

Microsurgery Training in Plastic Surgery

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Summary: Advances in surgical instruments, magnification technology, perforator dissection techniques, and vascular imaging over the past decades have facilitated exponential growth in the field of microsurgery. With wide application potential including but not limited to limb salvage, breast reconstruction, lymphedema treatment, and sex affirmation surgery, microsurgery represents a critical skill set that powerfully augments the reconstructive armamentarium of plastic surgeons. Accordingly, microsurgical training is now a critical component of the plastic surgery residency education curriculum. Trainees must meet minimum microsurgery case requirements in addition to the core competencies outlined by the Accreditation Council for Graduate Medical Education. Through the use of simulation models, residency programs increasingly incorporate early skills development and assessment in microsurgery in the laboratory. Beyond residency, microsurgery fellowships offer additional exposure and refinement by offering volume, complexity, autonomy, and possible focused specialization. With continued refinement in technology and advances in knowledge, new types of simulation training models will continue to be developed and incorporated into microsurgery training curricula. (*Plast Reconstr Surg Glob Open* 2020;8:e2898; doi: 10.1097/GOX.0000000000002898; Published online 17 July 2020.)

HISTORIC PERSPECTIVE

The field of microsurgery has grown exponentially in the last 120 years.¹ Following the invention of the vascular suture techniques, Carrel and Guthrie began to successfully perform replantations and transplantations in dogs in the early 1900s.¹ The development of heparin in 1916 allowed for these operations to be performed in humans. These advances were further compounded by the invention of the microscope in the early 1920s, allowing for magnification of small vessels and suture materials.¹ In the 1950–1960s, successful replantations and revascularization of hands and digits were reported.^{2–6} Buncke and Schulz,⁴ Buncke et al,⁵ and Buncke and Schulz⁶ performed numerous experiments in the laboratory, leading to the development of microsurgical principles and techniques. In 1960, Jacobson and Suarez^{7,8} completed the first successful microvascular anastomosis using an operating microscope and proceeded to develop specialized microsurgical

instruments. In the 1970–1980s, tissue transfer occurred at several centers internationally and free vascularized bone and joint transfers became a possibility.^{1,8} Over the next 50 years, the breadth and types of successful tissue transfers expanded with the growing understanding of vascular anatomy.^{1,8} New tissue donor sites and flap variations continued to be described and research efforts worldwide contributed to the field, including the exploration of composite tissue allotransplantation and regenerative medicine.^{1,9}

PRINCIPLES OF MICROSURGERY TRAINING

Microsurgical skills are part of the repertoire of a competent plastic surgeon, and residency training programs in the United States have embraced microsurgical education as part of their core curriculum. Microsurgery training requires dexterity and practice and is based on a unique set of principles that differ from the regular surgical skill set. The use of an operating microscope or magnification specialized instruments and the development of fine hand–eye coordination are among these skills. The traditional method of mastering surgical skills by being an “apprentice” in the operating room is antiquated. The modern education of a surgical resident has been replaced with core competencies determined by the Accreditation Council for Graduate Medical Education along with minimum case requirements. Programs are improving efficiency in surgical education by encouraging simulation-based and hands-on training. There has been

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an increase in training models among programs due to the realization that early skill development can occur in simulation laboratories.¹⁰ With competency-based surgical training limited by increasing number of residents, strict work-hour rules, and decreasing resident autonomy, microsurgical skill laboratories can be an effective complement to trainee education.

MICROSURGERY TRAINING MODELS

Modern microsurgery education consists of prosthetic, animal, and human cadaveric models to teach trainees the skill set to succeed as a microsurgeon. Although not specifically involved in enhancing the knowledge of microsurgery reconstruction, these models serve as a platform for learning and improving microsurgery technique before its use on formal patients in the operating room. It allows residents and fellows to develop manual dexterity and operative flow. These models have been incorporated into residency and fellowship training programs through didactic teaching, online resources, and simulation training courses. Many of these models have been formally validated, including specific methods such as diathermy pad, rubber pad, porcine eye, chicken leg, polyurethane card, rat femoral artery, silicone tubing, porcine free flap, earthworm, online curriculum, and simulation training courses.^{10–16} In addition, there are many nonvalidated training models that have also been used in resident training, including surgical gauze, colored beads, and surgical gloves.^{10,11}

