Catheterization and Cardiovascular Interventions 65:394–404 (2005)

Basic Science Review

Catheter-Based Ventricle-Coronary Vein Bypass

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The goal of this study was to investigate the feasibility of a catheter-based ventricle-to-coronary vein bypass (VPASS) in order to achieve retrograde myocardial perfusion by a conduit (VSTENT) from the left ventricle (LV) to the anterior interventricular vein (AIV). Percutaneous coronary venous arterialization has been proposed as a potential treatment strategy for otherwise untreatable coronary artery disease. In an acute setting, the VSTENT implant was deployed percutaneously using the VPASS procedure in five swine. Coronary venous flow and pressure patterns were measured before and after VSTENT implant deployment with and without AIV and left anterior descending artery (LAD) occlusion. In a separate chronic pilot study, the VPASS procedure was completed on two animals that had a mid-LAD occlusion or LAD stenosis. At day 30 post-VPASS procedure, left ventriculography and magnetic resonance imaging (MRI) were performed to assess the patency and myocardial viability of the VSTENT implants. Pre-VSTENT implantation, the mid-AIV systolic wedge pressure was significantly lower than LV systolic pressure during AIV blockage (46 ± 19 vs. 90 ± 16 mm Hg; $P < 0.01$). The VSTENT implant deployment was performed without complication and achieved equalization of the AIV and LV systolic pressures and creation of retrograde flow in the distal AIV (maximal flow velocity: 37 ± 7 cm/sec). At day 30 post-VPASS procedure, left ventriculography showed VSTENT implant patency. MRI perfusion images demonstrated myocardial viability even with an LAD occlusion. Coronary retrograde perfusion using the VPASS procedure is feasible and may represent a potential technique for end-stage myocardial ischemia. *Catheter Cardiovasc Interv 2005;65:000–000.*

Key words: coronary vein; left ventricle; coronary bypass; catheterization

INTRODUCTION

Despite advances in percutaneous and surgical treatment for coronary artery disease (CAD), there is a growing patient population in whom the extent of CAD or failure of prior therapy precludes traditional treatment strategies. These "no option" patients pose an increasing challenge to cardiologists worldwide. In situ coronary venous arterialization has been proposed as a potential treatment for these "no option" patients [1–3]. One of the fundamental challenges of this specific technique is the creation and positioning of an arteriovenous conduit, particularly given the inherent anatomical variability of both coronary arterial and venous systems [1,2,4,5]. Furthermore, myocardial hemorrhage has been observed in these coronary vein-to-artery bypass procedures.

These important challenges have prompted the development of a novel and minimally invasive technique of catheter-based ventricle-to-coronary vein bypass (VPASS), which provides an easy technique compared to previous percutaneous in situ coronary venous

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Grant sponsor: Percardia, Inc. (Merrimack, NH).

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Received 13 May 2004; Revision accepted 14 October 2004

DOI 10.1002/ccd.20312
Published online 8 April 2005 in Wiley InterScience (www.interscience.wiley.com).

arterialization, as well as retrograde perfusion to the ischemic myocardium by a conduit (VSTENT) between the anterior interventricular vein (AIV) and the left ventricle (LV). The present study was designed to test the following three hypotheses: whether the systolic pressure gradient between the LV and AIV can create retrograde perfusion; whether the VPASS procedure can be performed percutaneously; and whether the retrograde perfusion provided by the VSTENT implant creates sufficient and sustained blood flow to maintain myocardial viability. The goals of the study were therefore to investigate the feasibility, mechanism, and durability of the VPASS procedure in a preclinical porcine model.

MATERIALS AND METHODS

Experimental Study

The study was carried out according to the Guidelines for the Care and Use of Laboratory Animals and approved by the Massachusetts General Hospital, Subcommittee on Research Animal Care. Each swine received oral aspirin 325 mg/day and clopidogrel 75 mg/day tablets orally prior to the procedure. Seven Yorkshire swine (40–50 kg) were pretreated with atropine 0.04 mg/kg and acepromazine 0.1 mg/kg and subsequently anesthetized with telazol 4.4 mg/kg and xylazine 2 mg/kg. The animals were then intubated and ventilated with 98% oxygen and 2% isoflurane. Following sterile skin preparation, a 7 Fr sheath was placed in the right femoral artery and a 14 Fr sheath was placed in the right femoral vein using a standard Seldinger technique. Before catheterization, heparin (5,000 U) was injected to maintain an ACT of 250–300 sec.

Percutaneous Coronary Arterial Access

Via the right femoral artery, the left anterior descending coronary artery (LAD) was cannulated with a 7 Fr Hockey Stick guiding catheter under fluoroscopic guidance, 100 μg nitroglycerine injected, and baseline coronary angiography performed in orthogonal views. A 7 Fr standard angiographic pigtail catheter was also advanced retrogradely into the LV using a 0.035″ guidewire. Left ventriculography (LVG) and hemodynamic measurements were then performed.

Percutaneous Coronary Venous Access

Via the right femoral vein, the coronary sinus (CS) was selectively cannulated with a preformed porcine catheter (Transvascular Inc., CA) and a 0.035″ hydrophilic exchange wire (Terumo, Tokyo, Japan). The catheter was then advanced from the CS to the AIV. Over the exchange wire, a 14 Fr CS guide catheter with dilator (Transvascular Inc.) was delivered to the ostium of the CS. The exchange wire was then replaced with a 300 cm, 0.014″ BMW guidewire (Guidant, CA).

Pressure Measurements

In five swine, a 5 Fr, 110 cm wedge balloon (Arrow International, PA) was advanced to the AIV over the 0.014″ BMW guidewire. The wedge balloon was inflated and pressure measurements were performed at mid-AIV, the intersection of the AIV and the great cardiac vein (GCV), and mid-GCV (Fig. 1A). The systolic wedge pressure at each site was compared to the systolic LV pressure.

