REVIEW ARTICLE

Transesophageal echocardiography for the monitoring of transvenous lead extraction

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ABSTRACT
Transesophageal echocardiography (TEE) is regarded as the gold standard in diagnostic cardiology and has become an essential tool for monitoring the patient undergoing cardiac surgery and transcatheter procedures. Considering the increasing number of complications related to cardiac implantable electronic devices, TEE can also be used to detect these irregularities. Transvenous lead extraction (TLE) is the first-line treatment for cardiac implantable electronic device–related complications. The essence of TLE is the dissection of leads from connective tissue adhesions that attach them to the walls of the heart and vessels. Separation of strongly immobilized leads may cause injury to the veins or heart resulting in life-threatening bleeding. For this reason, the guidelines from the American and European cardiac societies recommend clinicians to use TEE for monitoring the patient undergoing TLE. The advantage of such an approach is immediate detection, localization, and evaluation of TLE complications and sequelae. Additionally, according to our experience, continuous monitoring of the TLE procedure enables the operator to be informed about the expected technical problems.

Introduction Transthoracic echocardiography (TTE) and transesophageal echocardiography (TEE) have evolved from 2-dimensional to real-time 3- and 4-dimensional imaging. Transesophageal echocardiography is performed not only to complement the TTE assessment, but it is considered the diagnostic gold standard, especially to visualize structures that would be difficult or impossible to see on TTE, for instance, left atrial appendage emboli and vegetations in the course of infective endocarditis and on valve prostheses, as well as to identify the underlying cause of structural heart disease and to assess artificially ventilated intensive care patients. This modality has also become an essential tool for monitoring the patient undergoing cardiac surgery and transcatheter procedures (left atrial appendage closure, MitraClip procedure). In recent years, with the increasing number of patients with cardiac implantable electronic devices (CIEDs), TEE has become indispensable in the visualization of the course of the lead within the heart, particularly in patients with lead-related complications requiring transvenous lead extraction (TLE).[1,2]

Transvenous lead extraction procedure According to the report of the European Heart Rhythm Association more than 9000 extraction procedures are performed annually in more than 350 centers.[3] Indications for TLE include infectious and noninfectious complications related to CIEDs. Transvenous removal of the leads involves cutting free the entire lead from fibrous binding sites within the walls of veins, the heart, and other anatomical structures. Leads are dissected using a polypropylene or rotational sheath advanced slowly over the lead from the venous entry site to the lead tip anchored in the heart. Nonpowered mechanical systems with various

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stylets and polypropylene telescoping (Byrd) dilators (Cook) are usually the first-choice tools for lead extraction. Powered mechanical sheath systems (Evolution, Cook, TightRail Spectranetics) are used if polypropylene telescoping sheaths appear ineffective. The femoral approach, using the femoral workstation with a basket, the Amplatz GooseNeck Snare Kit (Amplatz, United States), is used for free-floating leads with proximal endings in the lumen of the superior vena cava (SVC). In highly complex cases, a combination of various approaches (jugular, subclavian, femoral) sometimes has to be used for single lead extraction.[4-7]

Transvenous lead extraction is a relatively safe procedure with very high efficacy; the rates of major complications and periprocedural mortality range from 0.9% to 4% and from 0.2% to 0.4%, respectively.[1-7] Lead extraction procedures are most frequently performed in a hybrid operating room or in an operating room, in patients under general anesthesia, with invasive blood pressure measurements, in the sterile surgical field (if sternotomy is required), and with onsite cardiac surgical standby.[1,2,4,7-10]