Prosthetic Models

Prosthetic training models have been used to allow residents and fellows to develop and practice their microsurgical technique. Cardboard models, latex sheets/gloves, and surgical gauze are among the most cost-conservative examples.¹¹ The “round-the-clock” training model by Chan et al¹¹ has also been proposed where participants are tasked to pass a microsuture through the needle eyes and to complete the circle 3 times. This “Japanese noodle model” has shown close similarity to a rat’s femoral artery diameter and is an inexpensive practice technique.¹² Silastic tubes, polyethylene tubes wrapped with synthetic adventitia, and synthetic simulation vessels have been suggested to simulate blood vessel size and shape.^{13–16} A silicone-based simulation model has been proposed for use in peripheral nerve microsurgery training, mimicking human tissues mechanically and cosmetically.¹⁷

Animal Models

Animal models, both cadaveric and live, provide some of the opportunities for microsurgical simulation for trainees. Animal cadaveric tissue models are more similar to live human tissues and provide a superior training model, when compared with prosthetic models. The classic specimens used for training are chicken, rat, and porcine models.^{18–28} Chicken specimens are readily available and inexpensive, making them a popular choice for microsurgery simulation. The chicken aorta, which measures approximately 4mm in diameter, has been reported to be effective to practice microvascular anastomosis. The chicken thigh model has demonstrated

objective improvement in microvascular skills and a significant decrease in anastomosis time.^{18–20} In this model, there was a statistically significant decrease between the time required to complete the first stitch (235 seconds, 95% confidence interval, 198–272 seconds) and the time required to complete the last stitch (120 seconds; 95% confidence interval, 92–149 seconds), an average 48.7% (115 seconds) decrease in time ($P < 0.001$). Junior (postgraduate year 2–3) and senior (postgraduate year 4–5) residents had similar decreases in time (49.1% and 48.21%, respectively).¹⁸ The femoral neurovascular bundle has been used for micro-anastomosis practice, demonstrating efficiency in performance.²¹ The chicken wing model has also been used to learn microsurgical skills with the advantages of being affordable and readily available with similar blood vessel diameter to humans.²²

The Blue-Blood Chicken Thigh Model uses hydrogel microvessels to provide a training platform for residents. A microsurgical training course using this model demonstrated improved resident comfort and confidence in operating a microscope, handling microsurgical instruments, handling tissues, manipulating needles, microdissection, and performing end-to-end and end-to-side anastomoses. The model additionally provides an in vivo experience without live animals.²⁹

Porcine thigh models offer some advantages over other live animal models in that they have longer and larger blood vessel diameters, providing for multiple anastomosis attempts.^{23–25} Porcine spleen and coronary vessels have also been described in the literature for microvascular training. A pig foot training model has been used for practice of supermicrosurgery for lymphaticovenular anastomosis.²⁶ Furthermore, cryopreserved rat vessels, obtained from other laboratory experiments, have been used for learning microsurgical skills.^{27,28} These cadaveric porcine and rat models are useful; however, they may not be as readily available as chicken models.

Despite the affordability and availability of cadaveric animal models, live animal models have become the gold standard for microsurgery training due to their ability to best simulate the dynamic human tissue environment. Live rat models are frequently used by many training programs, due to their appropriately sized femoral blood vessels, active blood flow allowing assessment of vessel patency, and reasonable cost.^{30–32} The live rat model also allows for the simulation of clinical scenarios such as low flow states, vessel mismatch, and poor quality of recipient vessels seen in the operating room.^{33–35} Live rat models have also been used to practice raising perforator flaps, and similarly, live pigs have been used for breast reconstruction free flap harvest.^{30–32} Replantation techniques of rat tails, penis, and hindlimbs have been practiced on live rat models.^{33–35} Despite all the benefits, there are drawbacks to the use of live animal models, including a higher cost, ethical concerns, and their 1-time use limit.

Human Cadaveric Models

The use of human cadavers in microsurgical skills training is superior to animal cadaveric models because it provides the most “like” tissue available and represents

another education model for trainees to learn and refine their skills outside the operating room. Human cadavers are particularly useful for learning microsurgical reconstruction concepts, such as teaching flap elevation, pedicle dissection, and recipient vessel exposure.³⁶⁻³⁹ These concepts may not necessarily be learned on other animal models that do not allow for the replication of flap elevation and pedicle dissection. These cadaver models also offer specialized training for subspecialized procedures such as facial transplant.³⁹ In addition, human tissue cadavers that are still perfused have been developed and can be useful for microsurgical simulation. They are created by cannulation of large vessels to most closely simulate in vivo perfusion, allowing for assessment of microsurgical anastomosis and patency assessment. These techniques have been shown to be cost-effective and offer the highest level of training.³⁶⁻³⁸ Human cadavers are most preferred by trainees for simulation; however, they are not as cost-effective or accessible as other models previously described.

