PERCUTANEOUS DEVICE CLOSURE OF PARAVALVULAR LEAK: COMBINED EXPERIENCE FROM THE UNITED KINGDOM AND IRELAND

FIRST AUTHOR: CALVERT

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Patrick A Calvert PhD FACC[1,2,3], David B Northridge MB FRCP[4], Iqbal S Malik PhD FRCP[5], Leonard Shapiro MD FRCP[1], Peter Ludman[2], Shakeel A Qureshi BMBCh FRCP[6], Michael Mullen[7], Robert Henderson DM FRCP[8], Mark Turner[9], Martin Been MD FRCP[10], Kevin P Walsh MD FRCPI[11], Ivan Casserly BMBCh[12], Lindsay Morrison MD FRCP[13], Nicola L Walker PhD MRCP[14], John Thomson MD FRCP[15], Mark S Spence MD FRCP[16], Vaikom S Mahadevan MD FRCP[17], Angela Hoye PhD FRCP[18], Philip A MacCarthy[19], Matthew J Daniels PhD MRCP[20], Paul Clift[2], William R Davies MD MRCP[1], Philip D Adamson MBChB[3], Gareth Morgan[6], Suneil K Aggarwal MBBS MRCP[13], Yasmin Ismail[9], Julian O M Ormerod PhD MRCP[20], Habib R Khan[8], SujaySubash Chandran[21], Joseph de Giovanni MD FRCP, FRCPH[2], Bushra S Rana MD FRCP[1], Oliver Ormerod DM FRCP[20], David Hildick-Smith MD FRCP[21]

Institutions (United Kingdom unless stated)

[1]Papworth Hospital NHS Foundation Trust, Cambridge, [2]Queen Elizabeth Hospital, University Hospitals Birmingham, Birmingham, [3]Institute of Translational Medicine, University of Birmingham, [4]Royal Infirmary of Edinburgh, Edinburgh, [5]Imperial College NHS Trust, London, [6]Evelina Children's Hospital, London, [7]The Heart Hospital, London, [8]Nottingham University Hospital, Nottingham [9]Bristol Heart Institute, Bristol, [10]University Hospital

Coventry, Coventry, [11]Mater Misericordiae University Hospital, Dublin, Ireland, [12]Mater Private Hospital, Dublin, Ireland, [13]Liverpool Heart and Chest Hospital, Liverpool, [14]Golden Jubilee National Hospital, Glasgow, [15]Leeds General Infirmary, Leeds [16]Royal Victoria Hospital, Belfast, [17]Manchester Royal Infirmary, Manchester, [18]Castle Hill Hospital, Hull, [19]King's College London, London, [20]John Radcliffe Hospital, Oxford, [21]Royal Sussex County Hospital, Brighton.

Correspondance Address

Dr Patrick A Calvert

Department of Cardiology,

Lakeside Crescent,

Papworth Hospital NHS Foundation Trust

Cambridge,

CB23 3RE

UK

Tel +44 1480 830541

Fax +44 1480 831315

patrick.calvert@papworth.nhs.uk

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ABSTRACT

Background

Paravalvular leak (PVL) occurs in 5-17% of patients following surgical valve replacement. Percutaneous device closure represents an alternative to repeat surgery.

Methods

All UK and Ireland centers undertaking percutaneous PVL closure submitted data to the UK PVL Registry. Data was analyzed for association with death and major adverse cardiovascular events (MACE) at follow up.

