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Partial Occlusion Device - A Novel 3D-Printed Tool for Microsurgical Anastomosis Revision

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Abstract

Achieving reliable vascular anastomosis is essential in microsurgery, yet revisions are often required due to leakage at suture sites. Cotton-tip applicators are commonly used to temporarily occlude blood flow during these revisions, but their rounded tips can create an unstable operating surface and introduce fiber contamination. To address these limitations, we developed a novel Partial Occlusion Device (POD). In a rat femoral artery model, POD demonstrated comparable performance to standard cotton-tip applicators, with similar revision times and high rates of vessel patency, without statistically significant differences between groups. Histological evaluation likewise showed no significant differences in vascular injury or thrombus formation. Surgeons reported improved stability, visibility, and control when using POD, without fiber-related complications. These findings suggest that POD is a practical, reusable alternative that may improve the safety and efficiency of microsurgical training and practice.

Introduction

Background/History/Motivation

Microsurgical training relies heavily on animal models, where end-to-end vascular anastomosis is a foundational skill. Despite its importance, anastomotic revisions are frequently required due to leakage at suture sites, often resulting from technical challenges associated with small vessel diameter and fragility. Irregular suture spacing is a common contributor to post-anastomotic leakage, necessitating timely and effective revision to maintain procedural success. Historically, proximal vessel clamping was used to facilitate revision; however, this approach carries a risk of thrombosis and potential vessel injury. As an alternative, cotton-tip applicators were introduced to enable partial occlusion while preserving visualization and access to the operative field, and have since become the standard technique in microsurgical training

environments[1]. While effective, cotton-tip applicators present limitations, including an unstable operating platform due to the rounded tip and the risk of fiber shedding. The introduction of cotton fibers into the operative field raises concern for particulate contamination, which may increase the risk of embolic events and inflammatory responses[2]

Current techniques and Limitations

The existing literature on the topic of anastomosis revision originally put forth the use of clamps at the proximal end of a vessel when its sutures were being revised[3]. This practice in the clinical setting was found to often lead to a high risk of thrombosis, along with the potential for vessel damage depending on how long the revision was taking. The cotton swab, introduced as an occlusion device instead of the original clamping method, allowed for the complete disuse of the clamps, as the cotton fibers were able to soak up any blood and clear the surgeon's field of vision, and, along with that, the manipulation of the plastic rod of the swab allowed for the vessel to be elevated for successful occlusion . Despite this becoming the normal pedagogical practice in microsurgical labs and in training for clinical settings, research on the method showed that the use of the swabs raised concerns about an increased possibility of cotton particle infiltration in the body. This risk increased the likelihood of embolism, which could lead to granulomas in the patient or specimen and further complications and inflammatory responses in the body[4]. The novel approach presented in this study implements the use of a device known as POD, or Partial Occlusion Device. POD is a microsurgical tool that was engineered to act as a platform to elevate vessels to occlude them and stem blood flow, allowing for a clean field of vision to resuture any revisions. Ultimately, this instrument allows for the reusability of a clamp without the risk of thrombosis, along with the visibility of a cotton swab without the concern of contaminant introduction.

Methods

3D Design

The Partial Occlusion Device (POD) was designed to replicate the occlusion function of traditional cotton-tip applicators while addressing their limitations. The device (Figure 1) features a curved anterior surface that conforms to the contour of the vessel, allowing controlled elevation and occlusion while minimizing focal pressure.

To improve intraoperative stability, the POD incorporates a flat-bottomed base that prevents rolling during use. This design allows the device to remain stable within the surgical field without requiring continuous manual support. The superior surface of the device includes three saddles of varying heights, which serve as platforms for graded vessel elevation. These allow the surgeon to adjust the degree of occlusion by repositioning the vessel across different elevations,

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[1] Harb A, Levi M, Akelina Y, Kadiyala R, Ascherman J. A Novel Technique to Perform Microvascular Anastomosis Revisions without Clamps. Journal of Reconstructive Microsurgery Open. 2018 Jul;03(02):e58–61.
[2] Johnston B, Smith P, Heath D. Experimental cotton-fibre pulmonary embolism in the rat. Thorax. 1981. Available from: https://doi.org/10.1136/thx.36.12.910
[3] Harb, et al
[4] Johnston et al.

facilitating incremental restoration of blood flow and assessment of leakage without removing the device.

