Direct Visualization of Epicardial Structures and Ablation Utilizing a Visually Guided Laser Balloon Catheter: Preliminary Findings

E. KEVIN HEIST, M.D., PH.D., CONOR BARRETT, M.D., FRANCESCO PERNA, M.D., STEPHAN DANIK, M.D., JEREMY N. RUSKIN, M.D., and MOUSSA MANSOUR, M.D.

From the Cardiac Arrhythmia Service, Massachusetts General Hospital, Harvard Medical School, Boston, Massachusetts, USA

Epicardial Laser Balloon Ablation. ***Background*: Intrapericardial mapping and ablation can be utilized to target epicardial arrhythmic circuits. Current epicardial ablation strategies are associated with risk of damage to adjacent structures, including the coronary vasculature and phrenic nerves.**

***Objectives*: The purpose of this study was to evaluate the feasibility of an investigational, visually guided laser balloon catheter for manipulation within the pericardial space, visualization of epicardial structures, and delivery of laser ablation lesions to the ventricular myocardium.**

***Methods*: Pericardial access was obtained in 4 anesthetized swine by subxyphoid puncture. The laser balloon catheter was introduced into the pericardial space via a deflectable sheath, and was manipulated to predefined regions in all animals. Visually guided laser ablation was performed on the ventricular myocardium, with post mortem examination of lesion size and depth.**

***Results*: The laser ablation catheter could be manipulated to all targeted regions in all animals. Associated structures, including epicardial coronary arteries and veins as well as an endocardial catheter in the left atrial appendage, were easily visualized. A total of 9 laser energy applications at varying power/time settings were performed. Ablation utilizing moderate (7–8.5 W) power produced relatively uniform lesions (diameter 5–12 mm, depth 6–9 mm), while high (14 W) power produced a visible "steam pop" with a large, hemorrhagic lesion (22 × 11 × 11 mm).**

***Conclusions*: The investigational laser balloon catheter can be manipulated within the epicardial space, allowing for direct visualization of surrounding structures during ablation. Titration of laser power can be utilized to create moderate-sized ablation lesions while avoiding steam pops.** *(J Cardiovasc Electrophysiol, Vol. 22, pp. 808-812, July 2011)*

catheter ablation, epicardium, laser ablation, pericardium, ventricular myocardium

Introduction

Catheter ablation is widely utilized as a treatment for both atrial and ventricular arrhythmias. Most current ablation procedures are performed from the endocardial surface of the heart, accessed via the venous or the arterial circulation. Recently, there is increasing clinical utilization of epicardial mapping and ablation, accessed via subxyphoid puncture or via direct exposure of the heart with a cardiac surgical window.[1-3] Advantages of epicardial ablation include improved proximity to epicardial arrhythmic circuits, avoidance of clot and char formation within the heart leading to thromboembolism, avoidance of vulnerable endocardial structures, immediate access to the pericardial space if a pericardial effusion develops, and access to the heart when traditional endocardial access is not available due to vascular or valvular abnormalities.[4] Disadvantages of current techniques for epicardial catheter ablation include distance from endocardial arrhythmic circuits, the risks of obtaining epicardial access, postprocedural pericarditis, and the possibility of damaging structures adjacent to the pericardial space, including the epicardial coronary arteries and veins, the phrenic nerve and the lungs.[2,5]

The risk of damage to structures adjacent to the pericardial space results, in part, from difficulty in visualizing the anatomic relationship of structures such as the coronary vasculature to the ablation catheter. Furthermore, the pericardial space is a "potential space," which can result in proximity of an epicardial ablation catheter to adjacent structures outside the heart such as the phrenic nerves and lungs.[2,5] Recently, an investigational balloon-based laser ablation catheter has been developed intended to deliver endocardial visually guided

This work was supported in part by the M.G.H. Deane Institute for Integrative Research in Atrial Fibrillation and Stroke.

Conflict of Interest/Financial Disclosures reported: E.K. Heist: St. Jude Medical (consultant, honoraria, research grants), Boston Scientific (consultant, honoraria, research grants); C.Barrett: St. Jude Medical (research grants); J.N. Ruskin: Biosense Webster (consultant, fellowship support), Boston Scientific (fellowship support), CardioFocus (clinical oversight committee—no compensation), CardioInsight (scientific advisory board), CryoCath (scientific steering committee—no compensation), Medtronic (consultant, fellowship support), St. Jude Medical (fellowship support); M. Mansour: Cardiofocus (research grants), St. Jude Medical (research grants), Biosense-Webster (research grants). Other authors: No disclosures.