VSTENT Implant Deployment

A 6 Fr TransAccess CrossPoint-CX catheter (Medtronic) was advanced to the mid-AIV over the 0.014″ BMW guidewire through the CS guiding catheter. Utilizing the solid-state 64-element phased-array intravascular ultrasound imaging element (20 MHz), the CrossPoint-CX catheter was oriented in the direction toward LV chamber [1,2]. Figure 2A shows the puncture direction of the needle at 12 o'clock. The best landmarks are the locations of the coronary artery and pericardium. When the coronary artery is located between 8 and 9 o'clock, the pericardium is located between 4 and 5 o'clock and the puncture needle is oriented toward the LV chamber. A 24 G nitinol needle was then extended 9 mm into the myocardium and extended incrementally up to 22 mm based on the myocardial thickness. Once the needle exited the myocardium into the LV, a 300 cm, 0.014″ BMW guidewire was advanced through the needle lumen into the LV and then advanced into the ascending aorta through the LV chamber for support during the VSTENT implant deployment. The CrossPoint-CX catheter was removed and a 3.0 mm balloon advanced within a 9 Fr subselective catheter and inflated to 10 atm for the channel dilatation.

After balloon deflation, a novel VPASS percutaneous delivery system (Percardia, NH) was tracked to the target location. The VPASS delivery system design allows for tactile feedback in combination with fluoroscopic guidance to place a section of the VSTENT implant in the AIV and the remaining length in the myocardium. The delivery system was a double-balloon system consisting of a balloon to inflate the AIV VSTENT implant section and a balloon to inflate the myocardial VSTENT implant section (Fig. 2B and C).

After final positioning, the VSTENT implant was deployed. RAO and LAO fluoroscopic views showed the stent to be deployed satisfactorily. A venogram confirmed a connection from the AIV to the LV with flow distal to the VSTENT implant.

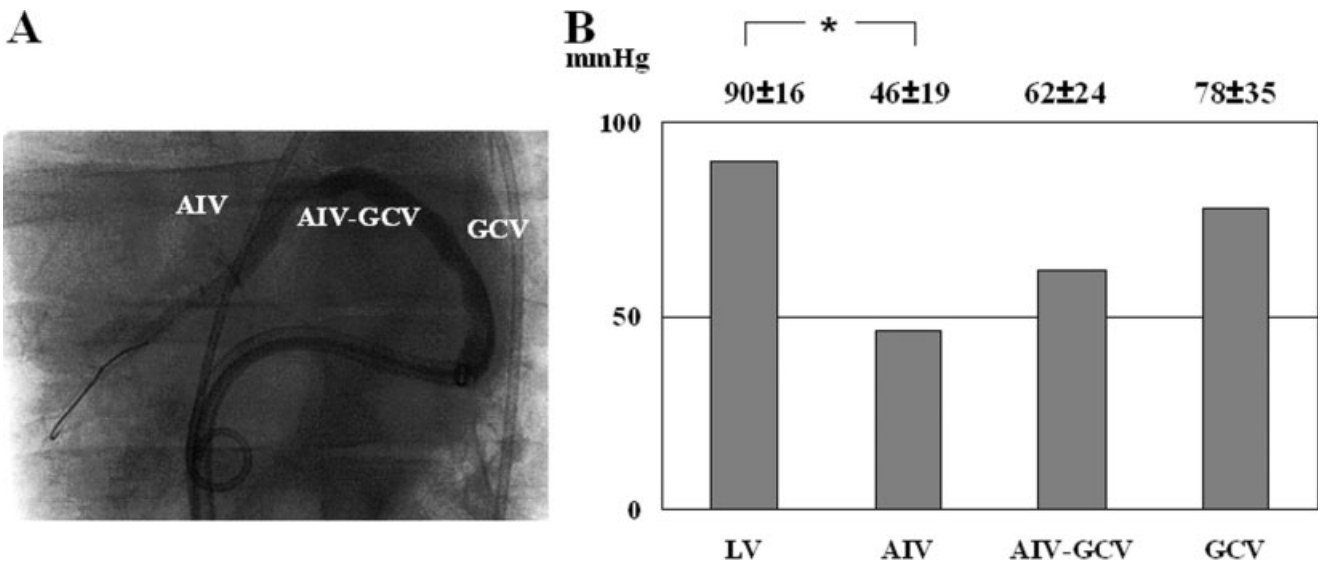

Fig. 1. A: Coronary venography with left anterior oblique (LAO) 30°. B: Systolic left ventricular pressure and the systolic wedge pressure at the AIV, the intersection between AIV and GCV, and GCV. Asterisk, $P < 0.01$.

Flow Velocity Measurements

A channel was made by the VSTENT implant to connect the AIV and the LV. Once this was confirmed by venography, a 5 Fr wedge balloon was advanced into the AIV. Using a 0.014″ Doppler guidewire (EndoSonics, CA), flow velocity measurements were performed through the wedge balloon in the distal AIV and in the mid-VSTENT implant. Maximal flow velocity (MFV) was measured in the distal AIV and compared with various settings of wedge balloon and coronary balloon occlusions. These settings were: no occlusion in AIV and LAD, AIV occlusion but no LAD occlusion, both AIV and LAD occlusions, and LAD occlusion but no AIV occlusion. Figures 4 and 5 show a plus sign to indicate an open vessel and a minus sign to indicate that the vessel is closed by an inflated balloon.

Percutaneous Ventricle-Coronary Vein Bypass Procedure

After the VSTENT deployment, a 5 mm balloon-expandable blocker stent (Vetour; Transvascular Inc.) was deployed 10 mm proximal to the AIV section of the VSTENT implant in the mid-AIV to establish retroperfusion into the myocardium [2]. In one animal (porcine 1), in order to create an acute myocardial infarction, a Tornado platinum embolic coil (0.035″, 4 cm length, 5 mm × 3 mm diameter; Cook) was deployed in the mid-LAD using a 5 Fr microcatheter (Tracker, Boston Scientific/Medi-Tech, Ireland) through a 7 Fr Hockey Stick guiding catheter. Coronary angiography was performed to confirm total occlusion with the coil.

Alternatively, one animal (porcine 2) received a restrictor stent (Percardia, NH) in the LAD to create an ischemic model. The restrictor stent is an encapsulated polytetrafluroethylene (ePTFE)-covered 316 L stainless steel stent mounted on a 3.0 mm balloon catheter. At the middle of the stent, the diameter is reduced to form a restricted blood flow path that leads to a total occlusion of the target vessel [6].

Final coronary angiography was performed to confirm occlusion or stenosis without perforation. Left ventriculography was performed to confirm flow through the VSTENT implant and an occlusion at the Vetour in the proximal AIV. The animals were allowed to recover and kept for 4 weeks, receiving aspirin 325 mg/day and clopidogrel 75 mg/day orally. They also received intramuscularly furosemide 20 mg/day for 3 days.

