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Correspondence and Communications

A multipurpose flowing vascular phantom for microsurgical training and flap-monitoring research

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Dear Editor,

Free flap reconstruction requires a reliable assessment of pedicle perfusion before wound closure. In clinical practice, surgeons combine information from multiple sources, including flap colour, capillary refill, Doppler signals, and direct inspection of the vessels.[1] Tactile feedback from the pedicle also informs intraoperative judgement, specifically when differentiating normal arterial pulsation from reduced flow, or normal venous compliance from increased firmness.[2] While this tactile skill is central to surgical experience, it remains difficult to teach in a structured manner. Clinical exposure varies, and trainees often have limited opportunities to examine vessels under diverse hemodynamic conditions.

Concurrently, reconstructive microsurgery needs practical training platforms that are reproducible, low-cost, and clinically relevant. While tissue phantoms are common in biomedical engineering,[3] their role in surgical education could expand beyond simple device validation. A vascular model that replicates both vessel geometry and physiological mechanical behaviour could support various areas of microsurgical training and research. In this proof-of-concept report, we describe a pressure-controlled silicone vascular model for microsurgery and outline three applications in education and research.

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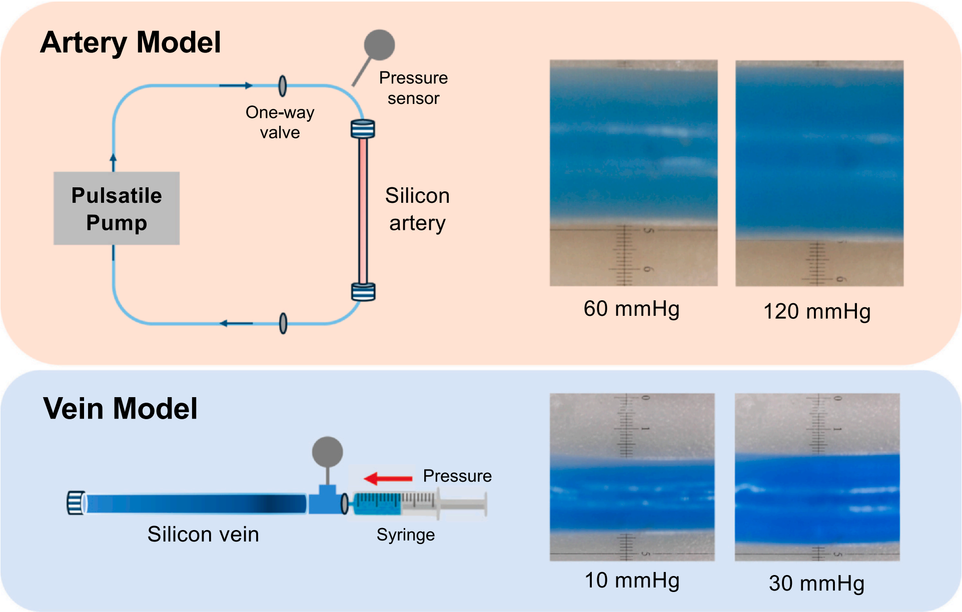


Figure 1 Construction of the pressure-controlled flowing circuit. The arterial phantom is connected to a pulsatile pump, allowing precise regulation of arterial pressure and heart rate. The venous phantom reproduces physiological firmness via pressure regulation within a closed circuit. By adjusting the silicone formulation, the synthetic vessels accurately mimic the distinct mechanical properties of human arteries and veins, providing a physiologically calibrated platform for haemodynamic simulation.

The model consists of silicone artery and vein phantoms integrated into a flow circuit (Figure 1). The mechanical properties of these phantoms were calibrated by adjusting the silicone mixing ratios to match the pressure-dependent distension of human vessels. While a pulsatile pump drives the flow, the inherent compliance of the silicone ensures that the phantoms exhibit realistic expansion and contraction. This approach provides a more accurate representation of operative conditions than standard synthetic tubing and demonstrates that a physiologically calibrated silicone model can serve as a practical platform for microsurgical simulation.

The first application involves training in tactile assessment (Figure 2). Before wound closure, experienced surgeons often perform a final check of the pedicle by pinching the vessels to assess arterial pulsation and venous firmness. While various objective monitoring tools are available, many experts rely on this manoeuvre based on their extensive clinical experience. Currently, there is little formal instruction for developing this tactile sense. Physiologically calibrated distension allows trainees to practice these assessments under standardised conditions. This approach helps translate intuitive clinical experience into a structured format for early microsurgical training.

