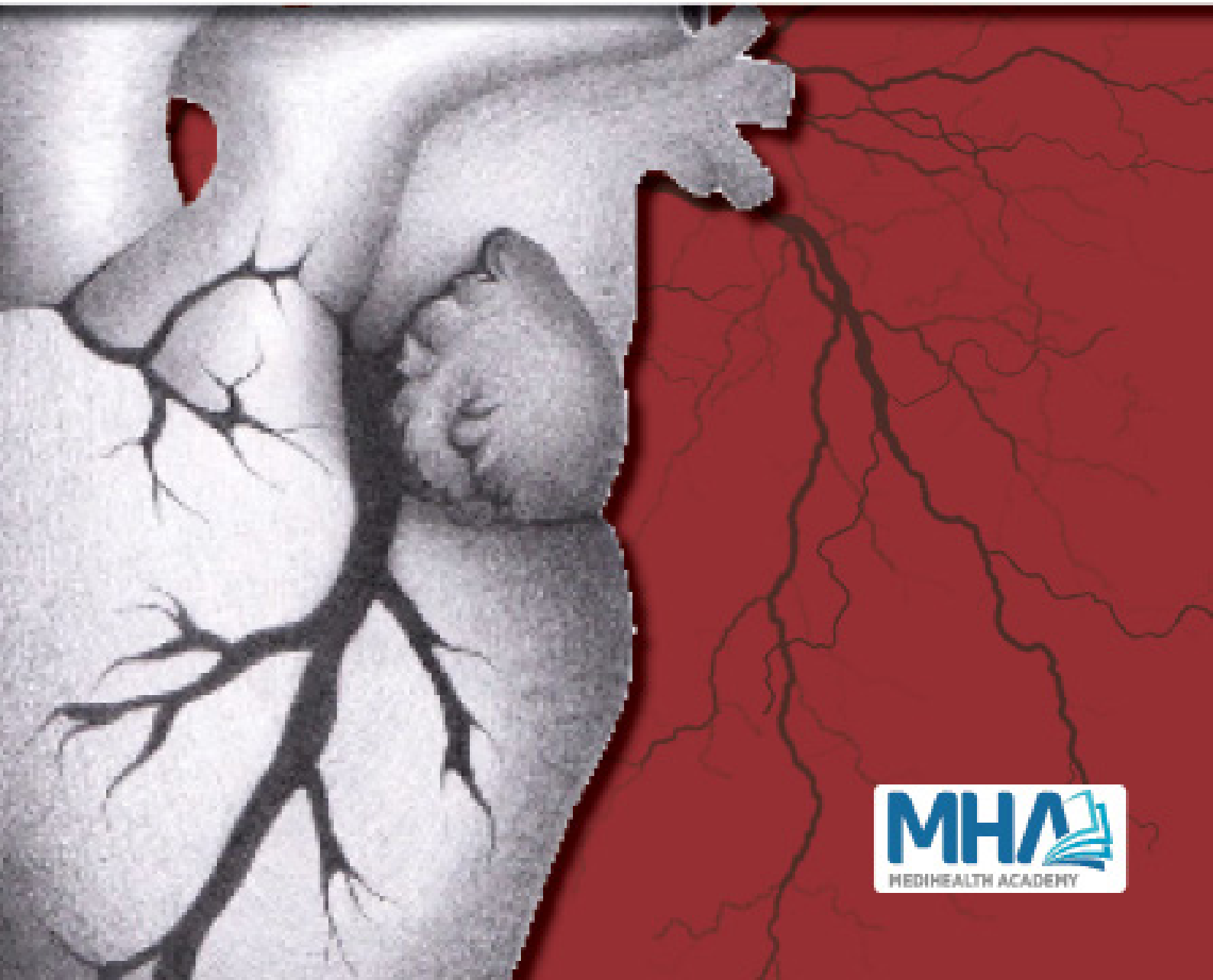
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Original Article

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Cardiopulmonary resuscitation knowledge among resident physicians: comparison of internal and surgical departments

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ABSTRACT

Aims: This study aimed to evaluate self-reported cardiopulmonary resuscitation (CPR) knowledge, attitudes, and opinions among resident physicians and to compare findings between internal and surgical departments.

Methods: Participants completed a 30-item questionnaire developed according to contemporary European Resuscitation Council/American Heart Association (ERC/AHA) CPR guidelines and reviewed by experienced emergency medicine and anesthesiology faculty members for content validity. A pilot assessment was conducted before final implementation. The questionnaire evaluated self-reported CPR-related knowledge, previous training and experience, rhythm recognition, medication and defibrillation knowledge, airway-related knowledge, and peri-arrest arrhythmia management.

Results: Relatively lower self-reported CPR-related knowledge appeared more common among urology/gynecology and obstetrics, orthopedics, and otorhinolaryngology residents; however, these findings should be interpreted cautiously because detailed subgroup analyses were limited.

Conclusion: Surgical residents had significantly lower self-reported CPR-related knowledge than internal residents, particularly regarding rhythm assessment, drug administration, defibrillation, airway confirmation, and peri-arrest arrhythmia management. Department-specific, repeated, simulation-supported CPR training may be needed, especially in surgical departments with limited routine exposure to resuscitation.

Keywords: Cardiopulmonary arrest, cardiopulmonary resuscitation, resident physicians, resuscitation training

INTRODUCTION

Cardiopulmonary arrest is characterized by abrupt loss of effective cardiac activity and systemic circulation. It should be suspected in an unresponsive individual with absent or abnormal breathing and no signs of circulation. Out-of-hospital and in-hospital cardiac arrest remain major causes of mortality, and survival depends on early recognition, high-quality chest compressions, timely defibrillation when indicated, and appropriate advanced life support interventions.[1,2]

Current resuscitation guidelines available during the study period emphasize immediate initiation of cardiopulmonary resuscitation (CPR), minimization of interruptions in chest compressions, early rhythm assessment, appropriate defibrillation, correct use of adrenaline and antiarrhythmic drugs, and structured post-resuscitation care.[3-5]

For physicians, CPR is not only a basic clinical skill but also a professional responsibility across specialties. Nevertheless, previous studies have reported heterogeneous knowledge levels among physicians and resident physicians, with knowledge varying according to clinical exposure, specialty, previous training, and opportunities to participate in real-life resuscitation.[6-11]

In tertiary hospitals, resident physicians from both internal and surgical departments may encounter cardiopulmonary arrest in wards, outpatient units, emergency settings, operating rooms, and intensive care areas. However, the frequency and context of exposure may differ across specialties. Identifying knowledge gaps by department may therefore help institutions design targeted resuscitation training programs. This study aimed to evaluate the knowledge, attitudes, and opinions of resident physicians working at our hospital regarding CPR and to compare findings between internal and surgical departments.

METHODS

Ethics

After the study was approved by the Kırıkkale University Faculty of Medicine Ethics Committee (Date: 12.03.2025, Decision No: 2025.03.13), the study was conducted among resident physicians receiving specialty training at Kırıkkale University Faculty of Medicine. All procedures were carried out in accordance with the ethical rules and the principles of the Declaration of Helsinki.

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Study Design

This study was designed as a single-center, cross-sectional questionnaire study. The study population consisted of 100 resident physicians: 50 from internal departments and 50 from surgical departments. Internal departments included family medicine, internal medicine, pulmonology, cardiology, and neurology. Surgical departments included anesthesiology and reanimation, general surgery, otorhinolaryngology, orthopedics, urology, and gynecology and obstetrics.

Participants completed a 30-item questionnaire developed according to contemporary European Resuscitation Council/American Heart Association (ERC/AHA) CPR guidelines and reviewed by experienced emergency medicine and anesthesiology faculty members for content validity. A pilot assessment was conducted before final implementation. The questionnaire evaluated self-reported CPR-related knowledge, previous training and experience, rhythm recognition, medication and defibrillation knowledge, airway-related knowledge, and peri-arrest arrhythmia management.

Statistical Analysis

All data analyses were performed using SPSS version 26.0. Descriptive statistics were presented as number and percentage, mean±standard deviation, or median (minimum-maximum), as appropriate. Categorical variables were compared between groups using Pearson Chi-square or Fisher exact tests. Nonparametric continuous variables were compared using the Mann-Whitney U test. A p-value below 0.05 was considered statistically significant. This exploratory study used convenience sampling, and no formal power analysis was performed. Because multiple comparisons were conducted across questionnaire items, the findings should be interpreted cautiously with awareness of potential type I error inflation.

RESULTS

Demographic Characteristics

A total of 100 resident physicians participated in the study, with 50 participants in the internal departments group and 50 in the surgical departments group. The mean age was similar between internal and surgical residents (28.36±2.77 vs. 28.78±2.48 years; p=0.545). Female gender was more frequent in the internal group, whereas male gender was more frequent in the surgical group (p=0.016). Residency year distribution was similar between groups (p=0.726) (**Table 1**).