Complications of transvenous lead extraction procedures As endocardial leads have contact with vascular and cardiac walls and flowing blood, they are covered with connective tissue, which gradually hardens and adheres to cardiovascular structures. Fibrous buildup appears within veins, the atrium, the tricuspid apparatus, and the ventricle. Freeing the leads may cause damage to the venous wall or cardiac structures resulting in life-threatening bleeding. Damage to the subclavian vein, the innominate vein, or the SVC leads to mediastinal hematoma, SVC rupture in its medial segment causes bleeding to the right pleural cavity, whereas SVC tear in its inferior segment and atrial wall laceration are associated with hemorrhage to the pericardial sac and tamponade.[6-9] Acute cardiac injury causes acute hemodynamic disorders and can be life-threatening. Only an immediate (within several minutes) surgical intervention may prevent dangerous events.[1,2,5,7-10] Sudden drops in blood pressure require immediate exploration of the area to find the bleeding site, and immediate TEE (complemented with TTE if needed, for instance, to assess the pleural cavity) is the most effective option.[11] The assessment of the bleeding dynamics helps the operator to make an extremely important decision as to whether a chest drain is required or it is enough to monitor the patient if the bleeding stops. In an emergency situation, there is usually no time for inserting an esophageal probe and starting diagnostic imaging.[12-18] Therefore, both the European and American guidelines on transvenous lead extraction recommend continuous TEE monitoring of patients undergoing TLE.[1,2,5]

Embolization is another dangerous complication associated with TLE, such as acute pulmonary embolism in the case when the vegetation size has been underestimated[19] and paradoxical embolism due to atrial septal defect.[20,21] Severe structural damage to the tricuspid valve may cause acute right ventricular failure requiring urgent valve repair.[22] Transesophageal echocardiography monitoring during TLE offers a possibility of immediate detection, localization, and evaluation of complications and sequelae, especially, pericardial tamponade, damage to the tricuspid valve, and migration of the embolic material.

However, TEE is a valuable imaging tool not only because of the potential for early detection of complications, but also due to the fact that intraoperative navigation helps extractors to dissect the leads slowly and gradually and to observe with close scrutiny the accompanying phenomena to prevent any complications.[17,18]

The extent of transesophageal echocardiography during transvenous lead extraction

The guidelines of the Heart Rhythm Society and the European Heart Rhythm Association emphasized the importance of maximizing extraction procedure safety through an appropriately trained extraction team, extractors' experience, a facility that provides all necessary equipment to perform procedures and manage complications, immediate availability of a cardiac surgeon and a surgical team including a qualified echocardiographer as its member, use of general anesthetics, and direct invasive blood pressure measurements.[1,2,4] Experts have precisely defined the role of echocardiography during the procedure and recommended using continuous TEE or intracardiac echocardiography as a complementary tool that increases procedural safety.[1,2,4] However, apart from the available guidelines, which are mainly expert consensus documents, there are only a few original and review papers on TEE as a monitoring tool in patients undergoing TLE.[12-18,23-25] Several case reports add valuable information to our medical knowledge.[19,21,26-31]

Transvenous lead extraction monitoring steps with transesophageal echocardiography Transesophageal echocardiography monitoring during TLE may be divided into 4 stages: a preprocedural stage from probe insertion to the start of lead dissection; stage 2—navigation of lead removal; stage 3—postprocedural assessment of procedure efficacy with the evaluation of possible damages; and additionally stage 4 during which TEE is used to guide new lead placement.

At the preprocedural stage, we check lead position and course, identify intracardiac structures associated with leads (vegetations, clots, connective tissue bands), evaluate tricuspid valve function, presence of interatrial defects (patent foramen ovale, atrial septal defect), left ventricular function, and assess possible fluid accumulation in the pericardial and pleural space. It is of importance to document these phenomena for postprocedural comparison.

The intraprocedural stage involves echocardiographic monitoring at the moment of lead removal to watch the process of pulling on cardiac walls and right ventricular caving inward, followed by a drop in systolic blood pressure in response to this maneuver. However, it may be the other way round, as it is often necessary to use TEE to elucidate the mechanism of the observed fall in blood pressure. Furthermore, it is vital for the extractor to control simultaneous pulling on the other lead in the case of lead-to-lead binding. It is also important to observe breaking off and dislodgement of a fibrous capsule surrounding the lead as well as breaking off and migration of vegetation fragments. It is of key importance to evaluate the buildup of excess fluid in the pericardial sac. If injury to heart walls occurs, TEE may help to localize the damage site by identifying the wall segment on which the greatest pulling force is exerted. Stage 3 ends with the TEE evaluation of the procedure completeness, looking for the remaining lead fragments and, if still present, monitoring their removal.

The postprocedural stage mainly involves the assessment of procedure efficacy, and monitoring the complications and treatment outcomes in patients with wall injuries. This stage also involves a comparative assessment of tricuspid valve function, connective tissue remnants, and possible fragments of vegetations.

