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Perez-Abadia, Gustavo; Pindur, Lukas; Frank, Johannes; Marzi, Ingo; Sauerbier, Michael; Carroll, Sean M.; Schnapp, Luis; Mendez, Manuel; Sepulveda, Sergio; Werker, Paul

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ORIGINAL ARTICLE

Intensive hands-on microsurgery course provides a solid foundation for performing clinical microvascular surgery

Gustavo Perez-Abadia[1,15] · Lukas Pindur[2,4] · Johannes Frank[3] · Ingo Marzi[3] · Michael Sauerbier[4] · Sean M. Carroll[5] · Luis Schnapp[6,7] · Manuel Mendez[7] · Sergio Sepulveda[8] · Paul Werker[9] · Xavier Libouton[10] · Oliver Barbier[10] · Jean-Paul Dehoux[10] · Marcelo E. Maquieira[11] · Cuahutemoc Marques Espriella[12] · Irving Joshua[1] · Zachri N. Ovadja[2,13] · Markus Spingler[14] · John H. Barker[2]

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Abstract

Purpose Microvascular surgery requires highly specialized and individualized training; most surgical residency training programs are not equipped with microsurgery teaching expertise and/or facilities. The aim of this manuscript was to describe the methodology and clinical effectiveness of an international microsurgery course, currently taught year-round in eight countries.

Methods In the 5-day microsurgery course trainees perform arterial and venous end-to-end, end-to-side, one-way-up, and continuous suture anastomoses and vein graft techniques in live animals, supported by video demonstrations and hands-on guidance by a full-time instructor. To assess and monitor each trainee's progress, the course's effectiveness is evaluated using "in-course" evaluations, and participant satisfaction and clinical relevance are assessed using a "post-course" survey.

Results Between 2007 and 2017, more than 600 trainees participated in the microsurgery course. "In-course" evaluations of patency rates revealed 80.3% (arterial) and 39% (venous) performed in end-to-end, 82.7% in end-to-side, 72.6% in continuous suture, and 89.5% (arterial) and 62.5% (venous) one-way-up anastomoses, and 58.1% in vein graft technique. "Post-course" survey results indicated that participants considered the most important components of the microcourse to be "practicing on live animals", followed by "the presence of a full-time instructor". In addition, almost all respondents indicated that they were more confident performing clinical microsurgery cases after completing the course.

Conclusions Microvascular surgery requires highly specialized and individualized training to achieve the competences required to perform and master the delicate fine motor skills necessary to successfully handle and anastomose very small and delicate microvascular structures. The ever-expanding clinical applications of microvascular procedures has led to an increased demand for training opportunities. By teaching time-tested basic motor skills that form the foundation of microsurgical technique this international microsurgery-teaching course is helping to meet this demand.

Keywords Microsurgery · Microsurgery training · Microsurgical skills · Surgical education

Introduction

Microvascular surgery has come a long way since 1960 when Jacobson and Suarez first introduced the concept of using a microscope in the operating room to anastomose tiny blood vessels [1]. The history of microvascular surgery can actually be traced back earlier to the 1920s when Carl-Olaf Nylen, an Otolaryngology resident at the time, used a high power monocular Brinell–Leitz microscope to view the cochlea in the inner ear to repair labyrinthine fistulas, at the University Clinic in Stockholm, in Sweden [2]. Based on this work, Nylen's chief, Gunnar Holmgren, improved on this concept introducing the use of a Zeiss binocular microscope with an external light source [3]. Subsequently, working with H. Littmann of the Carl Zeiss company, coaxial illumination, enhanced stability, adjustable height, and dual-viewer capabilities were added [4, 5], resulting in the development of the Zeiss OPMI-1 microscope, originally marketed for use in otology. In the 1960s, working in the US, Jacobson

Gustavo Perez-Abadia and Lukas Pindur contributed equally to this work.

