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PATENT FORAMEN OVALE CLOSURE: CURRENT THERAPEUTIC STRATEGIES WITH PARTICULAR FOCUS ON BIODEGRADABLE AND NON-BIODEGRADABLE OCCLUDERS

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ABSTRACT

Introduction: Percutaneous closure of patent foramen ovale (PFO) has become an established strategy for the secondary prevention of cryptogenic stroke in carefully selected patients. Although conventional non-biodegradable occluders remain the current standard of care, the search for technologies that reduce long-term device-related complications has led to the development of biodegradable occluders and implant-free closure techniques.

Materials and Methods: This narrative review summarizes the current evidence published between 2018 and 2026 regarding transcatheter PFO closure. Clinical trials, observational studies, registries and case reports evaluating conventional metallic occluders, biodegradable devices, and the NobleStitch EL suture-mediated system were analyzed with particular emphasis on procedural efficacy, safety, residual shunting, and long-term clinical outcomes.

Results: Conventional metallic occluders demonstrated excellent long-term efficacy and safety and remain the reference standard for PFO closure. Biodegradable devices showed comparable procedural success while offering the potential advantage of gradual implant resorption and improved biocompatibility. The NobleStitch EL system provides an implant-free alternative, although its effectiveness depends largely on favourable PFO anatomy and appropriate patient selection.

Conclusions: Emerging technologies broaden the therapeutic options for transcatheter PFO closure. While conventional occluders remain the gold standard, biodegradable devices and suture-mediated techniques represent promising alternatives that warrant further evaluation in large prospective studies with long-term follow-up.

KEYWORDS

Patent Foramen Ovale, Biodegradable Occluders, Non-biodegradable Occluders, NobleStitch EL, Pansy® Occluder, Cryptogenic Stroke

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Introduction:

Patent foramen ovale (PFO) is a common congenital cardiac abnormality affecting approximately one-quarter of the general population. Although usually asymptomatic, it has been strongly associated with cryptogenic ischaemic stroke, and transcatheter PFO closure has become an established strategy for secondary stroke prevention in carefully selected patients. Conventional non-biodegradable occluders remain the most widely used devices owing to their excellent procedural success and well-documented long-term outcomes. However, permanent intracardiac implants may be associated with complications such as residual shunting, device-related thrombosis, atrial arrhythmias, and, rarely, hypersensitivity reactions. These limitations have driven the development of biodegradable occluders and implant-free closure techniques, including the NobleStitch EL system, which aim to improve long-term biocompatibility while maintaining procedural efficacy. This review provides a comprehensive overview and comparison of currently available transcatheter PFO closure strategies currently available transcatheter PFO closure strategies, including conventional metallic occluders, biodegradable devices, and the NobleStitch EL system, with particular emphasis on their efficacy, safety, advantages, limitations, and future clinical perspectives.

Biodegradable Occluders:

Biodegradable occluders have been developed to overcome the limitations associated with permanent metallic implants while maintaining the high efficacy of transcatheter PFO closure. Their gradual degradation after successful endothelialisation is intended to preserve the structural integrity of the interatrial septum, potentially reducing the risk of long-term device-related complications and facilitating future transseptal cardiac interventions. In a prospective, multicentre, randomised trial, Zhang et al. evaluated the efficacy and safety of a novel biodegradable occluder designed for transcatheter PFO closure. The device consisted of a framework manufactured from polydioxanone (PDO) and poly-L-lactic acid (PLLA). A total of 190 patients were enrolled and randomly assigned to receive either the biodegradable device (n = 96) or a conventional nitinol occluder (n = 94). The primary endpoint was complete PFO closure at six months, assessed by contrast

transthoracic echocardiography. The biodegradable device demonstrated efficacy comparable to that of the standard nitinol occluder. Complete closure was achieved in 90.63% of patients treated with the biodegradable device and in 91.49% of those receiving the conventional occluder, successfully meeting the predefined non-inferiority endpoint. During the 24-month follow-up period, progressive degradation of the implant was observed, with complete disappearance of the device on echocardiographic imaging after two years. No deaths, device-related thrombosis, atrial septal erosion, or embolic complications were reported. The only serious adverse event consisted of device deformation during implantation in one patient, requiring surgical intervention. Based on these findings, the authors concluded that the biodegradable occluder provided efficacy and safety comparable to conventional nitinol devices over a two-year follow-up period while offering the additional advantage of gradual implant resorption. [1] Additional evidence supporting biodegradable technology was provided by the evaluation of the Pansy® PFO Occluder, a biodegradable closure system developed for patients with significant right-to-left shunting. The procedure was successfully completed in all 137 enrolled patients without any intraprocedural complications, corresponding to a procedural success rate of 100%. Follow-up demonstrated encouraging closure rates. No left-to-right shunts were detected at 12 months. Contrast echocardiography performed six months after implantation revealed a small residual right-to-left shunt during the Valsalva manoeuvre in only 2.9% of patients, whereas moderate or severe residual shunting was observed in 19.7%. Importantly, residual shunts were generally less pronounced than before intervention. By 12 months, only 2.9% of patients continued to exhibit moderate or severe residual shunting, indicating progressive sealing of the interatrial septum during follow-up. Device-related thrombosis (DRT) and residual shunting represented the most frequently observed complications. Three patients developed DRT, all of whom responded successfully to anticoagulant therapy without long-term sequelae. Two cases of small asymptomatic pericardial effusion and two episodes of transient atrial ectopic beats were also reported. The investigators suggested that persistent residual shunting was predominantly associated with unfavourable anatomical characteristics, including a long PFO tunnel, atrial septal aneurysm, or the presence of additional interatrial septal defects, highlighting the importance of careful anatomical patient selection before implantation. Overall, the Pansy® system was considered a safe and effective treatment option, although the authors emphasised the need for longer-term clinical evaluation. [2]