Table 1. Demographic characteristics of the participants

Variable	Internal departments (n=50)	Surgical departments (n=50)	p-value
Age, mean±SD	28.36±2.77	28.78±2.48	0.545
Female gender, n (%)	28 (56.0)	16 (32.0)	0.016
Male gender, n (%)	22 (44.0)	34 (68.0)	0.016
Residency year 1, n (%)	18 (36.0)	17 (34.0)	0.726
Residency year 2, n (%)	9 (18.0)	9 (18.0)	0.726
Residency year 3, n (%)	11 (22.0)	11 (22.0)	0.726
Residency year 4, n (%)	8 (16.0)	5 (10.0)	0.726
Residency year 5, n (%)	4 (8.0)	8 (16.0)	0.726

SD: Standard deviation

Cardiopulmonary Resuscitation (CPR) Training and Previous Experience

Previous CPR training was reported by 47 internal residents (94.0%) and 39 surgical residents (78.0%), with a statistically significant difference favoring internal departments (p=0.021). Prior CPR application was reported by 49 internal residents (98.0%) and 43 surgical residents (86.0%); this difference did not reach statistical significance (p=0.059). However, the estimated number of previous CPR applications was significantly higher in internal residents than surgical residents [median 27 (5-100) vs. 4 (0-100); p<0.001]. All participants stated that they knew how to recognize cardiopulmonary arrest, and nearly all stated that they knew the first action to take after recognition (**Table 2**).

Knowledge of Cardiopulmonary Resuscitation (CPR) Algorithm, Rhythm Assessment, Drugs, Defibrillation, and Airway Management

Most residents in both groups reported knowing the compression-to-ventilation ratio and shockable/non-shockable rhythms. However, internal residents more frequently reported knowing how to perform effective chest compressions (100.0% vs. 80.0%; p=0.001) and when to check rhythm during CPR (96.0% vs. 64.0%; p<0.001) (**Table 3**).

Table 2. CPR training, experience, and cardiopulmonary arrest recognition

Variable	Internal departments (n=50)	Surgical departments (n=50)	p-value
Previous CPR training: Yes, n (%)	47 (94.0)	39 (78.0)	0.021
Previous CPR application: Yes, n (%)	49 (98.0)	43 (86.0)	0.059
Estimated number of CPR applications, median (min-max)	27 (5-100)	4 (0-100)	<0.001
Knows how to recognize cardiopulmonary arrest: Yes, n (%)	50 (100.0)	50 (100.0)	-
Knows first action after recognizing cardiopulmonary arrest: Yes, n (%)	50 (100.0)	49 (98.0)	1.000

CPR: Cardiopulmonary resuscitation, Min: Minimum, Max: Maximum

Table 3. Knowledge of CPR application and rhythm assessment

Variable: Yes responses	Internal departments (n=50)	Surgical departments (n=50)	p-value
Knows compression-to-ventilation ratio during CPR	50 (100.0)	46 (92.0)	0.117
Knows how to perform effective chest compression	50 (100.0)	40 (80.0)	0.001
Knows shockable rhythms	48 (96.0)	47 (94.0)	1.000
Knows nonshockable rhythms	49 (98.0)	46 (92.0)	1.000
Knows rhythm-check intervals	48 (96.0)	32 (64.0)	<0.001

CPR: Cardiopulmonary resuscitation

Major between-group differences were observed in medication-related knowledge. Internal residents more frequently knew the adrenaline dose used during CPR (98.0% vs. 52.0%; p=0.001), the interval for repeating adrenaline (98.0% vs. 54.0%; p=0.001), which drug should be used in shockable rhythms (88.0% vs. 40.0%; p<0.001), after which shock medication should be administered (74.0% vs. 28.0%; p<0.001), and the amount of drug administered after shock (62.0% vs. 22.0%; p<0.001) (**Table 4**).

Table 4. Knowledge of drug administration during CPR

Variable: Yes responses	Internal departments (n=50)	Surgical departments (n=50)	p-value
Knows adrenaline dose during CPR	49 (98.0)	26 (52.0)	0.001
Knows interval for repeating adrenaline	49 (98.0)	27 (54.0)	0.001
Knows drug used in shockable rhythms	44 (88.0)	20 (40.0)	<0.001
Knows after which shock medication should be given	37 (74.0)	14 (28.0)	<0.001
Knows amount of drug given after shock	31 (62.0)	11 (22.0)	<0.001

CPR: Cardiopulmonary resuscitation

Knowledge of defibrillator pad placement, applicable energy level, perceived ability to recognize intubation during CPR, and the gold standard for confirmation of tracheal intubation was also significantly higher among internal residents than surgical residents. Knowledge about the survival implication of elevated end-tidal carbon dioxide was low in both groups and did not differ significantly (28.0% vs. 22.0%; p=0.488) (**Table 5**).

Table 5. Knowledge of defibrillation and airway-related issues during CPR

Variable: Yes responses	Internal departments (n=50)	Surgical departments (n=50)	p-value
Knows defibrillator pad placement	45 (90.0)	22 (44.0)	<0.001
Knows applicable defibrillation energy level	39 (78.0)	17 (34.0)	<0.001
Believes they can recognize intubation during CPR	47 (94.0)	24 (48.0)	<0.001
Knows gold standard for tracheal intubation confirmation	27 (54.0)	13 (46.0)	0.004
Knows how elevated end-tidal CO_2 affects survival	14 (28.0)	11 (22.0)	0.488

CPR: Cardiopulmonary resuscitation, CO_2: Carbon dioxide

Peri-Arrest Arrhythmia Management and Specialty-Level Findings

Internal residents reported higher knowledge regarding unstable tachycardia management (68.0% vs. 26.0%; p<0.001), stable tachycardia and QRS-related vagal maneuver decision-making (64.0% vs. 20.0%; p<0.001), initial atropine dose in bradycardia (84.0% vs. 26.0%; p<0.001), maximum repeatable atropine dose (70.0% vs. 24.0%; p<0.001), recognition of the presented rhythm (98.1% vs. 78.0%; p=0.002), and treatment of the presented rhythm (80.0% vs. 40.0%; p<0.001) (**Table 6**).

Table 6. Knowledge of tachycardic and bradycardic patient management

Variable: Yes responses	Internal departments (n=50)	Surgical departments (n=50)	p-value
Knows what to do in unstable tachycardia	34 (68.0)	13 (26.0)	<0.001
Knows whether vagal maneuver in stable tachycardia depends on QRS width	32 (64.0)	10 (20.0)	<0.001
Knows initial atropine dose in bradycardia	42 (84.0)	13 (26.0)	<0.001
Knows maximum repeatable atropine dose	35 (70.0)	12 (24.0)	<0.001
Knows preliminary diagnosis of the visually presented rhythm	49 (98.1)	39 (78.0)	0.002
Knows treatment needed to correct the presented rhythm	40 (80.0)	20 (40.0)	<0.001

The original thesis table contained an apparent typographical error for maximum repeatable atropine dose in the internal departments group; it was harmonized here as 35 (70.0%) according to the reported percentage and abstract result. QRS: QRS complex (Q wave, R wave, and S wave)

In exploratory specialty-level observations, relatively lower self-reported CPR-related knowledge appeared more common among urology/gynecology and obstetrics, orthopedics, and otorhinolaryngology residents. However, detailed subgroup statistical analyses were limited because of the relatively small sample sizes within each specialty.

DISCUSSION

The main finding of this single-center cross-sectional study was that surgical residents reported lower self-assessed CPR-related knowledge than internal residents despite most participants previously receiving CPR training and participating in CPR practice.

Early CPR and early defibrillation are among the most important determinants of survival after cardiac arrest. High-quality CPR, appropriate recognition of shockable rhythms, and rapid defibrillation are repeatedly emphasized in resuscitation science and guideline documents.[3-6]

In this context, the finding that all residents reported knowing how to recognize cardiopulmonary arrest is encouraging. However, recognition alone is insufficient if algorithm steps, rhythm assessment intervals, drug timing, and defibrillation practices are not applied correctly.

The observed difference in previous CPR exposure may partially explain the knowledge gap. Internal residents reported a substantially higher median number of previous CPR applications than surgical residents. Although surgical residents frequently work in perioperative settings where acute deterioration can occur, their day-to-day roles may not uniformly include repeated exposure to ward-based cardiac arrest algorithms, defibrillator operation, or medical management of peri-arrest arrhythmias. By contrast, several internal departments may encounter deteriorating medical patients and cardiac arrest scenarios more frequently in wards, coronary care units, emergency consultations, and intensive care-related rotations.

Our findings are consistent with prior studies reporting that CPR knowledge varies by specialty, clinical experience, and previous training. Turkish studies evaluating physicians and resident physicians have similarly shown that knowledge is not homogeneous across branches and that specific groups require repeated education.[7-10]

In the present study, the weakest areas among surgical residents were not basic arrest recognition but applied components of advanced resuscitation: adrenaline dosing and timing, amiodarone use in shockable rhythms, defibrillation technique, confirmation of tracheal tube placement, and tachycardia/bradycardia algorithms. These are precisely the steps most likely to affect the quality and continuity of resuscitation during real-life team-based CPR.

The specialty-level findings are clinically relevant. Urology/gynecology and obstetrics, orthopedics, and otorhinolaryngology residents had the lowest knowledge levels in several items. These departments may have fewer routine opportunities to lead resuscitation events, but their patients may still experience perioperative, postoperative, obstetric, airway-related, traumatic, septic, or hemorrhagic deterioration. Therefore, training should not be limited to departments traditionally perceived as resuscitation-heavy. Instead, institution-wide training should be adapted according to departmental risk profiles and previously identified knowledge gaps.