If new leads are inserted, navigation with TEE allows for optimization of lead course through the tricuspid valve, precise positioning of the lead tip in the desired site, and easier localization of the coronary sinus ostium.

Three- and four-dimensional transesophageal echocardiography during transvenous lead extraction

So far, only a single study has attempted to investigate the role of 3-dimensional TEE during TLE.[16] The advantages of 3-dimensional imaging have been documented in patients with expected technical difficulties during the extraction procedure. Transesophageal echocardiography was found helpful in distinguishing free-floating and adherent leads. Furthermore, 3-dimensional TEE allowed for more precise detection of the course of the leads and determination of the relationship between the lead and the tricuspid valve (leaflets, commissures, tendinous ring)[16,32] (Supplementary material, *Figure S1*).

Transvenous lead extraction monitoring: evaluation of echocardiographic phenomena

Damage to the tricuspid valve associated with lead removal The assessment of tricuspid valve (TV) function is one of the key components of TEE monitoring during TLE. Tricuspid valve damage, which may cause acute tricuspid regurgitation increase (TRI), only in recent guidelines has been considered the major complication of the procedure[1,2] (FIGURE 1). The incidence of acute TRI has been reported to range from 3.5% to 15%.[33-38] Risk factors for TV injury include patients' age (>75 years), female sex, presence of vegetations on the TV or the leads,[34-36,38] removal of multiple leads, and the need to use additional equipment[34,36] or laser energy.[34] However, the most crucial risk factor for TRI is probably the age of the extracted leads, as demonstrated by Park et al,[22] who detected 24 cases (11.5%) of TV damage in 208 patients (mean lead age, 11.8 years). In conclusion, the researchers suggested that "following TLE, TV damage and acute TRI were commonly detected by transesophageal echocardiography, particularly in patients with old leads. Lead abandonment strategies, which prolong implantation duration of future leads requiring extraction, should consider the potential long-term deleterious impact on TV function"[22] (FIGURE 1).

Monitoring of the traction on cardiac walls during dissection of the encapsulating fibrous tissue

Removal of adherent leads requires strong pulling on the lead and cardiac structures to which it is attached. Informing the extractor about binding sites and monitoring during dissecting sheath (polypropylene, mechanical rotational) manipulation facilitates the timely modification of the extraction technique to maximize procedure efficacy and minimize potential complications[17,18] (FIGURE 2).

Drop in arterial blood pressure during transvenous lead extraction: the role of echocardiography

The apex of the right ventricle (RV) may be pulled on during lead removal, thus decreasing ventricular volume, cardiac output, and, as a consequence, arterial blood pressure (Supplementary material, *Figure S2A* and *S2B*).

Hemodynamic instability requires urgent verification of its causes and, first of all, ruling out heart injury, bleeding, and tamponade. The inversion of the RV visible on 2-dimensional TEE may also be confirmed on 3-dimensional imaging and the cause of pressure fall can be quickly identified.[1,2,11-13,16,23,29]

Our experience shows that, apart from pulling on the RV, there may be other causes of transient systolic blood pressure fall ≥40 mm Hg from baseline. Such a significant drop in blood pressure occurs after premedication and intubation, when the ostium of the SVC to the right atrium is occluded.[17]

Vegetations and other asymptomatic masses on the leads Transesophageal echocardiography is used as an essential modality for the diagnosis