Training Curricula

There are a few training curricula that have been designed to enhance microsurgical training. These training curricula can be didactic lectures, online resources, and formal microsurgery courses. A validated training program by Masud et al⁴⁰ for trainee microsurgeons showed substantial improvement in microsurgical technique compared with the control. An initial didactic teaching session was attended by all trainees explaining all techniques and the use of a microscope. Using a chicken femoral artery anastomosis, an initial assessment determining the baseline level of each trainee and final assessment demonstrating improvement were performed. The 12-week program was structured based on lessons on needle dexterity, economy of movement, operative flow, and operative judgment. It focused on specific new tasks for each week and a review of weak tasks from the week before.⁴⁰ Various other microsurgery courses, such as an 8-week microsurgery course by Ko et al,⁴¹ and rat model courses by Holzen et al⁴² and Zhou et al,⁴³ have shown significant improvement in resident efficiency and global rating scales.^{10,44,45}

Hands-on Residency Training

An important component of microsurgical education is hands-on training during residency. Some authors have suggested that high operative volume and exclusive hands-on operative training and experience play a larger role in resident microsurgery performance compared with an apprentice training model. However, there are no current studies available that analyze the effect of preoperative skills training, operative volume, and microsurgery autonomy on the competency of plastic surgery residency graduates. Some authors argue that programs with less autonomy or volume should incorporate a formal microsurgery curriculum with validated laboratory training models and assessments.⁴⁵

Successful microsurgical reconstruction necessitates knowledge and mastering of the entire procedure from the beginning to the end. Many of the simulation training models focus on performing a successful micro-anastomosis.

However, to be a competent microsurgeon, one must develop the critical decision-making ability required for flap elevation, perforator selection, and recipient vessel selection and preparation. Moreover, a competent microsurgeon must know how to deal with unanticipated intraoperative events and flap salvage, thus making hands-on residency training a valuable component of microsurgical education. Simulation training can offer residents a great environment to practice technical skills, but the optimal way of developing these decision-making skills is to allow graduated resident autonomy. Striking the balance of patient safety and maximizing resident education are not always easy but are of paramount importance. A study by Zhang et al³³ examined the outcomes of resident-led microvascular reconstruction.⁴⁶ In comparison to the study by Jubbal et al⁴⁷ that examined the National Surgical Quality Improvement Program database for resident-assisted microsurgical reconstruction, Cho et al⁴⁶ reported a higher overall flap success rate (95.5% versus 93.6%) than the previous study and lower flap take back (7.0% versus 17.6%) in the resident-led cases.^{46,47} However, the average operative time was slightly longer (525 versus 519 minutes). The study did show higher donor site complications and rates of infection.⁴⁶ However, these results are attributed to minor wound disturbances that healed with local wound care, a disproportionate number of head and neck and lower extremity reconstruction patients, and a large population of diabetic patients, which was found to be the strongest predictor of any complication. Although the rate of intraoperative adverse events in practicing surgeons has not been reported as a comparison, the study achieved high overall flap survival and showed that maximum resident operative experience can be achieved without compromising patient safety in microsurgical reconstruction. The group cites several factors that allowed for successful resident-led outcomes, including the availability of microsurgical education material, animal laboratories, large microsurgical clinical volume, availability and dedication of the faculty to resident education, and commitment to resident independence with appropriate supervision. Overall, evidence clearly shows that early resident skill development will lead to improved independent operative skill and, in turn, patient safety.⁴⁶

PERFORMANCE ASSESSMENT TOOLS

Several validated assessment tools have been developed to monitor trainee progress during microsurgical practice, including self-evaluation, Imperial College Surgical Assessment Device, video-monitoring objective structured assessment of technical skills, the Stanford Microsurgery and Resident Training scale, Stanford motion analysis scoring system, and many more.⁴⁸ These tools have varying scales that allow for the assessment of resident and fellow skills and are rated using item task-specific checklists and a global rating scale.