A practical implication of these findings is that CPR education should be repeated, competency-based, and simulation-supported. Passive theoretical sessions may not be sufficient for long-term retention or for translating knowledge into performance under stress. Short, recurring workshops focusing on rhythm recognition, defibrillator use, drug timing, airway confirmation with waveform capnography, and peri-arrest arrhythmia algorithms may improve both knowledge and confidence. Department-specific scenarios may further increase relevance and retention.

Limitations

This study has several limitations. First, it was conducted at a single center with a relatively limited sample size, which may reduce generalizability. Second, the questionnaire primarily evaluated self-reported or perceived knowledge rather than objectively measured CPR competence or practical performance. Third, although the questionnaire items were developed according to current ERC/AHA recommendations and reviewed by faculty members, a Formal Large-Scale validation and reliability analysis such as Cronbach's alpha was not performed. Fourth, the study was exploratory in nature and no formal power analysis was conducted. Fifth, multiple statistical comparisons were performed without formal correction methods, which may increase the risk of type I error. Finally, specialty-level subgroup findings should be interpreted cautiously because detailed subgroup analyses were limited.

CONCLUSION

Resident physicians from surgical departments reported lower self-assessed CPR-related knowledge than residents from internal departments, particularly regarding rhythm assessment, medication use, defibrillation, airway confirmation, and peri-arrest arrhythmia management. These findings support the potential value of repeated, simulation-supported, department-specific CPR training programs.

ETHICAL DECLARATIONS

Ethics Committee Approval

This study was approved by the Kırıkkale University Faculty of Medicine Ethics Committee (Date: 12.03.2025, Decision No: 2025.03.13).

Informed Consent

Written informed consent was obtained from all individual participants prior to their inclusion in the study. Participants were fully informed about the study's aims, procedures, potential risks and benefits, and their rights-including the right to withdraw at any time without consequence. All participants voluntarily signed a written informed consent form.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

Financial Disclosure

The authors received no financial support for the conduct or publication of this research.

Author Contributions

Concept: ZB, IG; Design: ZB, IG; Control: IG; Data Collection and/or Processing: ZB; Analysis and/or Interpretation: ZB; Writing the Article: ZB, IG; Critical Review: ZB, IG, KP.

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Review

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3D printing technologies in implantable medical devices: principles, applications, and cost-effectiveness in cardiovascular surgery

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ABSTRACT

Three-dimensional (3D) printing technologies, also known as additive manufacturing, have revolutionized biomedical engineering and surgical applications by enabling the high-accuracy and patient-specific production of complex geometries. Over the past decade, these technologies have moved beyond mere prototype manufacturing into routine clinical and industrial use. This review summarizes the fundamental operating principles, clinical applicability, advantages, and limitations of major 3D printing technologies, including SLA, FDM, selective laser sintering, selective laser melting, and binder jetting. Furthermore, their applications in cardiovascular and cardiac surgery, cost-effectiveness analyses, and future trends are discussed.

Keywords: Three-dimensional printing biomaterials, selective laser sintering, stereolithography, selective laser melting, fused deposition modeling, additive manufacturing

INTRODUCTION

In additive manufacturing (AM), unlike machining methods, the part is produced in layers and production is done by accumulating the required amount of material rather than by subtracting from a block.[1]

3D printing technologies have revolutionized the design and production of medical devices and surgical instruments. The ability to physically reproduce patient-specific anatomical models derived from computed tomography (CT) or magnetic resonance (MR) data provides significant advantages in surgical planning and intraoperative applications. In cardiovascular surgery, where anatomical variation is substantial, these technologies enable precise, patient-specific planning and application.

Initially limited by high costs, material restrictions, and regulatory challenges, 3D printing has become increasingly widespread in hospitals due to advancements in hardware, biocompatible materials, and software.

PRINCIPLES OF 3D PRINTING PROCEDURE LAYER BY LAYER

The process typically involves:

- Creating a digital model (via CAD or medical imaging data)
- Slicing the model into layers
- Layer-by-layer printing
- Post-processing (cleaning, curing, surface finishing, sterilization)

Each technology uses different physical or chemical mechanisms to form these layers (**Figure 1**).

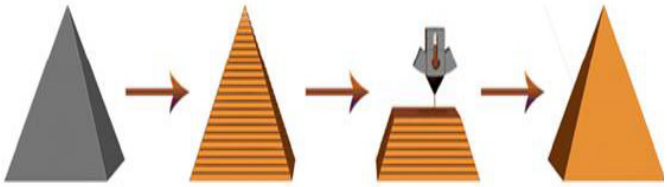


Figure 1. 3D printing principle

3D: Three-dimensional

MAJOR ADDITIVE MANUFACTURING (AM) TECHNIQUES

The materials, advantages, and disadvantages of the techniques are summarized in **Table**.

Fused Deposition Modeling (FDM)

Invented by Scott Crump in 1988, FDM became the first patented 3D printing technology in 1992 under Stratasys.[2] The principle involves heating a thermoplastic filament (such as polylactic acid (PLA), acrylonitrile butadiene styrene (ABS), polyethylene terephthalate glycol (PETG), or polyether ether ketone (PEEK) to its melting point, then extruding it through a nozzle that deposits the material layer by layer. After each layer solidifies, the platform lowers for the next layer to be added.[3]

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Table. The advantages and disadvantages of different techniques

Methods	Materials	Advantages	Disadvantages
FDM	ABS, PLA, Wax blend, nylon	High speed, high quality, used for a wide range of materials	Porous structure, weak mechanical properties, generally requires support for the binder
SLA	Resin (registered photo-curable resin such as acrylic or epoxy-based)	Large parts can be easily produced with high accuracy and surface quality	Use of photo-curable resins, limited mechanical properties, parts need to be post-cured
SLS	Metallic powder, polyamide, PVC	High resolution, high strength and durability	Applicable only to metallic and thermoplastic materials, surface roughness requires post-processing
3D inkjet printing	Photo-resin or hydrogel	Very fine detail, high surface quality	Fragile parts, weak mechanical properties

FDM: Fused deposition modeling, SLA: Stereolithography, SLS: Selective laser sintering, 3D: Three-dimensional, ABS: Acrylonitrile butadiene styrene, PLA: Polylactic acid, PVC: Polyvinyl chloride

- **Advantages:** Low cost, easy operation, wide material range.
- **Disadvantages:** Surface roughness, limited resolution and mechanical strength.
- **Clinical use:** Cardiac anatomical models, preoperative training models.
- **Cost:** Printers between 1,000-10,000 USD; model cost <50 USD.

Stereolithography (SLA) with Liquid Photopolymer

- **Advantages:** High resolution, smooth surface, ideal for fine details.
- **Disadvantages:** Brittle materials, some resins are not biocompatible.
- **Clinical use:** Surgical guides, molds for silicone vascular or cardiac models.
- **Cost:** Printers 5,000-100,000 USD; resin 150-200 USD/L (**Figure 2**).

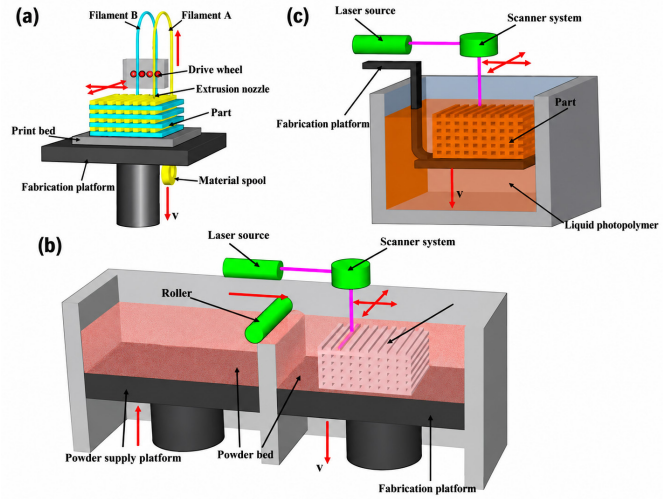


Figure 2. SLA uses a laser to polymerize liquid photopolymer resin
SLA: Stereolithography

Selective Laser Sintering (SLS) with Powder Delivery System

Developed by DTM in 1987 and patented by CR Dechard in 1988, SLS sinters powdered polymers using a laser to partially melt and fuse particles.[4]

- **Advantages:** High strength, no support structures, complex geometries possible.
- **Disadvantages:** Surface roughness, powder cleaning difficulty, high equipment cost.
- **Clinical use:** Vascular connectors, cannula housings, device casings.
- **Cost:** 100,000-500,000 USD; reduced per-unit cost in mass production (**Figure 3**).

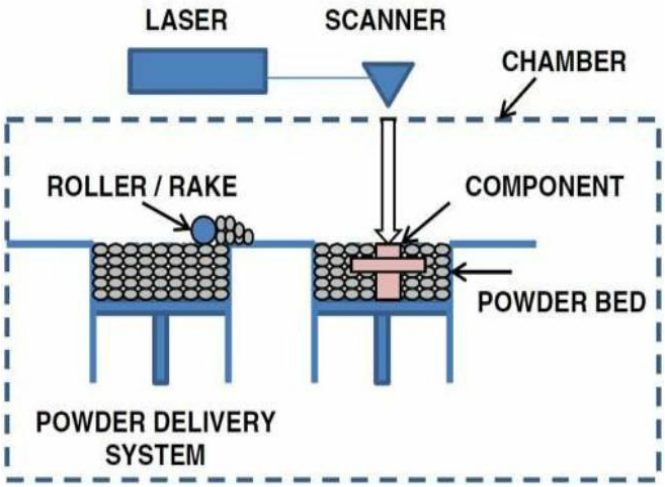


Figure 3. SLS procedure principle[5]
SLS: Selective laser sintering

Selective Laser Melting (SLM) and Electron Beam Melting (EBM)

SLM is an AM method used to produce components with complex internal structures.[6]

These techniques fully melt metal powders (titanium, cobalt-chromium, stainless steel) using laser or electron beams.

