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Three-dimensional Printed Microvascular Clamps: A Safe, Cheap, and Effective Instrumentation for Microsurgery Training

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Summary: Microsurgical training involves practice in ex vivo models during the early learning curve, and poor instrument handling by the inexperienced microsurgeons can cause damage to microsurgical instrumentation or clamps, which is particularly costly. To address this, we demonstrate the development, design, manufacturing, and application of 3 different types of 3-dimensional printed microvascular clamps in an ex vivo simulation training model. This report provides evidence of a low-cost and easily accessible device that facilitates the process of microsurgical training. The clamps were found to provide advantages akin to normal stainless-steel microvascular clamps in training settings. *(Plast Reconstr Surg Glob Open 2020;8:e3107; doi: 10.1097/GOX.0000000000003107; Published online 24 September 2020.)*

INTRODUCTION

In microsurgery, the anastomosis is a surgical task integral to the success of a free flap. This step requires precision and dexterity, which can be acquired only through deliberate practice and experience accumulated over a structured microsurgical training curriculum. The traditional curriculum involves simulation practice on the living rat training model. However, recent ethical concerns regarding the use of animals in research and the introduction of the 3Rs (replacement, reduction, and refinement) framework have shifted the barycentre of current microsurgery curriculums toward nonliving models. This is especially true during the early stages of the learning curve, with hybrid approaches typically introduced in a step-ladder-type training employing a combination of ex vivo and in vivo models.[1–4]

The minimum requirement for a basic 5-days microsurgical training course, based on International Microsurgery Simulation Society guidelines, is to have 1 microscope per trainee and instruments—including 2 forceps (1 curved), curved needle holder, microsurgical scissors, vessel dilator, 9/0 and 10/0 sutures, and at least 2 microvascular clamps.[5] This equipment is proved to be costly, especially in developing countries, and during the early stages in skills acquisition, it can sustain damage from the interaction of untrained hands of inexperienced microsurgeons.[6] Permanent instrument damage may arise from an excessive application of pressure during tissue manipulation or from an inappropriate use that overpowers the instrument's capabilities, resulting in the premature disposal of the unit.[7]

Recent developments in additive manufacturing have rendered 3-dimensional (3D) printing technologies very accessible to institutions and individuals alike, in terms of price and functionality. The flexibility in design and material variety afforded by these technologies is particularly attractive for the development of surgical instrumentation, both for low-cost prototyping and for customizing patient-precise dimensions when needed.[8,9] Here, we demonstrate a 3D design and method for the production of 3 types of microvascular clamps that can be used by microsurgeons in training. In addition to bridging issues associated with disparity in availability and design, we show that the low cost of production afforded by 3D printing can reduce the long-term running costs of microsurgical training laboratories.

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DEVICE PRODUCTION

All microvascular clamps were designed using Autodesk's Fusion 360 software, converted to machine tool code using an Ultmaker's Cura slicer and printed on an Ender 5 FDM 3D printer (Creality, Shenzhen, China) using a poly-lactic acid filament (1.75mm filament, RS-UK). This material was chosen because it proved to have sufficient tensile strength while maintaining the necessary elastic properties required for the application. Crucially this material has been found to conserve its mechanical properties after autoclave sterilization.[8] All prints were produced using a 0.4-mm-diameter brass nozzle head, with the exception of supermicrosurgery clamps, which were produced using a 0.2-mm-diameter brass nozzle head.

DISCUSSION

The first vascular clamp was developed by Edmund Höpfner in 1903.[10] As surgeons started applying vascular anastomosis operations to more refined operations, the need for new instruments rose, leading to Acland's first description of the microvascular clamp in 1970.[11] Microvascular clamp assemblies often include the clamp jaws and handles connected to a torsional spring, so as to produce a clamping force proportional to the elastic coefficient and the contraction of the spring.[12] The vessel resists the applied pressure due to the intravascular blood pressure and the resistance of the vessel against deformation. Therefore, a successful clamp ought to provide a sufficient clamping force to impede the blood flow, while also being delicate enough to prevent any damage to the vessel.

