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MICROSURGICAL EDUCATION IN THE USA: PAST, PRESENT AND FUTURE

K.H. Park[1, 2], G. Romero[1, 3], J. Paladino[1, 4], J. Daou[1, 3], Y. Akelina[1]

[1] *Columbia University Irving Medical Center, New York, USA*

[2] *Rutgers University, New Brunswick, New Jersey, USA*

[3] *International American University, USA*

[4] *Sidney Kimmel Medical College, Thomas Jefferson University, USA*

Microsurgery is a demanding surgical skillset which requires attention to detail and repeated practice to succeed. Microsurgery courses around the globe allow students to learn through performing a variety of technical exercises. Microsurgery education dates back to the late 1960s with notable instructors, Harry J. Buncke and Robert Acland. Currently, many microsurgery courses are available that share commonalities, and some important structural differences have been demonstrated to differentially affect student progression and competence. Multiple available training programs as well as the advancement of supermicrosurgery training is listed and described.

The microsurgery training course at Columbia University's New York Presbyterian Irving Medical Center led by Drs. Ronsenwasser, Strauch and Akelina provides students with expert instruction through a punctilious training curriculum. By imparting these techniques to the students, trainees's progression markedly improves relative to alternative microsurgery courses that do not incorporate expert instruction. The Covid-19 pandemic, has resulted in the development of a virtual microsurgery training program at the lab which focuses on building the foundation of basic skills for trainees unable to travel or receive adequate education.

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МИКРОХИРУРГИЧЕСКОЕ ОБРАЗОВАНИЕ В США: ПРОШЛОЕ, НАСТОЯЩЕЕ, БУДУЩЕЕ

К.Х. Парк[1,2], Г. Ромеро[1,3], Дж. Паладино[1,4], Дж. Дау[1,3], Е. Акелина[1]

[1] *Медицинский центр Ирвинга, Колумбийский университет, г. Нью-Йорк, США*

[2] *Ратгерский университет, г. Нью-Брансуик, Нью-Джерси, США*

[3] *Международный Американский университет, США*

[4] *Медицинский колледж Сидни Киммела, Университет Томаса Джефферсона, г. Филадельфия, Пенсильвания, США*

Микрохирургия – это сложный набор хирургических навыков, который требует пристального внимания к деталям и многократной практики для достижения успеха. Образование в области микрохирургии берет свое начало с конца 1960-х гг., ее основоположниками являются известные хирурги Гарри Дж. Банке (Harry J. Buncke) и Роберта Акланда (Robert Acland). Курсы по микрохирургии во всем мире позволяют студентам учиться, выполняя различные технические упражнения. В настоящее время доступно большое количество схожих по содержанию курсов, при этом было продемонстрировано, что некоторые важные структурные различия этих курсов по-разному отражаются на успеваемости и компетентности студентов. Перечислены доступные программы обучения, описано развитие процесса обучения супермикрохирургии.

Учебный курс по микрохирургии в Медицинском центре Ирвинга Колумбийского университета (г. Нью-Йорк, США) под руководством докторов Ронсенвассер, Штраух и Акелиной предоставляет студентам возможность квалифицированного обучения в рамках учебной программы. При этом успеваемость слушателей заметно повышается по сравнению со студентами, проходящими обучение по альтернативным курсам по микрохирургии, которые не включают инструктаж экспертов. Пандемия COVID-19 послужила причиной для разработки виртуальной учебной программы по микрохирургии в лаборатории, направленной на получение базовых навыков для обучающихся и получение ими адекватного образования.

Ключевые слова: *микрохирургия, обучение микрохирургии, виртуальное обучение, анастомоз, микрососудистая хирургия, микрохирургическое образование.*

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HISTORY OF EDUCATION IN MICROSURGERY