- **Advantages:** High mechanical strength, excellent biocompatibility, porous structures for osseointegration.
- **Disadvantages:** High investment cost, long print time, need for post-heat treatment and support removal.
- **Clinical use:** Patient-specific sternal plates, cardiac stent prototypes, valve supports.
- **Cost:** Printers 250,000-1,000,000 USD; titanium powder 300-600 USD/kg.

Binder Jetting and Material Jetting

In these systems, a binder agent is sprayed onto powder layers or photopolymer droplets are directly deposited layer by layer.

- **Advantages:** Fast production, multi-material and colored model printing.
- **Disadvantages:** Low mechanical strength, requires curing and infiltration.

- **Clinical use:** Colored models for demonstrating congenital heart diseases.
- **Cost:** Systems range from 50,000-200,000 USD.

BIOMEDICAL PRINTING MATERIALS

Biomaterials used in implantable medical devices via 3D printing can be classified as biomedical polymers, metals, ceramics, composites, and derivatives. Between 2019-2025, the diversity of biocompatible materials increased rapidly.

- **Polymers:** PLA, PEEK, PETG, thermoplastic polyurethane (TPU)-for anatomical models and surgical guides.
- **Metals:** Ti6Al4V, cobalt-chromium-for permanent implants.
- **Composites:** Hydroxyapatite, graphene-reinforced polymers.
- **Biomaterials:** Hydrogel, collagen, alginate-for tissue scaffolds and bioprinting.
- **Polymers:** Biomedical polymer materials can be divided into two categories based on their properties: non-degradable and degradable. Non-degradable polymer materials include polyethylene, polypropylene, and polyformaldehyde. This type of material has good physical and mechanical properties and can also remain stable in a biological environment for long periods.

Collagen is an example of a degradable biological material.

PLA, PEEK, PETG, TPU-for anatomical models and surgical guides.

Biomedical metal materials refer to the metals or alloys used in biomaterials, also known as surgical implant metals. Clinically used biomedical metal materials mostly include stainless steel, titanium and titanium alloys, cobalt-chromium-molybdenum alloys, and medical precious metals.[7] They possess high fatigue strength, mechanical strength, and corrosion resistance. They are preferred in bone and joint prostheses, spinal implants, and cardiovascular implants.

Biomedical Ceramic Materials

Biomedical ceramics are divided into three categories; biologically inert, active, and biodegradable. Bioinert ceramics include alumina, zirconium, and carbon. They have a stable structure, high strength, and good wear resistance. Among bioactive ceramics, materials such as bioglass,[8] which forms strong chemical bonds with tissues through chemical reactions in the body, can stimulate new bone growth. The main problems with biomedical ceramics are their low strength and toughness.

In cardiovascular surgery, PEEK and titanium are preferred for MRI compatibility and corrosion resistance.

- **Composites:** Hydroxyapatite, graphene-added polymers.

Biomedical composite materials consist of two or more different materials.[9] Composite materials significantly enhance the performance of a material by combining the superior properties of different materials. In addition to providing physical and chemical superiority, the composite material must also meet biocompatibility requirements. Biomedical composite materials are widely used to repair or replace human tissues and organs, enhance their function, and in the production of artificial organs.[10]

- **Biomaterials:** Hydrogel, collagen, alginate-for tissue scaffolding and bioprinting applications.

PEEK and titanium are particularly preferred in cardiovascular surgery due to their MRI compatibility and corrosion resistance.

APPLICATIONS IN CARDIOVASCULAR AND THORACIC SURGERY

Typical 3D Printed Implantable Medical Devices

3D printed implantable medical devices are applied to various parts of the human body. Typical products include vascular stents, heart valve prostheses, orthopedic implants, and artificial joint prostheses. Datasets can be obtained from MRI, CT, echocardiography, or rotational angiography.[11]

MRI datasets were used to print various right ventricular outflow tract models for preoperative guidance of percutaneous pulmonary valve implantation.[12]

Sternum Closure and Rib Fracture Repair

Methods for repairing bone defects include autografts, allografts, and artificial bone substitute materials such as metal and polymer materials. Autologous bone transplantation requires two operations. However, due to their different structures, allografts can cause immune rejection and carry the risk of contracting infectious diseases from the donor. Therefore, research on artificial bone repair has become a focus of many scientists.

3D printing has three primary applications:

- **Preoperative planning:** Patient-specific heart models for surgical strategy.
- **Surgical simulation:** Pre-surgical practice, especially in congenital heart disease.
- **Patient-specific implants and instruments:** Cutting guides, suture templates, sternal plates.

COST-EFFECTIVENESS ANALYSIS

- **Equipment and material costs:** FDM/SLA systems cost 3,000-10,000 USD; SLS/SLM 150,000-500,000 USD; materials range from 30 USD/kg (PLA) to 600 USD/kg (titanium).
- **Production efficiency:** 3D printing has reduced prototype/model fabrication time from weeks to hours. A heart model can cost <100 USD, while patient-specific metal implants remain cheaper than traditional machining.
- **Clinical contribution:** By reducing operation time and complications, 3D printing achieves indirect cost savings. Economic analyses (2022-2024) show 5-10% cost reduction in congenital surgeries.

LIMITATIONS AND CHALLENGES

Regulation: FDA and EU MDR require strict documentation.

- **Reproducibility:** Standardization of production and mechanical testing is limited.

- **Sterilization:** Some resins cannot withstand autoclave sterilization.
- **Hospital integration:** Image segmentation and model preparation are time-consuming.

FUTURE PERSPECTIVES (2025 AND BEYOND)

Next-generation applications include bioprinting, multi-material hybrid printing, and 4D printing (materials changing shape over time). Future directions in cardiovascular surgery focus on biodegradable stents, patient-specific vascular grafts, and bioprinted myocardial patches.

Additionally, AI-assisted modeling and automated segmentation will further accelerate production.

CONCLUSION

3D printing technologies have transformed cardiovascular surgery by enabling personalized and rapid production of surgical tools and implants. With the advancement of biocompatible materials such as titanium and PEEK, patient-specific implant fabrication is now clinically viable. Although challenges remain in cost and regulation, technological progress will likely make these systems standard surgical tools in the coming years.

ETHICAL DECLARATIONS

Peer Review Process

This review was externally peer-reviewed.

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Author Contributions

The author is solely responsible for the entirety of conception, execution, analysis, and writing of the manuscript.

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Review

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Management of venous ulcers in chronic venous insufficiency: a comprehensive review of etiopathogenesis, biomechanical failure, and evidence-based therapeutic strategies

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ABSTRACT

Chronic venous insufficiency (CVI)-induced venous leg ulcers (VLUs) represent the most advanced stage of venous disease (CEAP C6) and pose a significant clinical and socioeconomic burden. This review aims to evaluate the biomechanical failure of the calf muscle pump, the impact of environmental and systemic factors, and current evidence-based interventional strategies in VLU management. The pathophysiology of VLU is driven by ambulatory venous hypertension. Factors such as prolonged heat exposure, static occupational loading, and systemic comorbidities like diabetes mellitus and smoking further impair the healing process by promoting chronic inflammation and biofilm formation. A comprehensive literature review was conducted, focusing on key clinical trials including EVRA, ESCHAR, and RECOVERY, to analyze the efficacy of endovenous thermal ablations (EVLA, RFA), foam sclerotherapy, and advanced wound care modalities. Evidence confirms that early interventional treatment (ablation within 2 weeks of ulcer presentation) significantly accelerates healing rates. Biomechanical support via graduated compression therapy remains the gold standard for preventing recurrence. Furthermore, the role of "cell-friendly" wound cleansing using clean water, rather than cytotoxic antiseptics, is emphasized for maintaining the integrity of fibroblasts and keratinocytes. Successful VLU management requires a multidisciplinary approach focusing on three pillars: reducing venous pressure through early intervention and compression, activating the calf muscle pump through mobilization, and controlling systemic risk factors.

Keywords: Chronic venous insufficiency, venous leg ulcer, calf muscle pump, endovenous laser ablation, radiofrequency ablation, biofilm

INTRODUCTION

Chronic venous insufficiency (CVI) is a chronic and progressive disease characterized by the pooling of blood distally due to gravity, resulting from the loss of function in the valves of the lower extremity venous system or structural deterioration of the venous wall. Venous ulcers (VU) represent the most advanced clinical stage of this pathophysiological process and correspond to stage C6 in the CEAP classification.

Approximately 10% of the general population develops a chronic leg ulcer during their lifetime, the most common of which is venous pathology.[1] It is estimated that the prevalence of C2 disease ranges from 20% to 64%, and 5% of the general population presents with C3 to C6 disease. C5 and C6 disease are prevalent in 1% to 1.5% of the population. The prevalence of the disease increases with age, and approximately 4% of patients over the age of 65 have venous ulcerative disease.[2]

Epidemiological studies indicate that 70-80% of lower extremity ulcers are of venous origin. While the prevalence in the general population of Western societies is around 1-2%, this rate rises to 5% in individuals over 65 years of age.[3] More importantly, the recurrence rate of venous ulcers is remarkably high, at approximately 70%. This situation clearly demonstrates that treatment cannot be limited solely to local wound care; the underlying fundamental issue, venous hypertension, must be corrected (**Figure**).