✉ Gustavo Perez-Abadia
microsurgerycourse@gmail.com
http://www.microsurgerycourse.de

Extended author information available on the last page of the article

and Suarez described using a microscope, borrowed from their Otolaryngology colleagues, to anastomose 3 and 1 mm diameter carotid arteries in dogs and rabbits, respectively, and microvascular surgery was born [1]. Throughout the 1960s, the use of microscopes in clinical cases spread quickly from Otology [2] to Ophthalmology [6], Neurosugery [7], and later to Plastic Surgery [8]. This clinical introduction of operating microscopes, was accompanied by the development of smaller and finer microsurgical instruments, necessary to atraumatically handle and repair ever-smaller vessels and delicate tissue structures. Microsurgical instruments were not commercially available in the early 1960s and early pioneers in the field had to develop their own, using and adapting existing instruments from other trades, such as jewellery and watch making. In the 1960s, Jacobson developed small, crude single bulldog-like clamps to temporarily obstruct blood flow while anastomosing small vessels in animal models, and later in patients. Around the same time Susumu Tamai, in Japan, developed a double micro-clip device consisting of a pair of Scoville–Lewis clips, used in brain surgery, connected with a 22-gauge hypodermic needle, which evolved into a double clamp made and sold by Crown Company [9]. In 1971 Robert Acland, a Plastic Surgery resident at Canniesburn hospital in Scotland, together with German engineers, Werner Spingler and Gene Tritt, at their small company in Switzerland (S&T AG Microsurgical instruments), further refined these double clamps making it possible to anastomose vessels as small as 0.5 mm diameter. A slightly refined version of these same clamps are still manufactured by S&T and used widely [10]. In the early 1960s, the smallest available suture material was 7–0 silk [11] and needles measuring 127 µm in diameter [12]. In the late 1960s S&T worked with Turkish neurosurgeon Gazi Yasargil to develop smaller micro-needles measuring 100 µm in diameter, and later, between 1971 and 1974, with Acland, to further reduce needle size to 50 µm [13]. Today, even smaller, 30 µm, needles are produced and used clinically in supermicrosurgery.

Early pioneers in microsurgery developed these delicate surgeries on their own in small animals, mostly by trial and error and practice, practice, and more practice. US surgeon, Harry Buncke famously recounted his first attempts to reattach rabbit ear vessels, saying that he performed 25 that failed before getting the 26th to survive (personal communication). In 1964 Buncke and Schultz reported the successful replantation of rabbit ears, anastomosing 0.8 mm diameter vessels [14]. As the number of reports of successful anastomoses in animal models grew so did interest in applying these new microvascular methods in patients, and in the 1960s individual reports began to emerge of successful cases of digit, hand, and limb reattachments [8, 15–17]. Today, microsurgery is routine in several surgical subspecialties making it possible to perform an ever-expanding number of procedures, such as complex replantations, adipose flaps, vascularized nerve grafts and lymphaticovenular anastomoses [18–21]. In these many clinical applications the technical margins for error while performing the anastomosis are small. Seemingly minor errors like; uneven suture placement, partial tears in the vessel wall while passing the needle, leaving a piece of adventitia in the vessel lumen, damaging the vessel wall by improper handling, etc., dramatically increase the likelihood of intravascular thrombosis, compromised perfusion and failure. This underlines the importance of the surgeon possessing excellent microsurgical skills.

Microvascular surgery requires highly specialized equipment, instruments, and as importantly, individualized training to teach surgeons the skills required to perform and master the delicate fine motor skills necessary to successfully handle and anastomose very small and delicate microvascular structures. Little information exists about the first organized microsurgery-teaching programs; however, these were most likely established by the early pioneers in the institutions, where they worked [22]. An example of one such case was in 1964 at Nara Medical University in Japan, where Tamai purchased a set of microinstruments from Jacobson, and a Zeiss OPMI-1 microscope from Carl-Zeiss-Company and established a structured program for teaching microsurgery. In the 1970s a few other courses were established [23–25] one of which was in 1975 in Louisville, (Kentucky, USA), where Harold Kleinert, upon the suggestion a colleague, Graham Lister, recruited Robert Acland to establish a microsurgery-teaching laboratory in Louisville to train clinical hand surgery fellows at their institution [26].