Results

308 PVL closure procedures were attempted in 259 patients in 20 centers (2004-2015). Patient age was 67±13 years; 28% were female. The main indications for closure were heart failure (80%) and hemolysis (16%). Devices were successfully implanted in 91% of patients, via radial (7%), femoral arterial (52%), femoral venous (33%) and apical (7%) approaches. 19% of patients required repeat procedures. The target valve was mitral (44%), aortic (48%), both (2%), pulmonic (0.4%) or TAVR (5%). Pre-procedural leak was severe (61%), moderate (34%) or mild (5.7%) and was multiple in 37%. PVL improved post-procedure ($p<0.001$) and was none (33.3%), mild (41.4%), moderate (18.6%) or severe (6.7%) at last follow up. Mean NYHA improved from 2.7±0.8 pre-procedure to 1.6±0.8 ($p<0.001$) after a median follow-up of 110 [7-452] days. Hospital mortality was 2.9% (elective), 6.8% (in-hospital urgent) and 50% (emergency), ($p<0.001$). MACE during follow-up included death (16%), valve surgery (6%), late device embolization (0.4%) and new hemolysis requiring transfusion (1.6%). Mitral PVL was associated with higher MACE (HR=1.83, $p=0.011$). Factors independently associated with death were the degree of persisting

leak (HR=2.87,p=0.037), NYHA (HR=2.00,p=0.015) at follow up and baseline creatinine (HR=8.19,p=0.001). The only factor independently associated with MACE was the degree of persisting leak at follow up (HR=3.01,p=0.002).

Conclusion

Percutaneous closure of PVL is an effective procedure which improves PVL severity and symptoms. Severity of persisting leak at follow-up is independently associated with both MACE and death. Percutaneous closure should be considered as an alternative to repeat surgery.

Clinical Perspectives

What is new?

- This is the first multi-national series of percutaneous paravaular leak (PVL) closure
- This is the first large series that also includes results of procedures undertaken with ‘oblong’ devices which may be better shaped to deal with the crescentic shape of most PVLs
- Patients in whom a persisting PVL of mild or less was achieved at follow up had less death and less MACE
- For patients with PVL of a single surgical valve, mitral valves were associated with increased MACE on univariable analysis but not after multivariable adjustment

What are the clinical implications?

- PVL is a common and difficult problem after valve surgery and patients are high risk

- Percutaneous PVL closure is feasible and compares favorably with results of repeat operation
- This is a challenging procedure which should be undertaken by specialised structural interventional teams with advanced imaging support
- Operators should endeavor to achieve PVL severity of mild or less at follow up (associated with less death and less MACE)
- Once available, oblong devices accounted for 72% of devices implanted and resulted in a non-significant trend for less leak at follow up HR=1.37 [0.96-1.96], p=0.079. The oblong devices used in this series are not currently FDA approved.

Keywords:

paravalvular regurgitation, percutaneous closure, catheter, heart failure, survival

INTRODUCTION

Paravalvular leak (PVL) is a common and challenging problem that has existed since prosthetic cardiac valves were first implanted[1]. PVL occurs in 7-17% of mitral valve replacements (MVRs) and 5-10% of aortic valve replacements (AVRs) [2,3] and can be associated with disabling symptoms related to heart failure or hemolysis[4]. Repeat surgery to repair PVL is associated with significant mortality and morbidity[5,6,7,8]. Tissues around PVL are often calcified and friable and therefore leaks may recur[5,6]. Conservative management of mild to moderate leaks is also associated with high adverse event rates as leaks will tend to deteriorate over time. [9,10].

Percutaneous device closure of PVL was first reported in 1992[11]. Since then there have been multiple small case series reported describing the various techniques with transvenous, transarterial and transapical access[12,13,14]. The largest series so far reported outcomes in 126 patients from a single center of excellence in this procedures[15]. However, so far there has been no systematic report of real world experience from a national registry. We report the combined experience of percutaneous PVL closure from the United Kingdom (UK) and Ireland.

METHODS

Percutaneous device implantation of PVL has been undertaken in the UK since 2004. Units report numbers of cases to the British Cardiovascular Intervention Society (BCIS) audit office and figures are published annually at www.bcis.org.uk. All centers (n=20) where percutaneous PVL activity has been reported in the UK were contacted to participate in this study and all agreed to participate. Anonymized data were acquired from medical and electronic records regarding patient demographics, clinical features, pre-procedure clinical condition, echocardiographic features, procedural characteristics, procedural complications, in-hospital outcomes, adverse

events during follow-up and vital status. The protocol was approved by the Brighton and Sussex University Hospitals Review Board. No patient consent was required as this was a retrospect registry with anonymized data according to local policy.