Address for correspondence: Moussa Mansour, M.D., Cardiac Arrhythmia Service and Cardiac Unit, Massachusetts General Hospital Gray 109, 55 Fruit St., Boston, MA 02114. Fax: 617-724-1241; E-mail: mmansour@partners.org

Manuscript received 6 November 2010; Revised manuscript received 23 November 2010; Accepted for publication 7 December 2010.

doi: 10.1111/j.1540-8167.2010.02004.x

laser ablation to isolate the pulmonary veins for ablation of atrial fibrillation, and feasibility of this technique has been demonstrated in both animals and humans.[6–9] Although this laser balloon catheter has been developed for endocardial ablation adjacent to the pulmonary veins, this technology could potentially offer important advantages for epicardial ablation as well. These include direct visualization of the coronary vasculature and adjacent structures during mapping and ablation, as well as a design that would direct ablation directly to the epicardial surface while simultaneously pushing adjacent structures such as the lungs and phrenic nerve away from the ablation site, thus minimizing risk of damage to these structures. In this study, we tested the feasibility of the use of the laser balloon catheter to be manipulated within the epicardial space, to directly visualize epicardial structures and vasculature, and to deliver epicardial ablation lesions under direct visual guidance.

Methods

The study was approved by the Massachusetts General Hospital Subcommittee of Research Animal Care based on the standards of the American Association for Laboratory Animal Care.

Four fasting Yorkshire swine (40–55 kg) were placed under general anesthesia and mechanically ventilated (anesthesia induction with Telazol 4.4 mg/kg, and maintenance with isoflurane 1–4% with 2–3 L/min O_2). Vascular access was then obtained by cutdown, including the internal jugular and the femoral vein and artery, and a coronary sinus catheter was placed. Transseptal access was obtained with the use of intracardiac echocardiography and an 8F SL-1 sheath. Percutaneous pericardial access was obtained with contrast and fluoroscopy guidance as previously described.[10] After placing a 0.032 J tipped wire through the needle, an investigational deflectable guiding sheath (Cardiofocus Inc., Marlborough, MA, USA) was placed over the wire into the pericardial space. This was performed by "up-sizing" the wire to an Amplatz Super-Stiff 280 cm 0.035 exchange wire through which the sheath was advanced. The investigational sheath is unidirectional and is 15 Fr outer diameter and 12 Fr inner diameter. Through this sheath, the laser balloon catheter was advanced into the pericardial space. Of note, in order to avoid damage to the heart and/or pericardium by the sheath, the sheath was only advanced in the pericardial space over the wire, or over the balloon catheter.

The balloon catheter was then partially inflated with 1:1 saline and contrast medium, and manipulated by means of the deflection mechanism on the catheter and sheath to predetermined locations in the epicardial space (based on fluoroscopy and direct visualization of epicardial structures via the balloon endoscope) including the right and left ventricular free walls, the ventricular apex, the left atrial appendage and the left and right A–V grooves. In addition, a 4 mm tip traditional mapping/ablation catheter (Biosense-Webster, Diamond Bar, CA, USA) was placed into the left atrial appendage from the endocardial surface, and visualized from the epicardial surface with the balloon endoscope. Ablation was then performed over the right and left ventricular surface with direct visualization via the endoscope, at either moderate (7–8.5 W) or high (14 W) power. Multiple (4–5) ablations (20–30 seconds per ablation, for a total ablation time of 80–150 seconds at each site) were performed at each site until a visible, uniform ablation lesion was present based on visual inspection from the endoscope. Each ablation was performed as a "spot ablation" without intentional movement or dragging of the balloon catheter during the lesion.

Earlier versions of the investigational laser balloon catheter and deflectable sheath have been previously described.[6] The current version involves a deflectable catheter with an expandable/inflatable balloon containing an endoscope that allows visualization of the end of the balloon and a laser arc generator that can be manipulated by twisting and extending/retracting the generator to direct the laser ablation based on visual guidance from the endoscope.

At the end of the procedure, animals were euthanized with Euthasol. Post mortem examination was performed to evaluate for damage to adjacent structures, including the pericardium, heart, lungs, and mediastinal structures. Evaluation of ablation lesions (diameter in the long and short axis and depth) was performed.