At the University of Louisville, Acland developed a structured 5-day course in which he combined instructional videos with hands-on practice in glove rubber and live anesthetized rats. In his course Acland stressed the importance of learning the "proper" task-specific sub-skills he called "building blocks" from the beginning. Trainees were taught the consequences of using "improper" technique by receiving immediate feedback via one-on-one coaching by an experienced instructor. He insisted that, if in these critical early stages of learning trainees learn improper techniques, they could become bad habits that are very difficult to overcome later in clinical practice. Despite many advances in the field, Acland's microsurgery teaching methods have endured the test of time and are as valid and relevant today as they were when he conceived them more than 50 years ago. In 2007 Dr. Gustavo Perez-Abadia (a Pediatric Surgeons from Salta, Argentina), took over Acland's microcourse as Director and full-time instructor at the University of Louisville. While the videos and the hands-on instruction upon which the 5-day course was originally established remain largely the same, three major additions have been made to the teaching program. First, during the course, Dr. Perez-Abadia is present full-time, providing students with continuous one-on-one feed-back; second, in addition to being taught only in Louisville the location, where the course was taught was expanded internationally and is now being taught year-round in Germany, Ireland, Chile, The Netherlands, Mexico, Argentina and Belgium; and third, "in-course" and "post-course" evaluations are performed regularly to assess the courses' effectiveness and clinical usefulness.

Methods

Here we provide a brief description of the microsurgery course curriculum and the results of the "in-course" and "post-course" evaluations performed on 600 trainees, from 63 countries, taught at institutions located in 8 countries between 2007 and 2017: Louisville, US; Frankfurt am Main, Germany; Dublin, Ireland; Santiago, Chile; Buenos Aires, Argentina; Mexico City, Mexico; Groningen, The Netherlands and Brussels, Belgium.

The 5 days, 8 h/day course is taught in English and Spanish as follows:

Day 1: Basic posture, handling/care of instruments, suture exercises on glove-rubber.

Day 2: End-to-end anastomosis of femoral artery in live rats.

Day 3: End-to-end anastomosis of femoral vein in live rats.

Day 4: Interpositional vein graft technique in live rats.

Day 5: End-to-side anastomosis in live rats.

Trainees begin each day viewing videos that focus on the specific technique they will learn that day. They then go to the laboratory and practice, what they just saw on the videos, on glove rubber (day 1) and anesthetized live rat femoral vessels (0.8–1.2 mm diameter) (days 2–5) (Fig. 1), asking questions to the instructor and reviewing the videos as needed throughout the week. Trainees who advance more quickly go on to perform additional advanced anastomosis techniques (one-way-up and continuous suturing-techniques) not reached by all participants. The importance of learning each skill solidly before progressing onto the next is strongly encouraged while avoiding time-wasting repetition. The goal is that by the end of the 5-day course, participants should be able to perform the four standard anastomosis techniques (end-to-end artery and vein, inter-positional vein graft, and end-to-side technique) with comfort and peace-of-mind, consistent use of proper hand position, efficient use of microsurgical instruments and equipment, and a disciplined, step-by-step approach to the preparatory aspects of a microsurgical procedure [27].

To constantly assess and improve the microcourses' clinical usefulness, "in-course evaluations" are conducted, and "demographic information" is collected on all participants,

Fig. 1 Maximum of five trainees learning and practicing microsurgical skills guided by a fulltime, experienced instructor

and separately, former trainees were invited to participate in a *"post-course"* survey.

In-course evaluations

To assess progress made by trainees, as they learn each of the 4 individual anastomosis techniques the instructor assesses and records the number of "anastomoses performed", and the number of "patent anastomoses". These data are ultimately used to assess and improve the effectiveness of the teaching methodology.

Demographic information

During the course information about the participants' age, gender, nationality, specialty, previous microsurgery experience, and whether they had previously taken another microsurgery course, is collected to determine who is taking the course.

Post-course assessments

To assess trainee satisfaction and clinical applicability, 232 former course participants were sent emails inviting them to complete an anonymous, web-based online survey containing 6 questions, as listed in Table 1.

Animal care

Sprague Dawley rats weighing 300–350 g were used in all the surgeries at all the training facilities. Animals were kept in separate cages in temperature- (24 °C), light- (12 h/day), and air flow-regulated rooms and were provided a balanced rodent diet and water and libitum. The animals were anesthetized with intraperitoneal sodium pentobarbital (50 mg/kg), or a subcutaneous combination of ketamine (75 mg/kg) and dexmedetomidine (0.5 mg/kg). Upon completion of the surgery, rats were killed with an overdose of the anesthetics. All procedures were performed in accordance with the guidelines of each institution's Animal Care and use Committee according to the law in the country, where the course was taught.

Statistical analysis

The data obtained from the in-course, demographic and post-course evaluations were analyzed using descriptive statistics. No inferential statistics was applied.