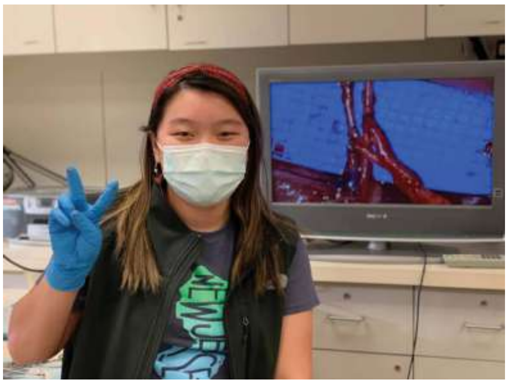
The field of microsurgical education dates back to the 1960s with a series of milestone procedures. These procedures introduced new methods of intraoperative magnification into surgical vascular procedures. First, Julius H Jacobson from University of Vermont and E.L. Suarez's paper titled "Microsurgery in anastomosis of small vessels" is widely recognized as the first microvascular procedure and is based on their completion of an anastomosis of a canine carotid artery in 1960 [1]. It had described that the operating microscope opened horizons for one-millimeter vessel repairs, of which Jacobson termed "microsurgery." Jacobson's pioneering procedure spawned many follow-on studies and procedures globally, highlighted by several of Harry J. Buncke's accomplishments such as his digit replantation procedure [2].

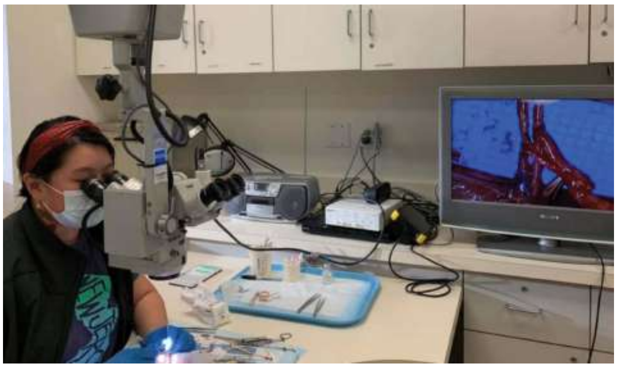
Encouraged by the possibilities of using the operating microscope, Bunke went on to perform his now well-known experiments of tissue transplantation in animal models – starting with the replantation of amputated rabbit ears. In 1967, along with other microsurgical pioneers of the 1960s, Bunke held the United States' first microsurgical panel at the Annual Meeting of the American Society of Plastic and Reconstructive Surgeons in New York

City which denoted the first in-person exchange of microsurgical findings and methods. Following the achievement of this gathering, the International Microsurgical Society was established in 1970. Buncke developed many central standards of microsurgery and is even considered "the father of microsurgery" for both his contributions to the field as well as his ~20 years of training microsurgeons all over the world [3, 4].

On the other hand, Robert Acland is noted as one of the world's greatest microsurgery instructors. After accepting an invitation to establish a microsurgery training laboratory at the Kleinert-Kutz Hand Center in Louisville, Kentucky [5], Acland would go on to teach over 3000 individuals in the Louisville lab. While there, Dr. Acland developed instructional videos and manuals for successful microvascular surgery, many of which are still widely used to this day [2].

The Microsurgery Training & Research Laboratory at New York-Presbyterian/ Columbia University Irving Medical Center was established in 1980 by Harold M. Dick, MD, former Chair of the Department of Orthopedic Surgery. The goal was to make microsurgery an integral part of a surgeon's training. Since its establishment, the laboratory has trained more than 4,000 physicians from 60 US institutions and over 70 countries. With the direction of Dr. Melvin P. Rosenwasser and instruction from Dr. Yelena Akelina, the basic & advanced courses have become internationally recognized.





DIFFERENT TRAINING PROGRAMS IN THE UNITED STATES AND THEIR CURRICULUM

There are a number of microsurgical training programs across the United States and have more recently gained traction in its importance among several surgical specialties that perform microsurgical procedures. Microsurgical procedures are performed in a variety of specialties including but not limited to plastic surgery, maxillofacial surgery, ENT, neurosurgery, orthopaedic surgery, urology, ophthalmology, and many more. Therefore, microsurgical training has been made an essential component in certain residency training programs such as plastic surgery [11] and others where Columbia University Medical Center requires the same of orthopedic surgical residents. Trainees must complete their microsurgical training curriculum and meet certain competency standards in order to successfully graduate the course.

Besides the training programs in the United States that are offered during residency, there are approximately 30 other fellowships in microsurgery offered to surgeons. These fellowships are usually 1 year in length with approximately 1 to 3 open slots per year, and more often than not, solely offered to plastic and reconstructive surgeons.