The posterior aspect of the POD includes a grooved handle designed for engagement with a standard microsurgical clamp applier. This feature enables controlled placement and removal of the device while maintaining stability during manipulation. The POD was designed using computer-aided design software and fabricated via 3D printing using biocompatible resin. The digital design allows for modification of device dimensions, including saddle height and curvature, to accommodate variations in vessel size and surgical application.

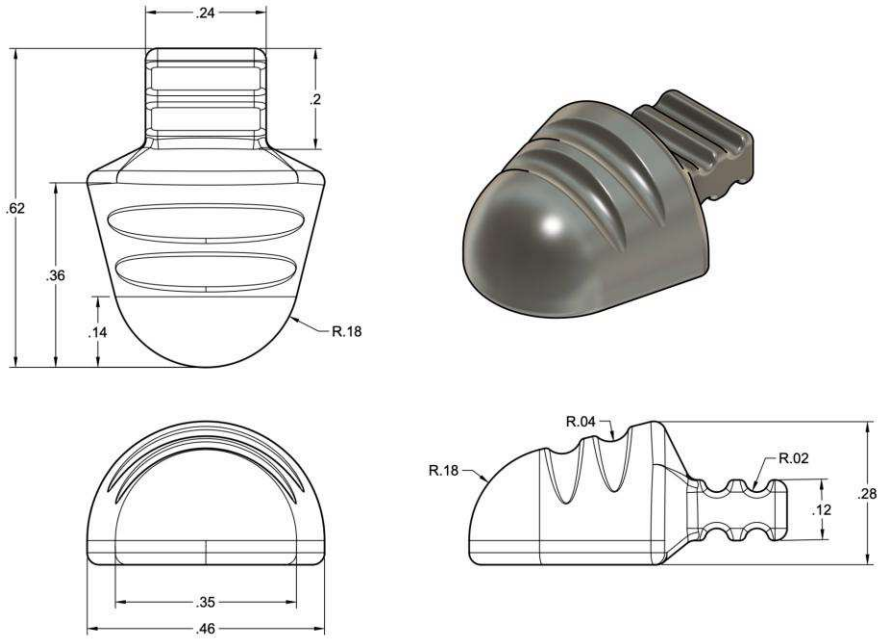


Figure 1. Engineering drawings of POD, showing the top, front, right and isometric views. Measurements unit in inches.

3D Printing

The original POD design file was imported into PreForm software (Formlabs Inc., Somerville, MA, USA) and prepared for printing. The model was oriented according to manufacturer's recommendations, and supporting structures were generated to ensure print stability.

Devices were fabricated using a Form 2 stereolithography (SLA) printer (Formlabs Inc.) with BioMed White Resin (RS-CFG-BMWH-01) at a layer resolution of 50 μm. To maintain biocompatibility, a dedicated resin tank, build platform, and accessories were used exclusively for this material.

Following printing, devices were removed from the build platform and washed in 99.9% isopropyl alcohol using a Form Wash unit for 5 minutes at high speed. The devices were then air-dried at room temperature for a minimum of 30 minutes to ensure complete solvent evaporation. Post-curing was performed using a Form Cure unit at 60 °C for 60 minutes to achieve full mechanical strength. After cooling, supporting structures were removed using cutting pliers, and device surfaces were inspected for residual artifacts. Final quality assessment ensured the absence of cracks, residual resin, or structural deformities, and any defective devices were discarded.

Surgical Procedure

The POD was evaluated in a rat end-to-end femoral artery anastomosis revision model. Male Sprague-Dawley rats were anesthetized with intraperitoneal ketamine and xylazine, with supplemental dosing administered as needed to maintain anesthesia. Animals were shaved, prepped with povidone-iodine and alcohol, and positioned supine. All procedures were approved by the Columbia University Medical Center Institutional Animal Care and Use Committee and performed under an operating microscope (Zeiss OPMI MD; Carl Zeiss, Jena, Germany).