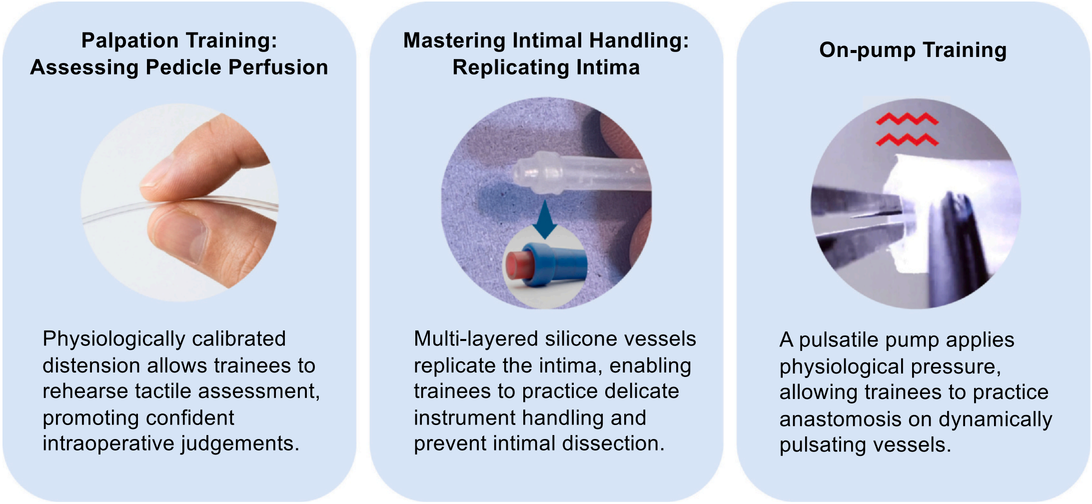
The second application is the simulation of intimal handling. Technical failure in microsurgery often results from intimal injury during vessel preparation or anastomosis. While biological models such as chicken thigh vessels are commonly used for training, they lack a distinct intimal structure that can be dissected. Consequently, these models do not allow trainees to practice the atraumatic techniques required to protect the inner vessel wall. Our model uses a unique coaxial dual-polymer engineering design, layering two different silicone formulations to replicate the intima as a separate inner layer. This design enables trainees to practice delicate instrument handling and learn how to prevent intimal dissection, which is essential for beginners learning to manipulate vessels without causing internal damage.

The third application is on-pump anastomosis training. Most microsurgical training relies on static models, with few systems reproducing a dynamically pulsating vessel under controlled pressure.[4] This feature is educationally significant because live surgery involves vessels that are not inert. In this model, the pulsatile pump applies physiological pressure, requiring the operator to stabilise the vessel and coordinate movements under conditions that resemble the operating field. This adds a temporal dimension to the simulation, which is absent in non-pulsatile models.

This platform also supports research. Because the model provides controllable arterial and venous conditions within a reproducible circuit, it is suitable for bench testing of flap-monitoring sensors or other devices designed to detect hemodynamic changes.[5] This is beneficial in early-stage development, where repeatability and the absence of biological variability are necessary. Thus, the model functions as both an educational tool and a standardised experimental platform for reconstructive research (Figure 2).

Non-biological materials offer practical advantages over conventional biological models. While chicken thigh femoral arteries are frequently used for training, their numerous side branches make them unsuitable for experiments requiring precise pressure control, as ligating each branch is labour-intensive (Video). In contrast, silicone models eliminate biohazard risks, degradation, and odours while providing an indefinite shelf life. Furthermore, the material cost is low, with silicone elastomers priced at approximately $50 per kg. Although fabrication requires specific techniques and practice, the process is manageable; each vessel pair requires about 20 min of preparation and a 3-hour curing period.

In summary, this proof-of-concept model suggests a role for physiologically calibrated phantoms in plastic and



Physiologically calibrated distension allows trainees to rehearse tactile assessment, promoting confident intraoperative judgements.

Multi-layered silicone vessels replicate the intima, enabling trainees to practice delicate instrument handling and prevent intimal dissection.

A pulsatile pump applies physiological pressure, allowing trainees to practice anastomosis on dynamically pulsating vessels.

Figure 2 Clinical and educational applications of the multipurpose vascular phantom. The model serves three primary training functions: (A) Palpation training: Matching pressure-dependent distensibility to human vessels enables trainees to develop tactile assessment skills, promoting confident intraoperative judgements. (B) Mastering intimal handling: The multi-layered structure replicates the intimal layer, allowing trainees to practice the delicate instrument handling essential for preventing intimal dissection during anastomosis. (C) On-pump training: Connecting the vessels to a pulsatile pump applies physiological arterial pressure, enabling trainees to rehearse microvascular anastomosis on dynamically pulsating vessels frequently encountered in clinical settings.

reconstructive surgery. By reproducing tactile flow states, layered vessel structures, and dynamic pulsation, the system addresses specific gaps in microsurgical training while offering a platform for sensor research. Future studies should assess how experienced surgeons rate the realism of the system and whether its use improves technical performance in training settings.

CRediT authorship contribution statement

Hiroki Kodama: writing – original draft, visualisation, project administration. James May: writing – project administration. Panicos Kyriacou: writing – project administration. Dariush Nikkhah: writing – review and editing, supervision, project administration.

Ethical statement

The authors have nothing to report.

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Data availability

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

Declaration of Competing Interest

The authors declare no conflicts of interest

Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.bjps.2026.04.036.

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