Figure. Venous ulcer CEAP C6

CEAP C6: The most advanced stage of venous disease

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ETIOLOGY AND PATHOPHYSIOLOGY

The development of venous ulcers cannot be explained solely by anatomical valvular insufficiency. Genetic predisposition, environmental exposures, occupational habits, and biomechanical factors are major determinants accompanying this process.

The Calf Muscle Pump

The "peripheral heart" Contrary to popular belief, venous return from the lower extremities to the heart is dependent on the rhythmic function of the calf muscles rather than cardiac suction power. The gastrocnemius and soleus muscles are, therefore, frequently described as the "peripheral heart." Venous leg ulcers (VLU) are the most common and difficult-to-manage leg ulcers. They result from venous congestion caused by the insufficiency of the calf pump or dysfunctional venous valves.[4]

Systolic phase: The increase in pressure applied to the deep veins during muscle contraction ensures that blood is propelled proximally. During this phase, the valves of the perforating veins close, preventing reflux into the superficial system.

Diastolic phase: The negative pressure formed in the deep veins when the muscle relaxes draws blood from the superficial system into the deep system through the perforating veins, preparing for the next pump cycle.

The disruption of this physiological mechanism forms the fundamental biomechanical basis for venous hypertension and, ultimately, ulceration.

Heat Exposure and Static Occupational Loading

In individuals working at high temperatures (such as bakers, cooks, and foundry workers), vasodilation in the venous walls reaches maximum levels. Heat impairs the coaptation of the valves by reducing venous tone. Thermal conditions, in particular, appear to regulate symptom severity; many patients report that heat exacerbates discomfort, while cold alleviates it.[5] In static occupations requiring prolonged standing without movement, the calf muscle pump cannot be adequately activated. Consequently, blood pools distally, and the increased pressure in the capillary bed leads to tissue destruction that initiates an inflammatory vicious cycle.

SYSTEMIC AND LOCAL FACTORS HINDERING HEALING

Molecular Effects of Diabetes and Smoking

Venous ulcers transform into a classic "non-healing wound" model in the presence of systemic risk factors.

Diabetes mellitus (DM): Concerns regarding poorer treatment adherence are increasing, particularly among diabetics, as adherence to diabetes treatment and lifestyle modifications is generally lower. Furthermore, the risk of CVD (chronic venous disease) and peripheral arterial disease is higher in diabetic patients. Patients with CVD should always be screened for the presence of diabetes, as its presence impacts CVD symptoms, diagnostic methods, and treatment strategies.[6]

Advanced glycation end products (AGEs) bind to collagen and elastin fibers, reducing tissue elasticity and preventing wound contraction.

Hyperglycemia creates an ideal culture medium for bacteria while impairing leukocyte chemotaxis and phagocytic capacity.

Increased matrix metalloproteinase (MMP) activity causes the degradation of newly formed granulation tissue before it can mature.

Diabetic neuropathy and autonomic dysfunction lead to skin dryness and fissures, increasing the risk of secondary infections.

Smoking: While nicotine causes tissue hypoxia by producing vasoconstriction in the microcirculation, carbon monoxide binds to hemoglobin, reducing the effective amount of oxygen transported to the tissues. Therefore, the wound healing rate is significantly lower in patients who smoke.

Wound Microbiota and the Biofilm Barrier

Different types of biofilms can be produced depending on the ulcer environment. Its formation begins with the attachment of a bacterium in planktonic form to an exposed surface, which can be biotic or abiotic. Subsequently, microorganisms establish connections among themselves and attach irreversibly. Then, they begin to multiply and activate quorum sensing. The biofilm grows and differentiates into a mature biofilm community, exhibiting structural characteristics. Subsequently, a matrix consisting of polymeric substances such as water, polysaccharides, proteins, and extracellular DNA is formed. Finally, the mature biofilm initiates a dispersal process through the detachment of cells or microcolonies. Dispersal can lead to the colonization of new niches and thus new infection sites by the biofilm.[7]

The most significant microbiological issue in venous ulcers is biofilm formation. The polysaccharide matrix secreted by bacteria protects them from both the immune system and antibiotics. In the absence of active purulent infection, the use of aggressive antiseptics exerts a cytotoxic effect on fibroblasts and keratinocytes. Therefore, gentle mechanical cleaning performed with clean water of drinking quality or saline is the most scientific approach to removing the biofilm layer while preserving viable tissue.

Evaluation of Arterial Circulation

In mixed ulcers, peripheral arterial circulation must be evaluated in every patient with a venous ulcer. Concomitant arterial insufficiency is present in approximately 15-20% of cases. The negative impact of arterial and venous diseases on each other should be examined in detail, and separate strategies should be developed for each.[8] Ankle-Brachial Index (ABI) measurement is, therefore, of critical importance. In patients with an ABI <0.5, high-pressure compression may impair tissue perfusion, leading to serious complications that can progress to gangrene.

DIAGNOSTIC STEPS AND ALGORITHM

Diagnosis is established through careful clinical evaluation and radiological confirmation.

Physical examination: Generally, shallow and exudative ulcers with irregular borders are observed around the medial malleolus. Evaluation of peripheral pulses is mandatory.

Color Doppler ultrasonography: Reflux duration (>0.5 sec) at the saphenofemoral and saphenopopliteal junctions and sequelae of deep vein thrombosis are investigated. It is the gold standard.

Ankle-Brachial Index (ABI): It must be measured to exclude arterial insufficiency before compression therapy.

PHARMACOLOGY AND COMPRESSION: FUNDAMENTAL SUPPORT

Venotonic Medications

Realistic expectations: It has been reported that sulexollide treatment shows a better potential probability (48%) compared to pentoxifylline (37%) and micronized purified flavonoid fraction (MPFF) (16%). While MPFF is a more effective treatment in reducing lower leg volume, CIVIQ-20 score, and pain VAS scale, calcium dobesilate has been evaluated as more effective in reducing foot volume and ankle circumference.[9]

MPFF and similar venotonics do not correct valvular insufficiency. Their effects involve reducing leukocyte adhesion, suppressing inflammation, and providing edema control. The literature supports the use of these agents as adjuvants to surgical or compression therapy, particularly for 3-6 months during the active healing period. Lifetime use is not required.

Compression Therapy

The gold standard no advanced technology can replace a correctly applied compression stocking. Graduated pressure, which is highest at the ankle and decreases proximally, increases valve coaptation by narrowing the vein diameter and activates the calf muscle pump. A pressure of 30-40 mmHg (class III) is generally preferred in patients with venous ulcers. Compression therapy should be maintained for life to prevent recurrence even after the wound has healed.

A fairly recent meta-analysis comparison of seven studies reported that there is moderate evidence that compression therapy heals venous ulcers more easily, regardless of the type of compression system, as long as it can provide consistent graduated compression.[10]

INTERVENTIONAL AND SURGICAL TREATMENT STRATEGIES

Endovenous Thermal Ablation (EVLA and RFA)

In modern approaches, endovenous ablation techniques have replaced the classic stripping method. The long-term anatomical success rates of EVLA and RFA are over 90%. The EVRA study demonstrated that early intervention performed as soon as the ulcer is diagnosed significantly shortens the healing time.

Foam Sclerotherapy and Perforating Vein Treatment

Closure of insufficient perforating veins, particularly those beneath the ulcer bed, accelerates healing by directly reducing local venous pressure. While the recurrence rate is high when applied alone, it is highly effective when combined with ablation methods.

Surgery and the ESCHAR Study

The ESCHAR study revealed that the addition of superficial vein surgery to compression therapy significantly reduces recurrence rates rather than the rate of wound healing. The primary role of surgery is to prevent the reopened wound from recurring.

It provides evidence that polidocanol foam is another useful intervention that can be included in the toolbox used to address venous abnormalities in patients with leg ulceration due to chronic venous insufficiency. The data presented here, along with ESCHAR, EVRA, and other studies, support the concept of aggressively treating all sources of abnormal venous flow in patients with VLU, especially those who do not respond to compression protocols.[11]

MODERN WOUND CARE APPROACHES

Considering the cytotoxic effects of aggressive antiseptics, the goal in modern wound care is to provide a moist, clean, and cell-friendly wound environment.

- **High exudate wounds:** Alginates and hydrofibers
- **Moderate exudate:** Polyurethane foam dressings
- **Epithelialization phase:** Hydrocolloids
- **Signs of infection:** Short-term silver-containing dressings

The choice of dressing should be continuously re-evaluated based on the dynamic characteristics of the wound bed. Many international guidelines for leg ulcers recommend cleaning both the leg and the ulcer, and most advise cleaning with drinking water.[12]

The hidden danger of antiseptics: "Cytotoxicity" and the clean water miracle while harsh disinfectants kill bacteria, they also kill living cells such as "fibroblasts" and "keratinocytes" that work hard for wound healing.

Cellular toxicity: In vitro studies have shown that even a 1% povidone-iodine solution kills human fibroblasts within seconds. If fibroblasts die, the wound cannot close.