A 2.5–3.0 cm incision was made along the medial thigh, and the femoral artery was carefully dissected free from surrounding tissues. The vessel was clamped proximally and distally using a double clamp and transected perpendicularly with micro-scissors. The artery was irrigated, trimmed of excess adventitial tissue, and dilated prior to anastomosis. End-to-end anastomosis was performed using either a two-stay suture technique or a one-way up technique. Following completion, clamps were removed sequentially, distal first and then proximal, to minimize bleeding.

After initial reperfusion, a fat pad was applied over the anastomosis site for 2–3 minutes to control bleeding. In cases of persistent leakage, revision was performed using the POD (Figure 2). The device was positioned beneath the anastomosis to achieve partial occlusion, allowing placement of additional sutures to control bleeding.

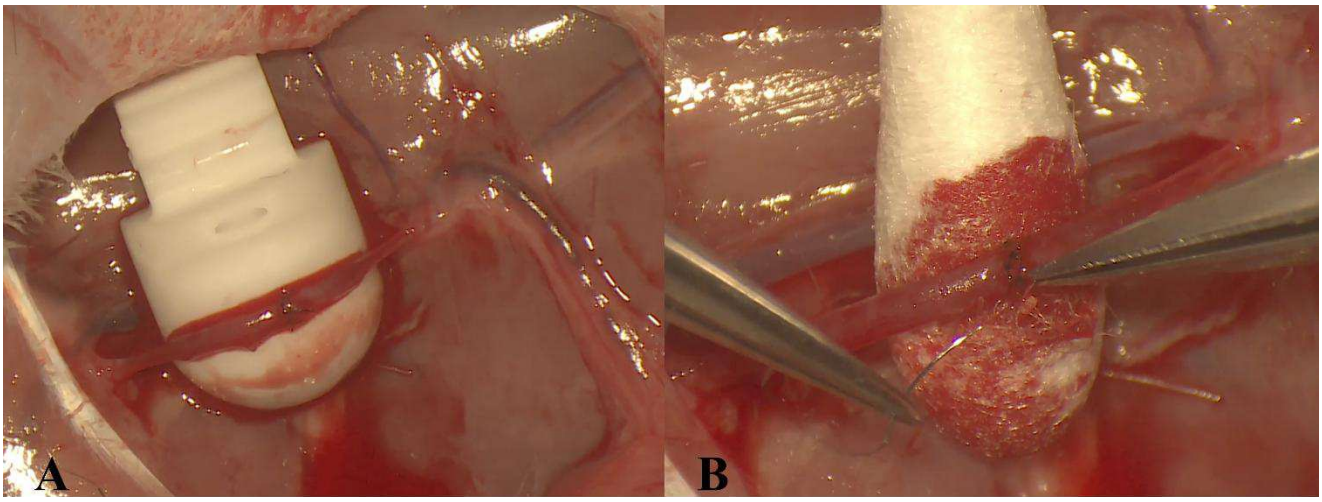


Figure 2: Anastomosis revision (A) utilizing the POD and (B) utilizing the traditional cotton swab.

Following revision, the fat pad was reapplied, and vessel patency was assessed at 20 and 40 minutes using the lift test. This involved gentle elevation of the distal vessel segment with angled forceps and observation for restoration of distal pulsatile flow [5].

Outcome Measures

Outcome measures included device utilization, revision time, vessel patency, and surgeon-reported usability. Device utilization was recorded based on the number of revisions performed using either the POD (n=22) or a cotton-tip applicator (n=13). Revision time was measured for each procedure from initiation of revision to completion of hemostasis. Vessel patency was assessed at 20 and 40 minutes following revision. Surgeon-reported usability was collected immediately after each procedure using targeted questions evaluating device maneuverability within the surgical field, ability to improve visualization and exposure of the anastomotic site, and perceived control of occlusion relative to conventional cotton-tip applicators.

