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Mixed Reality–Assisted Planning Enables Successful Coil Embolization of Anatomically Complex Peridevice Leak After LAAC

INTRODUCTION

Percutaneous left atrial appendage closure (LAAC) is an established stroke prevention strategy in patients with atrial fibrillation contraindicated for long-term anticoagulation.[1,2] However, peridevice leak (PDL) remains a significant limitation, occurring in 25.8% of patients at 45-day follow-up.[3] Persistent PDL is associated with a 4.25-fold increased risk of transient ischemic attack, ischemic stroke, or systemic embolism (adjusted subdistribution hazard ratio, 4.25; 95% confidence interval (CI): 1.91-9.44; $P < .001$).[4] Posterosuperior PDL locations present particular technical challenges for percutaneous closure. Mixed reality (MR) shows promise for preprocedural planning in complex structural interventions.[5] The first application of MR-guided planning for PDL closure after LAAC is reported.

CASE REPORT

A 69-year-old male with paroxysmal atrial fibrillation (CHA_2DS_2-VASc score 4), hypertension, insulin-dependent type 2 diabetes mellitus, dyslipidaemia, and hypothyroidism underwent LAAC. Anticoagulation was contraindicated due to spontaneous intracerebral haemorrhage in 2015.

In October 2023, a Watchman Flex 31 mm device (Boston Scientific, Marlborough, MA, USA) was implanted under general anesthesia with transoesophageal echocardiographic (TEE) guidance. Two redeployments were required due to initial shallow positioning. Dual antiplatelet therapy (aspirin 100 mg, clopidogrel 75 mg) was initiated following anticoagulation discontinuation at 6 weeks (patient timeline detailed in Supplementary Table 1).

Six-month TEE surveillance revealed a posterosuperior PDL (3 mm jet, 12 × 4 mm cavity) with color Doppler demonstrating bidirectional flow and systolic predominance, communicating with residual appendage tissue (Figure 1A and B). Cardiac computed tomography confirmed complex cavity morphology (12 × 6 × 9 mm) with asymmetric flow characteristics: wide communication between LAA and peridevice cavity (4.5-7.8 mm) (multimodality imaging analysis in Supplementary Table 2).

Preprocedural planning utilized the HJPHub MR (distinct from magnetic resonance imaging) system on Microsoft HoloLens 2 (Microsoft Corporation, Redmond, WA, USA)[6] (specifications in Supplementary Table 3). Three-dimensional holographic visualization enabled detailed assessment of complex left atrial anatomy (Supplementary Video 1), identification of optimal posteroinferior transseptal puncture site, and predicted the need for telescoping catheter technique (Figure 2).

In October 2024, PDL closure was performed under general anesthesia with TEE guidance. Following transseptal puncture, an Agilis 8.5 F steerable sheath and Vista IMA 6 F guiding catheter enabled cannulation of the posterosuperior