Modern approach: If there is no active, purulent infection in the wound, washing with water of drinking quality (or saline) and a mild soap is sufficient. This method removes the biofilm layer mechanically without damaging the healing tissue. Regular mechanical cleaning with clean water provides faster granulation (new tissue formation) than aggressive chemical use.

Dressing selection: Alginates should be preferred in exudative wounds, and foam dressings in the granulation phase. Silver-containing dressings should only be used for a short term for infection control.

CONCLUSION

Venous ulcers are a condition that dramatically reduces the patient's quality of life due to pain, odor, exudate, and social isolation. The need for long-term dressing changes and loss of workforce creates a serious economic burden. A successful treatment strategy is based on these three fundamental principles:

- **Reduce the pressure:** Compression and appropriate surgical intervention
- **Clean the wound:** Clean water and gentle debridement
- **Activate the muscle pump:** Walking and exercise

Permanent healing is not possible without smoking cessation, diabetes control, and early interventional treatment. While current cellular and biosynthetic treatments are promising, the gold standard today is the triangle of correct diagnosis, early intervention, and disciplined compression.

ETHICAL DECLARATIONS

Peer Review Process

This manuscript was subject to external peer review.

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Author Contributions

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Case Report

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A 3-year chronic post-sternotomy sinus tract maintained by a migrating pacemaker wire

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ABSTRACT

Chronic chest wall discharge following median sternotomy is a complex complication requiring a stepwise therapeutic approach. We present a 26-year-old male patient who underwent emergent mechanical mitral valve replacement for infective endocarditis and developed delayed sternal healing with persistent sterile discharge in the postoperative period. Suspecting a local tissue reaction, the ultra-high-molecular-weight polyethylene (UHMWPE) sternal bands were sequentially removed. Despite extracting all closure materials and excluding infection via negative tissue cultures, the chronic sinus tract discharge persisted for two years, necessitating regular wound care. A multidisciplinary surgical revision was performed to determine the underlying etiology. Exploration revealed that a temporary epicardial pacemaker wire had migrated anteriorly from the mediastinum into the subcutaneous tissue, presumably through a previous sternal band hole. Complete extraction of the retained wire, combined with short-term vacuum-assisted closure therapy, led to rapid and sustained wound healing. This case highlights that delayed sternal healing can be perpetuated by sequential foreign body reactions, and migrating pacemaker wires must be considered in persistent post-sternotomy sinus tracts.

Keywords: Delayed sternal healing, migrating pacemaker wire, UHMWPE sternal band, chronic sinus tract, open-heart surgery

INTRODUCTION

Median sternotomy remains the standard approach for the majority of open-heart surgeries.[1,2] Although traditional steel wires are widely used for sternal closure, non-metallic alternative materials, such as ultra-high-molecular-weight polyethylene (UHMWPE) sternal bands, have gained popularity in selected cases to potentially reduce complications like sternal dehiscence and metal hypersensitivity.[3]

Delayed sternal healing and chronic sterile sinus tracts following cardiac surgery are generally multifactorial conditions.[4] When persistent drainage occurs, initial management often focuses on addressing potential local tissue reactions to the primary closure materials. However, if the delayed healing process persists even after the removal of these materials, other retained surgical components may need to be investigated. In some cases, temporary epicardial pacemaker wires (TPWs) may be left in the mediastinum by cutting them at the skin level. Although generally uncomplicated, these wires can occasionally migrate over time due to respiratory and cardiac movements.[5]

This report presents a case of delayed sternal healing and a chronic sinus tract spanning a total of three years, wherein a local tissue reaction to UHMWPE bands was followed by the anterior migration of a retained temporary pacemaker wire, which appeared to maintain the chronic discharge until its ultimate removal.

CASE REPORT

A 26-year-old male patient (body-mass index: 24.3 kg/m^2, non-smoker, non-diabetic) presented to our emergency department with a cerebrovascular accident secondary to infective endocarditis, fever, and sudden-onset weakness in the right side of his body. Subsequent evaluations revealed infective endocarditis involving the mitral valve. Due to the neurological risks and acute mitral regurgitation secondary to active endocarditis, the patient was taken for emergent surgery. A mechanical mitral valve replacement (MVR) via median sternotomy was performed. For sternal closure, Ortholox® UHMWPE cerclage sternal bands, which were readily available in the clinic, were preferred over conventional stainless-steel wires. The early postoperative period was uneventful; the sternum was stable. Prior to discharge on the 8th postoperative day, an attempt was made to remove the temporary epicardial pacing wires. However, the wires, which were routinely secured to the myocardium with sutures, offered resistance upon pulling. To prevent myocardial injury or bleeding, the wires were cut sterilely at the skin level and left in situ as per standard clinical practice, after which the patient was discharged in good health.

During the first-month follow-up, a noticeable non-purulent wound discharge was observed at the sternotomy line, despite the sternum being completely intact and stable. The patient remained afebrile, and systemic inflammatory markers, including white blood cell count (6.13×10^3/μL), C-reactive

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protein (6 mg/L), and erythrocyte sedimentation rate (12 mm/h), were completely within normal limits. An allergy test performed during this period yielded a positive result, providing objective evidence for a hypersensitivity reaction. Furthermore, repeated superficial swab cultures and a subsequent deep tissue culture obtained from the wound bed were entirely negative for bacterial or fungal growth, definitively excluding an underlying chronic infection. Based on the positive allergy test, with close monitoring of sternal healing, the sequential removal of the sternal bands was planned and performed between the 2nd, 4th, and 6th postoperative months to eliminate the offending material.

Following the complete removal of the sternal bands, the skin partially closed; however, a low-volume sterile drainage from a localized sinus tract persisted. Over the subsequent two years, the patient visited our clinic for routine dressing follow-ups. Early thoracic computed tomography (CT) scans performed during this period did not suggest any focus of infection or foreign body reaction; the pacing wires were observed within the mediastinal space. However, due to the persistent drainage, a final thoracic CT scan was performed to re-evaluate the etiology. This scan revealed a linear, hyperdense image originating from the ventricle and migrating anteriorly into the subcutaneous tissue through the old wire transit hole left by the removed sternal band (**Figure 1**).



Figure 1. Sagittal thoracic CT image demonstrating the migrating temporary epicardial pacemaker wire. The green arrow and the 'A' marker indicate the linear, hyperdense radiopaque pacemaker wire located in the anterior mediastinum, extending just posterior to the sternal body and migrating toward the subcutaneous tissue

CT: Computed tomography

One month ago, a multidisciplinary surgical revision was performed concurrently with the plastic surgery department. During the deep exploration, the migrating temporary pacemaker wire, which had created a focus of mechanical irritation, was completely extracted from the subcutaneous tissue (**Figure 2A, B**). Following the procedure, a short, 4-day course of vacuum-assisted closure (VAC) therapy was applied. By the 10th postoperative day, the chronic sinus tract had completely closed. At the 1-month postoperative follow-up, the patient's chest wall was fully healed, and he remained asymptomatic (**Figure 2C**). A detailed chronology of the clinical events is summarized in **Table**.

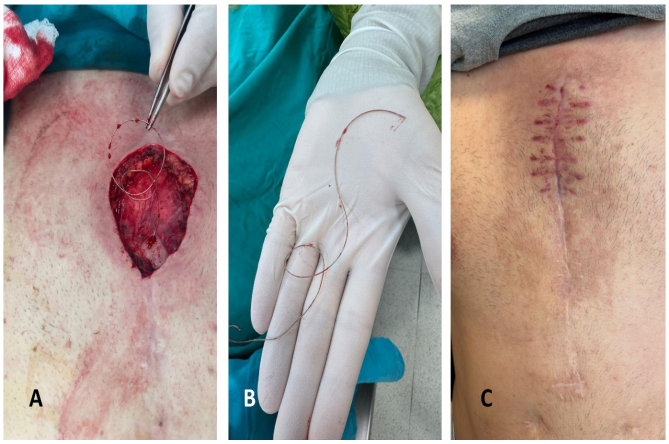


Figure 2. Intraoperative photographs demonstrating the surgical revision. (A) The sinus tract from which the migrating pacemaker wire emerged, showing the wound bed with bone wax application. (B) The fully extracted temporary pacemaker wire, illustrating the total length of the retained portion. (C) The final appearance of the surgical site following wire removal

Table. Chronology of clinical events

Date/timeframe	Clinical event
Month 0	Mechanical MVR surgery and initial discharge (post-op day 8)
Month 1	Onset of sterile drainage; negative cultures; normal WBC, CRP, ESR; positive allergy test
Month 2 to 6	Sequential removal of UHMWPE sternal bands
Month 6 to year 2	Persistent chronic sinus tract; early CT scans show pacing wire intact in the mediastinum
Year 2 (recent)	Final thoracic CT scan revealing anterior migration of the pacing wire
1 month ago	Multidisciplinary plastic surgery revision and pacing wire extraction
Post-op day 0-4	Application of VAC therapy
Post-op day 10	Complete closure of the sinus tract
Current	Last follow-up: chest wall fully healed, patient asymptomatic

MVR: Mitral valve replacement, Post-op: Postoperative, WBC: White blood cell, CRP: C-reactive protein, ESR: Erythrocyte sedimentation rate, UHMWPE: Ultra-high-molecular-weight polyethylene, CT: Computed tomography, VAC: Vacuum-assisted closure

DISCUSSION

Post-sternotomy chronic sinus tracts can present a challenging diagnostic process for cardiovascular surgeons.[1,2,4] When wound drainage is persistent, but cultures remain consistently sterile and systemic inflammatory markers are low; non-infectious etiologies tend to come to the forefront. As recently highlighted by Tanaka et al.,[3] UHMWPE bands are considered an effective, non-metallic alternative for sternal closure. In our clinic, we do not routinely use UHMWPE bands in all patients; however, in this young patient undergoing emergent surgery for infective endocarditis, we opted to use this readily available material given the absence of any known or diagnosed preoperative allergy history.