Quantitative Analysis

Immediately after implant and at 1 month post-VPASS procedure, coronary angiography, LVG and LV hemodynamics were performed to assess VSTENT implant patency and LV wall motion using a Siemens single-plane fluoroscopy system with online digital imaging software. Postoperative and follow-up left ventriculographies were analyzed by quantitative coronary angiography (ViewPlus, Sanders Data Systems, CA). The LV end-diastolic volume (EDV), end-systolic volume (ESV), and ejection fraction (EF) were obtained from ventriculography using the area-length method [7]. Postoperative coronary venography was

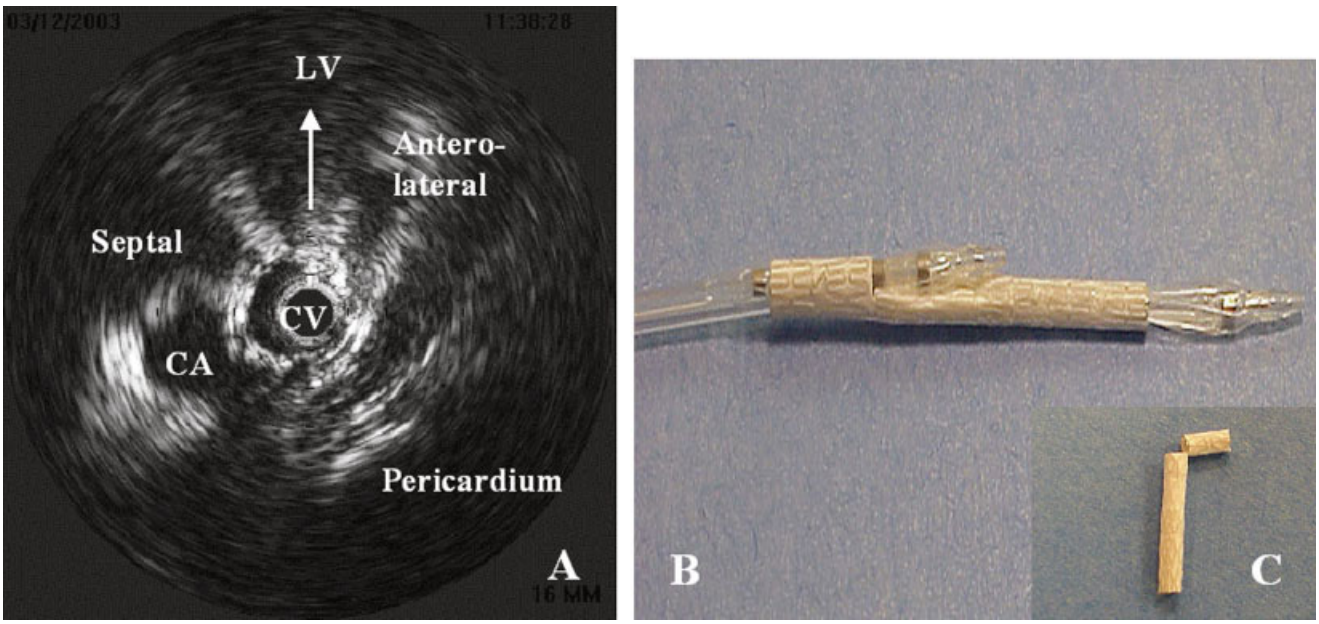

Fig. 2. A: Intravascular imaging shows the CrossPoint-CX catheter is placed in the coronary vein. The white arrow reveals the needle direction. The best puncture direction is when coronary artery is located between 8–9 o'clock on the image. CA, coronary artery; CV, coronary vein. B: VPASS system. The VPASS delivery catheter has two semicompliant balloons, each mounted on a separate shaft: a 4.0 mm diameter balloon for the myocardial segment and a 3.0 mm diameter balloon for the vein segment. The VPASS delivery system is supplied with a premounted VSTENT myocardial implant. This is accomplished by the balloons bifurcating as the myocardial balloon enters the myocardium and the venous balloon is positioned in the vein. This allows for precise positioning of the VPASS delivery system. C: VSTENT. The VSTENT implant consists of three important components: a metal stent scaffold, a covering, and a hemocompatible coating. The expandable stent scaffold provides the mechanical strength necessary to resist the cyclical compressive forces generated within the myocardium while providing for ease of deployment. The biocompatible covering minimizes tissue invasion into the channel, resists leakage of blood into interstitial spaces, and facilitates healing. Finally, the hemocompatible coating prevents thrombotic closure of the channel and enhances long-term patency and function. The metal scaffold is laser-cut from a 316 L stainless steel tube, creating an expandable device with high resistance to compression. The vein segment of the VSTENT has a balloon-expandable stent connected to the myocardial segment by a 316 L-covered flexible hinge. The hinge connection allows for seating the myocardial segment of the VSTENT implant at the vessel floor and minimizes the risk that the device will migrate following implantation. The VSTENT metal scaffold is encapsulated between two thin layers of ePTFE. The ePTFE layers are laminated to each other between the openings between the struts of the metal scaffold, completely encapsulating the metal stent, and the connecting hinge is also ePTFE-covered.

also analyzed to calculate the flow volume at the distal AIV and at the VSTENT implant.

Magnetic Resonance Imaging (MRI)

One month post-VPASS procedure, an MRI was performed with a 1.5T Signa Horizon CV/I MRI system (GE Medical Systems, WI). After identification of the long axis, 6 mm short-axis slices perpendicular to the long axis were obtained by a FIESTA (Fast Imaging Employing Steady-State Acquisition) sequence [repetition time (TR) = 3.5–4.5 msec; echo time (TE) = 1.5–2.0 msec; flip angle = 45–55°].

First pass perfusion images were performed after intravenous injection (0.2 mmol/kg) of gadopentetate dimeglumine (Magnevist, Berlex Laboratories, NJ), which was injected at the rate of 2.0 ml/s followed by 20 ml saline flush at the rate of 2.0 ml/s by an infusion pump. Imaging was acquired using echo-planer imaging sequence for 30 seconds after the injection. Imaging parameters are as follows: TR/TE/α = 7.6/1.7/25; echo train length = 4; image matrix = 128 × 128; slice thickness = 6 mm. LV was divided into six segments using the interactive program CINE (GE Medical Systems) [8]. To evaluate the quantitative myocardial viability, average percent signal intensity change (APSIC) was calculated and compared in each segment of anterior and lateral walls. Percent signal intensity change was defined as: (signal intensity at time t − signal intensity at time 0)/signal intensity at time 0 × 100 in a pixel [9].