CASE REPORT

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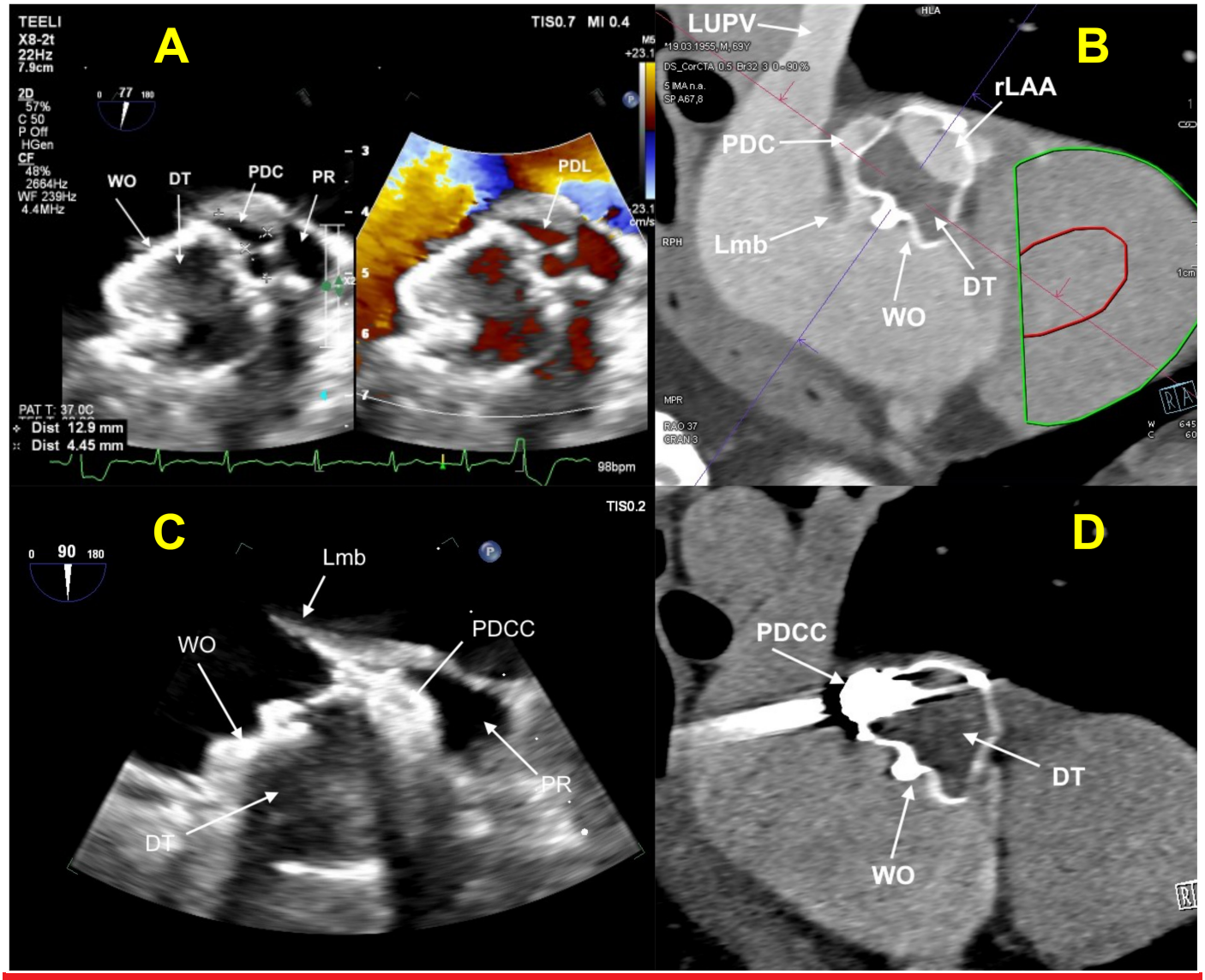

Figure 1. Posterosuperior peridevice leak and device-related thrombus: multimodality. Imaging before and after coil embolization. (A) Two-dimensional TEE with color Doppler demonstrates the WO with an echogenic mass representing DT located under the skirt of the occluder. A posterosuperior PDC (12.9 × 4.45 mm) is visualized adjacent to the occluder. Color Doppler reveals the PDL with flow communication between the rLAA and left atrium. The PR is identified as a distinct structure separate from the pathologic cavity. (B) Contrast-enhanced cardiac CT with multiplanar reconstruction demonstrates the complex anatomy of the PDC and its relationship to the LUPV, Lmb, and residual LAA. Device-related thrombus appears as a hypoattenuating mass within the WO. (C) Follow-up TEE 3 months after coil embolization demonstrates the PDCC with densely echogenic coil material. The Lmb and PR remain visualized as distinct anatomic landmarks. Complete PDL closure is achieved, with planned thrombosis evident. The DT now fills the entire residual LAA cavity—a desirable outcome confirming flow elimination. (D) Follow-up contrast-enhanced CT confirms complete occlusion with the PDCC showing no contrast opacification despite left atrial enhancement, indicating elimination of the peridevice leak. The WO and persistent DT are visualized. CT, computed tomography; DT, device thrombus; LAA, left atrial appendage; Lmb, limbus; LUPV, left upper pulmonary vein; PDC, peridevice cavity; PDCC, peridevice cavity closure (coil-filled); PDL, peridevice leak; PR, pericardial recess; rLAA, residual left atrial appendage; TEE, transesophageal echocardiography; WO, Watchman occluder.