Microsurgery skill training laboratories will be the main focus in this section, as it is considered the first step into mastering microsurgical techniques before its application into the clinical setting.

Training via microsurgery labs is one of the most common and efficient paths taken by surgeons in the US. These intensive training programs offer surgeons of varying skill levels the ability to develop their microsurgical technique in a controlled environment under the guidance of an experienced microsurgery instructor.

Microsurgical training laboratories typically offer basic and/or advanced levels of practical microsurgery training. This instruction commonly ranges from 15 to 40 hours over the course of a week, depending on program structure and curriculum. Courses may also use different models of both high fidelity, living models (rat) or low fidelity being non-living models such as chicken thigh, chicken wing, and synthetic vessel constructs.

The typical basic microsurgery curriculum will vary slightly across different programs, but will usually cover common topics such as:

1) the use of the operating microscope;

2) basic suturing techniques utilizing a plastic or latex model;

3) learning how to perform end-to end anastomosis of both arteries and veins;

4) learning how to perform end to side anastomosis (ie. end of the femoral artery to the side of the femoral vein);

5) peripheral epineurial repair;

6) free flap reconstruction.

In regards to advanced microsurgery training the student will typically:

1) learn to perform end-to-end and end-to-side bypass anastomoses;

2) learn to perform inter-positional vein grafts;

3) gain more exposure in the usage of free tissue flaps.

Many programs in the United States will also tailor learning to that student's specialty, for example focusing on vasovasostomy for urologists or organ transplants for transplant surgeons.

Towards the end of each course, students are assessed via a practical exam and different assessment objective and subjective tools.

A list and brief overview of microsurgery training programs offered in the United States are included in the Table 1.

Table 1. A list and brief overview of microsurgery training programs offered in the United States

Таблица 1. Список и краткий обзор программ обучения микрохирургии, предлагаемых в США

Training place	Program	Duration	Models	Assessments
Columbia University, New York	Basic Microsurgery Advanced Microsurgery (Super-microsurgery included in advanced course)	5 days (40 hours) 5 days (40 hours)	Non-living (latex glove, synthetic vessels, chicken thigh) and living (rat)	Subjective evaluations, quality control by *transonic auro flo, and a* practical exam with ALI score
Mayo Clinic, Minnesota	Basic Microsurgery Advanced Microsurgery (Super-microsurgery included in advanced course)	5 days (40 hours) 3 days (24 hours)	Living (rodent)	Subjective evaluations and a practical exam
University of Louisville, Kentucky	Basic Microsurgery	5 days (40 hours)	Non-living (rubber glove) and Living (rat)	Subjective evaluations and a practical exam
MOET Institute, California	Basic and Advanced Microsurgery combined into one course	10 days (80 hours)	Non-living (chicken thigh)	Subjective evaluations
Duke, North Carolina	Basic Microsurgery Advanced Microsurgery	5 days (40 hours)	Living (rat)	Subjective evaluations
Cleveland Clinic, Ohio	Basic Microsurgery Advanced Microsurgery	5 days (40 hours)	Non-living (rubber glove) and living (rat)	Subjective evaluations
University of Kentucky, Kentucky	Basic Microsurgery	5 days (15 hours)	Living (rodent)	Subjective evaluations and a practical exam
University of Illinois, Illinois	Basic Microsurgery Advanced Microsurgery	5 days (40 hours)	Living (rat)	Subjective evaluations
Oakland University William Beaumont School of Medicine, Michigan	Basic Microsurgery	5 days (40 hours)	Non-living (rubber glove) and living (rat)	Practical exam

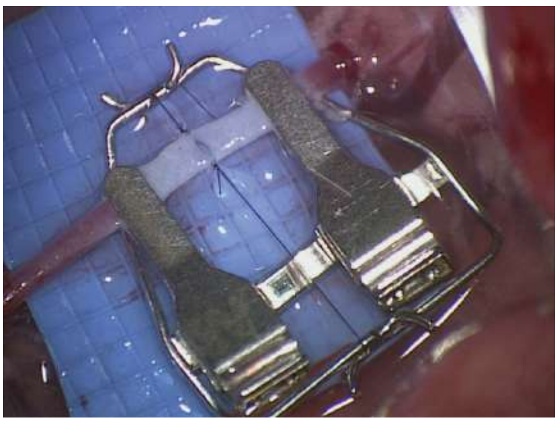
BASIC STEPS FOR END-TO-END AND END-TO-SIDE ANASTOMOSIS