The feasibility of biodegradable occluders has also been demonstrated in complex anatomical scenarios. A recently published case report described a 29-year-old woman with a longstanding history of migraine with aura refractory to medical therapy. Echocardiographic assessment revealed a large and anatomically complex PFO associated with an atrial septal aneurysm (ASA) and two small atrial septal defects (ASDs). Owing to this challenging anatomy, transcatheter closure was performed using a novel 34-mm biodegradable PFO-NBO occluder. The procedure was completed successfully without complications, achieving optimal device positioning and immediate elimination of the interatrial shunt. During two years of follow-up, gradual biodegradation of the implant was documented while maintaining complete closure of the PFO. No cardiac arrhythmias or other significant device-related adverse events occurred. Moreover, the patient experienced substantial clinical improvement, with both the frequency and severity of migraine attacks markedly reduced. According to the authors, this case illustrates that the biodegradable PFO-NBO device may represent a safe and effective therapeutic option even in anatomically complex PFO associated with ASA and small ASDs. An additional theoretical advantage of biodegradable technology is the preservation of native atrial septal tissue after device resorption, which may facilitate future transseptal procedures requiring access to the left atrium. [6] Potential applications of biodegradable occluders have also been reported in the management of residual shunts following previous PFO closure. A case report described a 52-year-old woman who experienced recurrent ischaemic stroke and persistent migraine symptoms 20 months after implantation of an 18-mm ceramic-coated Lifetech ASD occluder. Imaging studies demonstrated a residual interatrial shunt caused by incomplete device apposition and insufficient endothelialisation of the original implant. A repeat transcatheter intervention was therefore performed using the Memosorb biodegradable PFO occluder. The procedure resulted in complete closure of the residual defect, as confirmed by angiography and follow-up echocardiography. Throughout subsequent follow-up, no recurrent right-to-left shunting was detected, while the patient reported complete resolution of neurological symptoms together with a marked reduction in migraine frequency. The authors suggested that biodegradable occluders may provide a valuable therapeutic alternative in patients presenting with residual shunts after previous PFO closure. Their potential advantages include improved adaptation to the anatomy of the interatrial septum, excellent biocompatibility, and the possibility of reducing long-term complications associated with permanent metallic implants. [7]

Non-Biodegradable Occluders:

Conventional non-biodegradable occluders remain the cornerstone of transcatheter patent foramen ovale (PFO) closure owing to their well-established efficacy, favourable safety profile, and extensive long-term clinical evidence. Several devices have demonstrated excellent procedural success and durable prevention of recurrent cerebrovascular events, although differences in device design may influence the spectrum of procedure-related and long-term complications. A comparative evaluation of the most commonly used metallic occluders was performed using a matching-adjusted indirect comparison (MAIC) methodology, allowing indirect assessment of the Gore Helex Septal Occluder, Gore Cardioform Septal Occluder, and Amplatzer PFO Occluder in the absence of direct head-to-head clinical trials. By adjusting baseline characteristics between study populations, the authors sought to minimise potential confounding and improve the validity of the comparison. The analysis demonstrated no statistically significant differences between the evaluated devices with respect to recurrent ischaemic stroke prevention. Similarly, procedural safety was comparable across all systems, with no significant differences in the incidence of serious device-related adverse events. The occurrence of atrial fibrillation or atrial flutter—among the most frequently reported complications following transcatheter PFO closure—was likewise comparable between the investigated devices. Overall, the available evidence indicates that the Gore Helex, Gore Cardioform, and Amplatzer PFO occluders provide similar clinical efficacy and comparable safety profiles. Consequently, device selection should primarily depend on individual patient anatomy, PFO morphology, and operator experience rather than on expectations of superior clinical performance associated with a particular occluder. [14] One of the major concerns associated with permanent metallic occluders is the presence of nickel-containing nitinol, which may trigger hypersensitivity reactions in susceptible individuals. This issue was specifically addressed in a prospective, randomised, double-blind clinical trial evaluating the impact of nickel allergy on outcomes after PFO closure using the Amplatzer PFO Occluder and the Gore Cardioform Septal Occluder. Ninety-six patients with cryptogenic stroke attributed to PFO underwent preprocedural patch testing for nickel hypersensitivity and were subsequently followed to assess both procedural efficacy and implant-related symptoms.