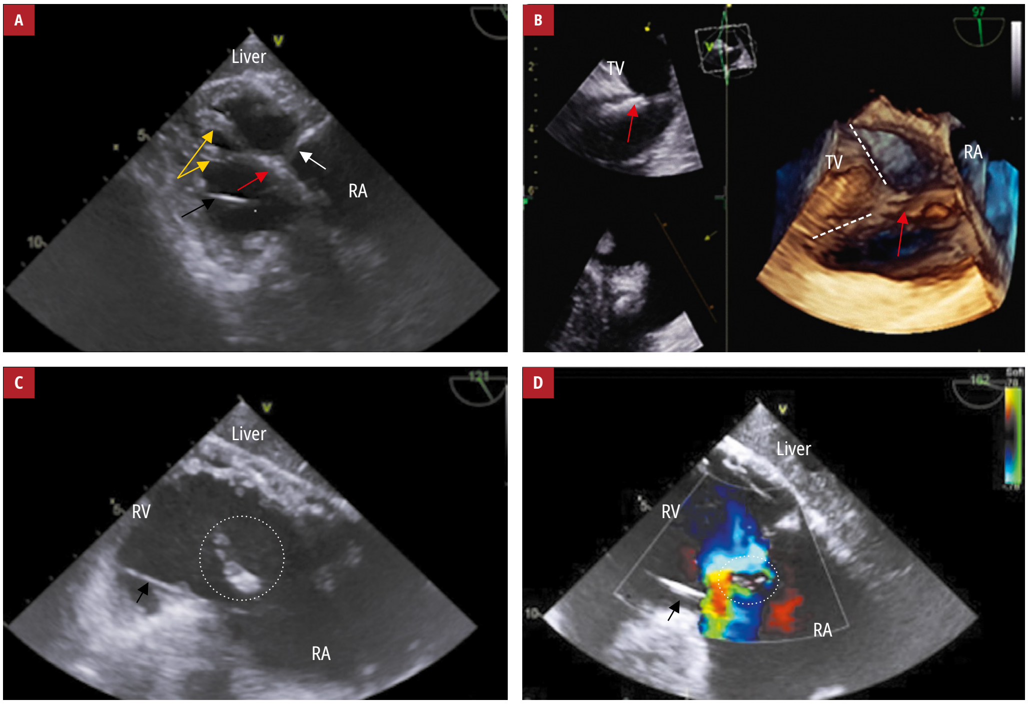

FIGURE 1 Tricuspid valve damage during transvenous lead extraction: **A** – transesophageal echocardiography (TEE; 2-dimensional, transgastric view) showing lead adhesion (red arrow) to the posterior leaflet (white arrow) and the subvalvular apparatus (yellow arrows) detected during lead extraction. Black arrows mark the lead for temporary pacing. **B** – TEE (3-dimensional, transgastric view from the right atrial side) showing pulling on the lead (red arrows) and the tricuspid valve (white arrows indicate the leaflets and the annulus); **C** – TEE (2-dimensional, transgastric view) showing a ruptured papillary muscle head prolapsing into the right heart chambers (white circle), **D** – TEE (2-dimensional, transgastric view) with color Doppler imaging showing the significant regurgitant jet extending into the right atrium and a fragment of the detached papillary muscle moving into the tricuspid ostium

Abbreviations: RA, right atrium; RV, right ventricle; TV, tricuspid valve

of intracardiac masses, both bacterial vegetations and asymptomatic masses on endocardial leads. The assessment of vegetations, their size, mobility, location, and contact with the leads and cardiac structures determines the choice of the TLE technique (routine procedure, baskets for pulmonary protection, referral for cardiac surgery).[12,17-19,39,40-44]

Lewis et al[25] described a novel way to use TEE navigation during the aspiration of vegetations by mechanical thrombectomy (System TM, Penumbra Inc., Alameda, California, United States or Angiovac, Angiodynamics, New York, United States) to prevent pulmonary embolism. In that study, the authors successfully performed single TLE with aspiration thrombectomy using the TM Penumbra Inc. system and a nitinol basket for protection against pulmonary embolism. The procedure ended with complete procedural success and was performed in a high-risk female patient with a large vegetation (about 3 cm^2) and multiple chronic conditions (FIGURE 3).

Fluid in the pericardial sac The accumulation of fluid in the pericardial sac during TLE is always an ominous sign indicating an injury to the cardiac wall that may cause tamponade. A quick detection of fluid preceding the development of the clinical symptoms is possible thanks to continuous TEE monitoring[26] using a combination of standard midesophageal 4-chamber projection and short-axis transgastric projection.[25] The choice of a therapeutic option (observation, pericardial sac drainage, quick opening of the chest, and repair of the injury) depends on the rate of fluid accumulation, right ventricular diastolic function, and the degree of hemodynamic disorders. Only the early detection of fluid helps to evaluate its accumulation and effect on cardiac hemodynamics (Supplementary material, *Figure S3*).