The following instructional passage delineates Dr. Akelina's (from The Microsurgery Training & Research Laboratory at New York-Presbyterian/Columbia University Irving Medical Center) procedural steps for the completion of the end-to-end (ETE), the end-to-end (ETE) "one way up technique," and end-to-side (ETS) anastomosis (arterial-to-venous anastomoses) for the rat femoral vessels (~1 mm diameter). Clinically, these procedures can be applied to re-vascularization during free tissue transfers, organ transplants, arterial-venous (AV) fistula, and venous-arterial (VA) anastomosis for dialysis, among others. Clinical applications for this procedure are far reaching.

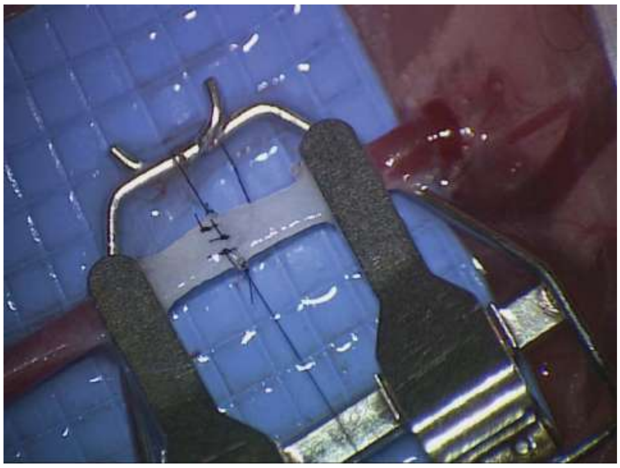
This part of the paper walks through a step-by-step procedure for all three exercises using the femoral artery and vein of the rat (part of the Basic Course). While this procedure can be easily extended to a variety of veins and arteries, the use of two autologous vessels are highlighted due to the similarities in vessel size and anatomical proximity. Although clinically the end-to-side is more commonly performed either artery-to artery or vein-to-vein, we use artery-to-vein and vein-to-artery anastomoses so students learn to perform both arteriotomy and venotomy [9, 10].

End-to-End Anastomosis step-by-step procedure (rat femoral vessel)

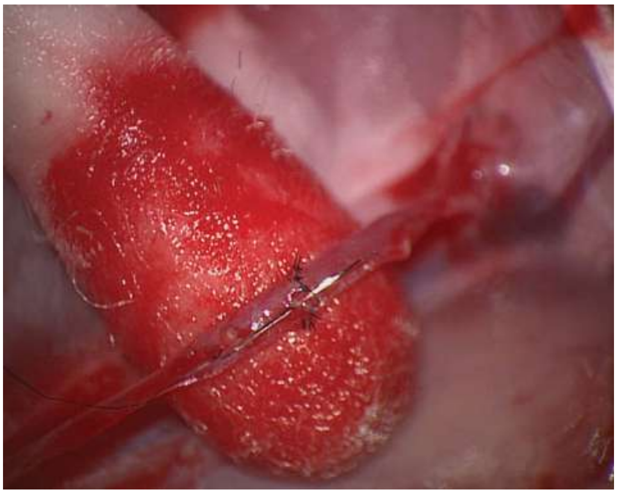
1. Perform blunt dissection of the fat pad to expose femoral vessels in the rat inguinal region.
2. Isolate the femoral artery and ligate and coagulate all muscular branches.
3. Place a double clamp with a frame into a central position on top of a blue background.
4. Divide the vessel in a middle between the double clamps.
5. Prepare the femoral artery edges by trimming adventitia and dilating the edges.
6. Place two interrupted stay sutures at the 12 o'clock and 6 o'clock positions, and fix the ends of each stay suture to the frame as stays.



7. Place three more interrupted sutures starting at 3 o'clock then 1 o'clock and 4 o'clock positions. You might leave the middle stitch longer for handling a wall to avoid catching the back wall.