Patients with positive patch-test results experienced device syndrome significantly more frequently than those without nickel hypersensitivity. Clinical manifestations included palpitations, migraine, chest discomfort, dyspnoea, and cutaneous reactions, with palpitations and newly developed or worsening migraine representing the most prominent symptoms. These findings suggest that an immune-mediated response to nickel released from the implanted device may contribute to post-procedural symptom development.

Importantly, nickel hypersensitivity had no measurable impact on major clinical outcomes. Rates of recurrent stroke, transient ischaemic attack, major arrhythmias, bleeding complications, and overall procedural success were comparable regardless of allergy status. Likewise, no differences were observed between the Amplatzer and Gore Cardioform devices regarding efficacy or safety. The authors therefore concluded that nickel allergy should not be regarded as a contraindication to transcatheter PFO closure. Nevertheless, the increased prevalence of subjective symptoms among sensitised patients highlights a limitation of permanent nitinol implants and supports continued development of alternative technologies, including biodegradable occluders, devices with improved biocompatibility, and implant-free closure techniques. Such innovations may reduce implant-related symptoms while preserving the proven effectiveness of transcatheter PFO closure in secondary stroke prevention. [15] Further insight into the long-term performance of conventional metallic occluders has been provided by a large retrospective analysis encompassing 23 years of experience at a single tertiary centre. The study included 716 patients undergoing PFO closure using one of four devices: Occlutech PFO Occluder, Amplatzer PFO Occluder, Gore Septal Occluder, or Cardia PFO-Star. Most procedures were performed for secondary prevention following cryptogenic stroke, while the remaining patients underwent closure because of transient ischaemic attack or peripheral embolic events. Overall procedural success reached 98.9%, with a very low incidence of major periprocedural complications that did not differ significantly between devices. During twelve months of follow-up, the frequency of residual shunting progressively declined, reflecting successful endothelialisation and durable closure of the interatrial communication. Similarly, no significant differences were observed regarding recurrent stroke or transient ischaemic attack among the evaluated occluders. Despite comparable efficacy, individual devices demonstrated distinct long-term complication profiles. Cardia PFO-Star was more frequently associated with delayed pericardial effusion and tissue erosion, whereas implantation of the Gore Septal Occluder resulted in a higher incidence of device-related thrombus formation. Newly diagnosed atrial fibrillation remained the most common late complication after PFO closure, occurring most frequently in the Gore Septal Occluder group, although intergroup differences did not reach statistical significance. The authors concluded that all contemporary metallic

occluders provide excellent procedural efficacy and favourable long-term clinical outcomes. Nevertheless, variations in device-specific complication profiles indicate that occluder selection should not rely solely on technical characteristics but should also consider individual patient anatomy, PFO morphology, and operator expertise. They further emphasised the need for prolonged follow-up studies evaluating newer generations of occluders to better define their long-term safety and clinical performance [17]. Long-term outcomes of conventional metallic occluders and Advances in surface-modified Devices. Additional evidence regarding the long-term performance of conventional metallic occluders has been provided by a retrospective study including 130 patients who underwent transcatheter PFO closure following cryptogenic stroke or stroke attributed to the presence of PFO. The investigators compared clinical outcomes between patients treated with the Amplatzer PFO Occluder and those receiving other commercially available devices, including the Occlutech, Cardiofix, and Biostar occluders. The primary objective was to evaluate the incidence of major adverse cardiovascular events (MACE), including recurrent stroke, newly diagnosed atrial fibrillation, and all-cause mortality during long-term follow-up. The study demonstrated comparable efficacy and safety across all investigated devices. No statistically significant differences were observed in recurrent ischaemic stroke, atrial fibrillation, or all-cause mortality between patients treated with the Amplatzer occluder and those receiving alternative closure systems. Likewise, Kaplan–Meier survival analysis revealed no significant differences in event-free survival between the study groups. Cox proportional hazards regression failed to identify any independent predictors of adverse clinical outcomes, including age, sex, comorbidities, occluder type, or device size. These findings further support the excellent long-term efficacy of transcatheter PFO closure irrespective of the metallic occluder used. The persistently low incidence of recurrent stroke and other major cardiovascular events suggests that both the Amplatzer PFO Occluder and other commercially available devices provide durable therapeutic benefit with comparable long-term safety. Nevertheless, the authors acknowledged several limitations of their study, including its retrospective design, relatively small sample size, and the heterogeneity of devices included in the comparison, highlighting the need for larger prospective studies to validate these observations. [18] In light of the previously discussed association between nickel hypersensitivity and device syndrome following implantation of conventional nitinol occluders, particular attention has recently been directed towards devices designed to minimise patient exposure to nickel. One such solution is the Cocoon occluder, which incorporates a nanostructured platinum coating covering the nitinol framework and thereby reduces direct contact between surrounding tissues and nickel ions. The clinical performance of this technology was evaluated in a retrospective observational study involving 21 patients with confirmed nickel hypersensitivity who underwent transcatheter closure of either PFO or atrial septal defect (ASD) using the Cocoon occluder. The majority of interventions were performed for secondary prevention after cryptogenic stroke associated with PFO. Patients were followed for a median of 27 months. Throughout the observation period, no serious device-related adverse events were reported. One patient developed mild transient dermatitis, while another experienced short-lasting palpitations without documented arrhythmia on Holter monitoring. Importantly, no cases of severe allergic reactions, device-related thrombosis, device embolisation, or explantation were observed. Interestingly, nickel hypersensitivity was frequently accompanied by allergy to other metals. Additional metal hypersensitivity was identified in 38.1% of patients, most commonly involving palladium, cobalt, gold, and chromium. Despite this coexistence of multiple metal allergies, no severe hypersensitivity reactions or complications requiring device removal occurred during follow-up. The authors noted that implantation of conventional nitinol occluders may be associated with a transient increase in circulating nickel concentrations, representing a potential concern in sensitised individuals. By contrast, the Cocoon occluder employs a nanoplatinum coating that enhances biocompatibility while limiting nickel ion release from the nitinol framework. According to the presented results, this technology appears to represent a safe therapeutic option for patients with confirmed nickel hypersensitivity. Nevertheless, the authors emphasised that larger comparative studies are required before definitive conclusions regarding its superiority over conventional nitinol devices can be drawn. [19] Further evidence supporting this novel surface-modified technology has recently been provided by the PROS-IT Registry, a prospective multicentre study specifically designed to evaluate the efficacy and safety of the Cocoon PFO Occluder. The registry enrolled 189 consecutive patients treated at 15 Italian centres between 2018 and 2020. The principal indications for PFO closure included cryptogenic stroke, transient ischaemic attack (TIA), medically refractory migraine, and professional indications requiring elimination of right-to-left shunting. Patients were followed for two years, during which both procedural efficacy and the incidence of early and late complications were systematically assessed. The Cocoon PFO Occluder is a self-expanding double-disc nitinol device coated with a nanostructured platinum layer. Although its overall design closely resembles that of the widely used

