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Transcatheter Electrosurgery – A Narrative Review

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Abstract

Transcatheter electrosurgery describes the ability to cut and traverse tissue, at a distance, without an open surgical field and is possible using either purpose-built or off-the-shelf devices. Tissue traversal requires focused delivery of radiofrequency energy to a guidewire tip. Initially employed to cross atretic pulmonary valves, tissue traversal has enabled transcaval aortic access, recanalization of arterial and venous occlusions, trans-septal access and many other techniques. To cut tissue, the selectively denuded inner curvature of a kinked guidewire (the "Flying V") or a single loop snare is energized during traction. Adjunctive techniques may compliment or enable contemporary transcatheter procedures, whereas myocardial slicing or excision of ectopic masses may offer definitive therapy. In this contemporary review we discuss the principles of transcatheter electrosurgery, and through exemplary clinical applications highlight the range of therapeutic options offered by this versatile family of procedures.

Keywords

Transcatheter electrosurgery; Transcatheter aortic valve replacement; Transcatheter mitral valve replacement; Left ventricular outflow obstruction; BASILICA; LAMPOON; SESAME; Catheter-Based coronary and Valvular Interventions; Aortic Valve Replacement/Transcatheter Aortic Valve Implantation

INTRODUCTION

Transcatheter electrosurgery is a newer component of the interventional catheterization armamentarium. Remarkably, electrosurgery can be applied not just in an open operative field insulated by air, but even within blood spaces, which short-circuit intended electrical pathways. Despite the challenge, targeted tissue vaporization is accomplished with simple bedside modification of interventional guidewires and other commercially available

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electrically conductive equipment. Using these tools, operators can traverse blood vessels and cardiac chambers, and can lacerate heart valve leaflets and even heart muscle without surgery. In this review we discuss the principles of transcatheter electrosurgery and exemplary clinical applications[figure 1].

Electrosurgical Principles

Basic physics of electrosurgery

Electrosurgery refers to delivery of high (‘radio’) frequency (240-470kHz) alternating current to cut or coagulate tissue. Electrosurgery may be performed in monopolar or bipolar[1] configurations with monopolar being the most common for transcatheter electrosurgery[2]. In monopolar mode, current flows in a circuit from a conductive object (an active electrode) to a target tissue, through the patient’s body and back to the electrosurgical radiofrequency generator via a dispersive electrode on the patient’s skin[figure 2]. Equal current flows through the active and dispersive electrodes, but the contact surface area of the active electrode is dramatically smaller and therefore concentrates energy. Tissue adjacent to the active electrode imparts resistance to current flow, converting electrical energy to heat. Continuous radiofrequency energy delivery (100% duty cycle ‘on’ [figure 2B]) causes rapid, focal heating above 100°C at the point of maximum current density, adjacent to the active electrode. Cells vaporize which therefore ‘cuts’ the tissue.

Electrosurgery is distinct from electrocautery, in which tissue is heated to induce coagulation and escharification. Electrocautery employs “coagulation” mode, which relies on interrupted current delivery (low duty cycle ‘on’) that induces heating with attendant denaturation (electrocoagulation), dehydration (electrodessication), or spark-spraying (electrofulguration) without vaporization.

Adaptations for transcatheter electrosurgery

Surgeons traditionally perform electrosurgery using hand-held active electrodes (such as electrosurgery pencils), under direct visualization, and within an insulating medium (air). By contrast, transcatheter electrosurgery vaporizes targets at a distance from the operator, internally and without visualization, and inside conductive blood or tissue media. Conductive metallic guidewires are the most common active transcatheter electrosurgical devices.

Guidewire denudation

Most commercial guidewires have polymer coating, such as polytetrafluoroethylene (PTFE) to improve mechanical properties such as lubricity and biocompatibility. Serendipitously these coatings are electrical insulators. Bedside-modification consists mostly of selectively stripping insulative coating —distally to expose/create the active electrode, and proximally to create contact points with connectors. The exposed proximal contact point is carefully clamped to electrosurgery accessories (such as ‘Bovie” electrosurgery pencils) to minimize energy loss when connecting to electrosurgery generators[Figure 3].

Electrosurgical tissue *cutting* is usually accomplished using the kinked shaft of a guidewire that traverses the tissue, and during traction[Figure 3]. The active electrode is the *inner* curve of the kinked guidewire shaft where it contacts the target tissue. However, electrosurgical charge tends to concentrate at convexities such as the *outer* curve of the kinked guidewire shaft. To resist this well-known phenomenon, insulation is selectively denuded from the inner curve and retained along the outer curve in order to concentrate electrosurgical charge at the tissue laceration target. The resulting “Flying-V” configuration[Figure 3, Video S1] self-orients when appropriately positioned across valve leaflets, and assures energy is appropriately targeted.

Coaxial catheter insulation of guidewires

Electrosurgical tissue traversal employs the tips of guidewires as active electrodes. Most unaltered commercial off-the-shelf guidewires have long uninsulated distal metallic tips having excessively large conductive surface area prone to current dispersal and inadequate charge concentration.

To counteract this phenomenon, a fundamental technique of transcatheter electrosurgery is to insulate all-but-the-tip of the guidewire, or all-but-the Flying-V of the guidewire, with a combination of microcatheters and guiding catheters. By exposing only small portions of the metallic guidewire beyond microcatheters and guiding catheters, conductive surfaces are minimized and charge is concentrated[figure 3].

Infusion of non-ionic solution such as dextrose/iodinated contrast

Blood is a highly conductive medium. When performing transcatheter electrosurgery, the active electrode is nearly always in contact with blood, allowing for charge dispersal through undesirable alternative current paths. By infusing a non-ionic solution of dextrose or iodinated contrast simultaneous with the application of radiofrequency current, blood is displaced and charge is concentrated in the target tissue[figure 3]. Blood displacement also minimizes electrode carbonization and local blood thromboembolism.

Clinical Applications

TISSUE TRAVERSAL

Pulmonary atresia—The first reported application of transcatheter electrosurgery was in pediatrics for pulmonary valve atresia with intact ventricular septum, using purpose-built electrosurgery guidewires[3]. Thereafter, electrosurgery-assisted pulmonary valvulotomy has become widely applied to treat pulmonary atresia with[4–6] and without[7] intact ventricular septa.

Transcaval aortic access—Transcaval aortic access describes electrosurgical entry to the abdominal aorta from the adjacent inferior vena cava[figure 4][8]. First described in 2013 as an alternative access for TAVR in otherwise ineligible patients[9], ‘transcaval’ has now been performed in thousands of patients worldwide and in many experienced centers is a routine option for large-bore arterial access to the aorta when iliofemoral arteries are small or diseased.

Technical overview: A suitable, calcium free crossing target is identified from a pre-procedure CT of the abdominal aorta[10]. Orthogonal fluoroscopic projection angles are planned, and the desired crossing site is related to anatomic fiducials, for example the superior margin of the iliac crests and nearest lumbar vertebrae which are then used for procedural co-registration. Safety and bailout options are planned by evaluating proximity of the crossing target to the renal vessels and aortoiliac bifurcation (minimum distance 15mm), presence of interposed structures such as small bowel, and femoral access for bailout covered stent delivery.

