

# 3D Printed Chest Wall: A Tool for Advanced Microsurgical Training Simulating Depth and Limited View

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**Summary:** The deep inferior epigastric perforator (DIEP) flap has become the free flap of choice for autologous breast reconstruction. However, anastomoses of DIEP pedicles to internal mammary vessels in the chest wall are difficult due to restricted access and the depth of the vessels. Successful performance of such demanding procedures necessitates advanced requirements for microsurgical training models. The current chicken thigh model has been used to acquire microsurgical skills, allowing early learning curve trainees to practice repeatedly in inconsequential environments. Despite the increasing use of this model for training purposes, the resemblance to a clinical environment is tenuous. Such models should include anastomosis practice within the depth where the recipient vessels are located. To address this, we developed a three-dimensional (3D) printed chest wall as an addition to the current chicken thigh model, which reliably mimics the complexity of the anastomosis performed during DIEP breast reconstruction. This form of rapid prototyping facilitates a newfound ability for early learning curve trainees to exercise end-to-end anastomoses on vessels located with variable depths. Our enhancement of the current chicken thigh model is simple, cost-effective and offers a significantly more realistic resemblance to a clinical situation. (*Plast Reconstr Surg Glob Open* 2021;9:e3817; doi: [10.1097/GOX.0000000000003817](https://doi.org/10.1097/GOX.0000000000003817); Published online 14 September 2021.)

## INTRODUCTION

Microsurgery is a precise surgical skill that requires high-volume hands-on training. Although living animal models, specifically those using rats, have been used for the acquisition and maintenance of microsurgical skills, ethical concerns can restrict the use of living animals for training purposes.<sup>1-3</sup> However, the use of nonliving animal models has the advantage of having no ethical concerns, being affordable and readily available, and most importantly, providing accurate reproducibility to allow for simulation and training of microsurgery outside of the operating theater.<sup>4</sup> The current gold standard, the

chicken thigh model, excels in technical simulation with similar blood vessel diameter to humans.<sup>5-7</sup> It is, therefore, an acceptable model for microsurgery, especially for novice microsurgeons and those wishing to practice before performing a microsurgical procedure.

With the extensive variety of procedures, microsurgery embodies a critical skill set that powerfully augments the reconstructive element of plastic surgery. Microsurgical anastomosis is a critical part for the success of a free flap reconstruction procedure. One of the most common indications for free flap surgery is breast reconstruction, with deep inferior epigastric artery perforator (DIEP) flap being the common flap of choice for autologous breast reconstruction.<sup>8,9</sup> Although this procedure is regarded as technically demanding, novice microsurgeons must become proficient in this procedure as it is one they will frequently encounter.

For a successful DIEP free flap, the microsurgeon should be able to perform atraumatic preparation of radiated internal mammary vessels and intramuscular perforator dissection through tight rectus muscle as well as the

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microsurgical anastomosis. However, arterial and venous anastomoses of DIEP pedicles to internal mammary vessels in the chest wall are difficult due to limited access and the vessels being deep.<sup>9</sup> This poses a visual and spatial challenge for the microsurgeon. Successful performance of such demanding skills necessitates advanced requirements for microsurgical training models. Such models should include anastomosis practice in the depth of operative procedure. Despite the increasing use of the chicken thigh model for training purposes, it does not eliminate the major limitation of lack of depth perception and loss of spatial orientation.

To address this challenge, we have devised a three-dimensional (3D) printed chest wall as an addition to the current chicken thigh model for the development of skills of microvascular anastomosis in a deep field. This approach allows early learning curve trainees the opportunity to rehearse microsurgical skills for DIEP breast reconstruction.

### DEVICE PRODUCTION

Stereolithography files (.stl) of the chest wall and the flexible blocks were designed on Autodesk's Fusion 360 software (Autodesk, San Francisco, Calif.) and manufactured on a commercial Fusion Deposition Modelling Ender 5 3D printer (Creality, Shenzhen, China) in polylactic acid (PLA) sourced from RS UK (1.75 mm filament by RS, Northants, United Kingdom) and flexible polyurethane filament (YOYI TPU) respectively. The main rib cage construct shown in Figure 1 weighs 23g and requires 2 hours of printing time (Table 1). The flexible blocks mimic the intercostal muscles and can be adjusted depending on the location of the vessels. Three of those blocks weigh 15g and take 1.5 hours to print (Table 1). (See figure, Supplemental Digital Content 1, which displays the 3D printed rib cage device over the chicken thigh vessels. The vessels run perpendicular to the rib and the access is minimized providing simulation training to the user, <http://links.lww.com/PRSGO/B783>.) The size of the 3D printed chest wall was designed to fit the chicken