Amplatzer PFO Occluder, the nanoplatinum coating represents its principal technological innovation. According to the authors, this surface modification serves as a protective barrier that limits nickel ion release into the bloodstream, thereby potentially reducing the risk of hypersensitivity reactions in susceptible patients while simultaneously improving overall device biocompatibility. The nanoplatinum coating may additionally reduce local inflammatory responses while decreasing the risk of cardiac tissue injury and device-related thrombus formation by providing a smoother implant surface. The study population primarily consisted of patients with a high probability of a causal relationship between PFO and a previous neurological event. Cryptogenic stroke represented the most frequent indication for transcatheter closure, while a substantial proportion of patients also presented with an atrial septal aneurysm (ASA), a recognised anatomical feature associated with an increased risk of paradoxical embolism. Procedures were performed according to contemporary standards for transcatheter PFO closure, with transoesophageal echocardiography (TEE) serving as the principal imaging modality for preprocedural assessment of atrial septal anatomy, device sizing, and intraprocedural guidance. Occluder size was selected individually according to the anatomical characteristics of the interatrial septum and PFO tunnel morphology. The registry demonstrated excellent procedural efficacy. Device implantation was successful in every patient, and the vast majority achieved complete closure immediately after the procedure. Only a small proportion of patients exhibited minimal residual shunting, whereas no moderate or severe residual shunts were detected. Follow-up imaging performed throughout the two-year observation period confirmed durable PFO closure and the absence of clinically significant residual interatrial shunting in all participants. The safety profile of the Cocoon PFO Occluder was equally favourable. No deaths, recurrent strokes, cardiac tamponade, device embolisation, or device malposition occurred during the periprocedural period. Only one episode of paroxysmal supraventricular tachycardia and one significant vascular access-site bleeding event were reported. No additional major procedure-related adverse events occurred during hospitalisation. Long-term follow-up further confirmed the excellent safety profile of the device. Notably, no cases of cardiac erosion, device-related thrombosis, device embolisation, or infective endocarditis were observed. Equally important, no allergic reactions attributable to nickel exposure were reported, representing one of the most significant findings of the registry. The only clinically relevant late complication consisted of two cases of paroxysmal atrial fibrillation, both occurring within the first weeks after implantation and successfully managed with pharmacological therapy. No recurrent stroke or other cerebrovascular ischaemic events were documented throughout the follow-up period. In their discussion, the authors emphasised that nickel hypersensitivity remains one of the principal limitations of conventional nitinol-based occluders. Previous reports have described both localised and systemic allergic reactions following implantation of devices such as the Amplatzer PFO Occluder, PFO-Star, and Gore Helex Septal Occluder. Nevertheless, they also pointed out that clinically significant hypersensitivity reactions remain relatively uncommon, and surgical device explantation is required only in exceptional circumstances. The principal innovation of the Cocoon PFO Occluder lies in its nanostructured platinum coating, which acts as a protective barrier limiting nickel ion release during the period preceding complete endothelialisation. The authors also referred to previous experimental investigations demonstrating that implantation of this device was not associated with increased circulating nickel concentrations, further supporting its improved biocompatibility. However, they acknowledged that direct comparative studies are still required to establish whether these theoretical advantages translate into meaningful long-term clinical benefits. Another important aspect discussed by the investigators concerns device-related thrombosis. They proposed that the polypropylene filling incorporated into the occluder may contribute to reducing thrombus formation on the implant surface. Despite the presence of coagulation disorders in a proportion of the study population, no cases of device-related thrombosis were identified during follow-up, providing additional evidence supporting the favourable safety profile of this system. Nonetheless, the authors stressed that definitive conclusions regarding the superiority of the Cocoon device over conventional nitinol occluders will require adequately powered head-to-head comparative studies. Overall, the findings of the PROS-IT Registry indicate that the Cocoon PFO Occluder is both an effective and safe option for transcatheter PFO closure. High rates of durable defect closure, the low incidence of device-related complications, and the absence of clinically significant nickel hypersensitivity reactions suggest that the incorporation of a nanoplatinum coating may represent an important step towards improving the biocompatibility of metallic occluders. However, the authors appropriately emphasise that larger prospective controlled studies with extended follow-up are required before this technology can be considered superior to conventional nitinol-based devices. [20]