Transcaval access offers superior ergonomics and greater operator distance from X-ray scatter compared with transaxillary and transcarotid approaches. A coaxial system comprising CTO-indicated angioplasty guidewire (*Astato XS20*, Asahi-Intecc), hubless locking 0.014”−0.035” microcatheter (*Piggyback*, Teleflex) or alternative 0.014” 130-150cm microcatheter, 0.035” x 90cm microcatheter (e.g. *NaviCross*, Terumo) and 6-7Fr renal length guiding catheter (IM or RDC1) are inserted from the right femoral vein to the crossing target and directed towards a single loop snare draped along the aortic target from a femoral artery[10]. The guidewire is electrified with a short burst of 30-50W ‘pure’ cut monopolar energy and advanced from vena cava into the awaiting aortic snare. Following guidewire ensnarement and advancement to the aortic arch, the coaxial catheters are advanced to the aorta to permit exchange for a stiff 0.035” guidewire (e.g. *Lunderquist*) over which the intended large-bore sheath is advanced into the aorta to perform TAVR or percutaneous LVAD delivery otherwise per standard practice. On completion, heparin anticoagulation is reversed with protamine, the system is withdrawn and the transcaval access tract is closed with a nitinol cardiac occluder (*Amplatzer Duct Occluder-1*, Abbott). Completion aortography typically demonstrates complete occlusion or residual aortocaval fistulae. Extravasation usually responds to balloon aortic tamponade, but otherwise covered stents are required in approximately 1-5% of cases.

Clinical experience and outcomes: Early transcaval access and closure was systematically studied with CT in 100 patients in a prospective, multi-center, single-arm, core-lab adjudicated, investigational device exemption (IDE) Trial of patients with no other access options for TAVR[8,11]. In this extreme risk cohort (STS predicted mortality 9.6±6.3%) access and closure was successful in 99 of 100 attempts, covered stent was required for hemostasis in 1, and there were no deaths attributable to transcaval access[8]. Systematic post-procedure CT identified bleeding complications not otherwise ascertained on other TAVR studies. At 12-months there were no post-discharge vascular complications despite universal implantation of permeable vascular nitinol occluders[11]. Results were similar in an early European[12] and Israeli[13] reports.

In a more contemporary report, 238 patients undergoing transcaval TAVR were compared with 106 undergoing transaxillary access. Transcaval access conferred bleeding and vascular complications similar to transaxillary access, but lower “femoral-like” rates of stroke and discharge directly to home[14]. Selection bias does not appear to account for the different outcomes, before or after inverse-propensity weighting of baseline characteristics. Sites included a mix of operators who preferentially employed one route or the other (3 transaxillary vs 5 transcaval), and 3 that abandoned the transaxillary approach before the study period. Overall these findings suggest transcaval TAVR is at least as safe as transaxillary.

Applications: Transcaval access has been used extensively for TAVR in native vessels [8,9,14,15], including through aneurysmal segments [16] and surgical abdominal aortic grafts[17,18]. In the setting of resistant aortic walls, transcaval crossing can be accomplished using angioplasty balloons or with laser atherectomy [19]. Recent creative applications employ transcaval access for large bore hemodynamic support devices [20,21], extracorporeal membrane oxygenation[22], for treatment of congenital heart disease [23] including subaortic stenosis [24], for congenital syndromes at prohibitive operative risk [25], and for thoracic aortic endovascular aneurysm repair [26].

Arterial occlusion—Pediatric patients with chronically occluded[27] or atretic[28] pulmonary arteries have been successfully recanalized following electrosurgical traversal, as has an iatrogenic endograft occlusion of the right pulmonary artery during transcatheter pulmonary valve replacement[29]. Aorto-ostial coronary artery occlusions are challenging due to a lack of antegrade options. In cases where conventional retrograde approaches failed, electrosurgical traversal (E-CART) has enabled successful coronary artery recanalization [30]. In aortic coarctation, electrosurgery has enabled stent placement in uncrossable lesions[31,32] and in late stent thrombosis[33].

Venous occlusion—Electrosurgical traversal is possible in complex central and peripheral venous occlusions when mechanical approaches fail. Electrosurgery has been applied for retrograde pulmonary vein recanalization in complex congenital heart disease[34], in longstanding left subclavian vein occlusion related to chronic hemodialysis catheters[35], to enable pacemaker upgrades[36], and for a chronically occluded portal vein, recanalized to treat recurrent, variceal, upper-gastrointestinal bleeding[37]. In a single-center experience of 20 central, otherwise-uncrossable, chronic venous occlusions, electrosurgical recanalization was successful in 80% with only one major, conservatively managed, complication[38].

Non-anatomic bypass—Electrosurgical traversal between superior vena cava and right pulmonary artery enabled a transcatheter Glenn Shunt to successfully palliate an adult patient with uncorrected functional single ventricle[39]. By connecting descending aorta and main pulmonary artery, transcatheter reverse Potts shunts have alleviated symptoms in adult and pediatric patients with supra-systemic pulmonary arterial hypertension[40,41].

Trans-septal access—Electrosurgical atrial transseptal access is straightforward using purpose-built needles and guidewires (*NRG* and *VersaCross*, Bayliss Medical)[42,43] and off-label angioplasty guidewires[44] for both structural heart and electrophysiology procedures. Electrosurgery reduces time to cross and number of crossing attempts compared to mechanical puncture[42,43,45], allows for more precise transseptal access by eliminating the forward force required for puncture using transseptal needles, and may reduce unintended “back-wall” left atrial injury.

Electrosurgical fenestration—Electrosurgical fenestration of chronic Type-B aortic dissection[46,47] creates communication between true and false aortic lumens, allowing access to or perfusion of visceral vascular branches.

In situ fenestration has allowed rescue of unintended pulmonary artery branch obstruction after transcatheter pulmonary valve implantation [29]. More important, electrosurgical fenestration has allowed *in situ* construction of complex endograft landing zones in patients with pulmonary arteries otherwise too large for commercial or investigational transcatheter pulmonary valve devices [48].

Electrophysiologic applications—Left ventricular access has been established by electrosurgical crossing from the right atrium, creating an iatrogenic Gerbode defect, to perform VT ablation in patients with mechanical aortic and mitral valves[49] and across the interventricular septum to enable direct LV endocardial pacing[50].

TISSUE LACERATION

Procedures discussed to this point have concentrated charge at guidewire tips, to traverse through or between structures. Eccentric denudation and kinking the mid-shaft of an angioplasty guidewire to create the “Flying-V” (described above) was a major advancement to slice tissues in a variety of settings[Video S1].

CARDIAC VALVE LEAFLET SLICING

LAMPOON (intentional Laceration of the Anterior Mitral valve leaflet to Prevent left ventricular Outflow ObstructioN)

Technical overview—LAMPOON is a transcatheter mimic of surgical anterior leaflet resection, commonly performed during mitral valve replacement to prevent left ventricular outflow obstruction[51][figure 5]. In addition to fixed LVOT obstruction, long anterior mitral valve leaflets can cause dynamic LVOT obstruction following TMVR despite capacious outflow tracts. Moreover, TMVR-displaced overhanging leaflets occasionally create flow patterns that disrupt normal TMVR leaflet coaptation[52] or create dynamic LVOT obstruction. All can be averted using LAMPOON.

