternative approach to treatment of infective endocarditis using AngioVac®. J Am Coll Cardiol 69(11):2194–2204
35. Gjeka R, Patel K, Vellanki S, Abdel-Hafez O, Field J (2019Mar) Percutaneous use of the AngioVac system in endocarditis patients who are poor surgical candidates. J Am Coll Cardiol 73(9):2908
36. Green EA, Pollema T, Pretorius V (2020) A case of CIED-associated endocarditis and septic emboli requiring lead extraction, AngioVac suction, and pulmonary endarterectomy. Cureus. https://doi.org/10.7759/cureus.11601
37. Xiao D, Dalton R, Fineman A, Benz M, Tsompanidis A. The use of AngioVac in a patient with severe infective endocarditis where open heart surgery is contraindicated: a case report. Cureus. 2023;15(5):e39639. Available from: https://pubmed.ncbi.nlm.nih.gov/37388576/. Cited 2023 Dec 14.
38. Eichelberger GS, Kocab M, Claudio R, Oller KL. Between a rock and a hard place: percutaneous aspiration and debulking for tricuspid valve endocarditis. Cureus. 2022 May 20;
39. Khan A, Ehtesham M, Asif H, Riasat M, Alsheikhly K. Successful debulking of tricuspid valve vegetation using suction filtration and veno-venous bypass. Cureus. 2022;14(3). Available from: https://www.cureus.com/articles/88119-successful-debulking-of-tricuspid-valve-vegetation-using-suction-filtration-and-veno-venous-bypass. Cited 2022 Oct 10.
40. Mittal N, Mittal R, Ramon MC, Sly Z, Ansari MM. A novel technique debulking vegetations in tricuspid endocarditis and venacava utilizing AngioVac Aspiration System. Cureus. 14(2):e22283. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8933142/.Cited 2023 Dec 14.
41. Riasat M, Hanumanthu BKJ, Khan A, Haseeb Riaz A, Anjum Z, Ehtesham M, et al. Outcomes and survival of patients undergoing percutaneous vegetectomy for right heart endocarditis. IJC Heart & Vasculature. 2023;47:101231. Available from: https://www.sciencedirect.com/science/article/pii/S2352906723000623. Cited 2023 Dec 14.
42. Pasley B, Mariam A, Shah S, Golzarian H, Thiel A, Saum J, et al. Percutaneous endovascular vacuum assisted removal of intracardiac lesions using the AngioVac system: a real-world experience. J Cardiol Cases. 2023;28(3):120–4. Available from: https://www.sciencedirect.com/science/article/pii/S1878540923000580. Cited 2023 Dec 14.
43. Abdelhabib M, Ruiz G, Wilson Z, Alkhatib B, Sawant A, Pershad A. Decreasing disease burden of right heart endocarditis using AngioVac technology in patients who cannot tolerate surgical interventions. 2021. Available from: https://journal.chestnet.org/article/S0012-3692(21)03223-2/fulltext.
44. Hritani R, Sanam K, Jain A, Arora V, Patel V (2022) Tricuspid valve endocarditis debulking: a novel approach with high success rate. J Am Coll Cardiol 79(9):2306–6
45. Pargaonkar SR, Takahashi T, Tiwari N, Sokol SI, Thankachen J (2023) Concomitant tricuspid valve vegetation and catheter-related atrial thrombus managed using AngioVac system. J Am Coll Cardiol 81(8):3002–2
46. Ali T, Paulenka Y, Hennessey KC (2023) Safe pregnancy and normal spontaneous vaginal delivery facilitated by the AngioVac system for treatment of infective endocarditis in pregnancy. J Am Coll Cardiol 81(8):3733–3
47. Stephens D, Arshad S, Abdelsalam MS, Gold GK (2022) AngioVac system as an aid in faster clearance of bacteremia in tricuspid valve endocarditis. J Am Coll of Cardiol 79(9):3214–4
48. Beshai R, Weinberg H (2022) A rare case of a failed AngioVac procedure used to debride tricuspid vegetation complicated by Ogilvie syndrome. Cureus. https://doi.org/10.7759/cureus.23584
49. Barrett K, Báez EM, Pope D, Ramsetty S, Hastings R, Rastogi N (2023) The role of AngioVac assisted vegetation extraction in a patient with fungal endocarditis: a Band-Aid or proven therapeutic aid. J Am Coll Cardiol 81(8):3839–9
50. Nguyen H, Berenji N, Konda S, Cheung PY, Contreras JF, Caldera AE (2022) Leadless pacemaker endocarditis managed with AngioVac vegetation debulking and pacemaker extraction. J Am Coll Cardiol 79(9):2435–5. https://www.jacc.org/doi/10.1016/S0735-1097%2822%2903426-X
51. Salomon Poliwoda, Durbach JR, Álvaro Monterrosa Castro, Herman J, Caltagirone C, Kurup A, et al. AngioVac system for infective endocarditis: a new treatment for an old disease. PubMed. 2023;26(1):105–8. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9997473/. Cited 2023 Dec 14.