Procedure

The majority of procedures were to treat PVL of surgical valves with only a minority to treat PVLs of transcatheter valves (TAVR) or annuloplasty rings. Most procedures were done under general anesthesia with transesophageal guidance (TEE). Three-dimensional (3D)-TEE contributed to pre-procedural and procedural planning (figures 1 and 2). PVL were often multiple and or with complex morphology.

Mitral valve PVLs were generally closed via a transvenous route with transseptal puncture in the anterograde direction. Real-time 3D-TEE images were used where available to guide guidewire and catheter placement across the defect (figure 1). A steerable transseptal sheath (eg Agilis, SJM, Plymouth, MN) was often useful in locating the leak. Through this a smaller catheter (multipurpose or Judkins Right 4 guiding or diagnostic catheter) was passed in a telescoping fashion to provide flexibility and support. Hydrophilic guidewires and delivery sheaths (Flexor Shuttle [Cook Medical, Bloomington, IN] or Destination [Terumo, Tokyo, Japan]) were often used. Occasionally arteriovenous loops were required to support passage of the delivery sheath. Some operators preferred to cross mitral PVLs in a retrograde direction either via transapical access (percutaneous or surgical) or via femoral artery access through the aortic valve, especially for PVLs close to the atrial septum.

Aortic valve PVLs were generally crossed in a retrograde direction with either femoral or radial arterial access. Crossing of the leak was facilitated by fluoroscopy and echocardiography. Devices to close PVLs were selected by physician preference, as until recently, there was no CE marked devices for this procedure (figure 3).

Statistical methods

Statistical analysis was performed using SPSS v22.0 (IBM Corp, Armonk NY). Where analysis pertained to patient related outcomes, only final attempts at percutaneous PVL closure were included in the analysis. Normally distributed data are presented as mean ± standard deviation and non-Gaussian data presented as median [first and third quartile (Q1-Q3)]. Categorical data are presented as frequency (percentage). Clinical and procedural variables were tested for an association with death and major adverse cardiovascular events (MACE) during follow-up using univariable Cox proportional hazard regression (figures 4 and 5). For continuous variables, the hazard ratio (HR) represents the increase in hazard per unit rise in that variable. Ordinal variables include baseline leak severity, NHYA class, LV function and presentation. For the categorical variables the comparison is between presence or absence of that factor. Those factors with $p<0.1$ on univariable analysis were entered into a multivariable model. MACE was defined as a composite of death, stroke, late embolization of device, infective endocarditis, new hemolysis requiring transfusion, new valve leaflet interference, repeat procedure or valve surgery. Changes in PVL and NYHA (ordinal variables) were assessed using Wilcoxon signed rank test.

RESULTS

Patient factors

308 PVL closure procedures were attempted in 259 patients in 20 centers (2004-2015). Patients' clinical variables are detailed in Table 1. Mean age was 67 ± 13 years. The majority of patients were male 72%. The indication for closure was heart failure (80%), hemolysis (16%) or both (2%). The procedure was elective (81%), urgent (17.4%) and emergent (1.6%). The median time from last valve surgery to

percutaneous closure attempt was 4.7 [1.4-8.9] years and 27% of patients had had more than one previous valve surgery.

Procedural Factors

Procedural variables are shown in Table 2. Devices were successfully implanted in 91% of patients. Device delivery sheath approach was via the transradial (7%), femoral arterial (52%), femoral venous (33%) and transapical (7%) routes. More than one closure procedure was required in 19% of patients. The target valve was surgical in 94% of cases (mitral 44%, aortic 48%, both 2%, pulmonic 0.4%). Transcatheter valves (TAVR) accounted for 5% of PVLs treated (Edwards 3.5%, CoreValve 1.5%). One patient (0.4%) had a PVL of a mitral annuloplasty ring treated percutaneously. The majority of PVLs were around mechanical valves (61.5%).