LAMPOON works by creating a midline incision in the anterior mitral valve leaflet that subsequently splays when displaced by TMVR, exposing THV cells otherwise covered by the anterior mitral leaflet. Serendipitously, chordal attachments to the papillary muscles remain intact, preserving ventricular function, and pulling the sliced leaflet halves safely outwards.

LAMPOON is not helpful when TMVR devices have lengthwise fabric skirts preventing blood flow across their stent frames. In this circumstance the risk of LVOT obstruction may be mitigated by septal reduction therapy (see SESAME, below).

Base-to-tip variants: In retrograde LAMPOON (“Classique”)[53], a guide catheter engages the base of the A2 mitral leaflet scallop from a percutaneous retrograde aortic approach. A 0.014” guidewire electrosurgically traverses the leaflet into to an awaiting multi-loop snare in the left atrium. The “Flying-V” is positioned at the base of the leaflet. Continuous, gentle, guide catheter traction during dextrose infusion and application of 70W “pure cut” electrosurgical energy creates a midline incision from base to tip. Because the retrograde aortic catheters are intrinsically aligned with the LVOT, retrograde LAMPOON remains the most reliable approach to true midline splitting of the A2 anterior mitral valve cusp.

Positioning of the retrograde aortic catheters can be technically demanding and can induce or exacerbate valvular regurgitation, and led to the development of an antegrade LAMPOON approach, which is now usually preferred for base-to-tip cases[54][figure 5]. Parallel deflectable sheaths are placed trans-septally in the left atrium to direct a pair of guide catheters; one snare catheter through the mitral valve orifice in the left ventricular outflow, the other delivering the coaxial electrosurgery crossing system to the atrial surface at the base of the anterior mitral valve leaflet. Following echocardiographic confirmation, leaflet traversal and snaring are accomplished. The key to successful midline laceration is creation of a central fulcrum in the left atrium using the deflectable sheaths; otherwise lacerations tend to be oriented obliquely towards the interatrial septum.

Tip-to-base variants: “Reverse,” or “tip-to-base” LAMPOON, is a further simplification for patients in whom either a prosthetic surgical ring[55] or valve replacement[56] creates a backstop to excessive laceration, protecting the aorto-mitral curtain and aortic valve. Because there is no leaflet traversal, the procedure is straightforward for newcomers. The procedure entails a balloon-wedge end-hole catheter floated from left atrium to LVOT to aorta to assure a chord-free trajectory. This catheter delivers a guidewire, pre-prepared with “Flying-V”, to be ensnared by a retrograde aortic snare. Traction is applied to guide catheters in the aorta and left atrium with the Flying-V straddling the leaflet tip. In resistant leaflets, laceration can be repeated. It is important during tip-to-base LAMPOON to assure no electrification near the aortic leaflets and to assure ring annuloplasty “backstops” protect the aortomitral curtain and transverse sinus, both evident on CT.

Rescue LAMPOON[57] describes a variation of tip-to-base LAMPOON in which the tip of a long anterior mitral valve leaflet that is causing TMVR leaflet dysfunction or dynamic LVOT obstruction is lacerated back to the THV frame.

Clinical experience and outcomes—In the prospective NHLBI LAMPOON IDE trial, 30 patients at prohibitive risk of LVOT obstruction were successfully treated using retrograde LAMPOON[58]. No procedural deaths were recorded in this extreme risk cohort (STS PROM 10.2±6.2) and 30-day survival was 93%. LAMPOON is most commonly performed in the setting of TMVR using balloon expandable THVs created for the aortic position, but has also enabled implantation of dedicated transcatheter mitral valves when overhanging anterior mitral valve leaflet would otherwise cause obstruction[59]. When implanting dedicated TMVR systems without uncovered cells LAMPOON may be combined with septal reduction techniques to synergistically prevent LVOT obstruction. After guidewire traversal through a non-calcified target, LAMPOON laceration is usually successful despite heavy anterior mitral leaflet calcification.

Liberation of double orifice mitral valve: In patients with prior surgical Alfieri stitch (ELASTIC; Electrosurgical Laceration of Alfieri STItCh [60]) or transcatheter edge-to-edge repair (ELASta-Clip; Electrosurgical Laceration And Stabilization of failed MitraClip(s) [61,62]), positioning of the "Flying-V" on the anterior mitral valve leaflet anteriorly, adjacent to the suture- or leaflet-bridge, liberates the leaflets upon electrosurgical laceration[figure 5]. This procedural adjunct enables TMVR devices to pin the suture or clip harmlessly and posteriorly along with the posterior mitral leaflet. As in all such electrosurgery procedures, the lacerating guidewire is used "off-label."

BASILICA (Bioprosthetic or native Aortic Scallop Intentional Laceration to prevent Iatrogenic Coronary Artery obstruction)

Technical overview—LAMPOON was adapted to aortic valve therapy as BASILICA[63]. Briefly, CT planning[64] assesses mechanisms and likelihood of threatened coronary obstruction (sinus sequestration or direct coronary ostial obstruction), and identifies procedural fluoroscopic projections. An appropriately sized coronary guide catheter engages the hinge-point of the target aortic leaflet; typically an oversized AL shape for the left and a JR4 or multipurpose for the right. Catheter shape is fine-tuned using rigid 0.035" guidewire back-ends during positioning. A co-axial traversal system comprising guidewire (*Astato XS20*) and microcatheter (e.g. *PiggyBack*) is advanced to the crossing target, clamped to the electrosurgical generator and, during brief application of 30-50W pure-cut energy, is advanced to a single-loop snare pre-positioned in the LVOT through a separate guiding catheter through the major orifice of the aortic valve[figure 6]. The Flying-V[65] is created and passed to the base of the leaflet during guidewire externalization. Guide catheters are advanced and slack removed from the system with gentle traction. Catheters are withdrawn towards the ascending aorta during application of 70W energy and with continuous dextrose infusion through both.

Careful electrosurgical technique, including the dextrose flushing, is essential to allow electrosurgical leaflet slicing rather than mechanical avulsion. Importantly, appropriately sliced leaflets continue to coapt sufficiently to prevent hemodynamic deterioration in the period between laceration and TAVR. Following TAVR, the midline leaflet incision preserves coronary artery flow through the open cells of the THV. If both arteries are at risk of obstruction a "*doppio*" procedure can be performed without hemodynamic decompensation[figure 6].

Clinical experience and outcomes—Approaches to predict iatrogenic coronary artery obstruction are sensitive but non-specific. Several high-risk features have been defined, including a coronary ostial height <12mm, virtual-valve-to-coronary (VTC) distance <4mm in bioprosthetic or <3mm in native valves, virtual-valve-to-sinotubular-junction distance <2mm and the presence of externally mounted prosthetic leaflets[66]. The BASILICA Trial, a prospective, investigator-led, IDE trial included 30 patients at risk for coronary obstruction. 30-day[67] and 1-year[68] outcomes demonstrated procedural efficacy and safety in native and bioprosthetic valves. The Multicenter International BASILICA registry reported real-world results from 214 patients at 25 centers in North America and Europe[69]. Procedural success was high, with laceration in 94% of cases. Importantly, stroke (2.8%) and disabling stroke

(0.5%) events were low and comparable to that reported in patients who do not undergo BASILICA[70].