52. Middleton M, McDaniel G, Attanasio S. AngioVac debulking of a tricuspid valve mass following complex lead extraction in a rare case of Austrian syndrome: a case report. Eur Heart J Case Rep. 2023;7(2):ytad070. Available from: https://pubmed.ncbi.nlm.nih.gov/36865082/. Cited 2023 Dec 14.
53. Stoker A, Gosling A, Williams A, Overbey D, Nicoara A, Pollak A (2022Sep) Transesophageal echocardiography–guided percutaneous aspiration of a large tricuspid valve vegetation in a patient with infective endocarditis. CASE 6(7):335–339
54. Boudova S, Casciani T, Weida J (2023) Percutaneous debulking of tricuspid vegetations due to infectious endocarditis in pregnancy: a case report. AJOG Global Reports 100204. https://doi.org/10.1016/j.xagr.2023.100204
55. Patel N, McDonald ML, Bradford NS, Smith JW, Beaty EH, Rytlewski JA, et al. AngioVac debulking in endocarditis patients with large, device-related vegetations. J Innov Cardiac Rhythm Manage. 2018;9(8):3291–6. Available from: https://pubmed.ncbi.nlm.nih.gov/32494503/. Cited 2023 Dec 14.
56. Patel N, Azemi T, Zaeem F, Underhill D, Gallagher R, Hagberg R et al (2013Feb 28) Vacuum assisted vegetation extraction for the management of large lead vegetations. J Card Surg 28(3):321–324
57. U.S. Food and Drug Administration. Office of Device Evaluation. Center for Devices and Radiological Health. AngioVac Cannula 510(k) Summary. 2014. Available from: https://www.accessdata.fda.gov/cdrh_docs/pdf13/k133445.pdf. Cited 2024 Aug 14.
58. Chin A K, Aklog L, deGuzman B J, Glennon M. InTech Rijeka Croatia; 2012. Application of a novel venous cannula for en-bloc removal of undesirable intravascular material; pp. 127–142. Available from: https://books.google.com.sa/books?hl=ar&lr=&id=mOuZDwAAQBAJ&oi=fnd&pg=PA127&dq=Chin+A+K+Aklog+L+deGuzman+B+J+Glennon+M+Application+of+a+novel+venous+cannula+for+en-bloc+removal+of+undesirable+intravascular+material+InTech+Rijeka+Croatia+2012+127+142+&ots=_DuZeBP0xv&sig=shJ0OIqWFNftwJoZAQoIrHc-KCQ&redir_esc=y#v=onepage&q&f=false.
59. George B, Voelkel A, Kotter J, Leventhal A, Gurley J (2017May 4) A novel approach to percutaneous removal of large tricuspid valve vegetations using suction filtration and veno-venous bypass: a single center experience. Catheter Cardiovasc Interv 90(6):1009–1015
60. Worku B, Salemi A, D'Ayala MD, Tranbaugh RF, Girardi LN, Gulkarov IM (2016) The AngioVac device: understanding the failures on the road to success Innovations: Technology and Techniques in Cardiothoracic and Vascular Surgery. 11(6):430–3
61. Moriarty JM, Liao M, Kim GHJ, Yang E, Desai K, Ranade M, et al. Procedural outcomes associated with use of the AngioVac System for right heart thrombi: a safety report from RAPID registry data. Vasc Med (London, England). 2022;27(3):277–82. Available from: https://pubmed.ncbi.nlm.nih.gov/35176918/. Cited 2024 Feb 21.
62. Al Badri A, Kliger C, Weiss D, Pirelli L, Wilson S, DeLaney ER, et al. Right atrial vacuum-assisted thrombectomy: single-center experience. J Invasive Cardiol. 2016;28(5):196–201. Available from: https://pubmed.ncbi.nlm.nih.gov/27145051/. Cited 2024 Feb 21.
63. Donaldson CW, Baker JN, Narayan RL, Provias TS, Rassi AN, Giri JS et al (2015May 13) Thrombectomy using suction filtration and veno-venous bypass: single center experience with a novel device. Catheter Cardiovasc Interv 86(2):E81–E87
64. Chaitu Dandu, Sardar Muhammad Alamzaib, Patel D, Naughton R, Polina A, Najam M, et al. Investigating the complications and causes of failure of the AngioVac system: a post-marketing surveillance from the MAUDE database. PubMed. 2023;15(8):e43720–0. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10505590/. Cited 2024 Feb 21.

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