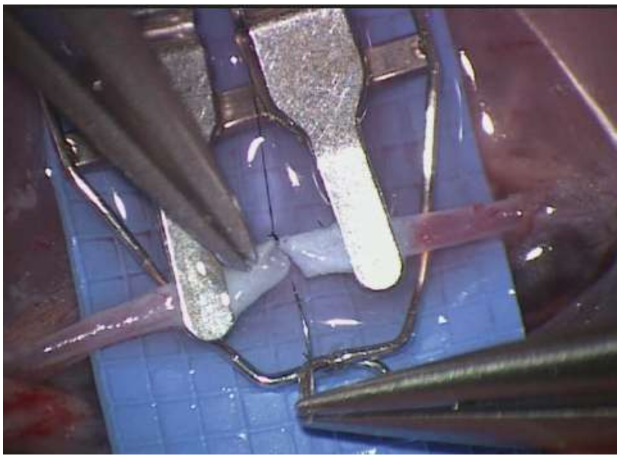


8. Flip the double clamp 180 degrees to expose the posterior wall and complete it the same manner.
9. After completion 8 stitches , release the stays and remove the clamp.
10. Place the fat pad and the gauze over the anastomosis for a few minutes for hemostasis before evaluating patency.
11. If bleeding occurs, repair the anastomosis with additional stitches using the partial occlusion techniques by Dr. Akelina shown below [20].

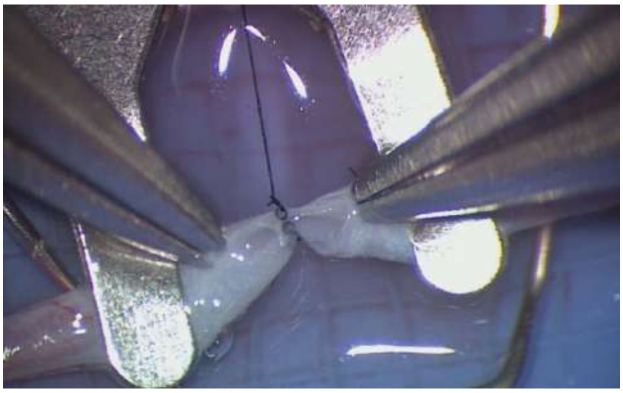


End-to-End Anastomosis utilizing the "One Way Up Technique"

1. Prepare the vessel in the same manner described previously.
2. Place a double clamp with the tips facing toward you. Prepare the vessel in the same manner described above in the normal ETE anastomosis.
3. Place and secure the first stay suture at 12 o'clock position.



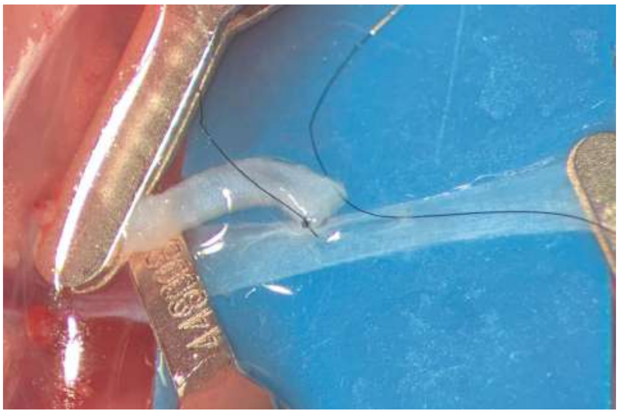
4. For the all [3] posterior wall stitches make the first pass outside-in using a backhand technique and the second pass inside out with the forehand technique described above.



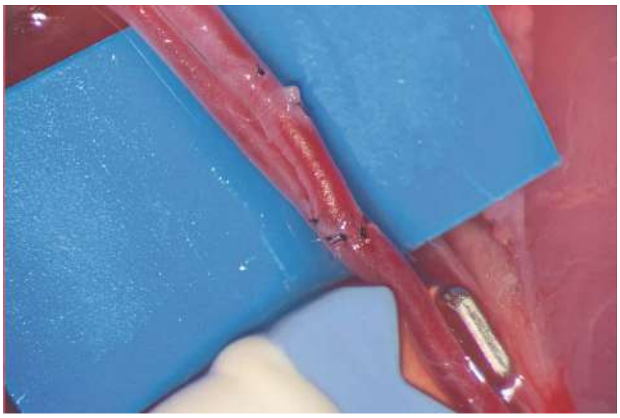
5. Put 6 o'clock stay once you reach the midpoint of the anastomosis
6. Proceed closing the anterior wall in the normal, single pass forehand manner with three more stitches.
7. Upon completion of the vessel sutures, release the stay suture and the vessel clamp.
8. If bleeding occurs, repair the anastomosis with additional stitches using the partial occlusion techniques by Dr. Akelina [20].