Outcomes

The pre-procedural leak was severe (61%), moderate (34%) or mild (5.7%) and was multiple in 37%. PVL leak improved significantly following closure ($p<0.001$) and was graded as none (33.3%), mild (41.4%) moderate (18.6%), or severe (6.7%) at final follow up (figure 6a). Mean NYHA improved from 2.7±0.8 pre-procedure to 1.6±0.8 over a median follow up of 110 [7-452] days ($p<0.001$) (figure 6b). New hemolysis requiring transfusion as a consequence of PVL closure occurred in 1.6% of patients. Hospital mortality amongst elective patients was 2.9% compared to 6.8% for urgent cases and 50% for emergencies ($p<0.001$, log rank). Overall hospital mortality was 3.9%. During follow up, 64 patients (24.8%) suffered MACE, which included death (42 patients - 16.2%) and valve surgery (15 patients - 6%). Two patients suffered from new hemolysis requiring transfusion (1.6%). Each of the following occurred in one patients (0.4%): late embolization of device, infective endocarditis and new valve leaflet interference. No patients suffered a stroke.

Factors associated with death and MACE are shown in figures 4 and 5 respectively. Age per decade (HR=1.28, p=0.02), presentation (HR=1.78, p=0.01), creatinine (HR=3.75, p=0.001), number of leaks (HR=0.57, p=0.053), NHYA at follow up (HR=1.57, p=0.008) and leak severity at follow up (HR=1.78, p=0.035) were entered into the multivariable model for association with death. The only factors independently associated with death were the degree of leak at follow up (HR=2.87 [1.07-7.73], p=0.037), NYHA at follow up (HR=2.00 [1.14-3.50], p=0.015) and baseline creatinine (HR=8.19 [2.39-28.08], p=0.001).

Age per decade (HR=1.17, p=0.092), presentation (HR=2.05, p=0.001), hemolysis (HR=1.93, p=0.006), creatinine (HR=2.41, p=0.017), target valve MVR (HR=1.78, p=0.012), procedural success (HR=0.43, p=0.005), NHYA at follow up (HR=1.88, p<0.001) and leak severity at follow up (HR=2.73, p<0.001) were entered into the multivariable model for association with MACE. The only factor independently associated with MACE was the degree of leak at follow up: HR=3.01 [1.48-6.12], p=0.002. Kaplan-Meier plots for survival and “survival free from MACE” according to residual PVL leak are shown in figures 7 and 8 respectively.

For those patients who had a PVL leak of a single surgical valve, PVL leak of the mitral valve was associated with increased MACE (HR=1.83 [1.15-2.91], p=0.011) and trend towards death (HR=1.63 [0.99-2.69], p=0.055). Mechanical valves were not associated with MACE (HR=1.17 [0.68-2.00], p=0.57) or death (HR=0.65 [0.39-1.09], p=0.10).

Device type

The types of devices and the frequency with which they were used are shown in table 2 and figure 3. The shape of the PVL, although complex and varied, is often crescentic (figure 2A). Therefore, oblong devices (Amplatzer™ Vascular Plug 3

[AVP3], SJM, Plymouth, MN and Paravalvular Leak Device [PLD], Occlutech®, Jena, Germany) carry a theoretical advantage for some PVLs over other devices with a circular cross section as they may conform better to the anatomy of the PVL. The first AVP3 device was used in the UK on 4th July 2008. Before that time only 26 other devices (mostly Amplatzer™ Duct Occluder (ADO) & muscular ventricular septal defect occluders (mVSD)) had been implanted. From that date, the AVP3 accounted for 68% of devices implanted. The Occlutech® PLD device was first used in the UK on 19th June 2013 and represents 3.9% of devices implanted. Use of oblong devices was associated with a non-significant trend for less leak at follow up (none or mild) (HR=1.37 [0.96-1.96], p=0.079) and also NYHA I-II symptoms at follow up (HR=1.30 [0.93-1.83], p=0.13). Both oblong devices are currently CE marked in Europe but have not achieved FDA approval.