Transesophageal echocardiography monitoring: the role in the assessment of post–transvenous lead extraction phenomena

Structures in the cardiac cavities and the vascular lumen after transvenous lead extraction A competent differentiation of structures remaining in the cardiac cavities and the vascular lumen after TLE is a relevant component of the postprocedural assessment.[1,2,18,25] Connective tissue structures should be distinguished from the remnants of vegetations, fragments of not extracted leads or insulation, as it is of vital importance for further treatment and clinical management. In patients in whom TLE is performed for noninfectious indications, connective tissue remnants do

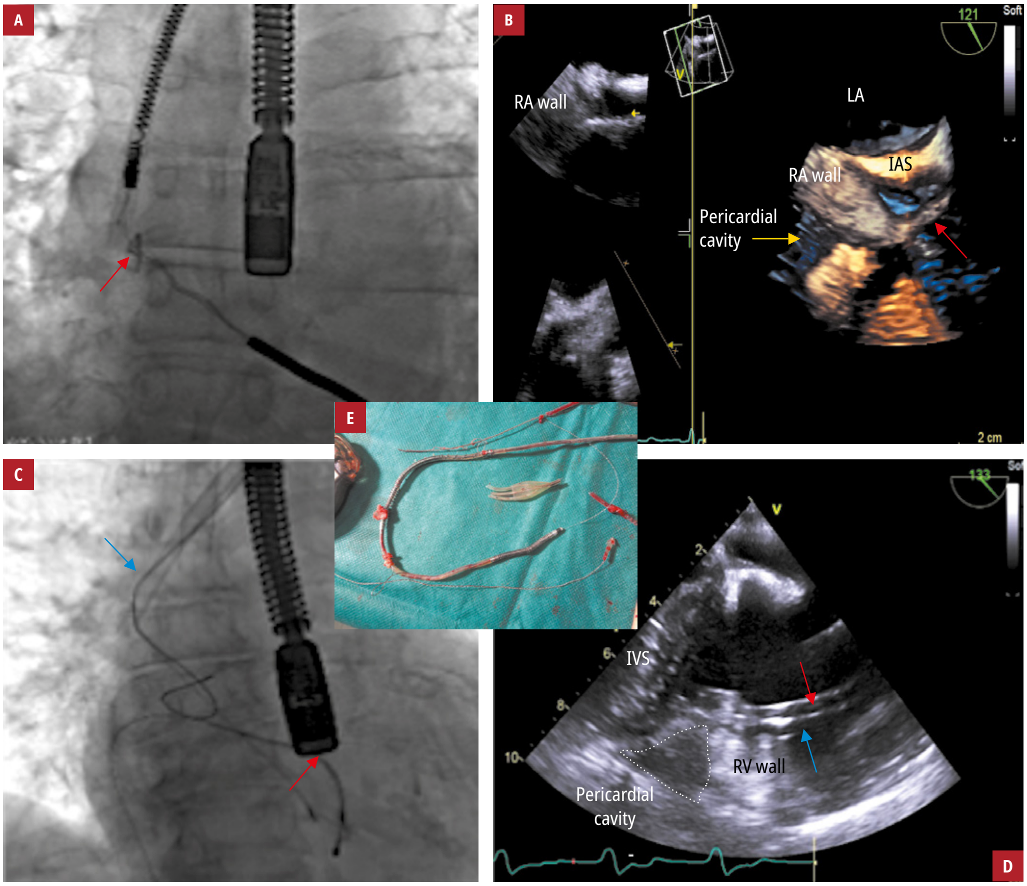

FIGURE 2 Monitoring of the process of pulling on the cardiac walls during lead dissection: **A** – fluoroscopy showing the extraction of a high-voltage lead, adhesion of the externalized coil to the right atrium wall (arrow); **B** – transesophageal echocardiography (3-dimensional, bicaval view) showing strong pulling on the right wall at the site of coil externalization and adhesion (red arrow), pseudo–cardiac tamponade (yellow arrow) due to separation of pericardial layers; **C** – ventricular lead extraction (red arrow) and the telescoping sheaths (blue arrow); **D** – transesophageal echocardiography (2-dimensional, midesophageal modified view) showing pulling on the wall of the right ventricle at the binding site, pseudo–cardiac tamponade (grey line)—pericardial separation due to ventricular wall traction. The uncoiled conductor (red arrow) is in the lumen of the sheath (blue arrow). **E** – the removed leads

