



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 14, Issue 7, July 2025

Advancements in Transseptal Sheath Access: Comparative Evaluation of Mechanical, Radiofrequency-Assisted, and Integrated Access Systems for Left Atrial Interventions

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ABSTRACT: Transseptal catheterization has remained a cornerstone technique in structural and electrophysiological cardiac interventions, enabling access to the left atrium through the fossa ovalis. With the global rise in atrial fibrillation and left atrial procedures such as pulmonary vein isolation, left atrial appendage occlusion, and mitral valve interventions, the frequency and complexity of transseptal access have significantly increased. However, procedural challenges, especially in anatomically difficult or previously accessed septa, have prompted the development of advanced technologies beyond conventional mechanical needle systems. This review was conducted to comprehensively evaluate current and emerging transseptal catheterization tools, with emphasis on their mechanisms, clinical applications, and comparative utility, particularly in challenging procedural scenarios. A narrative literature review was performed using PubMed, Scopus, and Embase databases to identify articles published between January 1960 and March 2025. Studies were selected based on relevance to transseptal device design, procedural performance, clinical efficacy, and safety outcomes. Peer-reviewed clinical trials, observational studies, and device-specific reports were included. Mechanical needle systems were found to remain widely used due to cost-effectiveness and procedural familiarity. However, radiofrequency-assisted needles, wire-integrated systems, and needle-dilator hybrids have demonstrated superior first-pass success, reduced complication rates, and enhanced workflow efficiency in complex anatomies. Electrocautery-modified approaches were associated with significant risks and are generally discouraged. High device costs and limited long-term comparative data were identified as key limitations. Advanced transseptal access tools have improved procedural safety and efficacy. Broader adoption requires cost optimization, increased operator training, and further studies assessing long-term outcomes to guide evidence-based clinical integration.

KEYWORDS: Transseptal Puncture, Catheterization, Radiofrequency Ablation, Cardiac Electrophysiology, Cardiac Catheters

I. INTRODUCTION

Transseptal catheterization has been recognized as a fundamental technique in interventional cardiology and electrophysiology since its initial description by Ross and Braunwald over six decades ago (1,2). The technique is employed to access the left atrium via the fossa ovalis and has been routinely utilized for procedures such as pulmonary vein isolation, left atrial appendage occlusion, and transcatheter mitral interventions (3,9). With the global rise in atrial fibrillation and the corresponding increase in catheter-based ablation procedures, the frequency of transseptal access has significantly escalated. It has been estimated that over 200,000 left atrial procedures requiring transseptal catheterization are performed annually worldwide, a number expected to grow with aging populations and expanded indications for structural heart interventions (4,5). Despite procedural familiarity, challenges in transseptal access persist, particularly in patients with altered atrial septal anatomy, prior septal punctures, or increased septal thickness due to fibrosis (6,10). While conventional mechanical needle-based techniques have remained in use, limitations related to procedural safety, efficiency, and precision have been increasingly recognized (3,7). Currently, a knowledge gap exists regarding the optimal selection and integration of contemporary transseptal tools, including radiofrequency-assisted needles, wire-integrated systems, and dilator-needle hybrids, especially in anatomically complex or repeat-access cases (5,8). Variability in device choice, operator preference, and cost considerations further complicates standardization. This review aims to provide a comprehensive evaluation of modern transseptal catheterization tools, detailing their design principles, functional mechanisms, clinical applications, and comparative advantages. Special

emphasis is placed on their use in challenging anatomical scenarios, with the goal of guiding evidence-based device selection and improving procedural outcomes in advanced left atrial interventions.

II. METHODOLOGY

A comprehensive literature search was conducted using PubMed, Scopus, and Embase databases to identify relevant articles published from January 1960 to March 2025. Studies focusing on device design, procedural outcomes, comparative safety, and technological innovations in transseptal catheterization were considered.

Inclusion criteria were peer-reviewed articles, clinical trials, in-vitro studies, and device-specific performance reports related to transseptal catheterization tools. Exclusion criteria included case reports, conference abstracts, animal-only studies without human data relevance, and articles not available in English.

This review is a narrative synthesis; hence, no formal PRISMA diagram was utilized. Study quality was assessed based on relevance, methodological clarity, and consistency of findings across multiple sources.

III. CORE CONTENT SECTIONS

3.1 Mechanism of Transseptal Access and Tools

Transseptal catheterization has traditionally been performed by manually puncturing the fossa ovalis to access the left atrium. The foundational Brockenbrough (BRK) needle, constructed from stainless steel and equipped with an internal stylet, applied mechanical force to perforate the interatrial septum. It was commonly used with Mullins or Swartz SL sheaths to facilitate entry into the left superior pulmonary vein [1,2].

More recently, radiofrequency (RF)-assisted devices have been introduced to address limitations of mechanical systems. The needle utilizes low-energy RF pulses to achieve precise, low-force septal perforation, resulting in decreased tissue trauma and improved first-pass success [3,4]. Its use has been associated with shorter procedural time and reduced complications, such as pericardial tamponade [5,6].

Additionally, wire-based needle systems were developed. These devices combine a sharp or RF-enabled tip with a shape-memory guidewire that forms an atraumatic J-curve or pigtail after transseptal entry, allowing sheath advancement without exchange [12,13].