DISCUSSION

This series of unselected cases undergoing percutaneous PVL closure represents the combined UK and Ireland experience of this procedure. Like the previous largest report, the residual leak post-closure is important in determining major adverse cardiovascular events[15]. However, residual leak in our series is also shown to be independently associated with death. The present analysis also differs in that it reports results of PVL closure with oblong devices which accounted for around two-thirds of devices in our series. Like prior percutaneous and surgical PVL closures series, this is a high risk cohort with high attrition rates at follow up despite technically and clinically successful procedures[6,7,15].

Paravalvular leak - aetiology

PVL is a frequent occurrence after valve surgery[2,3]. However, their occurrence can be difficult to predict. One series suggest that post-operative PVL is present in 33% of mitral valve replacements (MVRs) immediately post-operatively[3]. At 1.8y follow up, this had dropped to 15%. Similar figures for PVLs of aortic valve replacements (AVR) were 6% post-operatively and 10% at 1.8y follow up. Therefore, some PVLs may close with time, whilst new ones will form. The same series suggested that PVL occurrence was not associated with the extent or severity of annular calcification (seen at surgery), use of pledgeted sutures or identity of the operator. The only factors associated with PVL were MVR position, supra-annular AVR and continuous sutures in the mitral position. Continuous suturing of the MVR was frequently associated with PVL (41-67% of MVRs)[3,16,17].

The cause of PVL is uncertain and likely to be multifactorial. The regression of some PVLs in the early post-operative period especially with MVRs may relate to endothelialization of small PVLs or indeed suture tracts[3]. In our series the median time from valve surgery to PVL closure was 4.7 years. Such a long interval raised the possibility that there is some break down of cardiac tissue or sutures that progresses with time.

The PVL jet often follows a complex path and may be directed perpendicular to the usual direction of flow of blood, across the face of the surgical valve. Therefore, quantification of the leak severity by conventional echo criteria is difficult and severity is often under-estimated, although 3D-TEE helps overcome some of these issues. The size of the arc of valvular dehiscence is another useful metric in determining suitability for percutaneous closure and reflects both valvular stability and PVL size. It is best estimated on 3D-TEE.

PVL of MVR versus AVR

PVLs are not homogeneous and seem to occur in a higher proportion of MVRs than AVRs[3]. The reasons are unclear although it may simply relate to the longer circumference of the sewing ring. Our data suggests that PVLs of the MVR are associated with increased MACE. This, however, may relate to confounding factors such as co-morbidities since valve type was not associated with MACE after multivariable adjustment. Data from surgical treatment of PVLs report that surgery for mitral PVLs were twice as frequent as aortic PVLs and was associated with a non-significant trend for increased thirty day mortality (MVR 10.7% vs AVR 5%, p=0.1)[6,8]. Freedom from cardiac mortality at 12 years was less for surgical treatment of PVLs of MVRs than AVRs (56% v 78%, p=0.01)[6].

The importance of the residual leak

Although baseline creatinine and NYHA functional class at follow up were both independently associated with death at follow up, the only factor independently associated with both MACE and death was the degree of leak at follow up. As such it seems that achieving a PVL no greater than mild in severity at follow up is key to achieving a good outcome. This occurred in 74.7% of our patients.

Outcomes of PVLs

Both surgical and percutaneous series suggest that patients in whom PVLs occur are a high risk cohort[6,7,8,13,15]. The current gold standard of surgical re-operation is associated with thirty day / in-hospital mortality of 8.8-11.5%[6,7]. One series reported peri-operative stroke in 5.1%[8]. After repeat surgery, PVLs recurred in 16-37% of patients[7,8]. Long-term survival from surgical correction of PVLs remains poor at 30-57.8% and may reflect co-morbidity rather than the disease process itself, although clear data on this are lacking. One surgical series reports 12-year actuarial survival at 39% but freedom from cardiac death at 12 years of 54%[6].

Data on conservative management is sparse. One series suggest that it is associated with high events rates and generally fails with intervention being required[9]. Another non-randomized series suggests that even in patients without severe symptoms related to the PVLs, surgical correction was still associated with improved survival as compared to conservative treatment (log rank p=0.03)[10]. In this series, patients waited a median 4.6y from diagnosis of the PVL before undergoing corrective surgery.