Results

Demographic information

Of the 624 participants questioned 569 responded (91.1%) of which 144 (25.3%) were female and 425 (74.7%) were male. Their mean age was 34 years, (±5.6) and they were from 63 countries (primarily from the US and Europe).

The specialties of 537 participants who responded, in descending order, were Plastic and Reconstructive Surgery 185 (34%), Orthopedics 176 (33%), Traumatology 51 (10%), General Surgery 45 (8%), Hand Surgery 19 (4%), Otolaryngology 12 (2%), Neurosurgery 10 (2%), Maxillofacial Surgery 10 (2%), and 29 (5%) were from other specialties. Of 483 participants who responded, 94 had previously attended 1 to 3 other microsurgery courses. Of 481 participants, 40.5% had "no previous clinical microsurgery experience", 34.7% had "less than 1 year", 14.6% had "between 1–2 years", and 10.2% reported having had "more than 2 years". Despite our attempts to do so we were not able to collect complete a set of demographic parameters from all participants.

In-course evaluation

The results of "performed" and "patent" anastomoses are presented in Table 2. Several participants performed more than one arterial and venous end-to-end anastomosis; however, not all participants performed the more difficult anastomoses, (inter-positional vein graft, end-to-side (Fig. 2), one-way-up technique, venous end-to-end using one-way-up technique, and end-to-end using continuous suturing technique).

Post-course survey

Of the 232 participants contacted, 134 (57.7%) responded. The results are presented in Table 1. Of those who responded, 104 (77.6%) reported that after taking the course their *confidence in clinical microsurgery* had improved "a lot", 27 (20.1%) "somewhat", 2 (1. 5%) "slightly", and "not at all" 0. 107 (79.9%) responded that after taking the course their "*skills as an assistant*" had improved "a lot", 23 (17.2%) "somewhat", 3 (2.2%) "slightly", and "not at all", 1 (0.7%). When asked to rank the "*importance of individual aspects of the course"*, of the 123 who responded, 76 (61.8%) regarded the *"practice on live animals"*, and 32 (26.0%) considered the *"presence of the full-time instructor",* to be most important. When asked *"what additional technique(s), if any, participants would add to the course program"*, 41 (30.6%) responded they would add *"free*

Table 1 Post-course online survey questions and responses

1. How did your confidence in clinical microsurgery improve after taking the course?	
A lot	78.2%
Somewhat	20.3%
Slightly	1.5%
Not at all	0%
2. How did your skills as an assistant during microsurgical cases improve after taking the course?	
A lot	79.9%
Somewhat	17.2%
Slightly	2.2%
Not at all	0.7%
3. In order of importance, what aspect of the microcourse did you find to be the most important?	
Quality of instruments and equipment	4.9%
Acland´s Practice Manual ("red book")	2.4%
Practice on rubber glove	3.3%
Instructional videos	1.6%
Full-time presence of instructor	26.0%
Practice on live animals	61.8%
4. If you could add an additional technique to be taught during the 5-day microcourse, which of the following would it be? (You can choose one or more options)	
None, I think the course is fine as it is	17.2%
Anastomosis with microvascular coupler	24.6%
Free flaps	30.6%
Nerve coaptation	29.1%
Nerve grafting	23.9%
Replantation	18.7%
5. Did the fact that the microcourse was taught in a location closer to where you live/work impact your decision to take the course? (Only for course participant who took the course other than in the US)	
Yes	83.2%
No	16.8%
6. At the clinic you work:	
You have the opportunity to practice microsurgery on a live animal model	
Yes	17.4%
No	82.6%
You have the opportunity to practice microsurgery on a non-living model	
Yes	36.8%
No	63.2%
It is compulsory for microsurgeons to practice on a model before operating on patients	
Yes	62.9%
No	37.1%

Table 2 Number and patency rates of individual anastomosis techniques performed

	Total number of performed tasks	Total number of patent anastomoses	Total % of successfully performed tasks
Arterial end-to-end anastomosis	1413	1135	80.3
Venous end-to-end anastomosis	1065	415	39.0
Vein graft	495	288	58.1
End-to-side anastomosis	504	417	82.7
One-way-up artery technique	199	178	89.5
One-way-up vein technique	56	35	62.5
Continuous-suture-technique	51	37	72.6