Histological Analysis

Rat femoral arteries were harvested and fixed in 10% neutral buffered formalin at room temperature for 48 hours, then transferred to 70% ethanol for storage. Tissue samples were processed using an automated tissue processor (Leica ASP300S) and embedded in paraffin using a two-step orientation method. Specimens were initially embedded horizontally in tinted paraffin to facilitate visualization and alignment, then re-embedded vertically to ensure consistent sectioning from the proximal end.

Serial sections were cut at 6 µm thickness using a microtome (Leica RM2235) and mounted on charged glass slides (Globe Scientific). Sections were deparaffinized, rehydrated through graded

[5] Naides A, Noland R, Lu JG, Akelina Y, Marboe C, Strauch RJ. Histological Changes in the Rat Femoral Artery Following the Use of the Empty-and-Refill Test. J Reconstr Microsurg. 2018 May;34(4):270-276. doi: 10.1055/s-0037-1621727. Epub 2018 Jan 22. PMID: 29359296

ethanol, and stained with Harris Modified Hematoxylin (Mercedes Medical) and Eosin Y (LabChem Inc.). Following staining, slides were dehydrated, cleared in xylene (Fisher Scientific), and coverslipped using DPX mounting medium (Sigma-Aldrich).

Histological evaluation was performed using light microscopy (Olympus BX40) with digital imaging (CellSens Entry Software). All histopathological assessments were conducted by a board-certified pathologist. Vessel segments proximal and distal to the anastomosis were evaluated across control (C1,C2,C3), POD (P1,P2,P3,P4), and Q-tip (Q1,Q2,Q3,Q4) groups according to established criteria[6].

Histopathology (Shahab)

Scoring was focused on the most affected vessel section, specifically distal to the anastomoses; though, all sections were considered and descriptively evaluated. This involved evaluation and scoring of vessel intima, media, and adventitia. Scoring for the intima involved assessment of endothelial cell number, proliferation (circumference), proliferation (thickness), inflammation (circumference), inflammation (thickness), and clotting. Scoring for the media involved assessment of necrosis (circumference) and inflammation (circumference). And scoring for adventitia involved assessment of healing (smooth muscle proliferation circumference), healing (smooth muscle proliferation thickness), inflammation (circumference), and inflammation (thickness). Grading of higher numbers (ex. grades of 3 or 4) signified greater involvement and abnormality (Table 1), as transported by Naides et al [7]. The values for control, POD, and Q-Tip intima, media, and adventitia scoring were quantitatively compared between groups to denote differences for assessing anastomoses efficacy and potential complications. In addition to such statistic-based, literature backed assessment, vessels were narratively and descriptively analyzed as well.

Intima	
Endothelial Cells	
0 = endothelial cell loss	
1 = normal number of endothelial cells	
2 = endothelial cell proliferation	
Intimal Proliferation (circumference)	Intimal proliferation (thickness)
0 = no involvement	0 = no involvement
1 = 0-25% of circumference involved	1 = less than thickness of media
2 = 25-50% of circumference involved	2 = equal to thickness of media
3 = 50-75% of circumference involved	3 = greater than thickness of media
4 = 75-100% of circumference involved	
Inflammation (circumference)	Inflammation (thickness)

[6]Naides, et al.
[7] Naides, et.al.

Same as intimal proliferation (circumference)	Same as intimal proliferation (thickness)
Clot: 0 = absence, 1 = presence	
Media	
Necrosis (circumference): Same as intimal proliferation (circumference)	
Inflammation (circumference): Same as intimal proliferation (circumference)	
Adventitia	
Healing (smooth muscle proliferation) (circumference)	Healing (smooth muscle proliferation) (thickness)
Same as intimal proliferation (circumference)	Same as intimal proliferation (thickness)
Inflammation (circumference)	Inflammation (thickness)
Same as intimal proliferation (circumference)	Same as intimal proliferation (thickness)

Table 1: Scoring system for vessel grading and assessment, transported from Naides et al (2018).

