Off-pump epicardial ventricular reconstruction restores left ventricular twist and reverses remodeling in an ovine anteroapical aneurysm model

Yanping Cheng, MD,[a] Michael S. Aboodi, BS,[a] Lon S. Annest, MD,[b] Andrew S. Wechsler, MD,[c] Greg L. Kaluza, MD, PhD, FACC,[a] Juan F. Granada, MD, FACC,[a] and Geng-Hua Yi, MD[a]

Objective: The loss of normal apical rotation is associated with left ventricular (LV) remodeling and systolic dysfunction in patients with congestive heart failure after myocardial infarction. The objective of the present study was to evaluate the effect of epicardial ventricular reconstruction, an off-pump, less-invasive surgical reshaping technique, on myocardial strain, LV twist, and the potential alteration of myocardial fiber orientation in an ovine model of LV anteroapical aneurysm.

Methods: LV anteroapical myocardial infarction was induced by coil embolization of the left anterior descending artery. Eight weeks after occlusion, epicardial ventricular reconstruction was performed using left thoracotomy under fluoroscopic guidance in 8 sheep to completely exclude the scar. The peak systolic longitudinal/circumferential strains and LV twist were evaluated using speckle tracking echocardiography before (baseline), after device implantation, and at 6 weeks of follow-up.

Results: Epicardial ventricular reconstruction was completed in all sheep without any complications. Immediately after device implantation, LV twist significantly increased (4.18 ± 1.40 vs baseline 1.97 ± 1.92; $P = .02$). The ejection fraction had increased 17% and LV end-systolic volume had decreased 40%. The global longitudinal strain increased from −5.3% to −9.1% ($P < .05$). Circumferential strain increased in both middle and apical LV segments, with the greatest improvement in the inferior lateral wall (from −11.4% to −20.6%, $P < .001$). These effects were maintained ≥6 weeks after device implantation without redilation.

Conclusions: Less invasive than alternative therapies, epicardial ventricular reconstruction on the off-pump beating heart can restore LV twist and systolic strain and reverse LV remodeling in an ovine anteroapical aneurysm model. (J Thorac Cardiovasc Surg 2014;148:225-31)

CHD

Despite improved therapies to enhance survival, congestive heart failure associated with myocardial infarction (MI) remains a major health problem. Throughout disease progression, the formation of scar tissue after MI leads to changes in left ventricular (LV) shape and function. The normal elliptical LV deteriorates, with sphericity and chamber dilation.[1] A LV twisting motion (torsion), in which the apex rotates counterclockwise and the base rotates clockwise about the long axis during systole, is determined by the contractile force and has been as a proposed sensitive marker of LV function. Experimental and clinical studies have demonstrated that apical rotation represents the dominant contribution to LV twist,[2] and decreased apical rotation and loss of LV twist have been shown to be associated with significant LV remodeling, reduced systolic function, and increased filling pressure in patients with congestive heart failure.[3] Surgical ventricle reconstruction (SVR), a technique developed to restore LV shape, has been shown to improve symptoms and, potentially, the prognosis in patients with congestive heart failure after anterior MI with LV aneurysm.[4-8] Few modified SVR techniques have been reported to improve LV twist by re-creating a more elliptical LV geometry.[9,10] However, those SVR procedures require ventriculotomy and cardiopulmonary support. We introduce a novel device (PliCath HF; BioVentrix, San Ramon, Calif) that is designed to treat post-MI scars in a remodeled ventricle by excluding the noncontractile portion of the circumference of the left ventricle through an off-pump, less-invasive, epicardial ventricular reconstruction (EVR) procedure. EVR can achieve the same results as the traditional Dor procedure but less invasively and without the necessity for cardiopulmonary bypass.

In the present study, we evaluated the effect of EVR on myocardial strain and LV twist and the potential alteration

From the Skirball Center for Cardiovascular Research,[a] Cardiovascular Research Foundation, Orangeburg, NY; BioVentrix,[b] San Ramon, Calif; and [c]Drexel University, Philadelphia, Pa.

This study was supported in part by BioVentrix (San Ramon, Calif).

Disclosures: Authors have nothing to disclose with regard to commercial support.

Received for publication April 5, 2013; revisions received Aug 5, 2013; accepted for publication Aug 11, 2013; available ahead of print Sept 30, 2013.

Address for reprints: Geng-Hua Yi, MD, Skirball Center for Cardiovascular Research, Cardiovascular Research Foundation, 8 Corporate Dr, Orangeburg, NY, 10962 (E-mail: gyi@crf.org).

0022-5223/$36.00

http://dx.doi.org/10.1016/j.jtcvs.2013.08.030

Abbreviations and Acronyms

- EDV = end-diastolic volume
- ESV = end-systolic volume
- EVR = epicardial ventricular reconstruction
- LAD = left anterior descending artery
- LV = left ventricular
- MI = myocardial infarction
- SVR = surgical ventricle reconstruction

of myocardial fiber orientation in an ovine model of LV anteroapical aneurysm.

METHODS

Study Design

The study was conducted in accordance with the *Guide for Care and Use of Laboratory Animals* and was approved by the Institutional Animal Care and Use Committee of the Jack H. Skirball Center for Cardiovascular Research of the Cardiovascular Research Foundation. LV anteroapical acute MI was induced in 8 Dorsett hybrid sheep (weight, 36 ± 3 kg) by coil embolization of the left anterior descending artery (LAD). At 8 weeks after MI creation, EVR was performed using an open chest surgical procedure, and the device was implanted under fluoroscopic guidance. LV performance was evaluated by echocardiography for all sheep before MI creation (naive), before device implantation (baseline), immediately after device implantation, and at 6 weeks of follow-up.