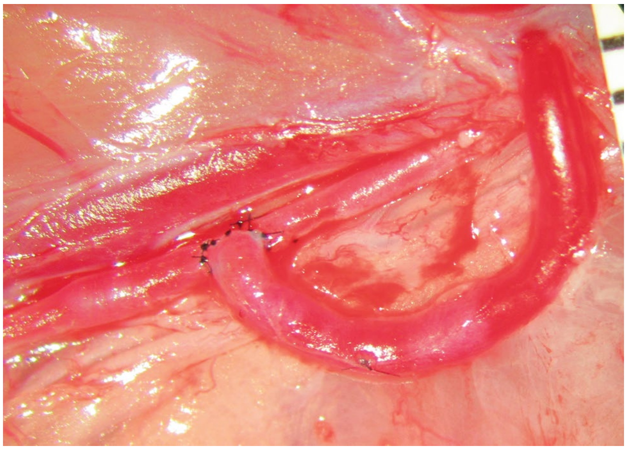

Fig. 2 End-to-side anastomosis after removing microvascular claps

flaps"; 39 (29.1%) answered *"nerve coaptation"*; 33 (24.6%) designated practicing *"anastomosis with microvascular coupler"*; 32 (23.9%) replied *"nerve grafting"*; 25 (18.7%) indicated *"replantation"*, and 23 (17.2%) responded that the course is *"good as is"*. The trainees from countries other than the US were asked, "*did the fact that the microcourse was taught in a location closer to where you live/work impact your decision to take the course",* and 94 (83.2%) answered *"yes"*, while 19 (16.8%) answered *"no"*. When asked *"do you have opportunities to practice the skills you learned in the course on live animals at your home institution"*, 23 (17.4%) answered *"yes"*, and 109 (82.6%) answered *"no"*. Forty-nine (36.8%) responded that *"they had the opportunity to practice on non-living models"*, and 84 (63.2%) did not. When asked if it was *"required to practice on a model prior to operating on patients at their home institution"*, 83 (62.9%) reported *"yes"*, and 49 (37.1%) responded *"no"*.

Discussion

While the need for instruction in basic microsurgical skills exists worldwide, unfortunately few surgical residency programs are equipped with the facilities, equipment, and/or the expertise to provide such training. A 2015 survey of US plastic surgery training program directors indicated that only half (51.8%) provide a laboratory and a microscope for microsurgery training [28]. In a similar survey conducted among plastic surgery *trainers* and *trainees* in Germany, half (52%) of the trainees reported they have no opportunity to practice microsurgery at their home facility [29]. Data from our post-course survey questioning the availability of laboratory-based microsurgery training opportunities differed considerably from country to country. While 23.1% of respondents currently training, or trained in the US and Germany, said they have, or had the opportunity to practice microsurgery on live animals, none from Ireland and Chile, and only 1 of 10 from The Netherlands had the opportunity at their home institutions. Despite this limited opportunity to practice, 64.3% of the respondents in the US, 59% in Germany, 50% in Ireland, 63.2% in Chile and 100% in The Netherlands indicated that hands-on practice is required at their home institutions prior to operating on patients. This relative lack of laboratory-based microsurgery training opportunities, in formal residency programs, combined with the requirement to practice prior to operating on patients [28, 29] causes many residents to seek training in courses outside their home programs. Since 2007 until 2017 more than 600 trainees from 63 countries, from more than 9 different subspecialties attended the microsurgery course described here in the US, in Europe, and Latin America.

The psychomotor skills involved in learning microsurgery can be subdivided into separate sub-skills or "building blocks". Acland's original teaching principles were based on careful analysis of microsurgical technique that he deconstructed into these building blocks, which he then reconstructs in a logical step-by-step fashion in his instructional videos. To enhance the learning experience and to make it easy to understand why each building block is critical he illustratively shows the "wrong way" to perform given tasks and follows it through to the end, thus highlighting a direct link between the wrong way and the resulting consequence. An example of this, still taught today, is when trainees complete an anastomosis, the instructor first assesses vessel patency, and then opens the vessel to show the trainee how the individual sutures they placed appear on the luminal surface of the vessel. This allows the trainee to assess the precision of his/her suturing technique as seen by the passing blood in the inner lumen (Fig. 3a), and how the consequence of poor suturing technique results in thrombus formation (Fig. 3b).