Statistical Analysis

Statistical analyses were performed using GraphPad Prism version 10.2.2 (GraphPad Software, San Diego, CA, USA). Operative time is reported as mean ± standard deviation and median values.

Data normality was assessed using visual inspection of Q–Q plots and formal normality testing. Results demonstrated significant deviation from normality ($p < 0.005$), and therefore, operative times between POD and Q-tip groups were compared using a two-tailed Mann–Whitney U test. Statistical significance was defined as $p < 0.05$.

Categorical outcomes, including vessel patency, are presented as counts and percentages. Due to limited sample size, no inferential statistical comparisons were performed for categorical variables.

Results

Results

Patency Outcomes

Among 22 revision procedures performed using the POD, 20 (90.9%) maintained vessel patency at 40 minutes. One case (4.5%) lost patency within 20 minutes post-revision, and one case (4.5%) lost patency prior to 40 minutes due to intraoperative mortality. In comparison, all 13 revisions performed using cotton-tip applicators (100%) maintained patency at 40 minutes.

Operative time

The mean operative time for revision using cotton-tip applicators was 3.81 ± 2.50 minutes (median 3.43), compared to 4.00 ± 2.15 minutes (median 3.73) for POD-assisted revisions. There was no statistically significant difference between groups ($p = 0.5382$) (Figure 3).

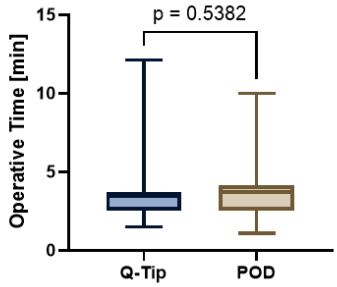


Figure 3. The operative time comparison between POD-applied and Q-Tip-applied revision surgeries. The surgeries' duration in the POD-applied group was not significantly longer than in the Q-Tip-applied group.

Surgeon Feedback

Surgeon-reported usability indicated favorable handling characteristics of the POD. Twelve surgeons reported that the device improved maneuverability, facilitated identification of anastomotic defects, and eliminated interference from cotton fibers. Eight surgeons did not provide specific feedback, and two reported a preference for cotton-tip applicators in cases requiring greater vessel elevation.

Histopathological Findings

The Histological evaluation demonstrated evidence of vascular injury in both POD and cotton-tip groups, primarily characterized by endothelial cell loss and inflammation, which were not observed in control vessels. Overall, findings were similar between POD and cotton-tip groups, with no evidence of necrosis in any specimens.

Endothelial cell loss was observed in both experimental groups. Intimal inflammation was present in all POD samples (4/4) and in three of four cotton-tip samples. Medial inflammation was also observed in all specimens across both groups. In one POD sample, focal vessel wall disruption with associated hemorrhage was noted.

Adventitial inflammation was identified in three of four POD samples and in all cotton-tip samples. No evidence of smooth muscle proliferation or healing was observed in any group.

Quantitative histopathological scoring demonstrated no statistically significant differences between POD and cotton-tip groups in intimal ($p = 1.0$), medial ($p = 0.50$), or adventitial ($p = 0.52$) injury scores (Table 2). However, when compared to control vessels, cotton-tip samples demonstrated significantly higher medial ($p = 0.009$) and adventitial ($p = 0.002$) scores, while POD samples demonstrated significantly higher intimal ($p = 0.03$) and medial ($p = 0.01$) scores.