Euthanasia

Upon completion of the protocol, the animal was sacrificed with intravenous pentobarbital 100 mg/kg; the heart was excised and examined grossly.

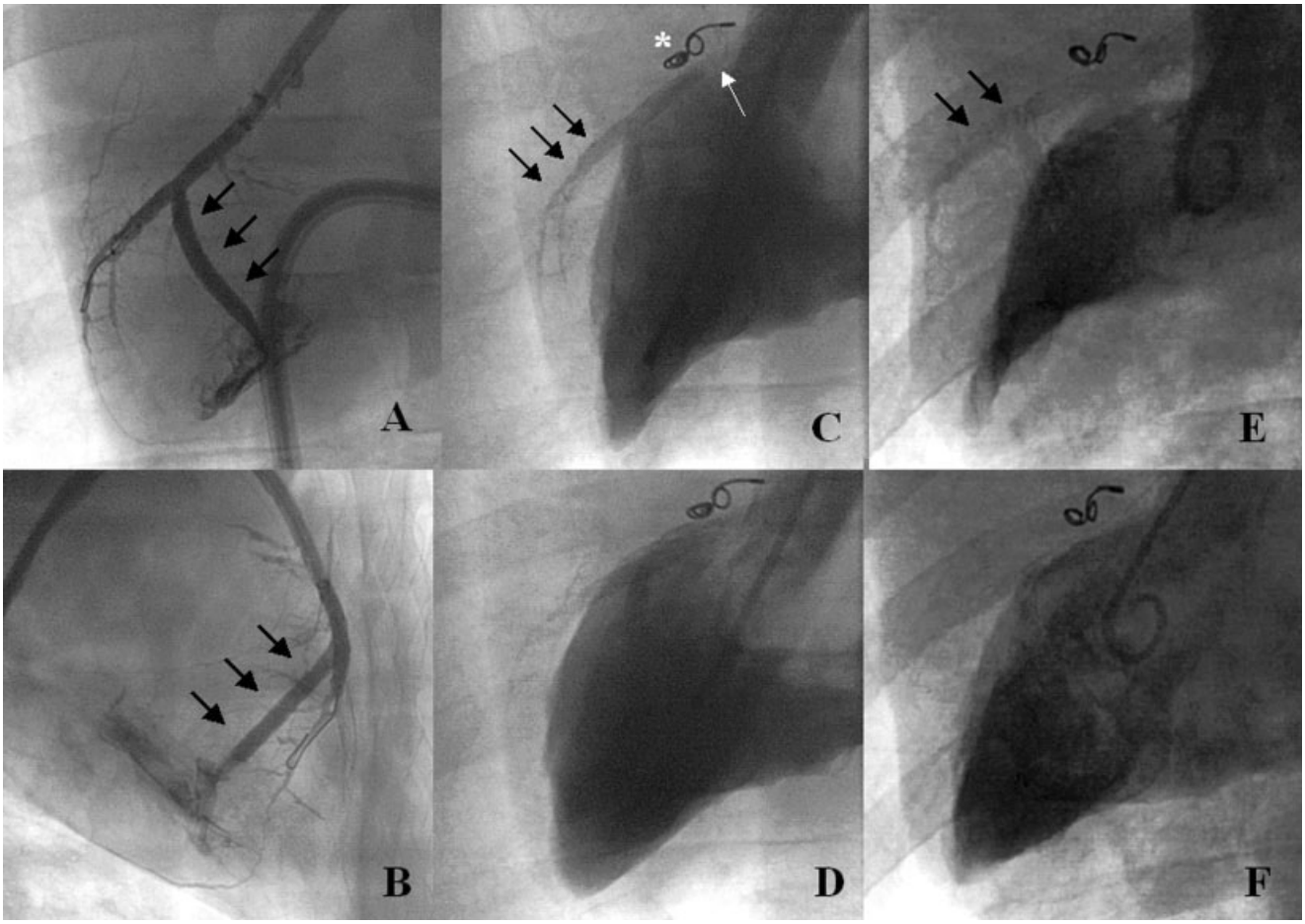

Fig. 3. VSTENT implant venography. Venography post-VSTENT implant with a 9 Fr subselective guiding catheter. A: LAO 30°. B: Right anterior oblique (RAO) 90°. Black arrow reveals the patent VSTENT. LVG post-VPASS procedure. Systolic LVG (LAO 30°; C) and diastolic LVG (D) 10 min after VPASS procedure with LAD occlusion. Black arrow shows the contrast flow in the AIV in systole. The blocker position was identified by where the contrast flow stops from the LVG (C). The white arrow shows the position of the blocker and a star shows the emboli coil. LVG 1 month post-VPASS procedure. E: Systolic LVG (LAO 30°) and diastolic LVG (F) 1 month post-VPASS procedure. Black arrow shows the contrast flow in the AIV in systole.

Statistics

All results were expressed as mean ± standard deviation. Data measured were compared between different groups using the unpaired *t*-test. P value < 0.01 was considered statistically significant.

RESULTS

The VPASS procedure was successfully performed in all seven animals without complication.

Pressure Measurements

Figure 1B demonstrates the pressure measurements at mid-AIV, the intersection of the AIV and GCV, and mid-GCV in normal coronary veins (n = 5). The systolic wedge pressure at each site was compared to the systolic LV pressure. There was a significant wedge pressure gradient between the AIV and LV (46 ± 19 vs. 90 ± 16 mm Hg; $P < 0.01$). After VSTENT deployment, the AIV systolic wedge pressure was increased to LV systolic pressure (85 ± 19 mm Hg).

VSTENT Implant Deployment

Via coronary sinus approach, the VSTENT implant was easily deployed into the myocardium without any complications. Premature ventricular contraction (PVC) was observed during puncturing and stenting. However, there was no continued PVC after puncturing and stenting.