In this case, the initial step that triggered the delayed sternal healing process was suspected to be a local tissue reaction to these polymer bands. However, even after the complete extraction of the offending closure materials, healing was not fully achieved. The sternal tract left behind by the removed bands provided an anatomical conduit for the retained temporary epicardial pacing wire to migrate anteriorly into the subcutaneous tissue. This migration acted as the secondary and primary perpetuating factor, causing the chronic discharge to persist and prolonging the delayed wound healing for years.

The mechanical resistance encountered during the removal of temporary pacing wires is the primary reason for their retention. Studies evaluating the biomechanical factors of temporary wire removal in the literature have shown that while the procedure is generally safe, the tension required for safe extraction can sometimes be quite high.[5,6] Accordingly, in our case, the significant resistance encountered prior to discharge necessitated cutting the wire sterilely at the skin level and leaving it in situ to prevent acute myocardial injury or bleeding complications; however, this inadvertently set the stage for its late anterior migration.

Complications associated with retained temporary pacing wires are rare but well-documented in the literature. Although cutting the wires flush with the skin surface is generally considered benign, comprehensive reviews indicate that this practice is not always safe and can lead to severe late complications.[6] Despite most cases remaining uncomplicated, it has been reported that following a long dormant period, migrating wires can travel intravascularly to the pulmonary artery or right heart, or extravascularly to the skin surface, peritoneal, and pelvic cavities, occasionally causing bronchocutaneous fistulas or mass formations.[6-9] In the context of the chest wall, chronic sinus tract formation due to a migrating wire is a highly uncommon phenomenon. Continuous cardiopulmonary movements are thought to propel the wire along the path of least resistance. In this instance, the tract left behind by the removed sternal bands guided the wire, and the continuous mechanical irritation caused by it prevented the closure of the chronic sinus tract.

Furthermore, while the extraction of the mechanical irritant was the primary step for definitive resolution, it is important to acknowledge that the subsequent application of short-term vacuum-assisted closure therapy significantly accelerated wound bed preparation and granulation;[10] the VAC therapy played a synergistic role in the rapid clinical resolution observed within 10 days.

Based on our experience, while superficial treatments and conservative follow-ups are common initial steps, we recommend that early high-resolution CT scanning become a standard diagnostic approach for chronic sinus tracts lasting longer than 3-6 months to improve patient comfort and prevent unnecessary, prolonged dressing costs. Since delayed sternal healing can be perpetuated by sequential foreign body reactions, migrating pacing wires must be kept in mind in the differential diagnosis of persistent post-sternotomy sinus tracts.

CONCLUSION

As a result, delayed sternal healing can be a complex process driven by sequential reactions and mechanical factors. Although UHMWPE bands are a valuable alternative for sternal closure, they can rarely trigger local allergic reactions, as suspected in this case. More importantly, retained temporary epicardial pacing wires may not always remain benign; they can migrate through pre-existing sternal defects and act as a secondary nidus that prevents complete wound healing. This case highlights that in patients with persistent, culture-negative post-sternotomy sinus tracts, the use of early and, when necessary, repeated high-resolution CT imaging is essential for the differential diagnosis, monitoring of retained foreign bodies, and achieving sustained resolution through a multidisciplinary surgical approach.

ETHICAL DECLARATIONS

Informed Consent

Written informed consent was obtained from the patient included in this report. Signed consent forms are retained by the authors and are available upon request.

Peer Review Process

This manuscript was subject to external peer review.

Conflict of Interest

The author declares no conflicts of interest related to this study.

Financial Disclosure

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Author Contributions

The author is solely responsible for the entirety of conception, execution, analysis, and writing of the manuscript.

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Case Report

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Wire-based percutaneous balloon mitral valvuloplasty after failed conventional valve crossing: a case report

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ABSTRACT

Percutaneous balloon mitral valvuloplasty (PBMV), an important treatment for rheumatic mitral stenosis (MS), can be technically challenging in cases with difficult anatomy. This article describes a new wire-based PBMV technique involving the advancement of an Inoue balloon over a pre-shaped rigid 0.035-inch wire. The procedure begins with a targeted transseptal puncture, followed by introduction of a steerable sheath into the left atrium and subsequent passage across the diseased mitral valve (MV), replacement with a preformed 0.035-inch stiff wire in the left ventricle, advancement and positioning of an appropriately sized Inoue balloon over the MV on the wire, and inflation of the balloon. This technique uses additional equipment such as a steerable sheath and a preformed 0.035-inch stiff wire, in addition to the standard Inoue balloon kit. This may make the technique more costly. Due to the rheumatic MS occurs less commonly, socioeconomically developed societies, the number of operators experienced in PBMV procedures is quite rare. PBMV can be performed safely and predictably on the wire using the approach described.

Keywords: Ballon valvuloplasty, rheumatic heart disease, mitral stenosis

INTRODUCTION

Percutaneous balloon mitral valvuloplasty (PBMV), an important treatment for rheumatic mitral stenosis (MS), can be technically challenging in cases with difficult anatomy. This article describes wire-based PBMV technique involving the advancement of an Inoue balloon over a pre-shaped rigid 0.035-inch wire. The procedure begins with a targeted transseptal puncture, followed by introduction of a steerable sheath into the left atrium and subsequent passage across the diseased mitral valve (MV), replacement with a preformed 0.035-inch stiff wire in the left ventricle (LV), advancement and positioning of an appropriately sized Inoue balloon over the MV on the wire, and inflation of the balloon. This technique uses additional equipment such as a steerable sheath and a preformed 0.035-inch stiff wire, in addition to the standard Inoue balloon kit. This may make the technique more costly. Due to the rheumatic MS occurs less commonly, socioeconomically developed societies, the number of operators experienced in PBMV procedures is quite rare. PBMV can be performed safely and predictably on the wire using the approach described.

The Inoue balloon, originally developed by Toray Medical, has served as the reference technique for PBMV for many years, thanks to its self-positioning design, stepwise and adjustable diameter feature, and rapid inflation-deflation mechanism.[1] Proper transseptal puncture and safe entry into the LV are the most fundamental steps for the successful completion of PBMV.[2] In the classic Inoue technique, after appropriate transseptal puncture, a freely floating balloon is used to cross the diseased MV. However, even in experienced operators, entry into the LV can be technically difficult in challenging anatomical conditions (e.g., critical MS, severe subvalvular disease, thickening or bulging of the interatrial septum, or suboptimal transseptal puncture localization).[3] In these clinical scenarios, various modifications to the standard Inoue technique have been described (e.g., reverse loop technique, double balloon technique, vertical approach, and use of LV pressure as a guide at the left ventricular inflow tract).[4-6] An alternative technique based on guidewire support has been developed, in which the MV is crossed with a 0.025-inch coil wire and the Inoue catheter is advanced over this wire.[3] However, the inability of the 0.025-inch coil wire to provide adequate support for the Inoue balloon catheter particularly in anatomically complex cases, has prevented its establishment as a routine technique.

The prevalence of rheumatic MS and the procedural volume of PBMV remain low, even in high-income countries; consequently, operators may be unable to acquire sufficient experience with these alternative techniques. Experience with balloon-expandable valves in transcatheter MV replacement (TMVR), particularly for degenerated surgical bioprostheses or annuloplasty rings, is relatively well established. In this report, we present a step-by-step demonstration of a wire-based PBMV technique using the Inoue balloon, following

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procedural steps analogous to those employed in TMVR interventions.

CASE REPORT

A 55-year-old female had NYHA functional class III heart failure symptoms. She had a history of rheumatic fever during childhood at the age of 10 years. On clinical examination, the first heart sound (S1) was notably loud and a diastolic rumbling murmur. Electrocardiography demonstrated atrial flutter (**Figure 1**). Transthoracic echocardiography (TTE) showed preserved left ventricular and right ventricular systolic function, along with marked biatrial enlargement. With the heart rate measured at 100 beats per minute, severe rheumatic MS was present, with a mean MV gradient of 12 mmHg. The MV area was measured as 1.1 cm^2 according to measurements obtained with the pressure half-time method and 0.9 cm^2 by the continuity equation. Only trivial mitral regurgitation was observed.

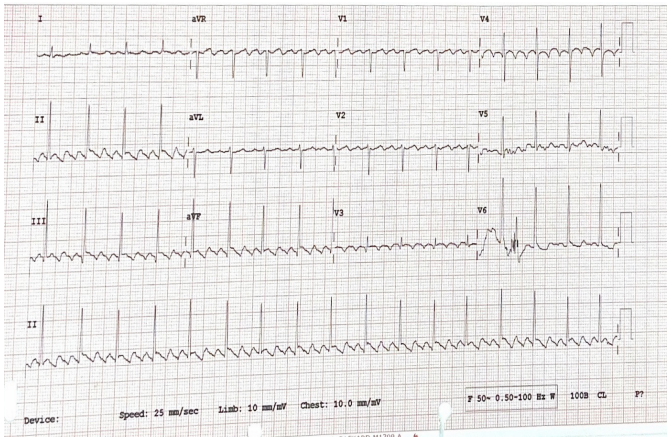


Figure 1. Atrial flutter

Transesophageal echocardiography (TEE) revealed a Wilkins score of 7, characterized by restricted leaflet motion predominantly at the leaflet bases during diastole, leaflet edge thickening, minimal subvalvular involvement, and increased echogenicity confined to a single area involving the anteromedial commissure. Assessment revealed an absence of thrombus in the left atrial chamber and appendage. Laboratory testing was largely normal, although N-terminal pro-B-type natriuretic peptide was elevated to 846 pg/ml. PBMV was planned for the patient. However, the MV could not be crossed using the classic Inoue technique. As an alternative, PBMV was planned using the Inoue balloon with a new wire-based technique.