Suture-Mediated PFO Closure: The NobleStitch EL System:

One of the most recent developments in transcatheter PFO closure is the introduction of implant-free closure techniques, designed to eliminate the need for permanent intracardiac devices. The NobleStitch EL system represents the best-established example of this approach, using a dedicated suture-mediated technique to approximate the septum primum and septum secundum without implanting a conventional double-disc occluder. According to the available evidence, this strategy has the potential to reduce complications associated with permanent metallic implants while preserving the effectiveness of transcatheter PFO closure. Nevertheless, long-term clinical experience remains limited, and further studies are required to define its role in routine clinical practice. [12] A crucial aspect of NobleStitch EL therapy is appropriate patient selection, as procedural success appears to depend largely on the anatomical characteristics of the PFO. In a multicentre study including 55 patients, investigators evaluated both the efficacy of suture-mediated PFO closure and the influence of atrial septal anatomy on procedural outcomes. Successful closure was significantly associated with shorter PFO tunnel length, smaller defect diameter, and lower tunnel volume. Periprocedural complications were uncommon, and only a single recurrent stroke occurred during follow-up. However, a proportion of patients developed clinically significant residual right-to-left shunting requiring secondary implantation of a conventional double-disc occluder. These findings emphasise that detailed preprocedural echocardiographic assessment is essential for identifying patients most likely to benefit from the NobleStitch EL system. [4] The available evidence has also been evaluated in a health technology assessment (HTA) comparing NobleStitch EL with the Amplatzer PFO Occluder. The analysis indicated that both techniques achieve high procedural and clinical success. However, owing to the absence of direct comparative clinical trials, the superiority of either approach could not be established. The principal theoretical advantage of NobleStitch EL is the absence of a permanent intracardiac implant, which may reduce long-term device-related complications and preserve the native anatomy of the interatrial septum. Conversely, the procedure was associated with higher treatment costs, and the currently available evidence was considered insufficient to recommend one strategy over the other. [5] Additional evidence supporting the feasibility of this technology has been provided by the NobleStitch EL Registry, reported by Gaspardone et al., which included 200 consecutive patients referred for transcatheter PFO closure. Anatomical characteristics were considered suitable for suture-mediated closure in 192 patients, while successful implantation was achieved in 186 cases, corresponding to a procedural success rate of 96%. During a mean follow-up of approximately seven months, complete closure of the interatrial communication was achieved in 75% of patients, whereas effective closure, defined as residual right-to-left shunting not exceeding grade 1, was documented in 89%. Importantly, no recurrent strokes, transient ischaemic attacks, atrial fibrillation, or major device-related complications were reported during follow-up. Based on these findings, the authors concluded that NobleStitch EL represents a safe and effective alternative to conventional occluder devices. Furthermore, elimination of a permanent implant may facilitate future transseptal cardiac procedures while reducing the risk of implant-related complications. [8] Further prospective evidence was provided by Beneduce et al., who evaluated the safety and efficacy of the NobleStitch EL system in 80 consecutive patients undergoing transcatheter PFO closure. Procedural success was achieved in 94% of cases. Follow-up transoesophageal echocardiography demonstrated effective closure, defined as absent or trivial right-to-left shunting ($RLS \leq 1$), in 82% of patients, while complete closure was achieved in 62%. No cases of device embolisation or detachment of the suture system were observed. However, isolated cases of device-related thrombosis and atrial septal injury were reported. Compared with conventional occluders, the overall closure rate appeared slightly lower. Nevertheless, the favourable safety profile and the absence of a permanent intracardiac implant make NobleStitch EL an attractive therapeutic option for carefully selected patients. The investigators additionally demonstrated that a PFO width greater than 4 mm and a tunnel length shorter than 10 mm were independently associated with an increased likelihood of incomplete closure following the procedure. [9] Complementary data were reported by Zannoni et al., who specifically investigated the mechanisms responsible for unsuccessful PFO closure following NobleStitch EL implantation. Their study included 122 patients undergoing suture-mediated closure. Although procedural success was high, approximately one-fifth of patients developed clinically significant residual right-to-left shunting during follow-up. Detailed transoesophageal echocardiographic evaluation identified the principal mechanisms responsible for procedural failure. The most common cause was partial suture dehiscence, resulting in reopening of the PFO tunnel and recurrence of right-to-left shunting. Less frequently, investigators observed atrial septal laceration adjacent to the suture site and embolisation of the Kwiknot fastening system into the pulmonary circulation. The study further demonstrated that several anatomical features—including atrial septal aneurysm, excessive septal mobility, the presence of a Chiari