cavity. Wire access was achieved with a Sion Black guidewire through a Lantern 130 cm microcatheter. Closure was accomplished using 1 RUBY POD 12 coil (Penumbra, Alameda, CA, USA) deployed within the cavity, followed by a 15 cm Packing Coil at the neck, achieving complete occlusion confirmed by TEE and angiography (procedural details in Supplementary Table 4 and Supplementary Video 2).

Three-month follow-up imaging demonstrated complete resolution with no contrast penetration behind the occluder on cardiac computed tomography (Supplementary Video 3) and no residual leak on TEE (Figure 1C and D). Given an absolute oral anticoagulation contraindication, the patient continues on aspirin monotherapy with planned annual imaging surveillance, without adverse events.

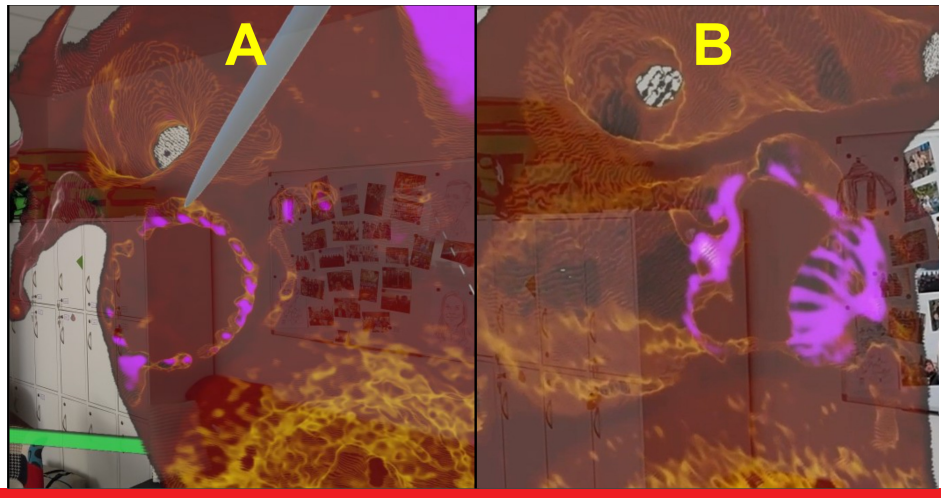

Figure 2. Mixed reality preprocedural planning for peridevice leak closure. First-person operator views through Microsoft HoloLens 2 displaying the HJPHub mixed reality system used for preprocedural planning. The three-dimensional holographic reconstruction visualizes the left atrial anatomy (orange volume rendering) and the Watchman Flex occluder with posterosuperior paradevice leak cavity (purple highlighted structures) superimposed onto the real-world clinical environment. (A) Anterior viewing angle demonstrates the planned transseptal catheter trajectory (gray line) targeting the posterosuperior peridevice cavity. The mitral valve annulus orientation and spatial relationship between the left atrial appendage occluder (purple mesh structure) and the peridevice cavity are clearly delineated, enabling identification of the optimal posteroinferior transseptal puncture site. (B) Rotated viewing angle provides enhanced visualization of the Watchman occluder (purple striped structure) and its relationship to the residual appendage tissue. This perspective demonstrates the complex three-dimensional geometry that predicted the need for telescoping catheter technique to navigate the challenging posterosuperior approach. Interactive manipulation between viewing angles during preprocedural planning facilitated comprehensive spatial understanding unattainable with conventional two-dimensional imaging. Technical note: The real-world clinical environment visible in the background (office furniture, wall-mounted displays) demonstrates the mixed reality augmented visualization capabilities of the HoloLens 2 system, where holographic reconstructions are seamlessly overlaid onto the operator's natural field of view.