Adaptations and future directions—Subsets of patients carry a higher risk for coronary artery obstruction, including those planned for TAVR-in-TAVR[71]. Balloon-augmented BASILICA (BA-BASILICA) may increase leaflet splay by expanding the traversal centrifugally closer to the bioprosthetic valve ring or native annulus, through balloon dilatation of the leaflet crossing point prior to laceration[72,73]. Purpose-built Pachyderm guide catheters[74] and custom guidewires are expected further to simplify the procedure.

CARDIAC VALVE LEAFLET REMOVAL

CATHEDRAL (CATHeter Electrosurgical Debulking and RemovAL)

A proportion of patients may experience coronary obstruction despite successful BASILICA laceration, such as from a prolapsing leaflet[73]. The CATHEDRAL procedure[75] uses transcatheter electrosurgery to energize a single-loop snare to cut and excise the aortic cusp. Further enhancements may prove important in the management of obstructive leaflets, especially for TAVR-in-TAVR.

Technical overview—Similar to BASILICA, the target aortic leaflet is electrosurgically crossed at its base, ensnared and externalized. In contrast, the kinked guidewire shaft is not denuded, allowing the leaflet to be grasped and minimizing injurious electrosurgical coupling in subsequent steps. A single loop snare is positioned over the V, at the base of the leaflet, tightened and energized whilst flooding the field with dextrose. Gentle guidewire countertraction assists excision and retrieves the excised leaflet.

MODIFICATION OF OTHER CARDIOVASCULAR TISSUE

SESAME (SEptal Scoring Along Midline Endocardium)

LVOT obstruction may still occur from TMVR when the THV fabric skirt obstructs outflow despite successful LAMPOON[76]. The SESAME procedure[77,78], still under development, is a transcatheter septal myotomy that increases LVOT area in patients with, or at risk for, LVOT obstruction from TMVR or hypertrophic cardiomyopathy[figure 7].

Technical overview—A retrograde aortic guiding catheter is engaged to the basal most interventricular septum, underneath the aortic valve, between the nadir of the right coronary cusp and right-left commissure to avoid conduction tissue. Using Intramyocardial Guidewire Navigation, a CTO-tipped angioplasty guidewire (*Astato XS20*)[79] traverses the septum and exits to a pre-positioned snare in the left ventricle. This trajectory lies away from the conduction system and defines the length and depth of subsequent myotomy. A modified “Flying-V” is fashioned with eccentric denudation of the mid-point of the guidewire, increasing the lacerating surface in contact with myocardium[78]. Electrosurgical laceration is performed under traction and 70W pure cut energy. The resultant myotomy immediately reduces LVOT gradient and splays further over 30 days[77]. In early experience there have been no major conduction disturbances and few anatomic exclusions, in contrast to transcoronary alcohol septal ablation[80].

PASTA (Pledget-Assisted Suture Tricuspid Annuloplasty)

In combination with other novel techniques, including guidewire-assisted suture and pledget delivery, electrosurgery has enabled tricuspid annuloplasty with the PASTA procedure[81,82].

Excision and removal of ectopic structures

Electrosurgery performed by energizing single-loop snares has resulted in successful resection of an aortic valve fibroelastoma[83], ruptured mitral papillary muscle[84] and most recently a right atrial myxoma; SEATTLE (Simplified Extraction of Atrial Tumor with Targeted Loop Electricity) procedure [personal correspondence, James M. McCabe]. A stray central venous catheter was removed from the superior vena cava of a post operative patient using a modified electrosurgical guidewire “lasso”[85].[47]

Troubleshooting

When faced with failure to traverse or cut, a few simple remedies usually suffice.

Connections and dispersive electrode

When guidewires are connected to electrosurgery generators via electrosurgery pencils, contact points should be examined to assure appropriate denudation of insulation. Avoid electrosurgery pencils having insulating (‘*Edge’*) coating, or otherwise strip the insulation.

The dispersive gel electrode should be in good (moist) condition and have good contact with clean and dry skin. We have experienced electrosurgical failure from mal-applied dispersive electrodes even when the generator contact quality indicator is illuminated. We recommend a low threshold to replace dispersive electrodes.

Catheter positioning

Successful tissue traversal requires orthogonal catheter positioning, which is analogous to guide catheter backup support in endovascular interventions. Calcification resists electrosurgical traversal, which succeeds only through calcium-free gaps, however small. If the guidewire is seen deflecting away from targets during electrosurgical traversal attempts, it is advisable to withdraw and reposition the guide and coaxial microcatheters, if only minutely, before further attempts.

Carbonization

The active electrode easily becomes coated with insulating organic materials (“carbonized”) when energized in the presence of blood or tissue. If other maneuvers do not correct electrosurgical failure, inspection and replacement of the guidewire may be required. This is part of the rationale for dextrose flushing during electrification, which reduces carbonization.

Power

Up-titration of applied power may aid electrosurgery. Using bedside-modified guidewires, we usually first attempt tissue traversal at 30W and increase to 50W as needed; we initiate tissue laceration at 50-70W and cautiously increase to 90W as needed.

How to adopt electrosurgery techniques into practice

Industry-sponsored proctorship is not generally available to physicians using significant-risk medical devices “off-label.” NHLBI has begun investigation of a dedicated BASILICA electrosurgical guidewire (*TELLTALE*, Transmural Systems, Andover, MA). Until commercial availability of such devices, new users can adopt electrosurgical techniques into their practices by combining study of medical literature and live or online video demonstrations; observing expert operators; and bringing patients to care alongside expert operators. On-site proctorship and even video-proctorship[86] are options, but proctors may require institutional indemnification against tort claims.

In our experience, transcaval TAVR is a good “entry-level” electrosurgical technique, followed by solo (single-leaflet) BASILICA. We recommend new users achieve proficiency in these techniques before tackling more complex ones such as multi-leaflet BASILICA and LAMPOON.

Conclusion

Transcatheter electrosurgery is a versatile tool that continues to inspire novel, innovative therapies for patients with complex anatomic challenges. Dedicated transcatheter electrosurgery devices will further simplify techniques and encourage routine adoption of these broadly applicable transcatheter electrosurgical procedures.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Disclosures

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TR is a consultant and physician proctor for Edwards Lifesciences, Medtronic and Boston Scientific; is a Medtronic advisory board member; and has an equity interest in Transmural Systems.