Abbreviations: IAS, interatrial septum; IVS, interventricular septum; LA, left atrium; others, see FIGURE 1

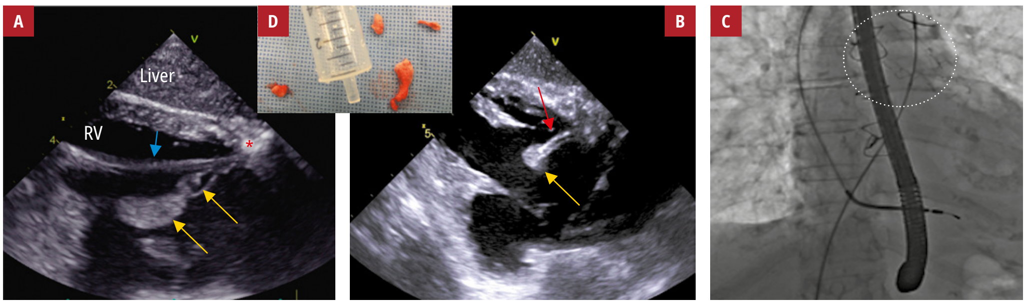

FIGURE 3 Transesophageal echocardiography monitoring of the aspiration of a vegetation attached to the lead and the tricuspid valve using the TM Penumbra Inc. system and pulmonary embolism protection during transvenous lead extraction: **A** – lead-related infective endocarditis and vegetations visible on the high-voltage lead (blue arrow) in the right ventricle (yellow arrows) attached to the lead and the tricuspid valve (red asterisk); **B** – aspiration of the vegetation using the TM Penumbra Inc. system under transesophageal echocardiography guidance (2-dimensional, transgastric view); **C** – simultaneous fluoroscopic image showing a nitrile basket (circle) in the pulmonary trunk to protect the pulmonary circulation; **D** – vegetations