Figure 3A and B show the post-VSTENT venographies from the 9 Fr subselective guiding catheter. A contrast injection through the guide catheter demonstrated

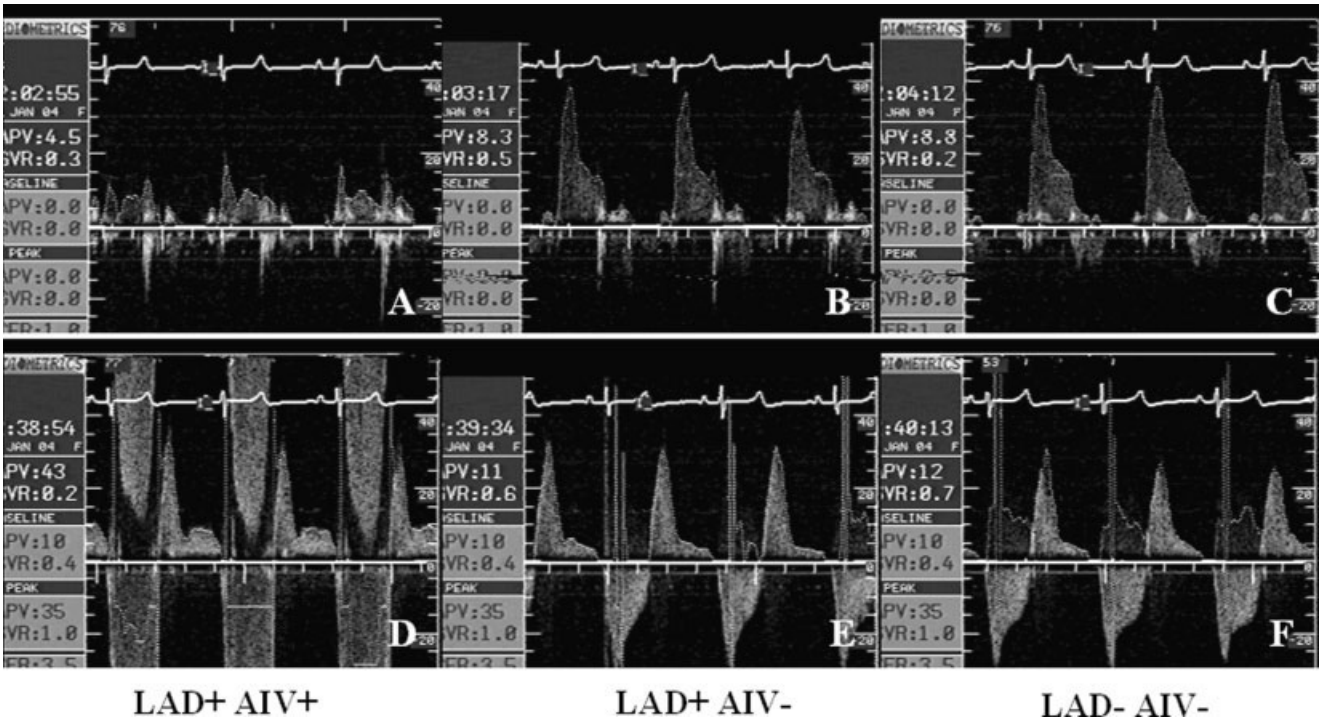

Fig. 4. Flow pattern in the AIV and VSTENT. A–C show the flow pattern in the distal AIV. D–F show the flow pattern in the mid-VSTENT. A and D are without any occlusion in AIV and LAD. B and E are with AIV occlusion but no LAD occlusion. C and F are with both AIV and LAD occlusions. Plus sign indicates the vessel is open and minus sign indicates the vessel is closed by an inflated balloon.

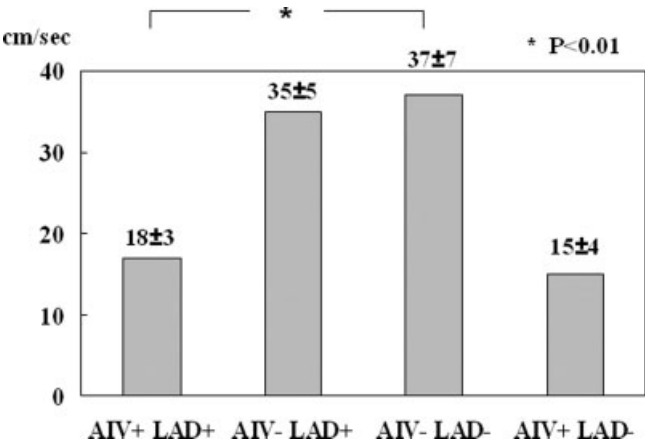

Fig. 5. Maximal flow velocity in the distal AIV. Maximal flow velocity during the different settings with occlusion of AIV and LAD. Asterisk, $P < 0.01$. Plus sign indicates the vessel is open and minus sign indicates the vessel is closed by an inflated balloon.

VSTENT implant patency, as well as capillary blush and contrast in the LV.

Flow Measurements

Flow velocity measurements were also performed post-VSTENT implant deployment. In the distal AIV, with AIV blockage (Fig. 4B), and simultaneous AIV and LAD occlusions (Fig. 4C), the systolic retrograde flow was increased as compared to no AIV and no LAD occlusion (Fig. 4A). Figure 5 demonstrates simultaneous AIV and LAD occlusion resulting in a significant increase in maximal flow velocity in the distal AIV (18 ± 3 vs. 37 ± 7 cm/sec; $P < 0.01$). Figure 4 shows the flow pattern in the distal AIV and mid-VSTENT implant.

In the AIV, the direction of the flow wire was toward the distal AIV. AIV vessel diameter was measured at 2.0 mm based on the 9 Fr subselective guiding catheter and the flow volume, with simultaneous AIV and LAD occlusion (Fig. 4C), was calculated to be 121 mm^3/beat or 10.6 ml/min. In the mid-VSTENT implant, the direction of the flow wire was toward the LV. The negative flow indicates systolic flow from the LV into the AIV.

The AIV blockage (Fig. 4E) and simultaneous AIV and LAD occlusions (Fig. 4F) created outflow from the LV in systole and inflow into the LV during diastole. The VSTENT implant diameter was also measured based on the 9 Fr subselective guiding catheter (VSTENT implant diameter: 3.4 mm) and flow volume with simultaneous AIV and LAD occlusion was calculated. The flow

volume was 477 mm^3/beat (42.0 ml/min) in systole and 348 mm^3/beat (30.6 ml/min) in diastole. The net flow was 129 mm^3/beat (11.4 ml/min). This was similar to AIV flow volume.