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Abbreviations

BASILICA	Bioprosthetic or native Aortic Scallop Intentional Laceration to prevent Iatrogenic Coronary Artery obstruction
HCM	Hypertrophic Cardiomyopathy
IDE	Investigational Device Exemption
LAMPOON	Intentional Laceration of the Anterior Mitral leaflet to Prevent left ventricular Outflow ObstructioN
LVOT	Left ventricular outflow tract
SESAME	Septal Scoring Along Midline Endocardium
AVR	Transcatheter Aortic Valve Replacement
TMVR	Transcatheter Mitral Valve Replacement

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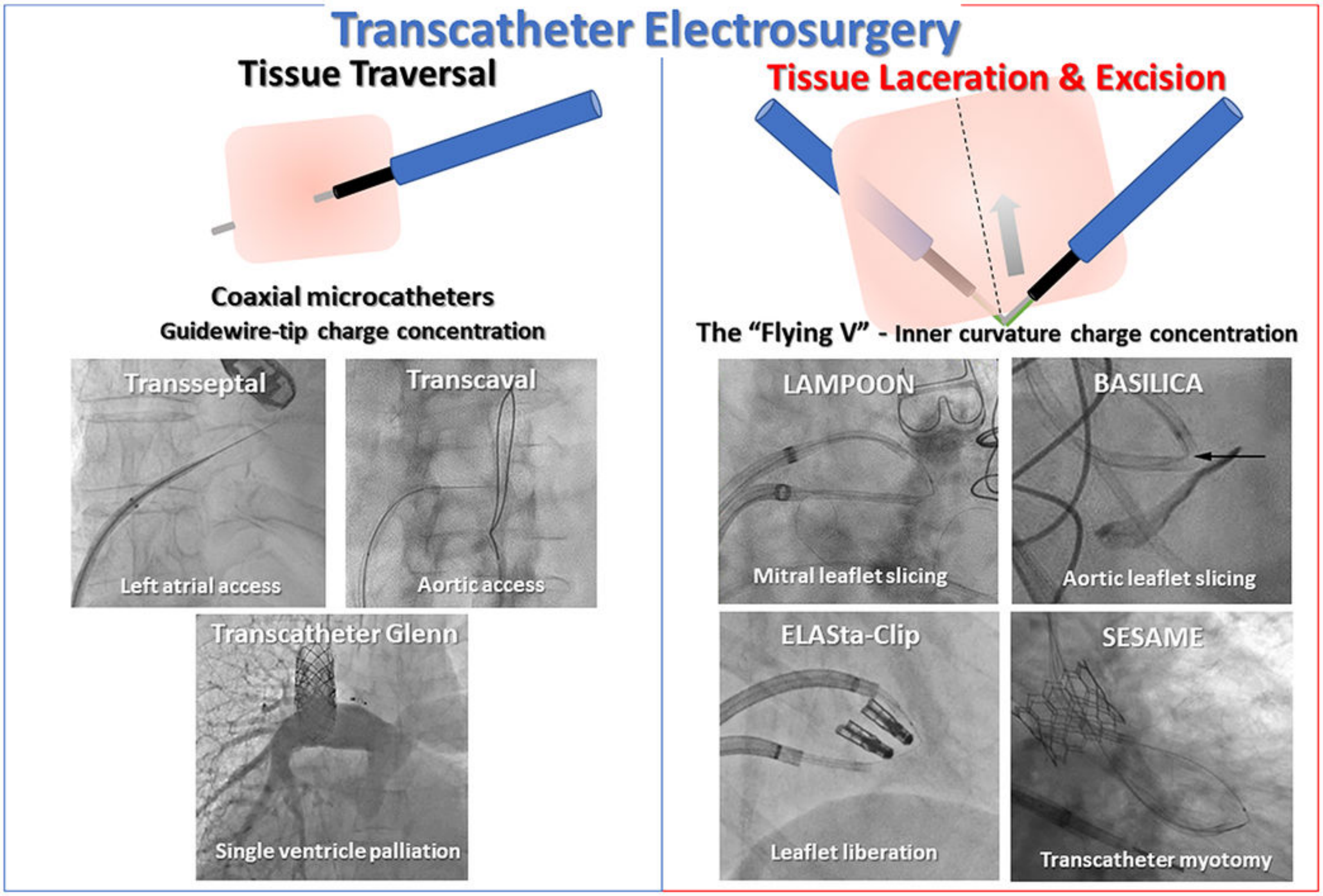

Fig 1.

Clinical applications of transcatheter electrosurgery.

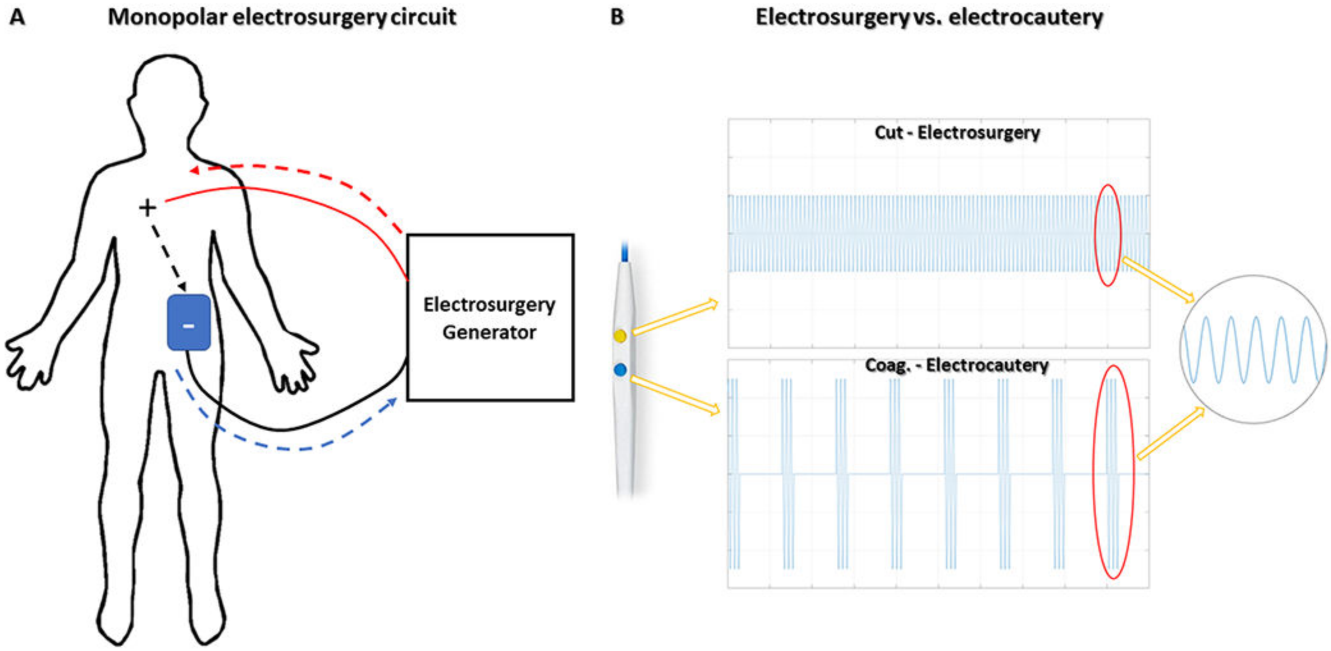

Fig 2. Monopolar electrosurgery circuit and radiofrequncy waveforms.

Monopolar electrosurgical circuits **(A)** consist of an active electrode(+) that receives current from an electrosurgery generator (red interrupted-arrow) and conducts through the body (black interrupted-arrow) to a dispersive electrode(blue patch), placed on the patient's skin, and thereafter back to the generator (blue interrupted-arrow). **(B) Continuous versus intermittent radiofrequency application** ("duty-cycle") creates different electrosurgical effects. Continuous (100% 'on') radiofrequency energy (top panel) vaporizes cells and cuts tissue at the point of maximum current density adjacent to the active electrode. In ("low duty cycle") electrocautery(bottom panel), interrupted radiofrequency energy causes tissue heating, protein denaturation, and blood coagulation. Reprinted from Khan et al. JACC, 2020[2].