Step by step procedure to perform end-to-side anastomosis

1. Dissect the femoral artery and vein by separating the vascular sheath. Use blunt dissection under high magnification. Ligate and coagulate all Murphy's branches.
2. Place a single clamp on the proximal end of the femoral artery and ligate distally towards the epigastric artery.
3. Prepare the edge of the artery by trimming adventitia, and then dilate the vessel edges.
4. Place two single clamps, one on the proximal and one on the distal end of the femoral vein (as shown below).
5. Make a small "v shaped" venotomy and flush the blood with heparinized saline.
6. Dilate the venotomy opening using a vessel dilator (20% larger than diameter of the femoral artery).
7. Connect the end of the artery with the side of the vein with the first stitches at "heel" and "toe" placing both stitches "*outside in, inside out*."



8. Complete circumferential stitches along the back wall to prevent inadvertent back-wall stitches.
9. Flip the arterial clamp to the opposite side and place a retraction stitch through the adventitia of the Murphy branch before securing it to the nearby muscle.
10. Complete the front wall by keeping the middle stitch open while placing two or more radial stitches.
11. Examine the anastomosis for gaps before releasing the clamps.
12. Place the fat pad over the anastomosis for hemostasis and examine the anastomosis.



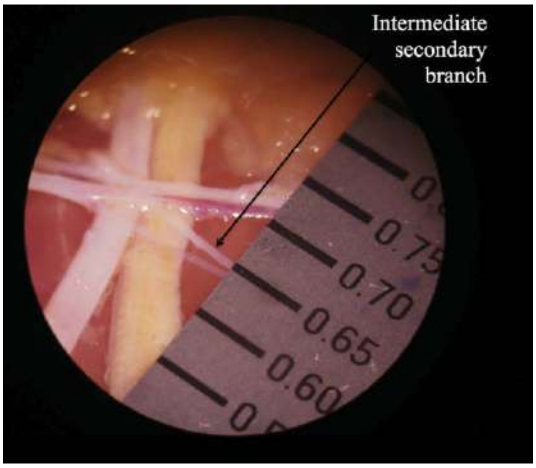
13. If bleeding occurs, repair the anastomosis with additional stitches using the partial occlusion techniques by Dr. Akelina [20].

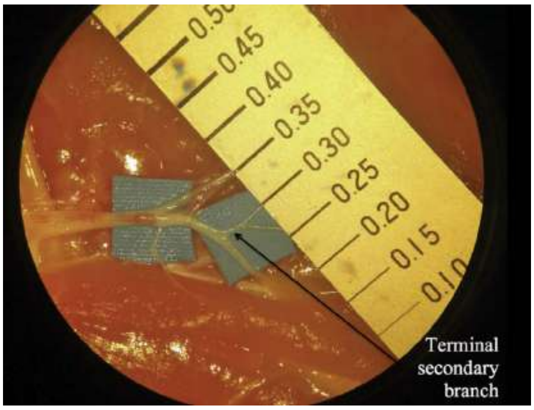
SUPERMICROSURGERY

Supermicrosurgery, a branch of microsurgery, was founded by Professor Isao Koshima, MD, at the University of Tokyo in 2000; it requires a specific set of skills and rigorous training in order to be able to perform successfully.