It is therefore clear that both patients and surgery are high risk, PVLs may recur despite surgical correction and long-term outcomes remain poor. It is on this background that the result of our series should be interpreted. An overall hospital mortality of 3.9% compares favorably with the surgical outcomes, especially given that one fifth of patients had urgent or emergent clinical presentations. In the present analysis, the percutaneous approach results in good improvements in PVL severity and NYHA classification and therefore is efficacious. Although the follow up is not long-term, it is clear that there is a significant attrition rate despite successful procedures and this is consistent with surgical outcomes as discussed above and likely reflects co-morbidities.

Closure devices

Despite the varied morphologies of PVLs, it is clear from this series that oblong devices are preferentially selected by implanting cardiologists for closing PVLs in the UK and Ireland. Once they were available in the UK and Ireland, they accounted for 72% of devices used. Patients who had oblong devices had a non-significant trend to less leak (HR=1.37, p=0.079) and better NYHA class (HR=1.30, p=0.13) at follow up. Although the AVP3 and PLD devices have a European CE mark for vascular

occlusion and paravalvular leaks closure respectively, neither device has been FDA approved[18].

Hemolysis

Hemolysis at baseline was the principle indication for PVL closure in 16% of patients. It was associated with MACE on univariable analysis but not after multivariable adjustment. New hemolysis requiring transfusion as a consequence of PVL closure only occurred in 1.6% of patients and therefore it seems that this feared complication of PVL closure is of less clinical importance.

Percutaneous PVL closure – technical aspects

Percutaneous closure of PVL can be a technically demanding procedure and the techniques have been discussed in detail above. It is clear that PVLs of the MVR are more challenging to treat and transseptal or transapical access are generally required. This procedure should only be undertaken by a team of structural and imaging cardiologists with a specialized interest in the technique and experience in advanced structural interventions. Careful pre-procedural planning and imaging is mandatory as is peri-procedural imaging.

Existing literature on PVL device closure

The previous largest report of percutaneous PVL closure described PVL in 126 patients from a single center of excellence of this technique[15]. This series similarly highlighted the importance of the final leak severity in determining MACE but did not link it with mortality. As this series was from the US, it did not include oblong devices. Other authors have presented smaller series including transpical approach (percutaneous[13] and surgical[19]), also with good outcomes.

Study Limitations

This is a retrospective registry rather than a randomized trial and this limits the conclusions that can be drawn.

CONCLUSION

Percutaneous device closure of PVL represents an effective approach to tackling a difficult problem in a high risk cohort and compares favourably with results from surgical series. Those with a reduction in PVL leak to none or mild (74.7%) had less MACE and death. Use of oblong devices were key in the evolution of this procedure in the UK and Ireland. Despite significant improvements in symptoms and leak severity, these patients have a poor long-term prognosis which probably reflects their co-morbidities. Percutaneous device closure of PVL should be considered in those with suitable anatomy and in the absence of infective endocarditis.

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Figure Legends

Figure 1. 3D-TEE images of bileaflet mechanical mitral valve replacement (MVR). (A) 3D-TEE ”surgical view” of the MVR viewed from the left atrial side. All the other panels are aligned in the same orientation. This view is used to guide crossing the mitral PVL with guidewire and delivery sheath from a transseptal puncture. The MVR sewing ring is indicated by the large arrow head in all panels. The MVR is seen with the leaflets in the open position (small arrows). Ao (aortic rim), LAA (left atrial appendage rim), IAS (inter-atrial septal rim), post (posterior rim), lat (lateral rim).
(B) Agilis steerable sheath (SJM, Plymouth, MN) (thin arrow) with deflectable tip with acute angulation in order to cross a PVL in the IAS rim.
(C) PVL in the LAA rim with a guidewire across it (thin arrow).
(D) PVL in the postero-septal rim with a device deployed in it (thin arrow).