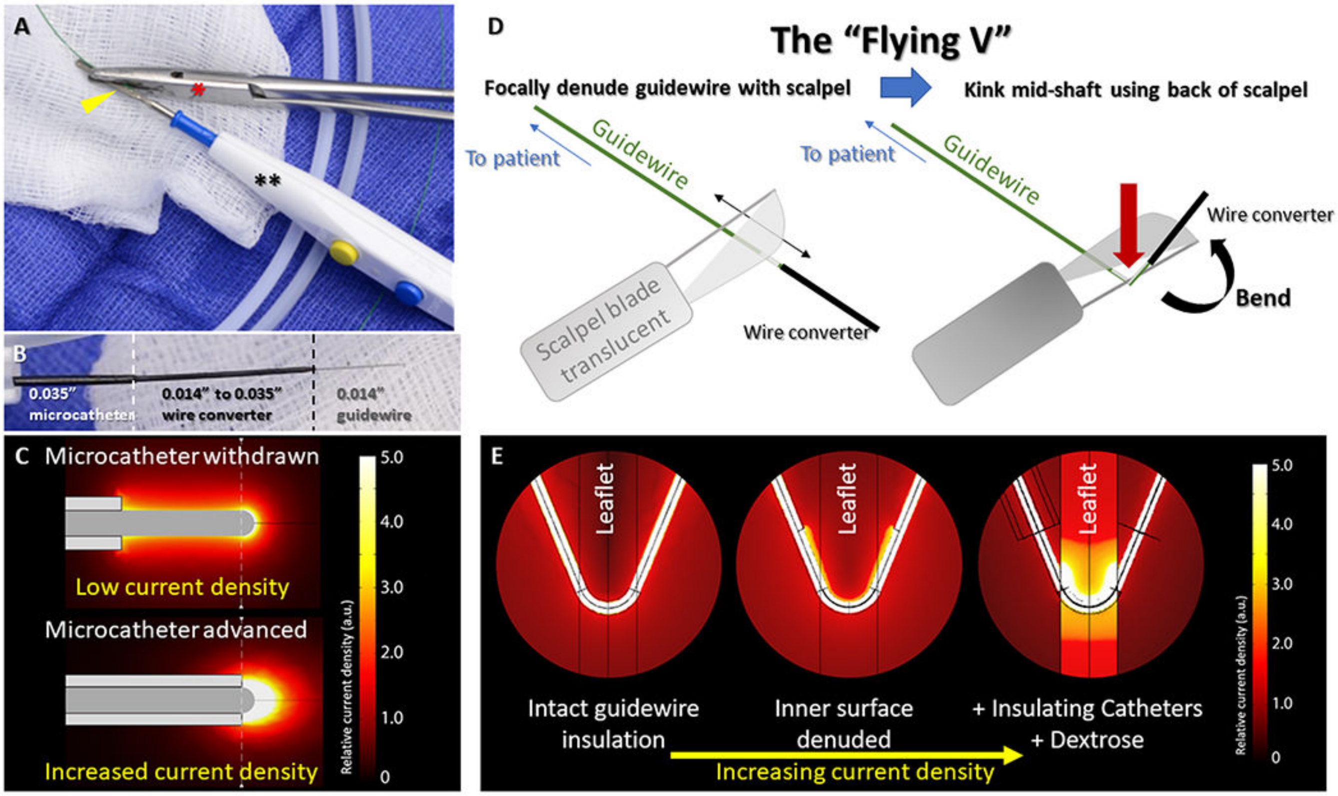

Fig 3. Guidewire modifications that enable transcatheter electrosurgery.

(A) The denuded back-end of a guidewire(yellow arrowhead) is clamped to an electrosurgery pencil(**) by hemostatic forceps(red*). **(B)** A 'crossing-system' for electrosurgical tissue traversal consists of an 0.014" guidewire inside a hubless-locking wire-converter, inside a 0.035" microcatheter. **(C)** Microcatheters increase current density at the guidewire tip increasing electrosurgical efficiency. Focal denudation and kinking the mid-shaft of the guidewire **(D)** create the "Flying V". When placed at the target tissue, inner curvature denudation focuses charge and increases current density **(E)**. Microcatheter insulation and dextrose infusion further enhance charge concentration. Reprinted from Khan et al. JACC, 2020[2].

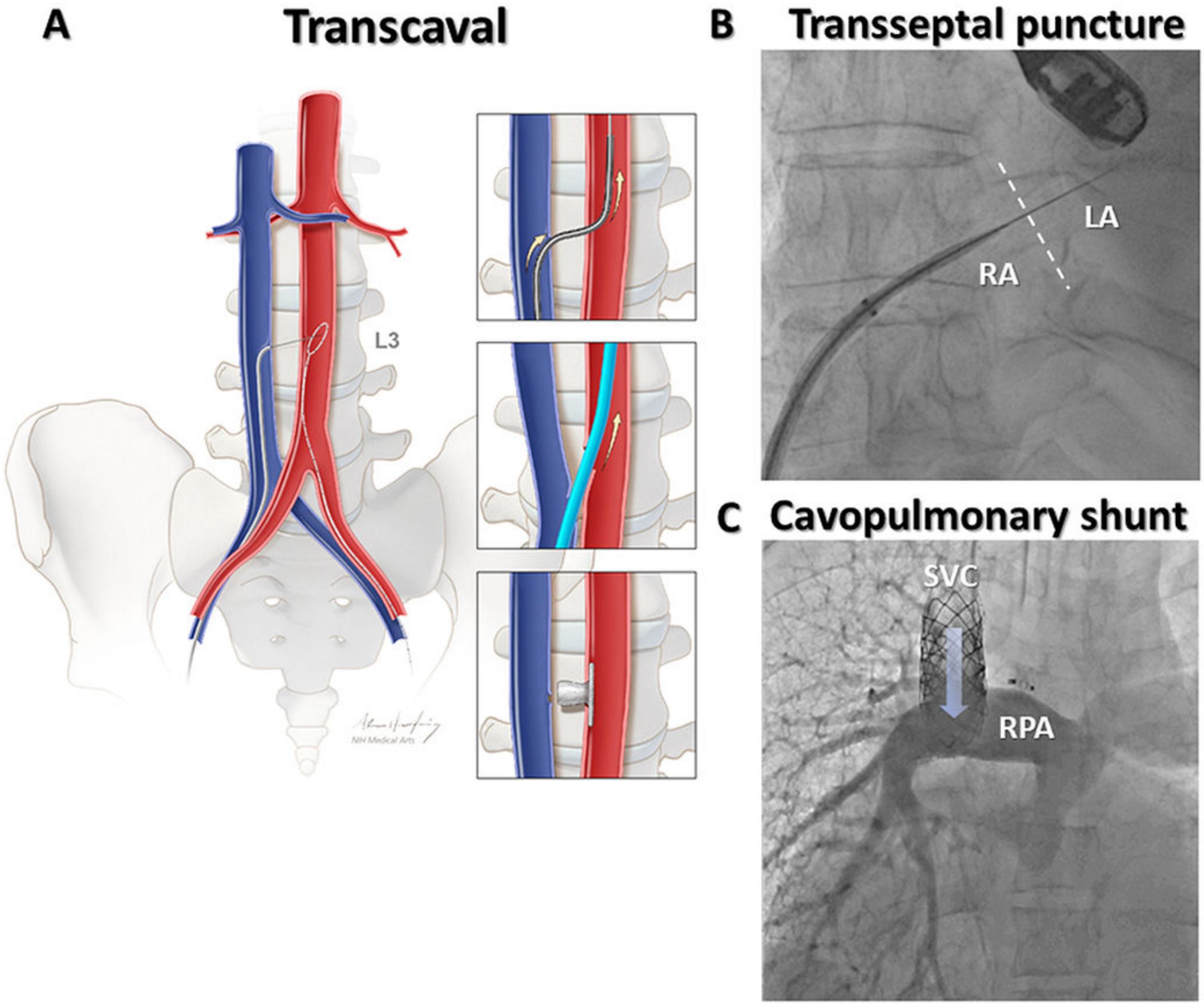

Fig 4. Clinical applications – Tissue Traversal.