Abbreviations: see FIGURE 1

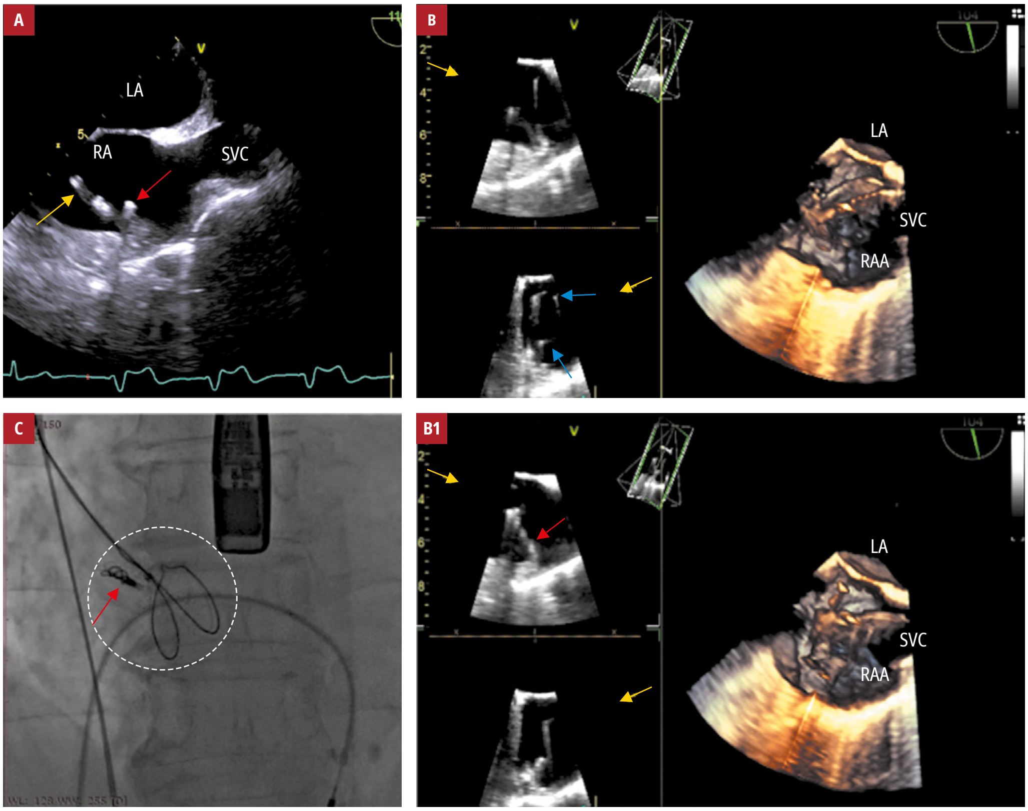

FIGURE 4 Attempted removal of the lead remnant using a lasso sheath: **A** – transesophageal echocardiography (2-dimensional, bicaval view) showing a fragment of the broken lead tip (red arrow) and the silicon tube (yellow arrow) in the right atrial appendage; **B** – transesophageal echocardiography (3-dimensional, bicaval view) showing grasping the broken pieces (**A**) with a lasso sheath (blue arrows). The tightened lasso loop around the target piece is shown on panel **B1**; **C** – fluoroscopy showing the broken lead (arrow) and the lasso sheath (circle)

Abbreviations: RAA, right atrial appendage; SVC, superior vena cava; others, see FIGURE 2

not affect long-term prognosis.[39,45,46] However, if TLE is performed for infectious reasons, the remaining vegetations and/or fibrous tissue (potentially infected) is a risk factor for recurrent infection[42] and higher long-term mortality.[47,48] The fragments of insulation and lead segments longer than 4 cm also have to be removed[1,27,30,31] (Supplementary material, *Figure S4*).

Silicone tube remnants Another important advantage of 2- and 3-dimensional TEE in patients undergoing TLE is the possibility to visualize and monitor the percutaneous removal of silicone tube remnants left in the cardiac cavities after TLE.[16] Insulation fragments remaining lodged in the cardiac cavities have been rarely described in the literature.[18,27,31] The silicone tube is invisible on fluoroscopy and that is why intraprocedural TEE is so crucial (Supplementary material, *Figure S5*). Transesophageal echocardiography not only detects lead remnants[49] but also allows for evaluating the chances of grasping them by gooseneck snares and complete removal. Such an extraction procedure may be challenging, because the free end of the lead remnant is usually strongly attached to the wall or anchored deeply within the myocardium[7,25,30,31] (FIGURE 4).

Assessment of the effectiveness of the surgical treatment of transvenous lead extraction complications Monitoring the TLE procedure with TEE is also useful in the event of complications requiring cardiac surgery. Evaluation of the effectiveness of cardiac surgery includes imaging of the pericardium after suturing a torn heart cavity, assessing left ventricular ejection fraction and function of the tricuspid valve, as well as visualization of the position of the newly implanted leads.

Role of transesophageal echocardiography in the implantation of a new system after transvenous lead extraction After completion of the extraction procedure, it is most frequently necessary to implant a new device, including placement of a left ventricular pacing lead. Transesophageal echocardiography facilitates monitoring the process of coronary sinus intubation, which may shorten fluoroscopy time (Supplementary material, *Figure S6*). Furthermore, TEE helps to evaluate lead position, especially at the level of the tricuspid valve. If high voltage leads are to be implanted, the relation between the proximal end of the coil and the level of the valve and its leaflets can be precisely assessed.

TABLE 1 Authors' experience in performing 1005 transvenous lead extraction procedures in a single reference center in Zamość (Poland) in the years 2015 to 2019