DISCUSSION

This case demonstrates several clinically important findings. First, a significant PDL with bidirectional flow was identified communicating with residual appendage tissue containing organized intracavitary thrombus, distinct from device-related thrombus on the occluder surface. The PDL constituted the primary indication for intervention, as persistent flow around the occluder represents ongoing stroke risk. This reinforces the importance of systematic PDL surveillance regardless of antithrombotic strategy, given the established association between PDL and thromboembolism (pooled odds ratio 2.04).[7]

Second, this represents the first application of mixed reality-guided planning for PDL closure. The HJPHub system enabled three-dimensional assessment of complex anatomy, facilitating optimal transseptal puncture site selection. Critically, despite real-time TEE navigation, the cavity entry could not be cannulated—even with live 3D TEE. Only by returning to MR planning during the intervention—to regain three-dimensional spatial orientation after TEE navigation had been exhausted—was successful navigation achieved; real-time catheter guidance was thereafter performed under fluoroscopy. The exceptional procedural complexity—fluoroscopy time 177.5 minutes (~11× published series), air kerma 4415.5 mGy (~10× typical LAAC values), and 6 catheter exchanges—underscores the technical challenge where TEE visualization may be suboptimal. Mixed reality planning proved indispensable, enabling success unattainable with conventional imaging alone. Notably, this indispensable contribution was qualitative in nature—three-dimensional spatial re-orientation rather than quantitative measurements or catheter simulation, neither of which is yet available in the current system; these capabilities represent clear directions for future development.

Third, coil embolization was selected for this irregular, noncircular cavity morphology. Detachable coils represent the most commonly utilized PDL closure device (42.3%) in multicenter registries, offering conformability advantages over plugs or occluders for complex geometries.[8,9] Residual leak represents a recognized complication across transcatheter structural interventions.[10]

Limitations include single-case observation, precluding generalizability, and the need for longer-term follow-up to assess durability. Randomized data evaluating MR-guided planning for structural interventions remain unavailable.

CONCLUSION

Peridevice leak closure procedures are inherently complex, requiring extensive operator expertise and specialized equipment. Mixed reality guidance using the validated HJPHub system facilitated successful coil embolization of a challenging posterosuperior PDL following LAAC.

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Informed Consent: Written informed consent was obtained from the patient.

Declaration of Interests: The authors have no conflicts of interest to declare.

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Supplementary Video 1. Mixed Reality-Guided Preprocedural Planning for Complex Peridevice Leak Closure. This recording from the operator's perspective (via Microsoft HoloLens 2) demonstrates the application of the HJPHub system for a 69-year-old patient with a posterosuperior peridevice leak (PDL) following Watchman Flex implantation. The 3D holographic reconstruction visualizes the left atrial anatomy (orange wireframe) and the complex, non-circular

Supplementary Table 1. Complete Patient Timeline with Antithrombotic Management

Date	Clinical Event	Antithrombotic Regimen
2007	Radiofrequency catheter ablation for atrial flutter	—
2015	Spontaneous intracerebral hemorrhage (temporo-parietal); managed conservatively; established contraindication to long-term OAC	—
August 2023	First documented paroxysmal AF; CHA_2DS_2-VASc score 4 (age 65-74: 1; HTN: 1; DM: 1; prior stroke/TIA: 2)	—
Aug 28-29, 2023	Pre-LAAO workup: coronary angiography (non-significant CAD); TEE (no LA thrombus, MR 2-3/4, LAA 21-26mm)	—
Oct 18, 2023	LAAO: Watchman Flex 31mm implanted; 2 redeployments due to shallow positioning	Apixaban 2.5mg BID + Clopidogrel 75mg
Nov 14, 2023	1-month TEE: Excellent occluder effect; no PDL; device well-seated	Apixaban 2.5mg BID + Clopidogrel 75mg
Nov 30, 2023	Protocol transition: apixaban discontinued	Aspirin 100mg + Clopidogrel 75mg (DAPT)
Apr 16, 2024	6-month TEE: Posterosuperior PDL (~3mm jet; 12×4mm cavity)	Aspirin 100mg + Clopidogrel 75mg (DAPT)
May-Sep 2024	Cardiac CT for 3D characterization; MR preprocedural planning with HJPHub	DAPT continued
Oct 16, 2024	PDL closure: RUBY POD 12 coils + 15cm Packing Coil; complete occlusion	DAPT + enhanced gastroprotection
Dec 2, 2024	6-week TEE: Coils stable; trace residual leak laterally; no thrombus	DAPT continued
Jan 13, 2025	3-month CT + TEE: Complete occlusion; no contrast behind occluder; no residual leak	Aspirin 100mg monotherapy