In transcaval aortic access **(A)**, the electrified guidewire is advanced through the walls of inferior vena cava and abdominal aorta where it is ensnared. Exchange for a stiff guidewire permits large bore access to the aorta in patients with unsuitable femoral arteries. The transcaval tract is closed with a nitinol vascular occluder. **(B)** Electrosurgical transseptal puncture using the dilator of a deflectable sheath for insulation. **(C)** A transcatheter superior cavopulmonary shunt was following electrosurgical traversal from superior vena cava to right pulmonary artery. RA=Right atrium; LA=Left atrium; SVC=Superior vena cava; RPA=Right pulmonary artery. Reprinted from Greenbaum et al. JACC, 2017[8].

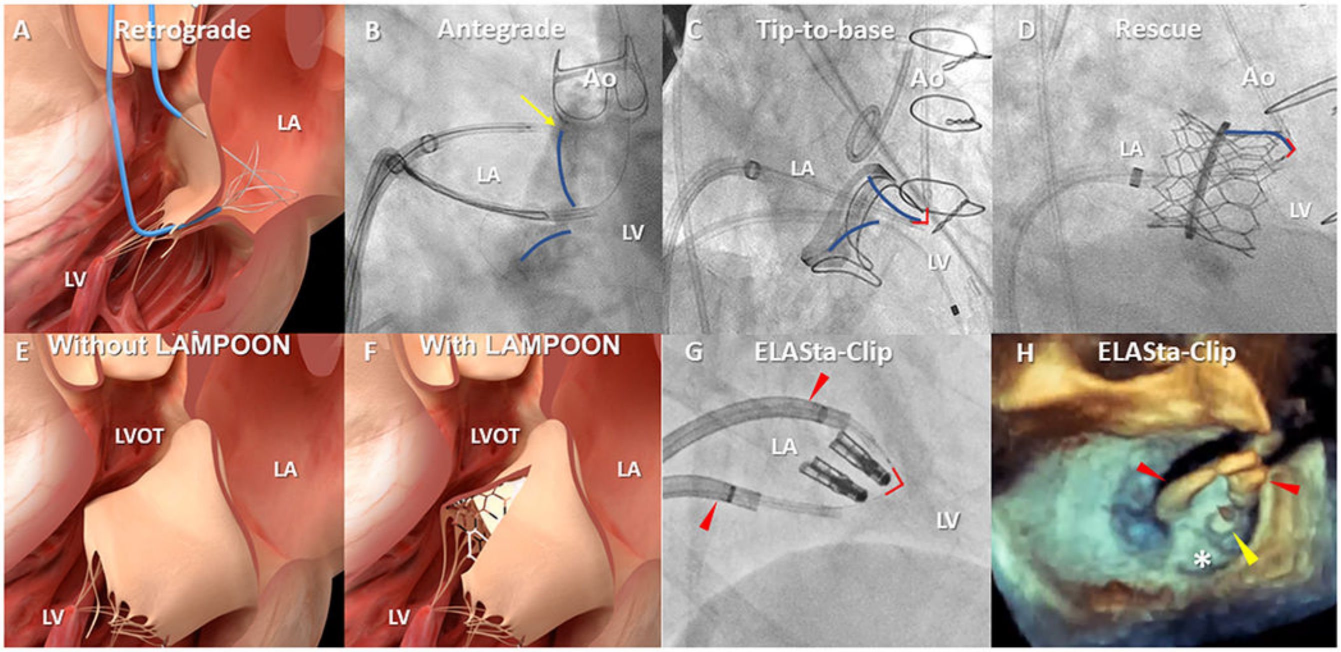

Fig 5. Clinical applications – Tissue laceration; Mitral leaflet modification.

The original, retrograde LAMPOON **(A)** crossed the base of the A2 mitral scallop across the aortic valve. Technical refinements include an antegrade approach **(B)** across the interventricular septum. One catheter is positioned on the atrial surface at the base (yellow arrow) of the A2 mitral leaflet (blue overlay) from where the guidewire is electrified towards a snare in the LVOT. Tip-to-base LAMPOON **(C)** lacerates the mitral leaflet (blue overlay) in reverse, without leaflet traversal, in patients with a suitable backstop such as a surgical prosthesis. The flying V (red-outline) is positioned on the tip and withdrawn until it meets a hard-stop. Rescue LAMPOON **(D)** similarly lacerates from tip backwards to slice long, overhanging leaflets causing dynamic LVOT obstruction after transcatheter mitral valve replacement. LAMPOON techniques uncover cells otherwise draped with anterior mitral valve leaflet tissue **(E&F)**. **(G)** A pair of deflectable sheaths(red arrowheads) for ELASta-Clip to liberate MitraClips from the anterior mitral leaflet to enable TMVR. **(H)** Positioning of sheaths(red arrowheads) anterior to the MitraClip(yellow arrowhead) allows TMVR to pin the posterior leaflet(white asterisk) harmlessly. Ao=Aorta; LA=Left atrium; LV=Left ventricle; LVOT=Left ventricular outflow tract.