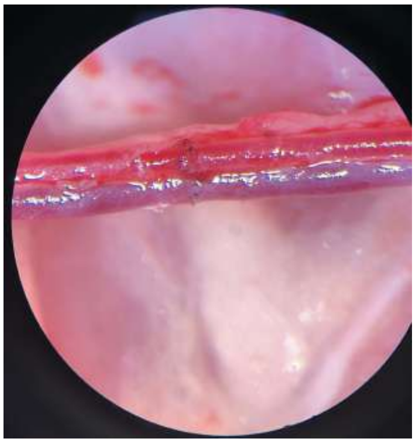
There are a few training centers that instruct trainees in supermicrosurgery in the U.S. Certain fellowships in the U.S. offer supermicrosurgery as part of their training curriculum in microsurgery such as the Cleveland Clinic [12]. Currently two microsurgery training laboratories offer supermicrosurgery training as part of their advanced course, these being Columbia University and Mayo Clinic [13, 14]. They may range from 24 to 40 hours in length over the course of 3 to 5 days. During these training courses, two models are utilized including non-living models such as a chicken thigh, a chicken wing, etc. and a living rat model.

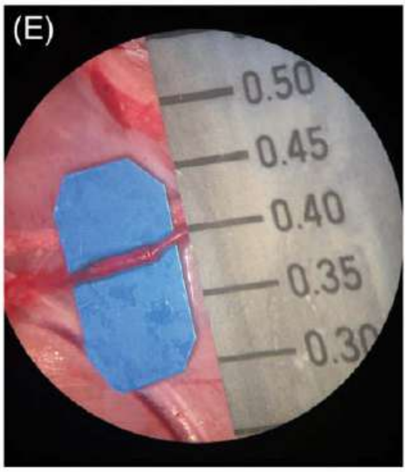
Previous literature noted that the chicken thigh and wing models are much easier to obtain and use [16, 18]. When using a chicken thigh as a model, intermediate and terminal secondary branches of vessels were measured to be from 0.3 to 0.8 mm, making them perfect targets for training specifically in lymphaticovenular anastomosis.

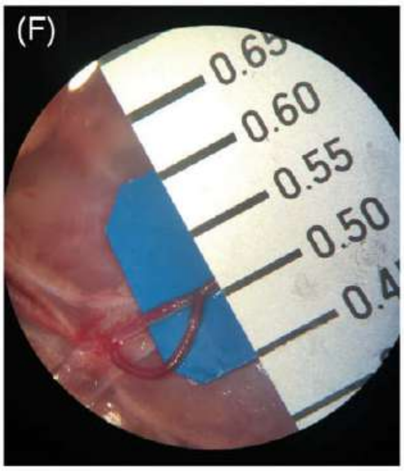




Still, the preferred model for training in terms of clinical practice is the live rat epigastric vessels from 0.3–0.5 mm diameter [17]. During Dr. Yelena Akelina's training, various anastomotic configurations of the live rat superficial inferior epigastric artery (SIEA) and vein (SIEV) are used with the following exercises: interposition SIEV graft between SIEA, end-to-side anastomosis or AV fistula, and SIEA bypass. A bypass graft from the contralateral leg SIEA can be looped to the recipient SIEA with double end-to-side anastomosis. Training with such small vessels fine tune the trainee's skills and increase their experience with supermicrosurgery to be utilized clinically as the diameter of both the SIEA and SIEV capture the character of a human lymphatic vessel or other small vessels [19].







FUTURE IN MICROSURGERY EDUCATION; VIRTUAL TRAINING

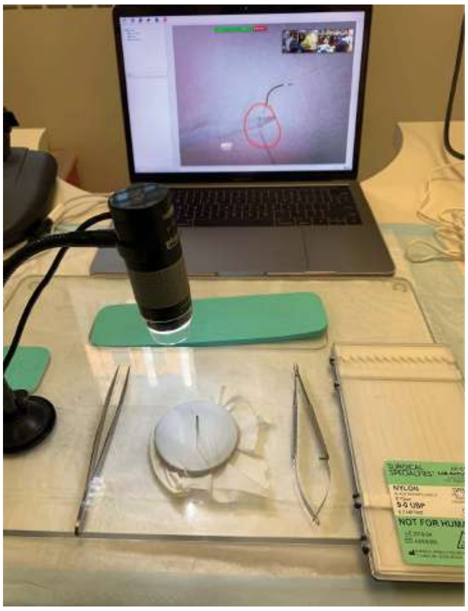
Since the beginning of the Coronavirus/ COVID-19 pandemic in February 2020, the United

States has been in a constant state of lockdowns and quarantines. Strict travel limitations, both domestic and internationally, has limited physician access to in-person, live microsurgery training for their future clinical applications. This has caused a rapid state of adaptations of microsurgical education around the evolving restrictions.