This timeline integrates clinical events with antithrombotic therapy, highlighting the critical finding that device-related thrombus developed while on dual antiplatelet therapy (DAPT).
AF, atrial fibrillation; BID, twice daily; CAD, coronary artery disease; DAPT, dual antiplatelet therapy; DM, diabetes mellitus; DRT, device-related thrombus; HTN, hypertension; LA, left atrium; LAA, left atrial appendage; LAAO, left atrial appendage occlusion; MR, mixed reality; OAC, oral anticoagulation; PDL, paradevice leak; TEE, transesophageal echocardiography; TIA, transient ischemic attack.

Supplementary Table 2. Multimodality Imaging Analysis

A. Preprocedural Dimensional Measurements: TEE vs Cardiac CT

Parameter	TEE Measurement	Cardiac CT Measurement
PDL orifice	~3mm jet width; 2.99mm drainage	4.5-7.8mm (wide communication)
Peri-device cavity	12×4mm (2D measurement)	12×6×9mm (volumetric)
LAA dimensions (pre-LAAO)	21-26mm	22×27mm
Flow pattern	Posterosuperior jet; systolic predominant	Asymmetric inflow-outflow identified

B. Follow-up Imaging Findings

Timepoint	Modality	Key Findings	Clinical Implication
Immediate post-procedure	TEE + Angiography	Complete PDL occlusion; no residual flow; coils well-positioned	Technical success confirmed
6 weeks (Dec 2, 2024)	TEE	Good procedural effect; coils stable; trace residual leak laterally; no thrombus	Continue DAPT; plan 3-month follow-up
3 months (Jan 13, 2025)	Cardiac CT	Occluder internally thrombosed; NO contrast penetration behind occluder; coils stable	Complete seal achieved; durable occlusion
3 months (Jan 13, 2025)	TEE	Complete occlusion; no residual leak; no thrombus visible	Transition to aspirin monotherapy

Comparative imaging findings demonstrating complementary value of TEE and CT, with follow-up results.
The 3-month CT finding of "no contrast penetration behind occluder" represents the key endpoint confirming complete LAA exclusion from systemic circulation, indicating that the combined Watchman device plus coil embolization achieved the intended goal of LAA isolation.
CT, computed tomography; DAPT, dual antiplatelet therapy; LAA, left atrial appendage; LAAO, left atrial appendage occlusion; PDC, peri-device cavity; PDL,paradevice leak; rLAA, residual left atrial appendage; TEE, transesophageal echocardiography.

peri-device cavity (solid purple structure). This immersive view allowed for the precise identification of the cavity's spatial orientation, facilitating the selection of an optimal posteroinferior transseptal puncture site and confirming the necessity for a telescoping catheter technique to navigate the challenging anatomy.

Supplementary Video 2. Fluoroscopic Deployment and Angiographic Confirmation. This intraprocedural fluoroscopic recording captures the selective cannulation and deployment of a detachable coil (RUBY POD 12) into the posterosuperior peri-device cavity using a telescoping catheter technique (Agilis sheath and Vista IMA guide). The final angiographic sequence demonstrates a dense, stable coil mass within the defect with no residual contrast extravasation, confirming the immediate and complete occlusion of the paradevice leak.