	C1	C2	C3	P1	P2	P3	P4	Q1	Q2	Q3	Q4
Intima											
Endothelial cell number	1	1	1	0	0	0	0	0	0	0	0
Proliferation (circ)	0	0	0	0	0	0	0	0	0	0	0
Proliferation (thick)	0	0	0	0	0	0	0	0	0	0	0
Inflammation (circ)	0	0	0	1	3	1	1	0	3	3	1
Inflammation (thick)	0	0	0	1	1	1	1	0	1	1	1
Clot	0	0	0	0	0	0	0	0	0	0	0
Media											
Necrosis (circ)	0	0	0	0	0	0	0	0	0	0	0
Inflammation (circ)	0	0	0	1	2	3	3	2	3	2	1
Adventitia											
Healing (smooth muscle proliferation) (circ)	0	0	0	0	0	0	0	0	0	0	0
Healing (SMP) (thick)	0	0	0	0	0	0	0	0	0	0	0
Inflammation (circ)	0	0	0	1	0	3	1	2	1	2	2
Inflammation (thick)	0	0	0	1	0	2	1	1	1	2	1

Table 2: Histological scoring of vessel segments distal to anastomoses, adopted from Naides et al (2018).

Although the scoring system captured the presence and extent of inflammation, it did not distinguish between sparse, circumferentially distributed inflammatory cells and denser inflammatory infiltrates within the same regions. Qualitative assessment suggested that cotton-tip samples exhibited greater inflammatory cell density compared to POD samples, despite similar scoring classifications (Figure 4).

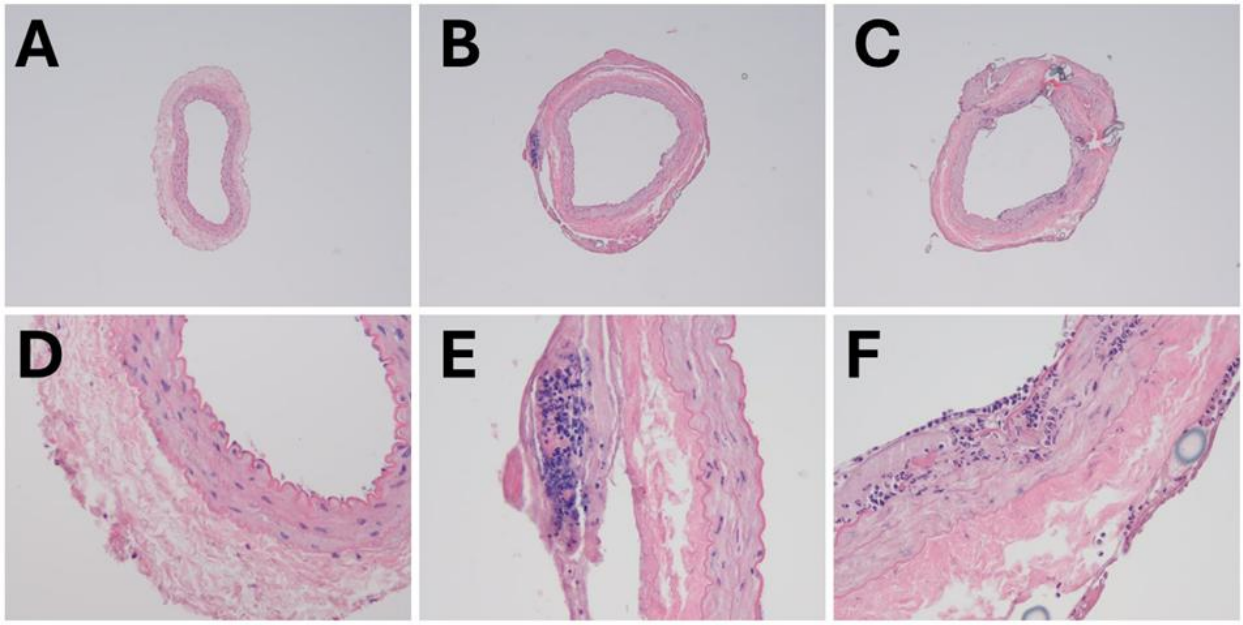


Figure 4: Femoral arteries show mild inflammation in POD and Q-tip experimental groups. Representative images of control (A, D), POD (B, E) and Q-tip (C, F) groups at low (4x) (A, B, C) and high (20x) (D, E, F) magnification. H&E sections show endothelial cell loss and relatively mild inflammation in experimental groups.

In summary, both POD and cotton-tip groups demonstrated endothelial cell loss and inflammatory changes without evidence of necrosis. While overall injury scores were comparable between groups, qualitative differences suggest a greater inflammatory burden in cotton-tip-treated vessels.