Results

Navigation

Pericardial access was obtained in all 4 animals. There was no significant delay in advancing the sheath over the guidewire, or in advancing the balloon catheter through the sheath into the pericardial space. Navigation to all 4 major chambers of the heart was easily and rapidly accomplished in all 4 animals using a combination of the deflection mechanism on the balloon ablation catheter and the deflectable sheath, with typical techniques used in epicardial mapping including extension/retraction as well as manual torque of the catheter and sheath. Placement of the balloon catheter in various positions in the epicardial space as assessed by fluoroscopy is demonstrated in Figure 1. Of note, the ablation catheter could be navigated through the epicardial space with the balloon both inflated and deflated, but in general it moved most easily when the balloon was partially inflated.

Visualization

The epicardial surface of the heart, as well as the parietal pericardium, could be easily visualized with the balloon catheter inflated in the pericardial space in all 4 animals. In addition, epicardial coronary arteries and veins could be visualized, and could also be distinguished based on a darker color of coronary veins compared to a redder color of coronary arteries. Pericardial vessels within the parietal pericardium could also be visualized. A predetermined plan was made to visualize the following structures in each animal: (1) right and left A–V groove and associated vessels, (2) anterior interventricular groove and associated vessels, (3) left atrial appendage, and (4) atrial and ventricular myocardium. All of these structures were easily visualized in all animals. In addition, a traditional 4 mm ablation catheter manipulated within the left atrial appendage from the endocardial surface could also be visualized from the laser balloon catheter placed within the epicardial space due to the translucency of the left atrial appendage myocardium (Fig. 2A). Structures external to the pericardium, such as the phrenic nerve, diaphragm and lungs, could not be visualized due to opacity of the parietal pericardium.

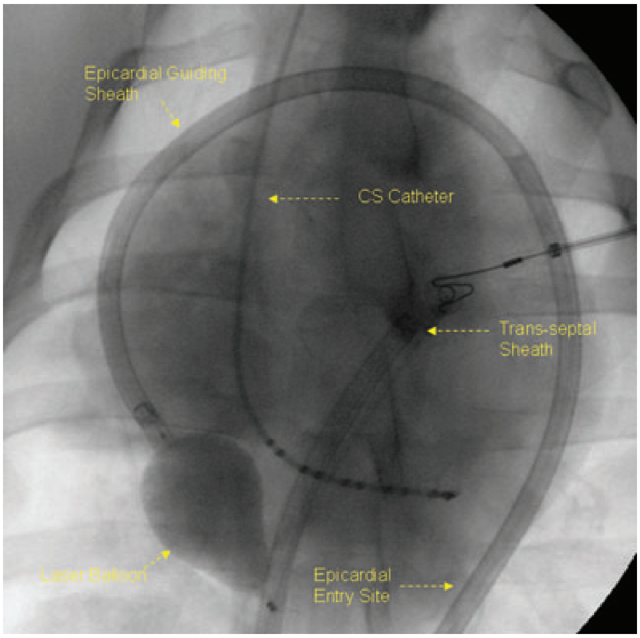

Figure 1. *Fluoroscopic image of epicardial manipulation of the laser balloon catheter. The laser balloon catheter has been placed into the epicardial space via a deflectable guiding sheath, and the balloon has been inflated. The balloon catheter has been placed over the right ventricular free wall near the apex.*