**Table 1. Parameters and Settings for 3D Printing the Rib Cage and Flexible Blocks**

| Manufacturing Parameters |                        |                    |
|--------------------------|------------------------|--------------------|
|                          | Rib Cage               | Blocks (x3)        |
| Material                 | PLA pro<br>(40 GBP/Kg) | TPU<br>(40 GBP/Kg) |
| Max speed (mm/s)         | 80                     | 40                 |
| Nozzle diameter (mm)     | 0.4                    | 0.4                |
| Filling density (%)      | 20                     | 20                 |
| Infill pattern           | Cubic                  | Cubic              |
| Printing time (h)        | 2                      | 1.5                |
| Layer height (mm)        | 0.28                   | 0.28               |
| Weight (g)               | 23                     | 15                 |
| Nozzle temperature (°C)  | 220                    | 225                |
| Bed temperature (°C)     | 60                     | 70                 |
| Cost (GBP/USD)           | 1.5/2.1                |                    |

Overall material cost for the four parts is provided.

thigh training model and is not anatomically accurate for human dimensions.

### DISCUSSION

Recent advances in 3D printing technologies have led to the introduction of promising applications in many fields of medicine and surgery. Although 3D printing in microsurgery is still in its infancy, it offers new avenues in research, teaching, and simulation training. Training on 3D models can be performed fundamentally anywhere, bypassing the cost and complexity of practicing in restricted anatomy labs and similar facilities required for animal models and human cadavers.<sup>4</sup> Three-dimensional printed models are particularly of great interest to early learning curve trainees given that it enables the practice of technically challenging procedures in inconsequential environments.<sup>10</sup> As a result, models have become increasingly important components of microsurgical training. As the standardization of microsurgical training models shifts towards the chicken thigh model, there is a need to ensure high-quality simulation that hinges on the accessibility, reliability, and availability of models. The current chicken thigh model offers a training experience that resembles a clinical setting to a considerable extent, however, is limited by depth perception-related constraints.<sup>6</sup> We present a 3D chest wall as an addition to



**Fig. 1.** Application of the 3D printed chest wall model. A, Application of our 3D printed rib cage device on the chicken thigh model using a digital microscope. Note the position of the hands which are raised rather than flat due to the difficulty of performing the anastomosis in depth. B, The 3D printed rib cage device with the added flexible blocks (red arrows) mimicking the intercostal muscles. The vessels run perpendicular to the ribs. C, View of the vessel under the digital microscope showing the rib on the superior part of the view.

the current chicken thigh model that reliably mimics the complexity of the anastomosis performed during DIEP breast reconstruction. Unlike the current model, the added advantage of increased depth perception with the incorporation of our 3D chest wall offers a significantly more realistic training experience.

The training model consists of a 3D printed anterior chest wall, including ribs which are placed perpendicular to the vessels and parallel to the sternum to provide realistic anatomical simulation (Fig. 1). In addition, flexible blocks are added on the ribs, reducing the exposure of vessels by mimicking the intercostal muscles (Fig. 1). (See figure, Supplemental Digital Content 1, which displays the 3D printed rib cage device over the chicken thigh vessels. The vessels run perpendicular to the rib and the access is minimized providing simulation training to the user, <http://links.lww.com/PRSGO/B783>.)

The flexible blocks can be adjusted, therefore modifying the level of complexity of micro anastomosis. Our device uses cheap and reusable materials, takes 1 minute or less to set up, and will offer a more realistic training experience. In addition, the added advantages include familiarization with anastomosing in a deep and narrow field. Our enhanced chicken thigh model is excellent for sharpening the skills of working with micro instruments in the deep surgical field, familiarizing working from an obstructed viewpoint, and exercising end-to-end anastomoses on vessels located with variable depths (Video). (See Video [online], which displays anastomosis of the femoral artery on the chicken thigh model with the use of our 3D printed chest wall device; part of the view is restricted by the rib which is indicated on this video.)

Our device, as an addition to the current chicken thigh model is simple, cost-effective and offers a significantly more realistic resemblance to a clinical situation. The device has been evaluated for accuracy and usefulness by senior microsurgeons, and junior trainees that have used it confirmed that it is a great tool to hone their microsurgical skills in an advanced setting. There is a high likelihood that such simulators translate to improved confidence and competence in surgical learning of microsurgical anastomosis techniques in autologous breast reconstruction amongst early learning curve trainees.

### CONCLUSIONS

We designed and produced a 3D printed chest wall simulation device which can be used as an addition to the chicken thigh anastomosis training model. The device is reusable, cheap and effective for advanced microsurgical

training for anastomosis in depth as performed during the DIEP reconstruction procedure. The device in combination with a low cost portable digital microscope expands the accessibility for microsurgical training for all level trainees, as they can hone their skills anywhere. Our experience demonstrates that 3D printing can be a useful addition to microsurgical institutions as it can allow for rapid incorporation of other similar devices that can enhance the experience of the trainees during simulation microsurgical training.

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*This study conformed to the Declaration of Helsinki.*

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