Usefulness of TEE for the navigation of lead extraction (procedure stages 2 and 3)	Value
Pulling on the RA / RAA during mechanical lead extraction	427 (42.5)
Pulling on the tricuspid leaflet during mechanical lead extraction	93 (9.3)
Pulling on the RV wall during mechanical lead extraction	271 (27)
Pulling on another lead (not being extracted) during mechanical lead extraction	120 (11.9)
Free-floating fragments of fibrous encapsulation ("ghosts") during lead extraction	137 (13.6)
Freeing vegetations during lead extraction	53 (5.3)
Monitoring of fluid accumulation in the epicardial space, tamponade, RV wall caving inward	14 (1.5)
Monitoring of fluid accumulation in the epicardial space, tamponade, blood clotting	1 (0.1)
Monitoring of fluid accumulation in the epicardial space, epicardial fluid without hemodynamic consequences, intra- and postprocedural monitoring	20 (2.1)
Maximum blood pressure drop during mechanical dilatation, mm Hg, mean (SD)	21.59 (15.5)
Significant blood pressure drop during mechanical dilatation	128 (12.7)
Elucidation of a significant drop in arterial blood pressure caused by pulling on the RV wall	119 (11.8)
Measurement of lead remnant length only	17 (1.7)
Navigation of grasping and extracting the proximal end of a broken lead remnant	36 (3.6)
Navigation of a new CS lead implantation (visualization of lead location in the CS ostium)	104 (10.3)

Data are presented as number (percentage) of patients unless otherwise indicated.

Abbreviations: CS, coronary sinus; RV, right ventricular; TEE, transesophageal echocardiography; others, see FIGURES 1 and 4

Importance of intraprocedural transesophageal echocardiography for the safety and effectiveness of transvenous lead extraction There is a large number of published studies that describe the significant role of echocardiographic examinations before and after the extraction procedure, but the present research emphasizes the importance of intraprocedural echocardiographic imaging. We provide a long list of echocardiographic findings detected in 1005 patients undergoing TLE in the years 2015 to 2020 in a single reference center and discuss them only with respect to the usefulness of TEE for lead extraction monitoring (stage 2 and 3 of the procedure) (TABLE 1).

There is no equivocal evidence showing that TEE monitoring of the patient undergoing TLE provides measurable benefits for procedure efficacy and safety. As major complications associated with TLE (0.9%–4%) or procedure-related deaths (0.2%–0.4%) are relatively rare, in order to confirm the substantial benefit of TEE, it is necessary to compare equally sized groups including more than 1000 procedures each. Appreciating the enormous usefulness of TEE monitoring in everyday practice, we analyzed 3185 TLE procedures in our previous study,[50] including 1079 with continuous TEE monitoring versus 2106 with TEE assessment only before and after the procedure (without TEE monitoring). The risk of major complications related to the procedure was estimated using the Transvenous Lead Extraction SAFeTY Score.[49] The study demonstrated that the continuous monitoring of TLE procedures significantly reduced the number of the most dangerous complications associated with cardiac and vascular wall damage in patients at potentially higher procedure-related risk. The results of our study for the first time confirmed higher procedural efficacy of TLE and a reduced risk of cardiovascular injury during TLE under TEE guidance. The study also showed that continuous TEE monitoring helped to achieve 100% periprocedural survival.[17,18]

Conclusions Transesophageal echocardiography monitoring of TLE procedures provides valuable information at each stage of the TLE procedure.

1 At the preprocedural stage, performed in comfortable conditions both for the patient and the extraction team, the TEE examination provides the operator with information about possible yet unknown difficulties that may influence the technique of extraction (the presence and size of vegetations and the degree of connective tissue buildup appear to be the most relevant factors).

2 The intraprocedural stage involves TEE monitoring at the moment of lead removal to control pulling on cardiac walls and right ventricular caving inward resulting in a drop in systolic blood pressure in response to this maneuver. Furthermore, it is vital for the extractor to control simultaneous pulling on the other lead in the case of lead-to-lead binding, to observe breaking off and dislodgement of the fibrous capsule surrounding the lead as well as breaking off and migration of vegetation pieces, and to evaluate the buildup of excess fluid in the pericardial sac. If injury to heart walls occurs, TEE may help to localize the damage site by detecting the loss of cardiac wall integrity or identifying the wall segment on which the greatest pulling force is exerted. Stage 3 ends with the TEE evaluation of the procedure completeness, looking for the remaining lead fragments and, if still present, monitoring their removal.

3 The postprocedural stage mainly involves the assessment of procedure efficacy, and the monitoring of complications and treatment outcomes in patients with wall injuries. This stage also includes a comparative assessment of tricuspid valve function, connective tissue remnants, and possible vegetations.

SUPPLEMENTARY MATERIAL

Supplementary material is available at www.mp.pl/kardiologiapolska.

ARTICLE INFORMATION

CONFLICT OF INTEREST None declared.

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