network, and greater PFO width—were associated with an increased risk of procedural failure. The authors therefore emphasised the importance of comprehensive preprocedural anatomical assessment together with systematic echocardiographic follow-up after intervention. According to their conclusions, improved patient selection and optimisation of implantation technique are likely to enhance the long-term effectiveness of the NobleStitch EL system. [10]

Comparison of Biodegradable Occluders, Conventional Metallic Occluders, and the NobleStitch EL System:

Direct comparisons between contemporary PFO closure strategies remain limited. However, recently published studies have provided valuable insight into the relative efficacy and safety of biodegradable occluders, conventional metallic devices, and implant-free suture-mediated techniques. In 2026, the first comparative study evaluating a fully biodegradable occluder was published. The investigators compared the Pansy® biodegradable occluder with conventional non-biodegradable devices in patients undergoing transcatheter PFO closure. The analysis included patients treated between 2019 and 2020, ultimately comparing 44 patients receiving the Pansy® device with 88 matched controls treated using conventional metallic occluders. Procedural success was achieved in 100% of patients in both groups. No deaths or major procedural complications were reported. The only clinically relevant difference was a higher incidence of device-related thrombosis (DRT) in the biodegradable occluder group. Importantly, all thrombi resolved after two to three months of rivaroxaban therapy without embolic complications or permanent clinical consequences. Device efficacy remained comparable throughout follow-up, with successful PFO closure rates of 88.64% versus 87.50% at six months and 95.45% versus 92.31% after twelve months for the biodegradable and conventional occluders, respectively. Based on these findings, the authors concluded that the Pansy® occluder provides clinical efficacy and overall safety comparable to established metallic devices while offering the potential long-term advantages associated with gradual implant degradation. [3] Alongside the development of biodegradable occluders, increasing attention has been directed towards implant-free approaches designed to eliminate permanent intracardiac devices altogether. In this context, a retrospective single-centre study compared conventional metallic occluders (Amplatzer PFO Occluder and Gore Cardioform Septal Occluder) with the NobleStitch EL suture-mediated closure system. The study included 55 consecutive patients, all treated by the same experienced operator, thereby minimising variability related to procedural technique. Both procedural characteristics and clinical outcomes were evaluated during a follow-up period of at least six months. Complete procedural success was achieved in all patients, with no major intraprocedural complications or deaths reported in either treatment group. Clinical efficacy proved comparable, and no patient developed clinically significant residual interatrial shunting during follow-up. In several patients treated with NobleStitch EL, placement of an additional suture was required to achieve complete closure. Importantly, this did not correlate with unfavourable anatomical characteristics such as a long PFO tunnel or atrial septal aneurysm. The investigators emphasised that the need for additional sutures should be regarded as part of the procedural strategy rather than as evidence of technical failure. Serial echocardiographic examinations performed before hospital discharge and during follow-up confirmed sustained closure of the interatrial communication, with no recurrence of clinically significant residual shunting in either group. Particularly noteworthy were the findings concerning procedural safety. Atrial fibrillation, the most frequently reported complication following transcatheter PFO closure, occurred exclusively in patients treated with conventional metallic occluders. Although all affected patients required temporary anticoagulant therapy, none experienced recurrent stroke or additional neurological complications. By contrast, no cases of atrial fibrillation were observed following NobleStitch EL implantation. While the relatively small study population precluded statistical confirmation of this difference, the authors suggested that the absence of a permanent intracardiac implant may contribute to a lower incidence of post-procedural atrial arrhythmias. The investigators additionally highlighted several practical advantages of the suture-mediated approach. Elimination of a permanent implant may represent an important benefit in patients with nickel hypersensitivity, coagulation disorders, or those likely to require future transseptal access to the left atrium for electrophysiological or structural heart interventions. Nevertheless, they acknowledged that the retrospective design, limited sample size, and single-centre nature of the study substantially restrict the generalisability of the findings. Consequently, larger prospective multicentre trials are needed to define the precise role of the NobleStitch EL system in contemporary PFO management and to determine whether the observed reduction in atrial fibrillation can be confirmed in broader patient populations. [16]

Conclusions:

Transcatheter closure of patent foramen ovale has become a well-established therapeutic strategy for the secondary prevention of cryptogenic stroke in appropriately selected patients. Conventional non-biodegradable occluders continue to represent the reference standard owing to their excellent procedural success, durable long-term outcomes, and well-established safety profile. Recent technological advances have expanded the range of available treatment options. Biodegradable occluders demonstrate encouraging early and mid-term results while offering the potential advantage of reducing the long-term presence of foreign material within the heart. Similarly, the implant-free NobleStitch EL system represents an innovative alternative that may be particularly beneficial in selected patients, although its success remains highly dependent on favourable PFO anatomy. Current evidence suggests that no single closure strategy is optimal for every patient. The choice of treatment should therefore be individualized, taking into account anatomical characteristics, clinical indications, device-specific features, and operator experience. Further large-scale prospective studies with long-term follow-up are required to better define the role of emerging technologies and to determine whether they provide clinically meaningful advantages over conventional metallic occluders.

As transcatheter PFO closure continues to evolve, future therapeutic strategies are likely to focus not only on achieving effective defect closure but also on improving long-term biocompatibility and enabling a more personalized approach to patient management.

REFERENCES

1. Zhang, F., Dong, J., Wei, P., Fang, W., Hu, H., Kong, X., Bai, M., Pan, J., Luo, Z., Zhang, P., Qu, B., Hu, J., Lu, Y., Wang, C., Wang, S., & Pan, X. (2026). Transcatheter closure of patent foramen ovale with a novel biodegradable device: A prospective, multicenter, randomized controlled clinical trial. *Circulation*, 153(2), 71–81. <https://doi.org/10.1161/CIRCULATIONAHA.125.074609>
2. He, L., Xie, H., Gao, Y., Zhang, G., Shen, Q., Wang, M., Wang, Q., Wang, Y., Du, Y., Zhu, X., & Zhang, Y. (2025). Biodegradable Pansy® occluder for patent foramen ovale closure: A multicenter, single-arm, prospective study. *Frontiers in Cardiovascular Medicine*, 12, Article 1464712. <https://doi.org/10.3389/fcvm.2025.1464712>
3. Li, B., Zeng, H., Xie, H., Lan, B., & Zhang, Y. (2026). Safety and efficacy of a novel biodegradable Pansy® occluder compared with traditional non-degradable occluders in the closure of patent foramen ovale. *Frontiers in Cardiovascular Medicine*, 13, Article 1704287. <https://doi.org/10.3389/fcvm.2026.1704287>
4. Witte, L. S., Renkens, M. P. L., Gasecka, A., El Bouziani, A., De Winter, R. J., Tijssen, J. G. P., Stella, P. R., Leibundgut, G., & Voskuil, M. (2023). Anatomical predictors for suture-based closure of the patent foramen ovale: A multicenter experience. *Catheterization and Cardiovascular Interventions*, 102(2), 273–280. <https://doi.org/10.1002/ccd.30691>
5. Gaetti, G., Beneduce, A., La Fauci, D., Scardoni, A., Chiappa, F., Bellini, L., Franzin, M., Natale, A. M., Marras, P., Ranieri, P., Signorelli, C., Bossi, E., Ferrario, L., Foglia, E., Montorfano, M., & Odone, A. (2022). Suture-mediated patent foramen ovale closure using the NobleStitch EL: Results from a hospital-based health technology assessment. *International Journal of Environmental Research and Public Health*, 19(13), Article 7863. <https://doi.org/10.3390/ijerph19137863>
6. Du, Y., Xie, H., Wang, X., Shao, H., He, L., & Zhang, Y. (2023). Successful percutaneous closure of a large complex patent foramen ovale with an atrial septal aneurysm and two small atrial septal defects using a novel biodegradable occluder. *European Heart Journal – Case Reports*, 7(2), yta043. <https://doi.org/10.1093/ehjcr/yta043>
7. Luo, D., Guan, L., Li, H., Lv, J., Hu, H., & Pan, X. (2025). Percutaneous closure of residual shunt after patent foramen ovale closure with a biodegradable occluder. *JACC: Case Reports*, 30(40), Article 105901. <https://doi.org/10.1016/j.jaccas.2025.105901>
8. Gaspardone, A., De Marco, F., Sgueglia, G. A., De Santis, A., Iamele, M., D'Ascoli, E., Tusa, M., Corciu, A., Mullen, M., Nobles, A., Carminati, M., & Bedogni, F. (2018). Novel percutaneous suture-mediated patent foramen ovale closure technique: Early results of the NobleStitch EL Italian Registry. *EuroIntervention*, 14(3), e272–e279. <https://doi.org/10.4244/EIJ-D-18-00023>
9. Beneduce, A., Ancona, M. B., Moroni, F., Ancona, F., Ingallina, G., Melillo, F., Russo, F., Ferri, L. A., Bellini, B., Vella, C., Chieffo, A., Agricola, E., & Montorfano, M. (2022). A systematic transoesophageal echocardiography study of suture-mediated percutaneous patent foramen ovale closure. *EuroIntervention*, 18(1), 63–67. <https://doi.org/10.4244/EIJ-D-21-00242>