VPASS Efficacy and VSTENT Patency

Porcine 1 underwent VPASS and LAD occlusion. Figure 3 demonstrates the systolic LVG (Fig. 3C) and diastolic LVG (Fig. 3D) 10 min after completing the VPASS procedure; the LVEF was 32% by quantitative analysis and anterior wall motion was preserved by the VPASS procedure, even in the setting of mid-LAD occlusion. There were no ischemic changes on electrocardiography or clinical signs of heart failure.

The black arrows show the patent flow in the distal AIV 10 min after completing the VPASS procedure (Fig. 3C). The blocker position was identified by where the contrast flow stops from the LVG (Fig. 3C). Placement was approximately 10 mm beyond the VSTENT implant in the proximal AIV. Angiography at 1 month demonstrated rich collaterals around the LAD occlusion, a patent and functioning VSTENT with AIV flow in systole (Fig. 3E), and preserved LV function (LVEF 59%).

Figure 6 shows the VSTENT implant position and deployment angle in the LV by MRI. Upper images are long-axis FIESTA images in systole (Fig. 6A) and diastole (Fig. 6B). Lower images are short-axis FIESTA images in systole (Fig. 6C) and diastole (Fig. 6D). Although there was an artifact from the VSTENT, the blood flow through the VSTENT implant could be clearly identified. Blood flow (star) entered the LV in diastole (Fig. 6D).

For an assessment of efficacy, porcine 2 received a restrictor stent and developed a total occlusion of the LAD after the second diagonal branch (Fig. 7A). Figure 7A shows coronary angiography and gross anatomy 1 month after restrictor stent deployment. Although the coronary angiography showed total occlusion of the LAD after the second diagonal branch, the gross anatomy (Fig. 7B) showed white scar tissue, which indicates a local infarction area in the third and fourth diagonal branch regions and viable myocardium distal to the VSTENT implant.

The first-pass perfusion image distal to the VSTENT implantation was evaluated for quantitative myocardial viability (Fig. 8). The graph shows the APSIC in the anterior (100–162%) and anteroseptal (100–153%) segments was similar to the APSIC in the inferoseptal (100–196%) and inferior (100–172%) segments. The increase of APSIC in the anterolateral and inferolateral was much smaller than the other segments due to the diagonal infarctions. The similar perfusion patterns of the anterior and anteroseptal segments compared to native coronary artery perfusion in the inferior and inferoseptal segments indicate that the anterior and anteroseptal segments were perfused by the AIV via the VSTENT implant.

DISCUSSION

This study demonstrates that the VPASS procedure can be safely and effectively performed in a large-animal model. The VSTENT implant provides retrograde perfusion into the ischemic myocardium between the AIV and LV. The systolic pressure gradient creates retrograde systolic AIV flow during concomitant LAD and AIV occlusions. One month post-VPASS procedure and LAD occlusion, the LVG demonstrates VSTENT implant patency and viable myocardium as assessed by MRI.

Method of Delivery

In the 1970s, Hochberg et al. [10,11] demonstrated that the selective retrograde coronary venous perfusion could effectively deliver oxygenated blood to the ischemic heart in acute and long-term animal experiments. However, growing success with coronary arterial bypass reduced the relevance of selective retrograde coronary venous bypass. In 1995, Oesterle et al. [1,2] reintroduced this concept with the introduction of percutaneous in situ coronary venous arterialization (PICVA), requiring anastamosis of coronary artery and vein. However, PICVA was complicated by a relatively high morbidity and myocardial hemorrhage, which precluded widespread clinical application [1,2]. Compared to the PICVA approach, the VPASS technique described here has the advantage that the LV is a much larger target and is easier to puncture.

Mechanism of VPASS

Coronary arterial flow is maximum in the diastolic phase of the cardiac cycle [12,13] and is therefore dependent on the diastolic pressure gradient between the aorta and LV. Conversely, an effective VPASS procedure requires the generation of a systolic pressure gradient between LV and coronary vein and the creation of retrograde blood flow from the LV into the distal AIV.

We investigated whether the systolic pressure gradient between the LV and a coronary vein could create retrograde blood flow into the distal AIV. Therefore, we measured the coronary venous wedge pressure in three different areas from the AIV to the GCV. The results demonstrated a significant systolic pressure gradient between the AIV and the LV. From this result, it is possible that the systolic pressure gradient creates