Coronary Coil Embolization–Induced MI

In the present study, LV anteroapical MI was induced by LAD coil embolization. All sheep received intramuscular Telazol (4 mg/kg) injections for induction and were then intubated and mechanically ventilated using 1.5% to 2.5% isoflurane. Heparin (100 U/kg) was injected to maintain an activated clotting time of ≥250 seconds. Under fluoroscopic guidance, the coronary coil (2.0-3.5 mm; Cook Medical, Bloomington, Ind) was delivered to the middle LAD, at a point 40% to 50% of the distance from the apex to the base and to the corresponding diagonals to block the coronary blood flow and induce MI. Coronary angiography was performed to confirm complete and persistent occlusion. All catheters and sheaths were removed 2 hours after LAD occlusion, and the sheep were allowed to recover.

EVR (Device Deployment)

The EVR procedure was performed at 8 weeks after MI creation. The sheep were intubated and anesthetized as previously. The PliCath HF System (BioVentrix, San Ramon, Calif) consists of implantable anchor pairs (including a hinged internal anchor with a tether and a locking external anchor) and a delivery system (Figure 1). The heart was exposed by left thoracotomy, and the LV anteroapical and anterolateral scarred segments were identified using epicardial echocardiography. The device components were pinpointed using fluoroscopy. After intravenous heparin administration (activated clotting time ≥ 250 seconds), EVR was performed. In brief, a custom-made puncture needle, which was connected to a pressure transducer (DTX Plus DT-XX; BD, Franklin Lakes, NJ), was used to puncture the LV free wall and interventricular septum. After confirming the position of the needle tip within the right ventricle using both fluoroscopy and ventricular chamber pressures, a flexible wire was advanced into the right ventricular outflow tract to the pulmonary artery under fluoroscopic guidance. Next, the needle was removed, and a 14F catheter with a dilator was placed over the wire into the right ventricle (Figure 1, *A*). The dilator was removed, and 1 anchor was deployed onto the right ventricular side of the septum (Figure 1, *B*). The wire was removed, and the anchor was pulled back to the septum (Figure 1, *C*). Next, an epicardial anchor was placed on the anterior wall of the left ventricle. Additional anchor pairs were placed to achieve the desired volume reduction (2-3 pairs; Figure 1, *D*). The anchors were plicated together (Figure 1, *E*) with a measured compression force of 2 to 4 N, and contrast was injected to confirm exclusion of the newly formed compartment (Figure 1, *F*). The number of anchor pairs used was determined by the preoperative LV volume and infarct area measurements from echocardiography. The target was either complete scar exclusion or an end-systolic volume reduction (ESV) of >30%. Figure 2 shows the heart before and after device implantation. A chest tube was placed for drainage, and all incisions were then closed using standard methods.

Echocardiography

Echocardiograms were performed at the naive stage, before device implantation (baseline), immediately after device implantation, and at 6 weeks of follow-up. Two-dimensional echocardiography images were acquired with the sheep in the right lateral decubitus position using a 5-MHz probe (iE33; Philips Medical Systems, Bothell, Wash) from standard parasternal long- and short-axis planes. The LV end-diastolic volume (EDV) and ESV were calculated using the Simpson's method, and the ejection fraction (EF) was calculated using a standard formula: ejection fraction = [(EDV − ESV)/EDV] × 100.

Grayscale images for offline speckle tracking echocardiography analysis were acquired at a high frame rate (65-90 frames/s) from standard long-axis and apical 4-chamber views. Short-axis images were acquired at 3 different levels (base, mid, and apical for a total of 16 segments). At least 2 consecutive cardiac cycles were recorded for offline analysis (QLab 6.0 software; Philips).[9] When a cardiac cycle with a good quality image was selected, a region of interest for speckle tracking was defined first at end-diastole using a semiautomated border detection method. The locations of the tracking points extending from the endocardial to epicardial borders were adjusted, and then the segmental myocardial strain curves were automatically generated by the system (Figure 3). The basal and apical rotations were analyzed as previously described,[11] and the data were exported to a spreadsheet program (Excel; Microsoft, Redmond, Wash) to determine the LV peak systolic twist. The LV peak systolic twist was calculated as the net difference in LV rotation at isochronal points between the apical and basal short-axis planes.[12]

For each sheep, the global peak negative systolic circumferential strain was derived from the mean value of all short-axis segments.[12] The peak systolic longitudinal strain in all LV segments (basal septum, mid-septum, apical septum, apex, apical lateral, mid-lateral, and apical lateral) was averaged to obtain a global value (global longitudinal strain).[13] The regional circumferential/longitudinal strain from the basal, middle, and apical level was averaged from the corresponding segments.[14]

Statistical Analysis

Statistical analyses were performed using Statistical Analysis Systems statistical software, version 9.2 (SAS Institute, Cary, NC). All measurements were tabulated as the mean ± standard deviation. The differences within groups at distinct points were assessed using 2-way analysis of variance with the post-hoc test (Bonferroni method). $P < .05$ was considered statistically significant.

RESULTS

Preoperative transthoracic echocardiography confirmed the absence of LV thrombus in all the sheep. EVR was completed in all cases without any adverse hemodynamic consequences. All the sheep recovered from the

CHD