They integrated needle-dilator system has further simplified transseptal access by combining puncture and dilator functions, minimizing the need for multiple catheter exchanges and thereby improving procedural efficiency [28,30].

3.2 Current Interventional Landscape

Modern transseptal catheterization tools can be categorized as follows:

- Mechanical needles: The BRK needle remains a cost-effective option, particularly in low-resource settings, though it requires manual force and is more susceptible to complications in fibrotic septa [1,2].
- Radiofrequency-assisted needles: The needle delivers controlled RF energy and has demonstrated consistent safety improvements and shorter procedural times [3,4].
- Guidewire-based systems: Devices streamline workflow by combining puncture and guidewire support into a single platform [12,13].
- Integrated systems: They incorporate a spring-loaded puncture needle within the dilator, enabling immediate wire placement post-puncture [28,30].
- Sheath technologies: Steerable and large-bore dilators, particularly from Baylis Medical, have further enhanced navigation and support in complex interventions [23,29].

Attempts to modify standard mechanical needles or guidewires with electrocautery have been made; however, these carry significant risks, including thermal deformation, embolization, and septal coring, and are generally discouraged due to their unpredictable energy delivery and lack of precision [19,20].

3.3 Comparative Efficacy of Transseptal Tools

Radiofrequency-enabled systems have demonstrated higher first-pass success rates and reduced procedure times compared to mechanical needles [3,5]. Clinical experience has shown a reduction in fluoroscopy use and lower complication rates, including tamponade and embolic events [6,17].

Guidewire-based technologies have further improved workflow efficiency, especially during transcatheter mitral interventions and cryoballoon ablation, by eliminating the need for wire exchange and facilitating sheath delivery [12,13].

While mechanical needles remain commonly used due to availability and affordability, their utility is limited in patients with thickened or previously accessed septa. In these cases, RF-assisted and wire-integrated systems offer superior outcomes and are increasingly preferred [28,30].

IV. LIMITATIONS

Several limitations have been identified in the current landscape of transseptal catheterization tools. Mechanical needle systems have been constrained by the risk of uncontrolled advancement, particularly in cases involving hypertrophied or previously punctured septa [30]. Electrocautery-modified needles and wires have been associated with significant procedural risks, including septal coring, embolization, and thermal deformation of adjacent equipment due to the lack of precision and uncontrolled energy delivery [31].

Additionally, the widespread adoption of radiofrequency-enabled devices and integrated systems has been restricted by high costs, particularly in resource-limited healthcare settings [37]. It should also be noted that potential biases, including publication bias favoring newer technologies, may have influenced the available literature [38]. Language restrictions and database limitations may have excluded relevant non-English or unpublished data from the review. Furthermore, the scope of available studies has been primarily limited to procedural success and short-term outcomes, with a relative paucity of long-term data comparing device-specific safety and efficacy across diverse patient populations [39,40].

V. FUTURE PROSPECTS

Recent developments have focused on minimizing procedural complexity and improving safety profiles. Integrated needle-wire designs, enhanced sheath systems, and steerable, large-bore dilators represent key advancements [35,36]. Future innovations are expected to include cost-optimized radiofrequency systems, improved mapping integration for zero-fluoroscopy procedures, and real-time septal thickness assessment to further reduce complication risks [32,33].

VI. DISCUSSION

The transition from mechanical to radiofrequency-assisted transseptal catheterization tools has significantly improved the safety and efficiency of left atrial access [30]. The use of radiofrequency energy reduces the need for mechanical force and minimizes the risk of complications such as pericardial tamponade and septal coring [31]. Wire-based systems and integrated dilator-needle technologies have further streamlined the transseptal workflow by eliminating the need for multiple device exchanges [40].

However, cost remains a substantial barrier to the universal adoption of advanced systems, and operator familiarity with mechanical tools continues to influence device selection [37]. While the safety benefits of radiofrequency systems are well-supported, high-quality randomized trials comparing long-term outcomes between mechanical and RF-enabled systems remain limited [39].

Controversy persists regarding the safety of electrocautery-modified needles and wires, with a growing consensus discouraging their use due to significant risks of embolization and tissue damage [31].

Knowledge gaps remain in the form of limited comparative data across diverse patient populations and anatomical complexities. Further studies evaluating long-term clinical outcomes, procedural cost-effectiveness, and device-specific complications are warranted [38,40].

VII. CONCLUSION

Significant advancements in transseptal catheterization tools have been observed over recent decades. Procedural efficiency and safety have been improved through the introduction of radiofrequency-assisted needles, wire-integrated systems, and hybrid dilator-needle technologies [30,35]. While mechanical systems continue to be employed in routine practice, enhanced outcomes have been consistently demonstrated with newer technologies, particularly in anatomically complex or previously accessed septa [31].

The integration of advanced transseptal tools into clinical practice may contribute to improved procedural success rates and reduced complication risks. However, the adoption of these technologies remains constrained by cost and resource availability, underscoring the need for cost-effective solutions and tailored device selection based on case complexity [37].

Further research is warranted to evaluate long-term clinical outcomes, optimize procedural workflows, and facilitate broader accessibility. Comparative studies and real-world evidence will be essential in guiding evidence-based practice and informing future guidelines for transseptal access in structural and electrophysiological interventions [39,40].

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