Process Stages

The intervention was carried out with the patient under conscious sedation and TTE guidance. A 6-F pigtail catheter, inserted through right femoral arterial access, was positioned at the noncoronary aortic cusp to support transseptal puncture. A 16-F sheath was inserted through the right femoral vein. A VersaCross sheath (Boston Scientific) was then advanced through the 16-F sheath over a 0.032-inch guidewire into the left innominate vein (**Figure 2**). Subsequently, a transseptal puncture was used in the posterior position under TTE and fluoroscopic guidance. The VersaCross wire was guided into the left upper pulmonary vein. Following septostomy, a 14-F septal dilator was used over the VersaCross wire to dilate the left upper pulmonary vein. The medium-curvature steerable Agilis sheath (Abbott Vascular) was placed in the left atrium over the VersaCross wire. The wire and sheath dilator were subsequently removed. A standard 0.035-inch J-wire and a 6-F pigtail catheter were delivered to the left atrium with support from the Agilis sheath. Under TTE and fluoroscopic guidance, the steerable Agilis sheath was oriented toward the MV orifice, allowing the valve to be traversed with a pigtail catheter. A pre-shaped Safari XS wire (Boston Scientific) was then positioned to the LV apex. The pigtail catheter and Agilis sheath were subsequently removed. A 26 mm Inoue balloon was prepared to a maximum inflation size of 26 mm using standard technique (patient height: 160 cm). We then reloaded the balloon onto the Safari XS wire. The Inoue balloon was then inserted through the sheath and advanced through the septostomy and diseased MV in a tapered configuration to facilitate easier passage. The balloon was then returned to a dumbbell configuration on the Safari XS wire and inflated (**Figure 3**).

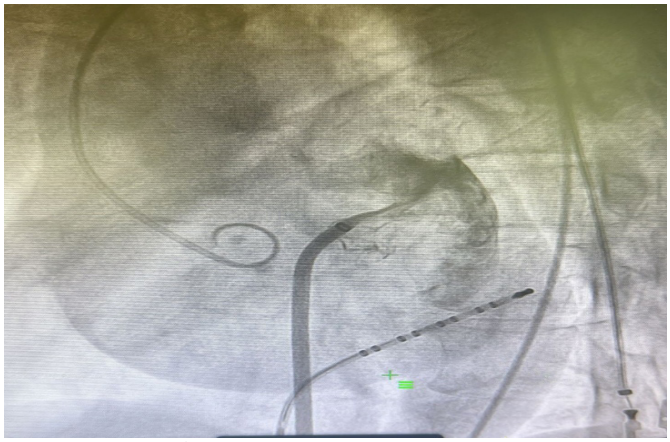


Figure 2. Transseptal puncture

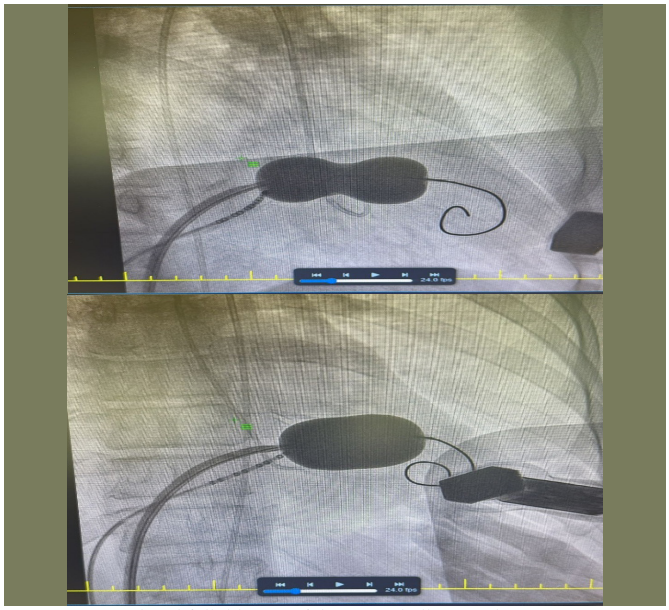


Figure 3. Partial and full dilation of the Inoue balloon catheter

Subsequently, PBMV was successfully performed in a standard manner by applying a single dilation via the wire. After the procedure, effective separation of the medial commissure, a marked increase in valve mobility, a decrease in the mean MV gradient to 4.5 mmHg by TTE (**Figure 4**), and no increase in the degree of mitral regurgitation were observed. Subsequently, the Inoue balloon was deflated. The pre-shaped

left ventricular (LV) wire was safely removed via the pigtail catheter and the venous sheath was removed to minimize the risk of MV and left ventricular damage.

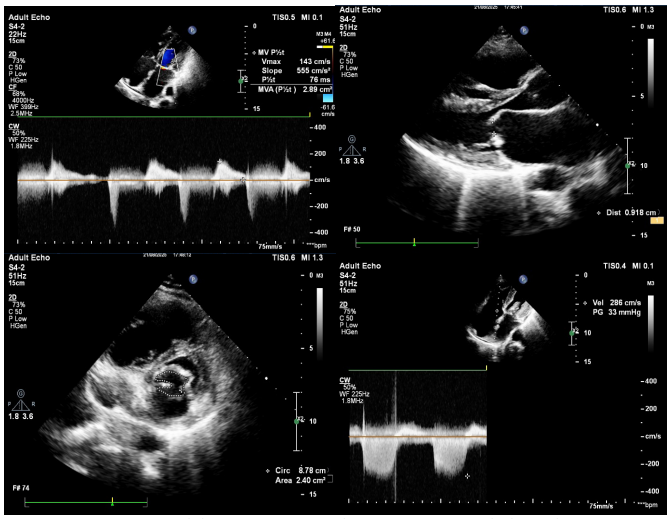


Figure 4. Parasternal long-axis view showing increased diastolic excursion and mobility of the anterior mitral leaflet. MV Doppler analysis demonstrates a mean MV gradient of 4.5 mmHg at a heart rate of 97 beats/min. The MV area was 2.89 cm² by the pressure half-time method. These echocardiographic images were obtained three months after PBMV

MV: Mitral valve, PBMV: Percutaneous balloon mitral valvuloplasty

A mean MV gradient of 5 mmHg was documented on post-procedural TTE when the heart rate was 94 beats per minute; the MV area was calculated as 1.8 cm² using the continuity equation and 2.0 cm² by pressure half-time assessment. The estimated systolic pressure of the right ventricle decreased from 50 mmHg before the procedure to 20 mmHg (**Figure 4**). The patient was discharged the next day without complications. Significant improvement in the patient's clinical symptoms was observed at the first- and third-month follow-ups.

DISCUSSION

Relative to the conventional Inoue technique, this approach requires additional devices, including a steerable Agilis sheath and a pre-shaped left ventricular wire, which may increase procedural costs and limit its routine use in resource-constrained settings. In the present case, the procedure was performed under conscious sedation with fluoroscopic and transthoracic echocardiographic guidance. The pre-shaped Safari XS wire was selected to provide stable support for balloon advancement; its position was monitored during the procedure, and it was removed through a pigtail catheter to reduce the risk of ventricular perforation, chordal entanglement, or mitral apparatus injury.

Alternative strategies have been described for technically demanding cases. In the reverse loop technique, a double loop is created in the left atrium by rotating the J-shaped stylet counterclockwise, positioning the Inoue balloon toward the MV orifice.[4] This approach may be useful in patients with marked left atrial dilatation, particularly after a low and anterior transseptal puncture.[7] Our case demonstrates the application of the previously described wire-based approach after conventional valve crossing failed. Because this report describes a single case, the safety and reproducibility of the approach require further evaluation.

CONCLUSION

This case illustrates the successful use of a previously described wire-based Inoue balloon technique after conventional MV crossing failed. A pre-shaped guidewire positioned in the LV provided support for balloon advancement, using procedural steps familiar from transcatheter MV interventions. Although the procedure was successful in this patient, its safety and reproducibility cannot be established from a single case.

ETHICAL DECLARATIONS

Informed Consent

Written informed consent was obtained from the patient included in this report. Signed consent forms are retained by the authors and are available upon request.

Peer Review Process

This report underwent external peer review.

Conflict of Interest

The authors declare no conflicts of interest.

Financial Disclosure

This case report did not receive any financial support.

Author Contributions

Concept: MAG, MK; Design: MAG, MK; Control: MAG, MK; Resources: MAG, MK; Materials: MAG, MK; Data Collection and/or Processing: MAG, MK; Analysis and/or Interpretation: MAG, MK; Literature Review: MAG, MK; Writing the Article: MAG, MK; Critical Review: MAG, MK.

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