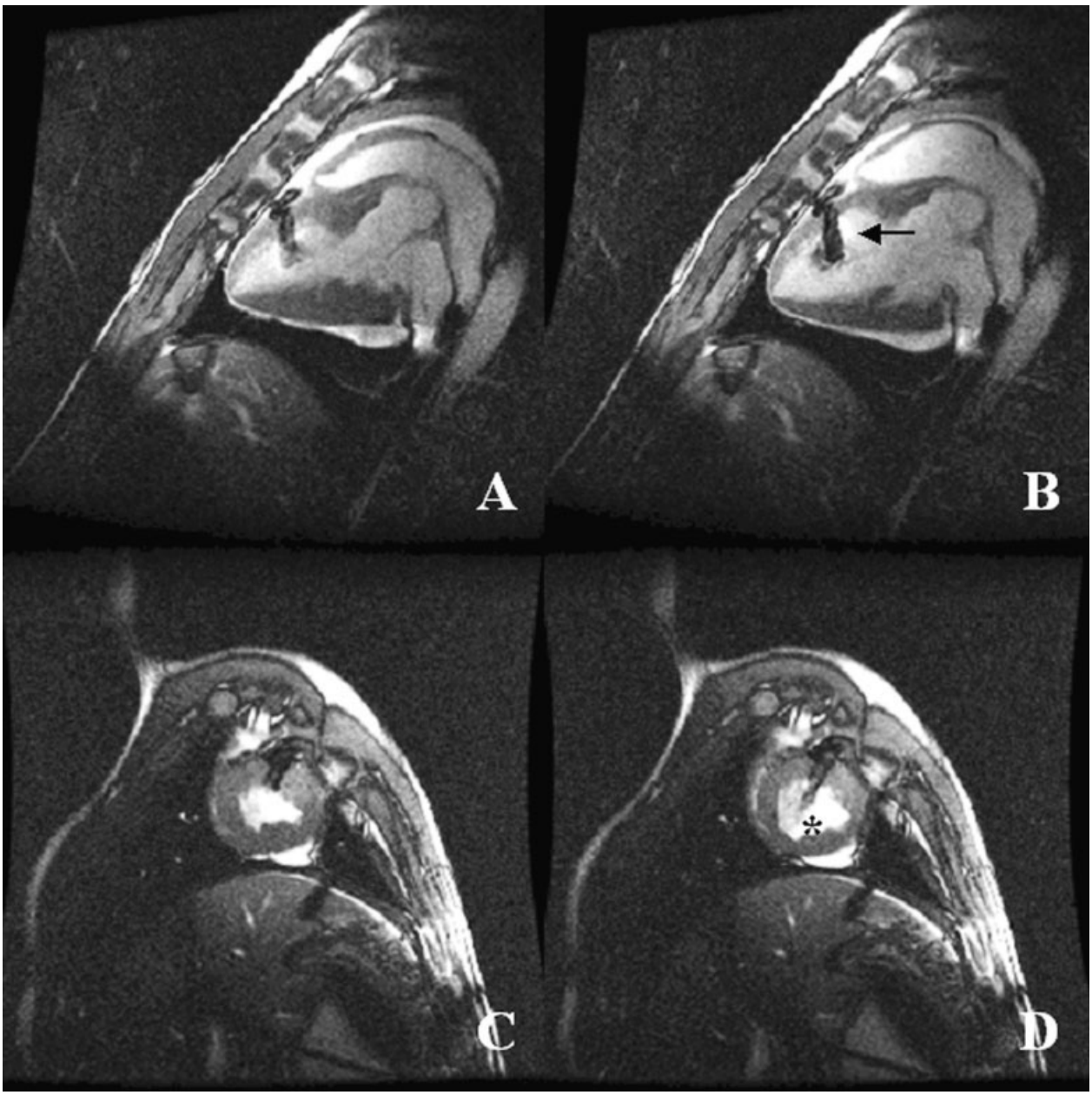

Fig. 6. FIESTA MR images 1 month post-VPASS and LAD occlusion. Upper images show long-axis view in systole (A) and in diastole (B). Lower images show short-axis view in systole (C) and in diastole (D). Black arrow indicates the VSTENT artifact (B). The flow (star) is coming back through the VSTENT into the LV in diastole (D).

the retrograde flow from LV to AIV in the coronary vein similar to the diastolic pressure gradient between the aorta and LV in the coronary artery.

A further question is whether the VPASS procedure with the VSTENT implant can generate retrograde perfusion in the distal AIV. In the current study, the flow pattern in the distal AIV was measured with various different anatomical settings. Occlusion of the AIV and LAD provided systolic retrograde flow in the distal AIV (Fig. 3C). In this setting, there was a greater systolic outflow from the LV through the VSTENT implant than diastolic inflow into LV, resulting in net retrograde flow in the AIV (10.6 ml/min). This study indeed demonstrated that the VPASS procedure could create the low-flow retrograde perfusion into the AIV.

However, the optimal flow volume to perfuse the ischemic myocardium is unknown. Williams et al. [14] reported the prolonged perfusion with 50 ml/min and

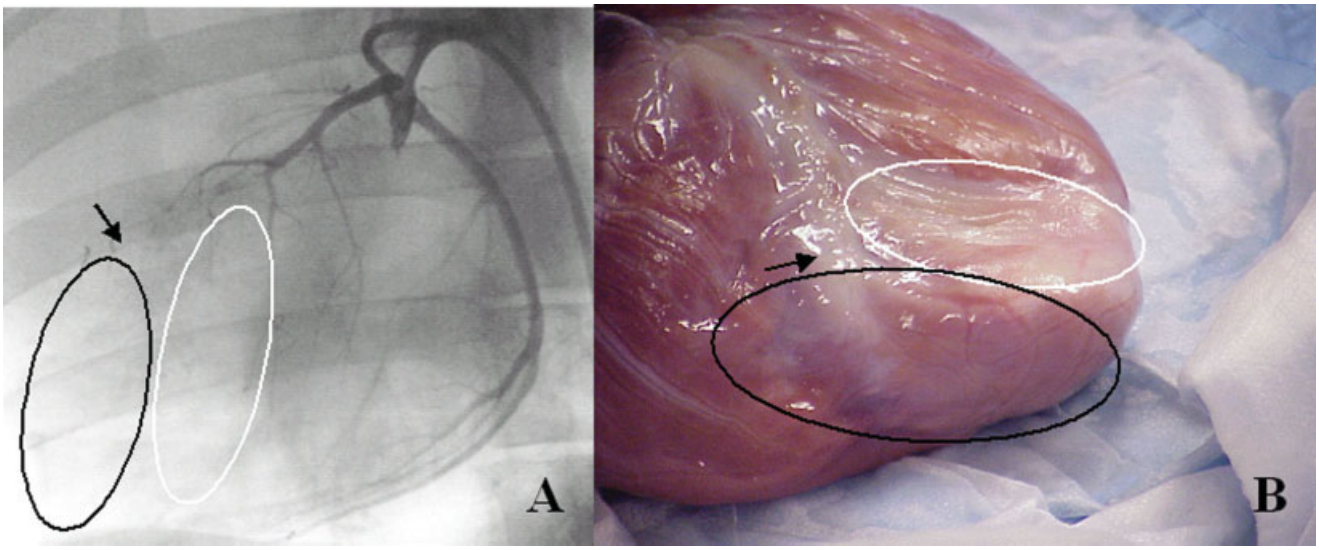

Fig. 7. Coronary angiography and gross anatomy 1 month post-VPASS. The restrictor stent developed a total occlusion of the LAD after the second diagonal branch (A). Gross anatomy showed a white scar tissue, local infarction (white circle), and viable myocardium (black circle), which match the coronary image.