The Imperial College Surgical Assessment Device is a validated motion-tracking device attached to the surgeon's hand that tracks objective data, including movement length in 3 planes, individual hand movements, and time. The video-modified objective structured assessment of

technical skills examines video recordings judging based on the economy of movement, confidence of movement, respect for tissue, and precision of operative technique, measured on a Likert scale. Multiple studies have demonstrated both instruments' construct validity with significant improvement in skill before training to after training.^{48–50}

The Stanford Microsurgery and Resident Training Scale is a validated measure that examines resident skills using video-modified global rating scale and consists of 9 categories, such as “respect for tissue” and “suturing technique” on a Likert grading scale. Construct validity is measured by higher scores achieved by senior residents compared with junior residents.⁵¹

The Structured Assessment of Microsurgery Skills is a valid instrument for assessing microsurgical skill, providing individualized feedback with acceptable inter-evaluator reliability. It examines 12 items in 4 areas: dexterity, visuospatial ability, operative flow, and judgment. In a study performed to validate the instrument, all skill areas and overall performance significantly improved and operative errors decreased significantly between the first and second time periods (81 versus 36; $P < 0.05$).⁵²

CURRENT TRAINING RESOURCES

A survey conducted by Mueller et al⁴⁵ evaluated the current variation in microsurgery training across integrated plastic surgery residency programs in the United States and demonstrated that although 94% of program had access to training microscopes for residents, 78% of programs lacked a formal curriculum. The prevalence of programs with anastomosis models for training was 69% for prosthetic vessels, 50% for nonliving biologics (ie, chicken thigh), and 66% for living biologics (ie, live rats). Sixteen percent of programs required microsurgical skills assessment before resident's participation in microsurgery in the operating room, and none of the programs recorded residents in the operating room or used video-based reviews. Thirty-eight percent of programs sent their residents to microsurgical training courses. Most programs (77%) revealed that offering a formal microsurgical training curriculum would be beneficial, whereas 23% felt the opposite. Those programs that reported the latter explained that a formal curriculum would not be helpful as their program already provided a formal microsurgical curriculum or that their program provided enough case volume for training. The majority of integrated plastic surgery residency programs provide access to training microscopes and a variety of anastomosis models regardless of program size or microsurgery fellowship.⁴⁵

MICROSURGERY FELLOWSHIPS

Microsurgery fellowships offer additional exposure and training in microsurgery following residency. The earliest fellowships were established in the 1980s, and currently in the United States, the American Society for Reconstructive Microsurgery sponsors the Microsurgery Fellowship Match, which has been established since 2010. Match day was typically in June of the previous year, preceded by 2 months of in-person interviews. These fellowships typically provide a

1-year training experience and, on average, approximately 110 cases for the year (range, 60–180).^{53–56} Numerous studies have demonstrated that fellowships help expedite the learning curve. Rather than purely focusing on microsurgery technique, fellowships provide the opportunity for additional training in microsurgical reconstruction. In a study of 20 microsurgery fellows, using a validated assessment tool of microsurgical skills, pre- and post-fellowship evaluation showed that regardless of initial skill level, all fellows improved over the course of the year and the overall difference in skill level was significantly narrowed. Almost all fellows achieved a high level of microsurgical skill by the end of the year. Furthermore, fellows with lower initial assessments improved their technical abilities more rapidly, whereas fellows with higher initial assessments made their greatest improvement in speed and efficiency.⁵³ Microsurgery is a highly technical field where high-volume hands-on training was necessary.⁵⁴ On a survey of 26 fellows gauging the average comfort level from 1 to 5 on independently performing a deep inferior epigastric perforator (DIEP) free flap, this score rose from 2.7 on the first day of fellowship to 4.8 by the final day.⁵⁵ More importantly, the year of focus on microsurgery goes beyond technical skills because it offers increased exposure to all aspects of microvascular reconstruction, including the clinical decision-making process as well as research and exploring experimental questions in microsurgery.⁵⁶

CONCLUSIONS

The training of a competent and versatile microsurgeon requires early exposure to simulation-based training models in conjunction with consistent resident independence and appropriate supervision. Plastic surgery programs in the United States are incorporating validated methods of microsurgical training skills into residency training. With future microsurgical and technologic advances, new types of simulation training models will continue to be developed and incorporated into microsurgery training curricula across the country.

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