For microsurgical operations, clamps ought to be in the millimeter range to be practical with respect to accessibility to the operating field. Given the dimension restrictions, alternative compression mechanisms to torsional springs are often sought after. Several manufacturers of microsurgical clamps provide single-piece stainless-steel devices whose V-shaped design takes advantage of the innate elasticity of the material.

Single-material designs are particularly suited for 3D printing, as the device can be produced directly without further assembly and used directly off the build plate. Given that fusion deposition modeling (FDM) compatible materials offer less elastic compressibility to metal analogs, we modified the traditional V-shape design to a parabolic analog (Fig. 1) to increase the clamp jaw travel distance, while providing the necessary clamping force required for blood vessel occlusion. We defined the device's adequacy criterion as being able to induce vessel occlusion. (**See Video 1 [online]**, which displays the elasticity validation test.) (**See Video 2 [online]**, which displays the occlusion validation test.)

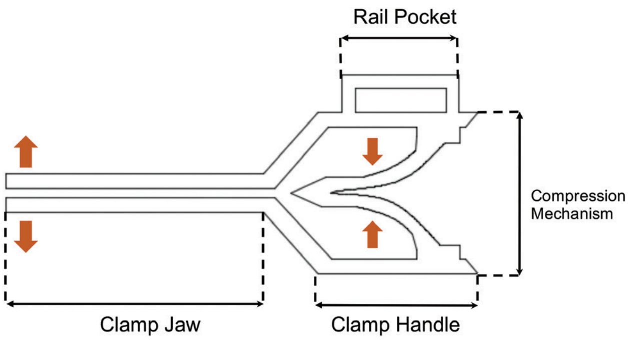

Fig. 1. Illustration of the parabolic design of the microvascular clamp. Orange arrows show the force direction; when compressing the handles of the clamp, the jaws would open wide.

A set of medium double clamps (including the rail) can be printed in 5 minutes at a material cost of 0.01 GBP/0.013 USD. Given a relatively medium performance printer such as the one we used in this study costs in the range of 300 GBP/379 USD, an estimated turn-around period to initial equipment investment could be foreseen within the same timescale it would take to accumulate 4 S&T double-clamp (average price estimated based on quotes received from 3 UK suppliers) replacements for a microsurgical training laboratory. The reusability of the clamps was tested and found to be adequate for 25 repetition tests after their use in silastic vessels and also in biological ex vivo models (ie, chicken thigh). The 3D printed clamps demonstrated occlusion capabilities akin to commercial analogs in a range of vessels varying in diameter between 0.8 and 2.4mm (**see Video 2**).

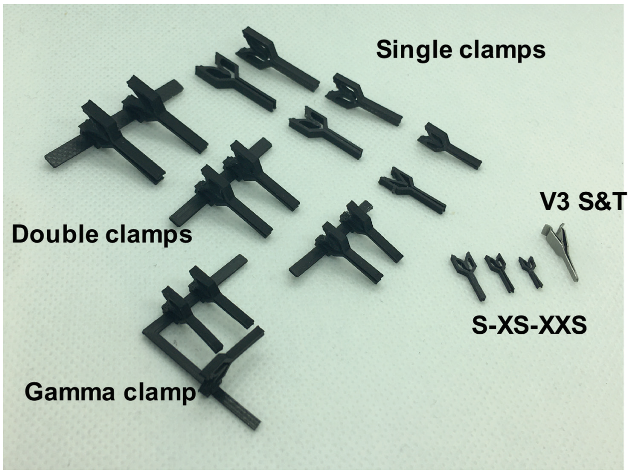

Fig. 2. Isometric view showing all 3 types of 3D printed microvascular clamps: single, double, and "gamma" clamp for end-to-side anastomosis. Sizes shown (XXS–XL). Comparison is made on the smaller sizes (ideal for supermicrosurgery) with the classic V3 S&T metallic clamp.