Simulated surgical training is one modality microsurgical training labs have turned to. Microvascular surgery training is not new to virtual reality training. In the early 21st century, Stanford University created a system where novice physicians could practice simple microsurgical procedures using virtual reality. Making the operator immersed in this virtual environment makes it a risk-free and repetitive tool. The workstation displays the virtual procedure while real microsurgical instruments are used as input devices [6]. Although this technology is rapidly developing, we believe that it takes away from simulations that offer more hand-on exercises and execution with a physical model.

Virtual training is making its way to the forefront of microsurgical training as it effectively eliminates many of the issues that are faced today. A teleconferencing software is used to connect an expert instructor with a student live. This does allow for all training and communications to happen online yet does not take away expert instruction; it has been previously noted that there are clear benefits in both progress and proficiency to receiving microsurgical training from an expert instructor [7].

Conversely, traditional operating microscopes could be used if available to the student but these have also been seen as a considerable barrier for training as it is not easily accessible.



A “home lab set-up” using either smartphone or digital microscope acquired by the student which is portable, relatively inexpensive and can be easily set up.

The digital microscope is connected to a tablet device and the live capture is broadcast onto the teleconferencing software. This is optimized for training as the instructor could provide immediate feedback. A previous study reported that the use of the digital microscope presented measurable improvements among resident trainees [8].

During a virtual microsurgical training course physicians will be able to learn basic microscope setups, correct body posture and hands positions, basic suturing techniques, and anastomotic procedures. This type of training is currently offered with Dr. Akelina. Thus, within a student's home/lab environments, low fidelity models and live instructions there is a way to familiarize themselves with the appropriate basic techniques in microsurgery.

Although virtual training can never truly replace in-person and live instruction of microsurgery, it is a great starting point in introducing the wide audience of students all over the globe; in hopes that the basics of microsurgery could be taught without the limitations that come with either current events or finances.

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Information about authors:

Katherine H. Park, Department of Orthopedic Surgery, Columbia University Irving Medical Center, New York, New York, USA; Department of Biomedical Engineering, Rutgers University, New Brunswick, New Jersey, USA.

Gessel Romero, BS, Department of Orthopedic Surgery, Columbia University Irving Medical Center, New York, New York, USA; Department of Medicine, International American University, USA.

Joseph Paladino, BS, Department of Orthopedic Surgery, Columbia University Irving Medical Center, New York, New York, USA; Department of Orthopedics, Sidney Kimmel Medical College, Thomas Jefferson University, USA.

Jonathan Daou, BS, Department of Orthopedic Surgery, Columbia University Irving Medical Center, New York, New York, USA; Department of Medicine, International American University, USA.

Yelena Akelina*, DVM, MSc, Department of Orthopedic Surgery, Columbia University Irving Medical Center, New York, New York, USA.
E-mail: ya67@cumc.columbia.edu

Сведения об авторах:

Кэтрин Х. Парк, отделение ортопедической хирургии, Медицинский центр Ирвинга, Колумбийский университет (г. Нью-Йорк, США); Департамент биомедицинской инженерии, Ратгерский университет (г. Нью-Брансуик, Нью-Джерси, США).

Гессель Ромеро, бакалавр медицины, отделение ортопедической хирургии, Медицинский центр Ирвинга, Колумбийский университет (г. Нью-Йорк, США); Медицинский факультет Международного Американского университета (США).

Джозеф Паладино, бакалавр медицины, отделение ортопедической хирургии, Медицинский центр Ирвинга, Колумбийский университет (г. Нью-Йорк, США); отделение ортопедии, Медицинский колледж Сидни Киммела, Университет Томаса Джефферсона (г. Филадельфия, Пенсильвания, США).

Джонатан Дау, бакалавр медицины, отделение ортопедической хирургии, Медицинский центр Ирвинга, Колумбийский университет (г. Нью-Йорк, США); Медицинский факультет Международного Американского университета (США).

Елена Акелина*, DVM, MSc., отделение ортопедической хирургии, Медицинский центр Ирвинга, Колумбийский университет (г. Нью-Йорк, США).
E-mail: ya67@cumc.columbia.edu