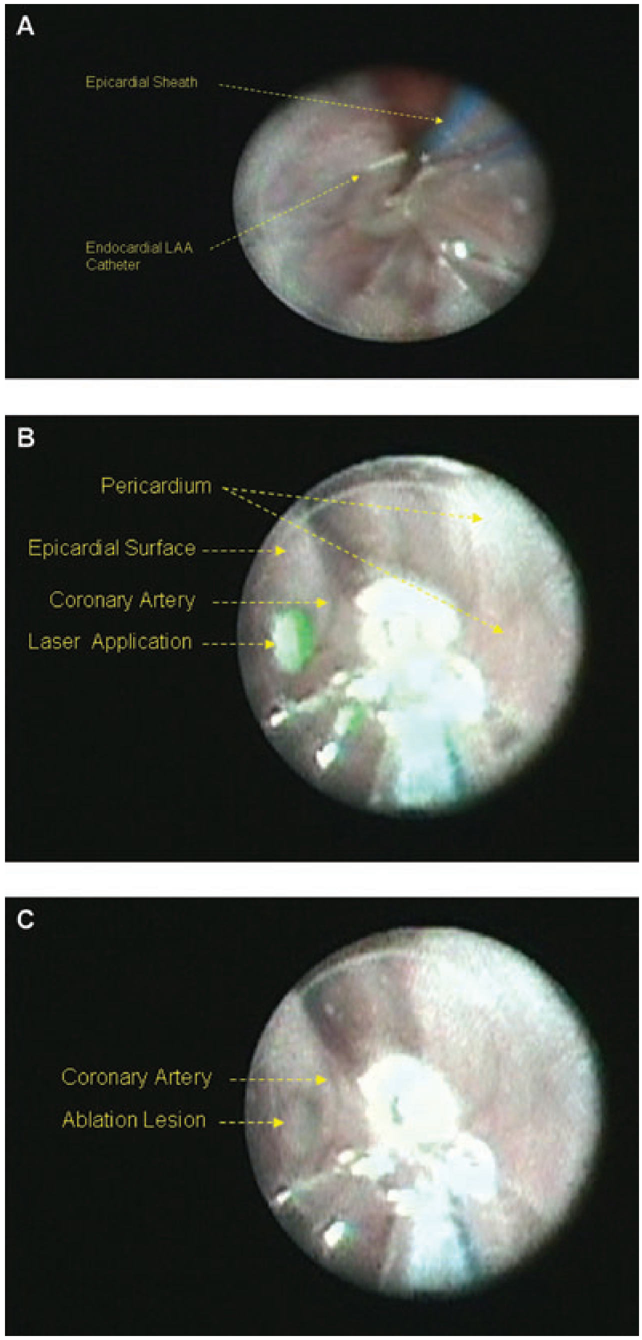

Figure 2. *Images from the laser balloon endoscope placed in the pericardial space. (A) The blue epicardial guiding sheath, as well as a separate 4 mm traditional ablation catheter that has been placed inside the left atrial appendage (from the endocardial surface). Note that the endocardial ablation catheter is easily visible from the pericardial space through the translucent myocardium of the left atrial appendage. (B) The laser balloon positioned over the left ventricular epicardium, with laser ablation turned on. The green dot is a visual landmark to identify the site where the laser ablation is applied. A coronary artery is visible near to the site of ablation. (C) The visible ablation lesion resulting from the laser application shown in 2B near the coronary artery.*

Ablation

Ablation was performed with direct visualization of ablation formation on the right and left ventricular epicardial surface, adjacent to the coronary vasculature (Fig. 2B and C). The technology employed allows the ablation lesion to be targeted by the operator to most regions visualized by the balloon, by extending/retracting and twisting the inner core of the laser catheter, just as is done when the catheter is used for pulmonary vein isolation. A total of 9 ablation lesions were performed. Of these 9 lesions, 7 were delivered with moderate power (7–8.5 W), while 2 were delivered with high power (14 W). All of the moderate power lesions produced uniform ablation lesions; formation of the ablation lesion could be observed in real time with the balloon endoscope. The distance of the forming ablation lesion from adjacent epicardial vasculature, as well as patency of the vasculature, could also be visualized during and after ablation. Of the 2 ablation lesions performed at high power, 1 of these lesions resulted in a "steam pop" with a clearly visible burst of bubbles, resulting in a large, irregular myocardial lesion.

Post mortem examination of the hearts demonstrated no identifiable damage to the epicardial surface of the heart or to the pericardium, other than the ablation lesions and the pericardial puncture that was performed for access. In addition, no damage could be identified to the lungs or other mediastinal structures. The moderate-power laser ablation produced relatively uniform ablation lesions, with an oval shape similar to the dimensions of the laser beam used for ablation, a diameter of 5–12 mm and a depth of 6–9 mm (Fig. 3). The high power ablation lesion that resulted in the steam pop resulted in a much larger lesion (22 × 11 × 11 mm) with a visible disruption in the myocardial tissue and significant hemorrhage into the lesion (Table 1). Of the 9 lesions, only the lesion resulting in a steam pop was transmural and could be identified on the endocardial surface. None of the other 8 lesions were transmural. Despite careful examination, no ablation lesions were evident on the parietal pericardium or on the lungs.