Discussion

Quantitative Comparison with Previous Studies, Interpretation

The success of anastomosis revision depends on a balance between surgical technique and the application of an effective occlusion strategy, both of which influence vessel integrity and post-revision patency. Each stage of the revision process, including vessel handling, suturing, and hemostatic control, introduces mechanical stress that can compromise endothelial integrity. By minimizing bleeding and improving visualization, the POD is designed to reduce unnecessary manipulation and support efficient revision.

Post-revision vascular integrity remains a critical measure of success. In this study, cotton-tip–assisted revisions demonstrated a 100% patency rate (13/13) at 40 minutes, whereas POD-assisted revisions demonstrated a 90.9% patency rate (20/22). One POD case (4.5%) failed

within 20 minutes post-revision, and another (4.5%) failed prior to 40 minutes due to intraoperative mortality. While the cause of one failure remains unclear and the second may have been influenced by systemic factors, these findings suggest that POD performance, while comparable overall, may be more sensitive to subtle intraoperative variables.

Operative efficiency between the two techniques was comparable. The mean operative time for Q-tip–assisted revisions was 3.81 ± 2.50 minutes (median 3.43), compared to 4.00 ± 2.15 minutes (median 3.73) for POD-assisted revisions, with no statistically significant difference ($p = 0.5382$). These findings indicate that use of the POD does not introduce additional procedural burden and can be incorporated into existing microsurgical workflows without increasing operative time.

Advantages and Potential of POD

The POD offers several functional advantages over traditional cotton-tip applicators. Its flat-bottomed design prevents rolling and provides a stable platform, allowing surgeons to perform revisions without continuous manual stabilization. The grooved handle enables secure manipulation with standard microsurgical clamp appliers, improving precision during placement and removal.

A major advantage of the POD is the elimination of cotton fiber shedding. Traditional cotton-tip applicators carry a risk of introducing fibers into the surgical field, which may contribute to thrombotic complications, foreign body reactions, or interference with suture integrity. The resin-based construction of the POD removes this risk while maintaining a clean and controlled operative environment.

Surgeon feedback further supports these functional advantages, with 12 surgeons reporting improved maneuverability, enhanced visualization of the anastomotic defect, and elimination of fiber-related interference. Eight surgeons did not provide specific feedback, while two reported a preference for cotton-tip applicators in situations requiring greater vessel elevation.

Histopathological Interpretation and Limitations

Histological evaluation demonstrated endothelial cell loss and inflammatory changes in both POD and cotton-tip groups that were not observed in control vessels. Intimal inflammation was present in all POD samples (4/4) and in three of four cotton-tip samples, while medial inflammation was observed in all specimens across both groups. Adventitial inflammation was present in three of four POD samples and all cotton-tip samples. No necrosis was identified in any vessels, although one POD specimen demonstrated focal wall disruption with associated hemorrhage.

The absence of observable healing, including smooth muscle proliferation, is likely attributable to the short interval of approximately two hours between surgical intervention and tissue harvest, which is insufficient to capture early regenerative responses.

Quantitative scoring demonstrated no statistically significant differences between POD and cotton-tip groups in intimal ($p = 1.0$), medial ($p = 0.50$), or adventitial ($p = 0.52$) injury scores. Compared to control vessels, cotton-tip samples demonstrated significantly higher medial ($p = 0.009$) and adventitial ($p = 0.002$) scores, while POD samples demonstrated significantly higher intimal ($p = 0.03$) and medial ($p = 0.01$) scores. Although the scoring system identified the presence and extent of inflammation, it did not differentiate between sparse, circumferentially distributed inflammatory cells and more densely clustered infiltrates within the same regions.