Supplementary Video 3. Holographic Verification of Complete Peridevice Leak Closure. This three-dimensional reconstruction, derived from three-month follow-up cardiac computed tomography, visualizes the spatial relationship between the implanted Watchman Flex device (purple mesh) and the coil-embolized residual shunt space (green volume). The transition to solid blood volume rendering (red) demonstrates a smooth endocardial contour with the absence of contrast penetration into the green occluded cavity, confirming the complete resolution of the paradevice leak.

Supplementary Table 3. HJPHub Mixed Reality System Specifications

Specification	Values
Hardware platform	Microsoft HoloLens 2 (Microsoft Corporation, Redmond, WA, USA)
Software platform	Unity-based HJPHub application
Frame rate	59.6 ± 0.7 fps
Local latency	14.3 ± 0.5 ms
Registration accuracy (TRE)	1.61 ± 0.33 mm
Multi-user latency	26.9 ms (P95: 52.4 ms)
System Usability Scale (SUS) score	77.5 ± 3.8 ("good usability")
Calibration time	38 seconds
Validated applications	LAAO, structural heart interventions

The HJPHub system utilized for preprocedural planning has been previously validated for structural cardiac procedures.
Reference: Hecko J, Precek D, Januska J, et al. Design and validation of a mixed reality workflow for structural cardiac procedures in interventional cardiology. Front Virtual Real. 2025;6:1690439.
Abbreviations: fps = frames per second; LAAO = left atrial appendage occlusion; ms = milliseconds; P95 = 95th percentile; SUS = System Usability Scale; TRE = target registration error.

Supplementary Table 4. Procedural Details

A. Procedural Parameters (October 16, 2024)

Parameters	Values
Total procedure duration	5 hours 10 minutes (13:30-18:40)
Fluoroscopy time	177.5 minutes
Contrast volume	260 mL
Cumulative air kerma	4415.5 mGy
Dose area product	352 Gy·cm^2
Vascular access	Right femoral vein
Anesthesia	General anesthesia with TEE guidance
Transseptal puncture location	Posteroinferior (MR-guided planning)
Number of catheter exchanges	6 (see Part B below)
Complications	None

B. Catheter Exchange Sequence

Step	Catheter/Equipment	Outcome	Rationale for Change
1	Mullins 8.5F → Agilis 8.5F steerable sheath	Base sheath established	Required steerability for posterosuperior approach
2	Flexor 5F 110cm	Insufficient support	PDL orifice reached but inadequate backup for wire advancement
3	MPA 4F 125cm	Better angle but lacked stability	Improved coaxial alignment but catheter tip deflection persisted
4	JR4 125cm diagnostic catheter	Initial leak probing; inadequate backup	Successfully entered PDL cavity but insufficient support for coil delivery
5	MPA GC 7.5F Sheathless (Asahi)	System tension; position loss	Excessive friction between guide catheter and steerable sheath; abandoned
6*	Vista IMA 6F guide catheter	FINAL - Adequate support achieved	Optimal deliverability, backup support, and lumen for microcatheter

C. Closure Device Specifications

Device	Specifications	Deployment Location
RUBY POD Coil (×2)	12mm diameter; detachable; platinum/tungsten (Penumbra, Alameda, CA, USA)	Peri-device cavity (bulk fill)
Packing Coil	15cm length; platinum/tungsten (Penumbra, Alameda, CA, USA)	PDL neck/drainage channel

Table A: Comprehensive procedural parameters including catheter exchange sequence and closure device specifications.
Table B: The posterosuperior PDL location necessitated multiple catheter exchanges. MR planning predicted the need for telescoping technique.
Device Selection Rationale: Detachable coils were selected based on: (1) irregular geometry of peri-device cavity (12×6×9mm), not amenable to plug-type devices; (2) narrow drainage channel (1.8-3.2mm), suitable for coil packing; (3) published evidence supporting coil use in 42.3% of PDL closures in multicenter registries; (4) 100% acute procedural success and 85.9% one-year success rates in the LAA Leak Study.
*Final configuration: Agilis 8.5F steerable sheath + Vista IMA 6F guide catheter + Sion Black guidewire + Lantern 130cm 45° microcatheter