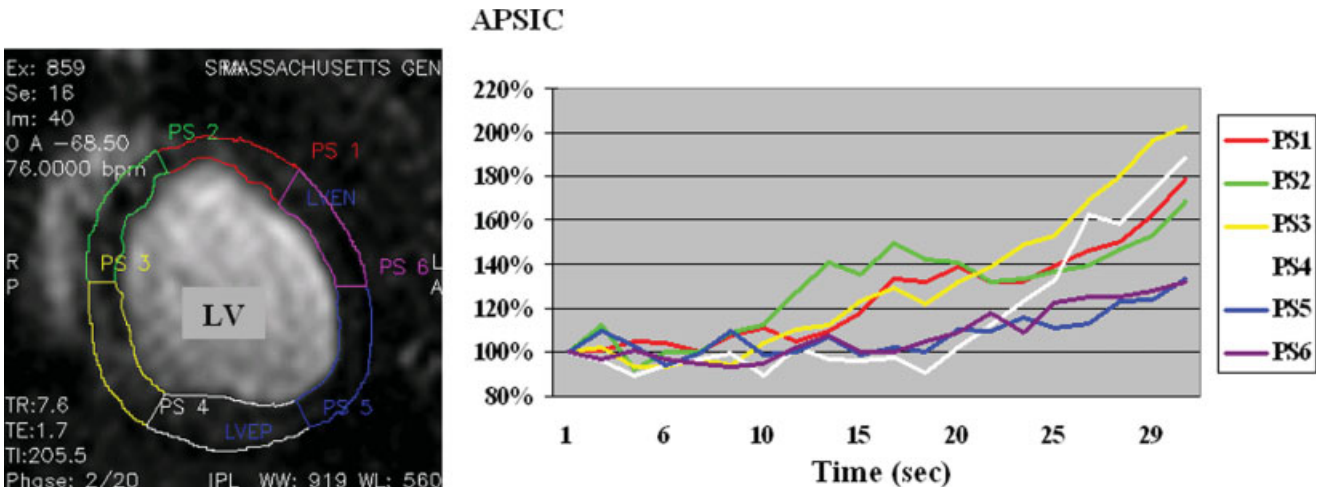

Fig. 8. MRI perfusion images 1 month post-VPASS and a graph of the APSIC in each segment. PS1, anterior (red); PS2, anteroseptal (light green); PS3, inferoseptal (yellow); PS4, inferior (white); PS5, inferolateral (blue); PS6, lateral (purple).

more than 60 mm Hg perfusion pressure developed hemorrhagic and stiffened myocardium [14]. Since outflow from the VSTENT implant will not increase the retroperfusion pressure due to either inflow and/or outflow in the VSTENT, the low-flow and low-pressure retrograde coronary venous perfusion could be beneficial for long-term myocardial protection [10,15].

After VSTENT implantation, the proximal AIV has to be blocked to establish retrograde perfusion. The wedge pressure measurement performed before the VPASS procedure is an important determinant of the positioning of the blocker within the AIV. If the wedge pressure were high, the VPASS procedure would have to be reconsidered. In the proximal AIV, high pressure after Vetour deployment could create congestion of the myocardium that might lead to severe edema or hemorrhagic infarction [10,15].

The wedge pressure in the AIV depends on LAD flow and venous shunts. The LAD flow in diffuse coronary arterial disease is lower than the normal coronary artery. Von Ludinghausen [5] and Ortale et al. [16] reported that the AIV connected to the posterior interventricular vein and septal veins and drained directly into the right atrium. In fact, six swine in this study had venous shunts confirmed by venography before the VPASS procedure. These low LAD flow

and shunts might prevent excessive pressure in the capillaries and reduce edemic complications.

VPASS Perfusion for Ischemic Myocardium

A number of other questions have to be examined. Can this systolic retrograde flow perfuse enough blood into the ischemic myocardium, and can this systolic retrograde flow contribute to recovery following acute myocardial infarction? We performed the VPASS procedure in a model of anterior infarction with excellent results and no evidence of acute or chronic ischemia, suggesting a protective effect of VPASS. At 1 month, LVG also demonstrated VSTENT patency and the persistence of AIV flow, suggesting this model is robust.

VPASS Efficacy

The VPASS procedure and LAD occlusion did not cause ST elevation, significant arrhythmia, or hemodynamic compromise. In general, the animals recovered smoothly. These acute results were similar to previous animal experiences in the 1970s. Bhayana et al. [17] and Hochberg [10] demonstrated the retrograde venous retroperfusion from saphenous vein to AIV markedly improved ST elevation and effectively restored some level of anterior perfusion in the acute setting. The VPASS procedure definitely proved to be effective acutely after LAD occlusion. One-month LVG also revealed the VSTENT implant was patent with AIV flow (Fig. 3E).

We also performed the VPASS procedure with a restrictor stent to see its effect in a model of chronic myocardial ischemia. Anatomical inspection and the quantitative perfusion analysis suggested viable myocardium, presumably by perfusion of the distal AIV through the VSTENT implant even in the presence of a total occlusion of the LAD. This study suggests that the VPASS procedure may contribute to recovery of acute myocardial damage, retrograde perfusion for ischemic myocardium, and can provide enough oxygenated blood in diastole if the myocardium is perfused from the VSTENT implant.

The concept of the VPASS procedure still needs further evaluation in the setting of chronic ischemia. In our experiments, both stents were patent and there was no thrombus in the VSTENT. However, there was some narrowing and intimal growth in the stents, where they were not covered by PTFE. Further studies are needed to evaluate the long-term patency and intimal growth in the VSTENT. However, these initial studies demonstrate a technical feasibility and benefit provided by the VPASS procedure in the setting of acute ischemia. This is the first study to show selective retroperfusion with MRI.

Study Limitations

These studies are clearly preliminary, but we believe they demonstrate an important proof of principle, that the concept of retrograde LV-AIV systolic perfusion may provide an avenue for therapeutic potential. Nevertheless, a number of limitations remain. Substantial natural variability exists in the human coronary venous system [5]. The treatment area is also likely to be limited to the anterior myocardium because of access for VSTENT implant deployment.

Although on MRI the VSTENT implant caused artifact when trying to assess the infarction area, the quantitative perfusion analysis showed the viable myocardium. Despite this, however, we demonstrated retroperfusion blood supply in the targeted myocardium and VSTENT implant patency and myocardial viability.

These data demonstrate the feasibility of LV-AIV retroperfusion using the method of the VPASS procedure. This technique provides potential means of percutaneous coronary bypass. In addition, the VPASS procedure is relatively straightforward, only requires conventional techniques of percutaneous intervention, and has potentially wide applicability.

Although preliminary, only performed in a small number of animals, and requiring confirmation of long-term patency and efficacy in larger cohort studies, these data suggest catheter-based ventricle-to-coronary vein bypass is feasible and effective. If confirmed by larger studies, an alternative percutaneous form of coronary bypass may be possible, an observation of potentially immense clinical importance given the limited bypass options currently available to many patients.

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