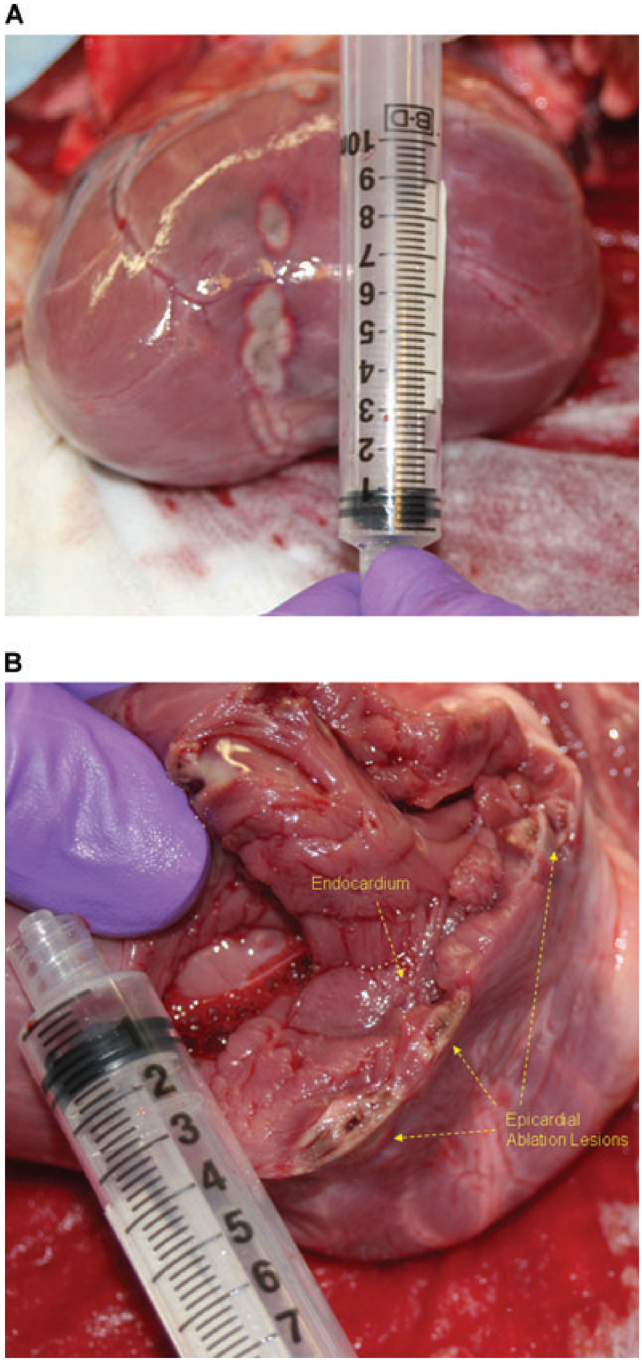

Figure 3. *Post mortem pathologic analysis of ablation lesions produced by the laser balloon catheter. (A) Ablation lesions on the epicardial surface of the left ventricle. (B) The depth of the ablation lesions shown in 3A with an incision made in the wall of the left ventricle through the center of the ablation lesions. Note on the lower ablation lesion a dark spot representing local hemorrhage within the ablation lesion.*

TABLE 1
Ablation Lesions

Lesion No	Power (W)	Duration (s)	Lesion Size (mm, Length × Width × Depth)
1	14 W	80 s	10 × 8 × 9
2	14 W	80 s	22 × 11 × 11 (*steam pop, transmural lesion)
3	7 W	150 s	12 × 8 × 9
4	7 W	120 s	9 × 7 × 8
5	8.5 W	150 s	7 × 7 × 7
6	8.5 W	150 s	10 × 8 × 9
7	8.5 W	150 s	11 × 7 × 7
8	8.5 W	150 s	6 × 6 × 6
9	8.5 W	150 s	5 × 9 × 7

Discussion

This study has produced several important findings. First, the laser balloon catheter, which was designed for endocardial pulmonary vein isolation, can be placed into the pericardial space and can be manipulated to specific atrial and ventricular locations, with ease of manipulation that is qualitatively similar to a typical point ablation catheter. Second, cardiac structures such as the A–V groove, the atrial and ventricular myocardium, and the epicardial coronary vasculature can be directly visualized with this balloon. Third, ablation can be delivered by this technology under visual guidance, with real-time visualization of the formation of ablation lesions. Fourth, power titration will be necessary using this ablation technology to maximize safety and efficacy, as potentially dangerous steam pops can be created by this system, similar to those observed with traditional ablation catheters.