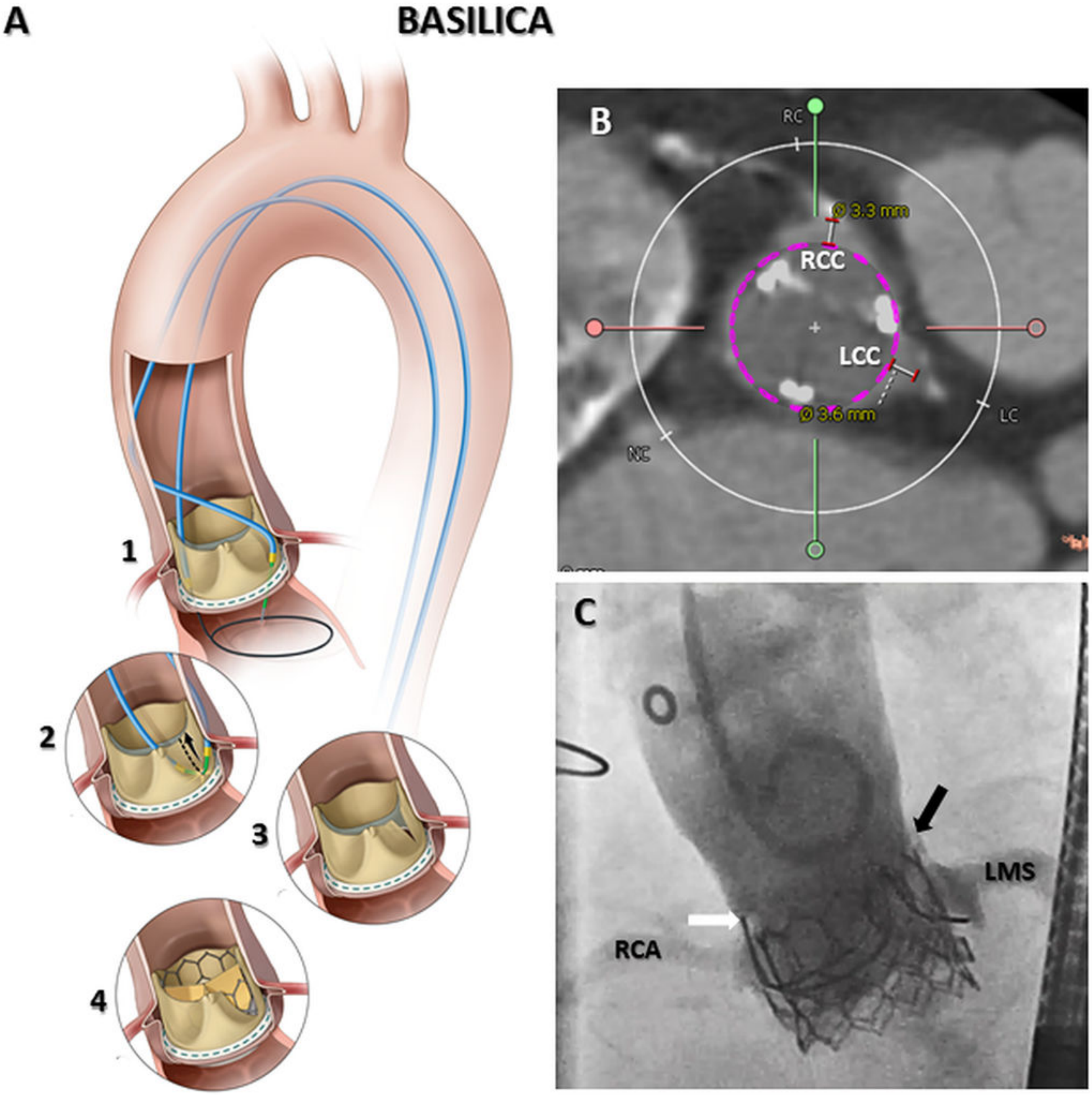

Fig 6. Clinical applications – Tissue laceration; BASILICA.

Tissue traversal at the base of the offending aortic leaflet **(A1)**, followed by tissue laceration **(A2)** creates a midline slice in target aortic leaflet **(A3)**. BASILICA enables leaflet splay following transcatheter heart valve implantation, preventing coronary artery obstruction **(A4)**. In cases where both right and left coronary ostia are at risk **(B)** BASILICA can be performed on both leaflets in a 'doppio' procedure. In **(C)** brisk coronary flow remains following TAVR despite surgical valve leaflets being visible above left (black arrow) and right (white arrow) aortic sinuses. RCA=Right coronary artery; RCC=Right coronary cusp; LCC=Left coronary cusp; LMS=Left main stem. Reprinted from Khan et al. JACC: Cardiovascular Interventions, 2018[63].

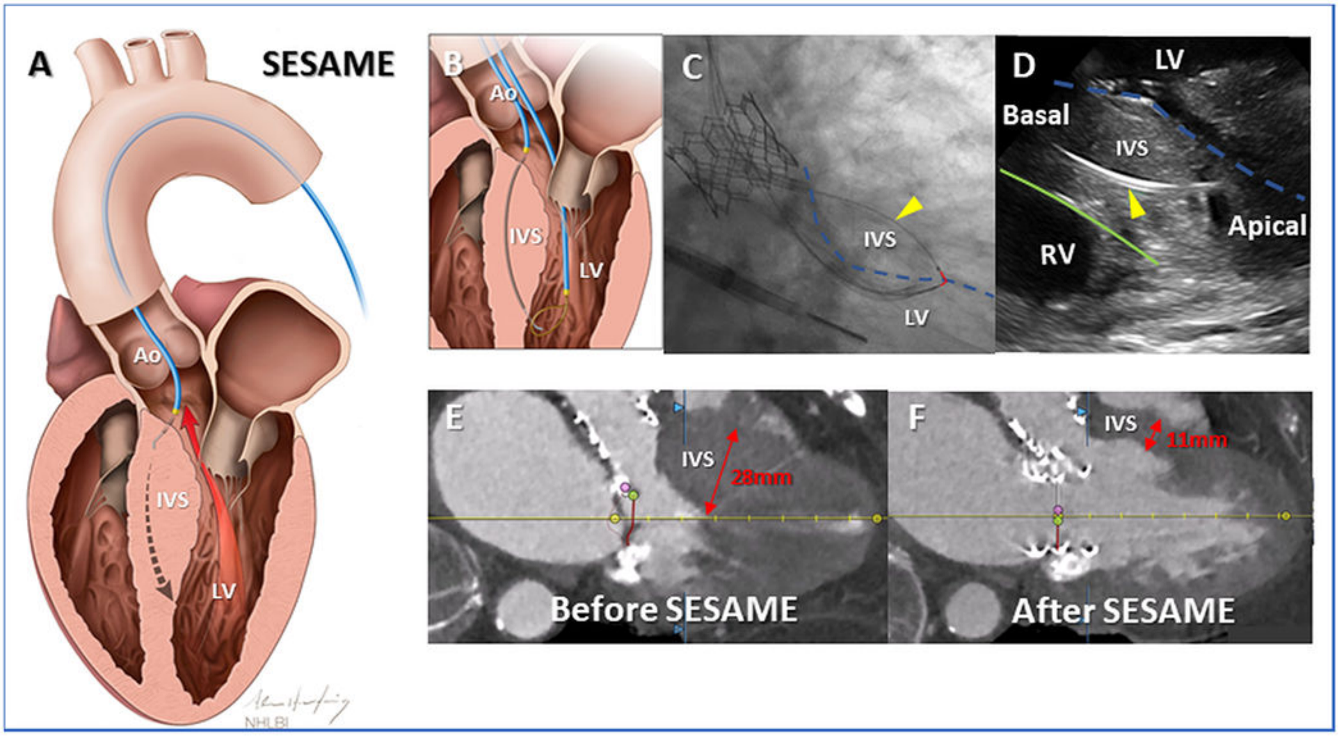

Fig 7. Clinical applications – Myocardial slicing.

(A) In SESAME transcatheter septal myotomy, a guidewire traverses the interventricular septum, defining length and depth of subsequent myotomy. Once ensnared **(B)** the flying V **(C**, red overlay) is positioned on the left ventricular endocardium(broken blue-outline). Fluoroscopic **(C)** and intracardiac echocardiographic **(D)** appearance of catheters, one wholly within septal myocardium(yellow arrowhead), safely deep to right ventricular endocardium (green outline), positioned ready to cut muscle during guidewire electrification. SESAME creates space in the left ventricular outflow tract to enable TMVR **(E&F)**. Ao=Aorta; IVS=Interventricular septum; LV=Left ventricle; RV=Right ventricle. Reprinted from Khan et al. Circulation: Cardiovascular Interventions, 2022[78].