When qualitative features were considered, cotton-tip–treated vessels demonstrated greater inflammatory cell density compared to POD-treated vessels, despite similar quantitative scores. In POD-treated vessels, inflammatory cells were typically sparse and distributed circumferentially, whereas cotton-tip samples demonstrated more concentrated cellular infiltrates within comparable regions. These findings suggest that conventional scoring methods may underestimate meaningful differences in inflammatory burden between devices

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Limitations and Considerations

Despite its advantages, the POD demonstrates some limitations. While 90.9% (20/22) of POD-assisted revisions maintained patency at 40 minutes, all Q-tip–assisted revisions (13/13) remained patent at the same time point. Although one failure was unexplained and another likely influenced by systemic factors, these results suggest that POD performance may be more susceptible to intraoperative variability.

Additionally, some surgeons required greater vessel elevation than the POD could provide. While the multi-level saddle design allows for controlled adjustment, it may not accommodate all surgical scenarios, as reflected by two surgeons who preferred cotton-tip applicators in cases requiring increased elevation.

Future Directions

While the POD demonstrated promising performance in a controlled microsurgical model, further investigation is needed to support broader application and clinical translation. Larger studies are required to increase statistical power and better characterize variability in outcomes such as vessel patency and inflammatory response. Expanded cohorts would also allow evaluation across vessel size, anatomical location, and surgeon experience.

The device was fabricated using a single biocompatible resin; future work should explore alternative 3D printing materials with varying mechanical properties, durability, and sterilization tolerance to optimize performance and long-term use.

Longer-term in vivo studies are needed to assess vascular healing, endothelial recovery, and the progression of inflammatory responses, as the short interval between intervention and tissue harvest in this study limits evaluation of regenerative processes.

Device design optimization is also warranted. While the multi-level saddle provides controlled occlusion, some surgeons required greater vessel elevation than the current design allows, indicating a need for expanded height configurations or adaptable geometries.

Validation beyond a single-institution setting will be critical. Multi-center studies and regulatory evaluation are necessary to establish reproducibility, safety, and effectiveness across diverse surgical environments and to support broader adoption.

Conclusion

The Partial Occlusion Device (POD) represents a novel alternative to traditional cotton-tip applicators for microvascular anastomosis revision. Its flat-bottomed design, multi-level saddle system, and grooved handle provide a stable platform that enables controlled occlusion and independent device use, improving intraoperative stability and maneuverability. In addition, elimination of cotton fiber shedding addresses a key limitation of conventional applicators and reduces the risk of particulate contamination.

In this study, the POD achieved a high rate of vessel patency (90.9%) with operative times comparable to cotton-tip applicators ($p = 0.5382$), supporting its feasibility without increasing procedural burden. While variability in patency outcomes warrants further investigation, these findings demonstrate that the POD performs comparably to current techniques while offering distinct functional advantages. Overall, the POD provides a customizable, biocompatible, and efficient tool for anastomosis revision and represents a promising advancement in microsurgical practice.

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Author contributions

Yuzhu Huang, Abraham Joshua Johnson, Jonas Zhao, Shahabeddin Yazdanpanah, Elan Shukhmakher, Omer Bilal, Hui Zhang, PhD; Tina Moon, Sophia Jao, Stephen Fox, Sharon C. Usip, Jennifer Baccon, MD, PhD, Fayez F. Safadi, PhD, Yelena Akelina, DVM

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Data availability

No datasets were generated or analyzed during the current study.

Declarations

Ethics approval and consent to participate

All procedures received approval from the Columbia University Medical Center Institutional Animal Care and Use Committee. All procedures are adherent to Columbia University's Animal Research Handbook (2025).

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

References

Harb A, Levi M, Akelina Y, Kadiyala RK, Ascherman J. A Novel Technique to Perform Microvascular Anastomosis Revisions without Clamps. Journal of Reconstructive Microsurgery Open. 2018. Available from: https://doi.org/10.1055/s-0038-1669451

Johnston B, Smith P, Heath D. Experimental cotton-fibre pulmonary embolism in the rat. Thorax. 1981. Available from: https://doi.org/10.1136/thx.36.12.910

Akelina Y, Ballestín A. Microsurgery 101: Tips and tricks for microvascular and peripheral nerve repair techniques. Springer; 2024.