Direct visualization of the removal of chronically implanted pacing leads from an unfixed human cadaver

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Introduction
As the number of patients with cardiac implanted pacemakers and defibrillators increases, the need for associated lead removal will increase as well. Additionally, many patients do not currently have access to a center of excellence for lead extraction, indicating a clear need for more highly trained extractors. An extraction procedure is defined as lead removal after it has been implanted for more than a year or if specialized imaging and/or when removal equipment is required.†‡ Extraction can be performed using manual traction or by employing mechanical or cutting sheaths (radiofrequency or laser). Chronically implanted leads are removed for many reasons, including infection, malfunction, venous occlusion impeding additional lead placement, and/or an acute need for magnetic resonance imaging.† Further, these implanted leads can adhere to the walls of the venous vasculature, the tricuspid valve, and/or other cardiac tissues, thus potentially making their extractions high-risk procedures that can lead to serious complications, including death. Highly trained physicians with unique experience (ie, those in high-volume centers) are commonly recruited to perform such lead extractions because of the extensive imaging knowledge required for safe removal.† It is commonly noted by these skilled extractors that it is difficult to adequately train and maintain the skillset needed for extraction.

KEYWORDS Device tissue interaction; Lead extraction procedure; Lead fibrosis; Lead preparation; Visualization; 3-D modeling

Here we obtained unique educational views of lead extractions utilizing direct visualization, fluoroscopy, and subsequent 3-D models. Hence we sought to provide novel insights relative to how an extraction tool may interface with the associated human vasculature and heart. An educational training video is further provided to better prepare physicians for such clinical experiences.

Case report
A 91-year-old female unfixed cadaver with chronically implanted right atrial and ventricular leads was donated through the University of Minnesota Anatomy Bequest Program and was subsequently used for these investigations. Vasculature was cannulated and flushed with high volumes of saline to remove as many clots as possible and to allow for videoscopic assessments. Next, a full-body computed tomography (CT) scan was completed prior to the extraction procedure, to note the pre-explant lead orientations. The leads were cut, prepped with a locking stylet, and secured with suture on the insulation. A Spectranetics TightRail Rotating Dilator Sheath (Spectranetics, Colorado Springs, CO) was advanced over each lead. During the procedure, standard fluoroscopy visualization was aided by direct endoscopic visualization (Olympus Corp, Tokyo, Japan) inserted in the right jugular vein (see Supplemental Video). To remove each lead, the extraction tool was advanced into the left subclavian vein by slight forward pressure on the sheath. When resistance was met, the rotating blade on the tip of the sheath was utilized. There was notable adherence of the leads to the walls of the superior vena cava (SVC); additionally, the right ventricular lead had attachment along the free wall of the right ventricle (Figure 1). Finally, postextraction CT scans were performed and then utilized to create models of right- and left-side cardiac blood volumes, the anatomic locations of both fibroed leads, and the paths of the extraction device.

The Supplemental Video enables the viewer to follow along through a lead extraction procedure, from preparing...
the pocket to complete lead removal. It begins with exposure of the leads, removal of the silicone lead coverings, and the insertion of the locking stylets. Lead extractions may be high-risk procedures that can lead to serious complications.

**Discussion**

Utilizing different imaging modalities, we were able to uniquely identify the interactions of a mechanical extraction sheath with the leads, the scar tissue on the leads, the venous vasculature, and the heart. There was significant fibrosis over the leads at the junction of the left brachiocephalic vein and the SVC. Through the use of endoscopic cameras, it was observed that when the leads were externally manipulated, both lead bodies moved synchronously because they had fibrosed together within the SVC. In the future, if extractors notice this trend of 2 lead bodies jointly moving in rhythm with the heartbeat or upon traction, they may have a better understanding of what may be causing these unique motion patterns. This novel visualization of encapsulated leads being extracted from a human’s vasculature and heart provides valuable knowledge of potential device–tissue interactions for clinicians as well as device designers. Particularly, we noted significant movement of the sheath–lead complex during cutting near the point of lead fixation to the heart. With each turn of the mechanical dilator sheath handle and subsequent rotation of the exposed circular blade, there was substantial twisting of both the vasculature tissue and fibrotic growth, visible through the endoscopic cameras. Considering the direct visualization of the tearing/shearing forces that the cutting sheath exerted on the cardiac tissue and the potential embolic debris created, we advise extractors to use extreme caution when working to free the leads near each point of fixation. Furthermore, by comparing the fluoroscopic and endoscopic images, one perhaps can gain a greater understanding of typical lead extraction procedures. We hope these images will supplement physician training, ultimately aiming to improve patient outcomes.

**Conclusion**

There is a growing need for lead extractions, as well as highly skilled physicians that can safely remove chronically implanted leads. Transvenous lead extractions are considered complicated cardiac procedures with serious potential complications such as SVC tear, induced cardiac tamponade, the release of embolism, and/or death. To gain unique perspectives on these extraction procedures, we performed atrial and ventricular lead extractions from an unfixed human cadaver. Here we simultaneously obtained videoscopic

**Figure 1** Extraction of a lead from a 91-year-old female cadaver. **A:** A fluoroscopic view of the cardiac silhouette can be seen with the endoscope, lead, and extraction sheath in the right atrium. **B:** The Spectranetics TightRail Rotating Dilator Sheath is used to free the lead tip from the tissue that has adhered at the point of lead fixation.
internal footage and associated fluoroscopy, which provided novel insights as to how adhered leads and the tools used to remove them interact without compromising the vasculature and cardiac anatomies. We encourage extractors to watch such videos as part of their training, as it may complement educational studies performed on cadavers or other benchtop models. The video presented here could also serve as a refresher tutorial for experienced extractors, as direct visualization may help them to appreciate a facet of a lead extraction procedure they had not yet considered. Also, we further emphasize caution when performing lead extractions in clinic, as—based on viewing the severe sheath–lead movement in a cadaver—it is very understandable how vascular perforations or cardiac tamponade could occur. Noticing that the leads extracted in this case study were active fixation leads, a viewer could extrapolate the potential damage to the vasculature and cardiac tissues that may be induced when removing passive leads or implantable cardiac defibrillator leads (which can have increased fibrotic tissue growth over the coils). Overall, we hope the educational video will supplement knowledge associated with cardiac lead extraction procedures.

Future studies could include other cadaver lead placements, as it is often necessary for extractors to remove leads from other locations within the heart (ie, coronary sinus). Additionally, the use of the model could be expanded to include haptic feedback. This means the user could hold a catheter and feel resistance while navigating through the venous vasculature in addition to visualizing the 3-D models of the heart, leads, and extraction device. Our future steps in this project are directed toward further helping lead extractors prepare for their complex cardiac cases.

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**Appendix**

**Supplementary data**

Supplementary data associated with this article can be found in the online version at https://doi.org/10.1016/j.hrcr.2017.12.003.

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