To show the applicability afforded by this technology, we designed and produced 3 types of simulation clamps in all 6 basic sizes (XXS–XL), as can be seen in Figure 2. We found our 3D printer model could produce operating clamps with dimensions as small as 5mm in length. The extra small size clamps could potentially be used in the innovative novel applications of supermicrosurgery such as lymphovenous anastomosis (LVA) and perforator flaps surgery.[13] The types designed included single, double, and gamma clamps. To introduce our trainees to a wider range of anastomosis technique options for end-to-side anastomosis, we designed an adaptation to the original gamma (Γ) clamp rail format described by Baek et al[14] in 1980, which is currently not available with commercial vendors. The gamma rail clamp uses a third clamp and a rail positioned in a direction orthogonal to the main vessel flow direction. This setting allows fine tuning of the approximation of the side vessel to the main branch and alleviates the need for surgical assistance during end-to-side anastomosis.

CONCLUSIONS

We designed and produced 3D printed microvascular clamps for use in training. The clamps are reusable, could sustain multiple applications, and were proved effective in ex vivo models during microvascular anastomosis training. Traditional stainless-steel instrumentation remains the gold standard in training and practice. Nonetheless, our experience demonstrated that 3D printing can find itself in the corner of microsurgical laboratories, as it has the ability to reduce long-term costs (especially in low-fidelity tasks training) and allow the rapid adoption of advances in instrumentation. We demonstrated the latter by restoring the designs of the commercially unavailable gamma rail clamp. This example showcased how creative applications of 3D printing can reinforce the training opportunities of trainees and may prove to facilitate the quick adoption of state-of-the-art instruments described in the literature directly to the microsurgical laboratory.

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REFERENCES

1. Guerreschi P, Qassemyar A, Thevenet J, et al. Reducing the number of animals used for microsurgery training programs by using a task-trainer simulator. *Lab Anim*. 2014;48:72–77.
2. Kim E, Norman ICF, Myers S, et al. The end game—a quantitative assessment tool for anastomosis in simulated microsurgery. *J Plast Reconstr Aesthet Surg*. 2020;73:1116–1121.
3. Onoda S, Kimata Y, Sugiyama N, et al. Analysis of 10-year training results of medical students using the Microvascular Research Center Training Program. *J Reconstr Microsurg*. 2016;32:336–341.
4. Olijnyk LD, Patel K, Brandão MR, et al. The role of low-cost microsurgical training models and experience with exercises based on a bovine heart. *World Neurosurg*. 2019;130:59–64.
5. Ghanem A, Kearns M, Ballestín A, et al. International microsurgery simulation society (IMSS) consensus statement on the minimum standards for a basic microsurgery course, requirements for a microsurgical anastomosis global rating scale and minimum thresholds for training. *Injury*. 2020;S0020-1383(20)30078-4.
6. Chihena HB, Pafitanis G, Mitsunaga N, et al. Challenges in global reconstructive microsurgery: the sub-Saharan African Surgeon's perspective. *JPRAS Open*. 2019;20;19–26.
7. Acland R. Notes on the care, restoration and repair of microsurgical instruments. *Indian J Plast Surg*. 2006;39:1.
8. Alshomer F, Alhazmi B, Alowais F, et al. A low-cost 3D-printed tool with multiaxial/angular vessel orientation for microvascular anastomosis training. *Plast Reconstr Surg Glob Open*. 2020;8:e2567.
9. Papavasiliou T, Lipede C, Chatzimichail S, et al. Development of a customized 3D printed paediatric hand retractor for patient-precise dimensions and enhanced surgical autonomy. *J Hand Surg Eur Vol*. 2020. https://doi.org/10.1177%2F1753193420925016
10. Sachs M. History of surgical instruments: the development of tangentially closing vascular clamps. *Chir*. 1996;121:1085–1088.
11. Fricker J. Robert Acland: Pioneer of microsurgery who forged a second career in anatomical teaching. *BMJ*. 2016;352:i1761.
12. Trobec R, Gersak B. Direct measurement of clamping forces in cardiovascular surgery. *Med Biol Eng Comput*. 1997;35:17–20.
13. Masia J, Olivares L, Koshima I, et al. Barcelona consensus on supermicrosurgery. *J Reconstr Microsurg*. 2014;30:53–58.
14. Baek SM, Jacobson JH II. A new clamp for end-to-side microvascular anastomosis. *J Microsurg*. 1980;1:465–469.