Epicardial ablation is now an accepted alternative to ablation of arrhythmias that cannot be easily or safely targeted by a traditional endocardial approach.[11] Complications from epicardial ablation remain an obstacle to widespread adoption of this technique, however, including but not limited to the potential for damage to structures adjacent to the epicardial space, including epicardial coronary vessels as well as the phrenic nerve and the lungs.[2,12] A technology such as the laser balloon described in this study may help to overcome some of these challenges. Currently, epicardial ablation is typically performed with coronary arteriography to determine if a major coronary artery is in close proximity to an ablation site. In contrast, the laser balloon allows direct, real-time visualization of the epicardial coronary vasculature, both before and during ablation, and the relationship of the forming ablation lesion to the vessel can be assessed during ablation. Additionally, coronary veins can also be assessed with the laser balloon. It is not clear whether ablation over a coronary vein poses a real risk to a patient, but clearly epicardial coronary veins in addition to arteries can be visualized and avoided using the laser balloon.

Structures outside the heart, including the phrenic nerve and lungs, can also be damaged by traditional epicardial ablation. Structures such as the lungs may receive collateral damage during epicardial ablation, although in most cases this damage is not recognized and the clinical consequences have not been established. In regard to the phrenic nerve, high output pacing is typically performed prior to traditional epicardial ablation at sites that may be adjacent to the phrenic nerve, with ablation avoided if phrenic nerve capture is noted. In some cases, this leads to failure to ablate an arrhythmia. In other cases, techniques such as infusion of air/fluid or placement of balloon into the pericardial space have allowed for ablation with a traditional catheter at an epicardial site adjacent to the phrenic nerve.[13,14] In contrast, the laser balloon naturally pushes structures such as the lung and phrenic nerve away from the ablation performed at the epicardial surface. We observed no damage to the lungs or other adjacent mediastinal structures during epicardial laser ablation. Although we did not test for phrenic nerve damage, it is highly unlikely that it would occur with this technology, given that the highly directed laser ablation is targeted directly toward the heart and held away from the phrenic nerve by the balloon.

Visualization of catheters within the left atrial appendage was surprisingly clear through the thin, translucent myocardium (as shown in Fig. 2A), and this could offer another potential use for this technology, in guiding endocardial procedures within the atria (it is not possible to visualize catheters placed within the ventricles from the epicardial space using existing technology, given the thickness and opacity of ventricular myocardium).

The investigational laser balloon catheter that we utilized in these procedures was designed for endocardial pulmonary vein isolation, and this design has clear limitations for epicardial ablation. However, this study demonstrated that it can be used easily in the in the pericardial space with good maneuverability, visualization and ability to deliver ablation lesions. It does not, however, have any electrical mapping or pacing capabilities, which would necessitate the use of a separate catheter to map the epicardial surface and determine sites of ablation. A laser balloon catheter able to electrically map, pace, and create electroanatomic maps would vastly improve the usefulness of such a system for epicardial ablation. This would require a substantial redesign of the current balloon technology.

Limitations

This is a small animal study, and our findings will need to be validated in larger studies before consideration could be made for clinical use of this technology for epicardial ablation. In addition, the limitations described above to the current catheter design, with its lack of mapping and pacing capabilities, limit its current applicability for epicardial ablation, which generally requires these features. We did not study the electrophysiologic properties of the ablation lesions created by this system (for example, by placing an EP recording catheter over the site before and after ablation), although post mortem analysis did reveal dense lesions as shown in Figure 3, similar to lesions demonstrated in the pulmonary veins when this catheter is used for pulmonary vein isolation. Given published data on the ability of this system to isolate the pulmonary veins, it is likely that these lesions would have similar effects to traditional ablation lesions on the epicardium, but this will need to be proven in subsequent studies. Finally, ablation was performed over only the ventricles and not the atria, and so this study does not provide data on the effects of epicardial laser ablation on the atria. We chose to focus on ventricular ablation as we feel that this tool, if adapted for epicardial ablation, would be used most often for ventricular rather than atrial arrhythmias, but there are potential atrial ablation applications for epicardial laser ablation as well.

Conclusions

The investigational laser balloon catheter can be manipulated through the epicardial space, where it allows visualization of epicardial structures and delivery of ablation lesions. Further redesign of this technology could provide a powerful tool that could potentially improve the efficacy and safety of epicardial ablation.