Figure 2. TEE and fluoroscopic images of PVLs of aortic and mitral valve replacements during device closure
(A) TEE image of a PVL of an aortic valve replacement (AVR) with the perimeter traced with the dotted line. Note the crescentic shape. The image cross-section is just out of plane of the surgical valve leaflets.
(B) TEE image of a guidewire (white arrow) crossing a PVL of an AVR (red arrowhead).
(C) Fluoroscopic image of an AVP3 device (white arrow) deployed across an AVR (red arrowhead) but still on the delivery cable.
(D) Same device as panel C with the device now released. Each disc is highlighted with a white arrow. Note the device conforms to the shape of the PVL.
(E and F) Fluoroscopic image of an AVP3 device deployed across a PVL of an MVR (white arrowhead). The device is still on the delivery cable. Note the patient also has

an AVR (red arrowhead). Each of the discs of the device is highlighted with a white arrow. Note that the device has shaped up well suggesting the device is not oversized. In Panel E the orientation of the image is cross-sectional to the MVR which is good for deploying the device's discs. In Panel F the orientation of the image is 'en face' to the MVR which is good for ensuring that the device's discs do not interfer with the movement of the MVR leaflets.

Figure 3. The six most frequent devices used for paravalvular leak closure with frequencies. AVP (Amplatzer™ Vascular Plug, St Jude Medical [SJM], Plymouth, MN), ADO (Amplatzer™ Duct Occluder, SJM, Plymouth, MN), mVSD (muscular Ventricular Septal Defect Occluder, SJM, Plymouth, MN), PLD (Paravalvular Leak Device, Occlutech®, Jena, Germany). AVP3 and PLD were not available for the entire duration of the study and are not currently FDA approved. Images reproduced with permission of SJM and Occlutech®

Figure 4. Univariable analysis for variables associated with death on follow up. Data plotted are unadjusted hazard ratio (HR) (box) and 95% confidence interval (stems). y (years), LV (left ventricle), NYHA (New York Heart Association), MVR (mitral valve replacement), std dev (standard deviation). For definitions of HR comparisons please see statistical methodology. *Factors entered into multivariable analysis.

Figure 5. Univariable analysis for variables associated with MACE on follow up.

Data plotted are unadjusted hazard ratio (HR) (box) and 95% confidence interval (stems). MACE (major adverse cardiovascular event, y (years), LV (left ventricle), NYHA (New York Heart Association) , MVR (mitral valve replacement), std dev (standard deviation). For definitions of HR comparisons please see statistical methodology. *Factors entered into multivariable analysis.

Figure 6. (A) Severity of Paravalvular Leak and (B) New York Heart Association Functional Classification before and after percutaneous closure attempt

Figure 7. Kaplan-Meier cumulative survival plots according to the severity of the residual PVL leak at follow up

Figure 8. Kaplan-Meier cumulative "survival free from MACE" plots according to the severity of the residual PVL leak at follow up

MACE (major adverse cardiovascular event)

Table 1. Clinical variables

CLINICAL VARIABLES	N(%) / mean ± std dev / median [Q1-3]*
Age	67±13 years
Male sex	186 (72%)
Presentation	
Elective	209 (81%)
Urgent	45 (17%)
Emergent	4 (2%)
NYHA	
I	17 (7%)
II	65 (26%)
III	128 (52%)
IV	38 (15%)
Diabetes	37 (17%)
Hemolysis	82 (34%)
Creatinine>200µmol/L (2.26mg/dL)	22 (11%)
Anaemia<100g/L	99 (41%)
LV function	
Good	163 (69%)
Moderate	50 (21%)
Poor	22 (9%)
Number of previous valve surgeries	
1	174 (72%)
2	45 (19%)
3	14 (6%)
≥4	7 (3%)

Time since last valve operation	4.7 [1.4-8.9] years
Principle indication for closure	
Heart failure	187 (80%)
Hemolysis	37 (16%)
Both	5 (2)%
Target Valve	
Mitral	115 (44%)
Aortic	123 (48%)
Both	5 (2%)
Pulmonic	1 (0.4%)
Edwards TAVR	9 (4%)
CoreValve TAVR	4 (2%)
Mitral annuloplasty ring	1 (0.4%)
Valve type	
Bioprosthesis	91 (38%)
Mechanical	148 (57%)
Other	1 (0.4%)