10. Zannoni, J., Popolo Rubbio, A., Tusa, M. B., Corciu, A. I., Casenghi, M., Cannone, G., Barletta, M., Stefanini, E., Mantovani, V., Gorla, R., Brambilla, N., Testa, L., Bedogni, F., & De Marco, F. (2022). Mechanisms of ineffective patent foramen ovale closure using the percutaneous suture-mediated NobleStitch system. *EuroIntervention*, 18(1), 68–70. <https://doi.org/10.4244/EIJ-D-21-01021>
11. Randhawa, S., Mehta, J. L., & Dhar, G. (2024). Percutaneous patent foramen ovale closure: Stroke and beyond. *Current Cardiology Reviews*, 20(3), 77–86. <https://doi.org/10.2174/011573403X276984240304044109>
12. Sperlongano, S., Giordano, M., Ciccarelli, G., Bassi, G., Malvezzi Caracciolo D'Aquino, M., Del Giudice, C., Gaio, G., D'Andrea, A., Postolache, A., Cappelli Bigazzi, M., Scognamiglio, G., Sarubbi, B., Russo, M. G., Golino, P., & Lancellotti, P. (2022). Advances in percutaneous patent foramen ovale closure: From the procedure to the echocardiographic guidance. *Journal of Clinical Medicine*, 11(14), Article 4001. <https://doi.org/10.3390/jcm11144001>
13. Shi, F., Sha, L., Li, H., Tang, Y., Huang, L., Liu, H., Li, X., Li, L., Yang, W., Kang, D., & Chen, L. (2023). Recent progress in patent foramen ovale and related neurological diseases: A narrative review. *Frontiers in Neurology*, 14, Article 1129062. <https://doi.org/10.3389/fneur.2023.1129062>
14. Kasner, S. E., Sondergaard, L., Nakum, M., Gomez Montero, M., Hashim, M., & Landaas, E. J. (2024). A matching-adjusted indirect comparison of results from REDUCE and RESPECT: Two randomized trials on patent foramen ovale closure devices to prevent recurrent cryptogenic stroke. *Journal of Medical Economics*, 27(1), 337–343. <https://doi.org/10.1080/13696998.2024.2320604>
15. Apostolos, A., Gregoriou, S., Drakopoulou, M., Trantalís, G., Tsiogka, A., Ktenopoulos, N., Aggeli, K., Stratigos, A., Tsioufis, K., & Toutouzas, K. (2025). Patent foramen ovale closure in patients with and without nickel hypersensitivity: A randomized trial. *Circulation: Cardiovascular Interventions*, 18(4), e015228. <https://doi.org/10.1161/CIRCINTERVENTIONS.125.015228>
16. Kluck, B. W., Gupta, R., & Orzel, A. (2025). Retrospective comparison of device versus suture for patent foramen ovale closure. *Heart International*, 19(1), 48–56. <https://doi.org/10.17925/HI.2025.19.1.4>
17. Kayvanpour, E., Matzeit, E., Kaya, Z., Pleger, S., Bahrmann, A., Reichardt, C., Ringleb, P. A., Frey, N., Meder, B., & Sedaghat-Hamedani, F. (2024). Comparative effectiveness of devices for interventional patent foramen ovale closure: Insights from a 23-year monocentric analysis. *Journal of Clinical Medicine*, 13(21), Article 6354. <https://doi.org/10.3390/jcm13216354>
18. Yapan Emren, Z., Emren, S. V., Karagöz, U., Çelik, A., Özdemir, E., Çitekçi, F. T., Aktürk, S., & Akar, B. (2026). Long-term comparative efficacy and safety of different patent foramen ovale closure devices: Real-world evidence from a 15-year cohort. *Journal of Clinical Medicine*, 15(9), Article 3429. <https://doi.org/10.3390/jcm15093429>
19. Sorysz, D., Gładys, K., Węgiel, M., & Bartuś, S. (2026). Transcatheter closure of interatrial communication using the Cocoon occluder in patients with confirmed nickel hypersensitivity: A long-term observational study. *Postępy w Kardiologii Interwencyjnej (Advances in Interventional Cardiology)*, 22(1), 137–140. <https://doi.org/10.5114/aic.2026.160010>
20. Testa, L., Popolo Rubbio, A., Squillace, M., Albano, F., Cesario, V., Casenghi, M., Tarantini, G., Pagnotta, P., Ielasi, A., Popuso, G., Paloscia, L., Durante, A., Maffeo, D., Meucci, F., Valentini, G., Ussia, G. P., Cioffi, P., Cortese, B., Sangiorgi, G., & Bedogni, F. (2023). Patent foramen ovale occlusion with the Cocoon PFO Occluder: The PROS-IT collaborative project. *Frontiers in Cardiovascular Medicine*, 9, Article 1064026. <https://doi.org/10.3389/fcvm.2022.1064026>