References

1. Sosa E, Scanavacca M: Epicardial mapping and ablation techniques to control ventricular tachycardia. J Cardiovasc Electrophysiol 2005;16:449-452.
2. Sacher F, Roberts-Thomson K, Maury P, Tedrow U, Nault I, Steven D, Hocini M, Koplan B, Leroux L, Derval N, Seiler J, Wright MJ, Epstein L, Haissaguerre M, Jais P, Stevenson WG: Epicardial ventricular tachycardia ablation a multicenter safety study. J Am Coll Cardiol 2010;55:2366-2372.
3. Zei PC, Stevenson WG: Epicardial catheter mapping and ablation of ventricular tachycardia. Heart Rhythm 2006;3:360-363.
4. Hsieh CH, Thomas SP, Ross DL: Direct transthoracic access to the left ventricle for catheter ablation of ventricular tachycardia. Circ Arrhythm Electrophysiol 2010;3:178-185.
5. Di Biase L, Burkhardt JD, Pelargonio G, Dello Russo A, Casella M, Santarelli P, Horton R, Sanchez J, Gallinghouse JG, Al-Ahmad A, Wang P, Cummings JE, Schweikert RA, Natale A: Prevention of phrenic nerve injury during epicardial ablation: Comparison of methods for separating the phrenic nerve from the epicardial surface. Heart Rhythm 2009;6:957-961.
6. Reddy VY, Neuzil P, Themistoclakis S, Danik SB, Bonso A, Rossillo A, Raviele A, Schweikert R, Ernst S, Kuck KH, Natale A: Visually-guided balloon catheter ablation of atrial fibrillation: Experimental feasibility and first-in-human multicenter clinical outcome. Circulation 2009;120:12-20.
7. Gerstenfeld EP, Michele J: Pulmonary vein isolation using a compliant endoscopic laser balloon ablation system in a swine model. J Interv Card Electrophysiol 2010;29:1-9.
8. Dukkipati SR, Neuzil P, Skoda J, Petru J, d'Avila A, Doshi SK, Reddy VY: Visual balloon-guided point-by-point ablation: Reliable, reproducible, and persistent pulmonary vein isolation. Circ Arrhythm Electrophysiol 2010;3:266-273.
9. Leite L, Su W, Johnson SB, Milton M, Henz B, Sarabanda A, Santos SN, Packer DL: Utility of intracardiac ultrasound imaging to guide pulmonary vein ablation using laser balloon catheter. Arq Bras Cardiol 2009;93:616-621.
10. D'Avila A, Neuzil P, Thiagalingam A, Gutierrez P, Aleong R, Ruskin JN, Reddy VY: Experimental efficacy of pericardial instillation of anti-inflammatory agents during percutaneous epicardial catheter ablation to prevent postprocedure pericarditis. J Cardiovasc Electrophysiol 2007;18:1178-1183.
11. Natale A, Raviele A, Al-Ahmad, A, Alfieri O, Aliot E, Almendral J, Breithardt G, Brugada J, Calkins H, Callans D, Cappato R, Camm JA, Della Bella P, Guiraudon GM, Haissaguerre M, Hindricks G, Ho SY, Kuck KH, Marchlinski F, Packer DL, Prystowsky EN, Reddy VY, Ruskin JN, Scanavacca M, Shivkumar K, Soejima K, Stevenson WJ, Thermistoclakis S, Verma A, Wilber D: Venice Chart International Consensus document on ventricular tachycardia/ventricular fibrillation ablation. J Cardiovasc Electrophysiol 2010;21:339-379.
12. Roberts-Thomson KC, Steven D, Seiler J, Inada K, Koplan BA, Tedrow UB, Epstein LM, Stevenson WG: Coronary artery injury due to catheter ablation in adults: Presentations and outcomes. Circulation 2009;120:1465-1473.
13. Lee JC, Steven D, Roberts-Thomson KC, Raymond JM, Stevenson WG, Tedrow UB: Atrial tachycardias adjacent to the phrenic nerve: Recognition, potential problems, and solutions. Heart Rhythm 2009;6:1186-1191.
14. Matsuo S, Jaïs P, Knecht S, Lim KT, Hocini M, Derval N, Wright M, Sacher F, Haissaguerre M: Images in cardiovascular medicine. Novel technique to prevent left phrenic nerve injury during epicardial catheter ablation. Circulation 2008;117:e471.