Table 1. N (number), std dev (standard deviation), Q1-3 (first-third quartile), NYHA (New York Heart Association), TAVR (transcatheter aortic valve replacement). *The numbers may not add up to the column totals nor do the percentages add up to 100% due to missing data

Table 2. Procedural variables

PROCEDURAL VARIABLES	N (%) / mean ± std dev / median [Q1-3]	
	AVR (plus TAVR) N = 164*	MVR (plus annuloplasty) N=147*
General anaesthesia	115 (71.4%)	143 (97.3%)
Delivery sheath access site		
Radial artery	17 (10.4%)	0
Femoral artery	134 (81.7%)	17 (13%)
Femoral vein	0	91 (70%)
Transapical	8 (4.9%)	20 (15%)
Sheath size (French)	8 [6-9]	8 [7-11]
Approach		
Anterograde	8 (5.0%)	96 (68%)
Retrograde	150 (93.2%)	23 (16%)
both	3 (1.9%)	14 (10%)
Transseptal puncture	5 (3.1%)	113 (80%)
Arteriovenous rail	3 (1.8%)	29 (20%)
Leak position* **		
anterior	25 (42.4%)	10 (14%)
posterior	19 (32.2%)	25 (35%)
septal		23 (32%)
lateral	15 (25.4%)	13 (18%)
Number of defects		
1	111 (70.3%)	108 (78%)
2	36 (22.8%)	26 (19%)
3	5 (3.2%)	2 (1%)

	≥4	3 (1.9%)	2 (1%)
Number of devices implanted	**0**	15 (9.4%)	17 (12%)
	1	104 (65.4%)	97 (69%)
	2	36 (22.6%)	25 (18%)
	3	2 (1.3%)	1 (0.7%)
	4	2 (1.3%)	1 (0.7%)
Largest defect length (mm)		7.2±3.0	10.4±5.3
Largest defect width (mm)		4.4±1.8	4.8±1.8
Deployment success			
	Yes	148 (93.1%)	121 (86%)
	No (unable to cross defect with wire)	4 (2.5%)	7 (5%)
	No (unable to cross defect with sheath)	3 (1.9%)	4 (3%)
	No (unable to deliver device)	1 (0.6%)	2 (1%)
	No (unsatisfactory position therefore withdrawn)	1 (0.6%)	5 (4%)
	No (device embolized)	1 (0.6%)	0
	No (other)	0	2 (1%)
Device implanted (n=333)			
	AVP2	3 (1.9%)	6 (4%)
	AVP3	105 (67.7%)	79 (57%)
	AVP4	11 (7.1%)	2 (1%)
	ADO	2 (1.3%)	4 (3%)
	ADO2	4 (2.6%)	2 (1%)
	ASO	19 (12.3%)	1 (0.7%)
	mVSD	19 (12.3%)	22 (16%)

	PLD	2 (1.3%)	9 (7%)
Procedure time (mins)		100 [80-132]	140 [104-180]
Screening time (mins)		24 [14-40]	42 [24-64]
Total X-ray dose (cGy.cm2)		7459 [2940-15177]	7769 [3104-16590]

Table 2. Procedural variables. AVR (aortic valve replacement), TAVR (transcatheter valve replacement), MVR (mitral valve replacement), N (number), std dev (standard deviation), Q1-3 (first-third quartile), mm (millimeter), AVP (Amplatzer™ Vascular Plug, SJM, Plymouth, MN), ADO (Amplatzer™ Duct Occluder, SJM, Plymouth, MN), ASO (Amplatzer™ Septal Occluder, SJM, Plymouth, MN), mVSD (muscular Ventricular Septal Defect Occluder, SJM, Plymouth, MN), PLD (Paravalvular Leak Device, Occlutech®, Jena, Germany).

**The numbers may not add up to the column totals nor may the percentages add up to 100% due to values counting in more than one category, missing data and non-inclusion of patients with paravalvular leaks of both MVR and AVR or pulmonic valve replacments. ***Leak position as defined as on TEE.