The effectiveness of this cause-and-effect approach, taught by one-on-one teaching method is reflected in trainees' response, in the post-course survey. When asked to rank "*the importance of individual aspects of the course"*, respondents said they considered the presence of the full-time instructor to be *the* most important aspects of the course.

While other microsurgery courses teach additional procedures, in our experience it would be difficult to increase the number of tasks taught in 5 days, and still lay a solid foundation in the fundamental skills of microsurgery. Acquiring and firmly establishing the many building blocks required to perform proper microvascular anastomoses requires hours of concentrated work under the microscope and we have found that the 5-day course leaves most participants exhausted. The ultimate goal of a basic microsurgery-training course is to provide participants a solid foundation upon which

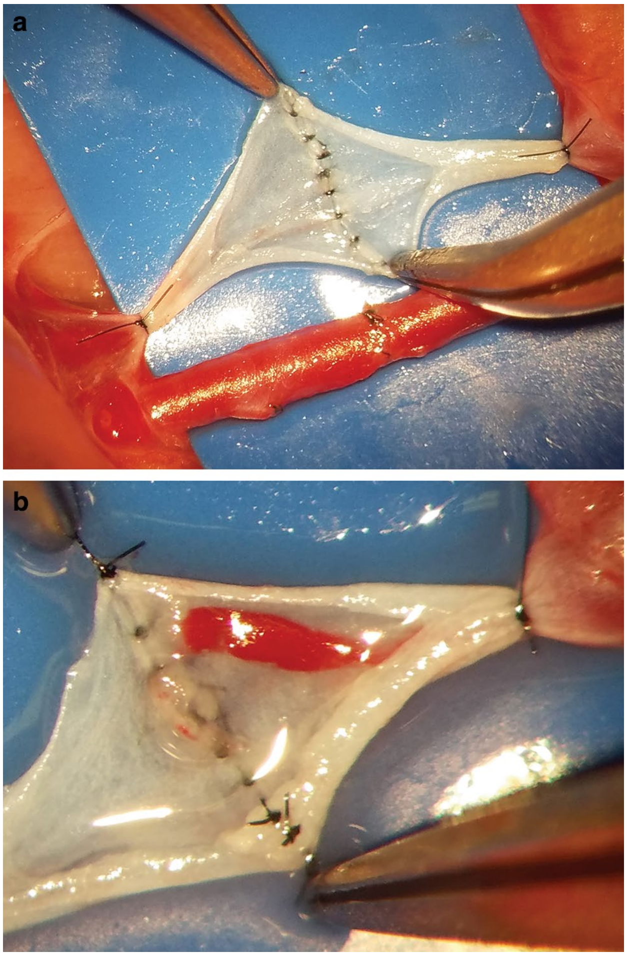

Fig. 3 **a** Venous anastomosis seen from the lumen. **b** Venous anastomosis seen from the lumen with thrombus

to build sufficient manual skills to be able to feel comfortable performing clinical microsurgery. In our experience, most participants begin the course thinking that they are not able to perform a microvascular (~ 1 mm ø) "arterial" or "venous" anastomosis. Yet, after 5 days of intensive focus and guided hands-on practice, most gain an acceptable level of proficiency, and even confidence in performing this task. In a separate question 80% said that after taking the course their "*skills as an assistant in microsurgery procedures'* had improved *"a lot"*, 23 (17.2%) responded *"somewhat"*, 3 (2.2%) responded *"slightly"*, and 1 (0.7%) answered *"not at all"*.

The number of anastomoses performed and accompanying patency rate data showed that there is a clear difference in the level of difficulty between the different anastomosis techniques taught. Of the 1413 *arterial end-to-end anastomoses* performed, 80.3% were patent. In contrast the patency rate of the *vein end-to-end anastomosis* was only 39.0%. These numbers clearly indicate that venous anastomoses are considerably more challenging to perform than arterial anastomoses. This observation is echoed in a report by Hui KC, et al. in which the authors claim that "25–30 venous anastomoses are necessary for a beginner to reach patency rates comparable with experienced microsurgeons" [30]. We have observed that one of the main reasons for this lower success and patency rates in veins, is related to the difficulty trainees experience initially, preparing (dissecting out), the vein, prior to performing the anastomosis. Unlike the rat femoral artery, the accompanying vein has a thin wall and is very delicate and must be freed-up/dissected out taking extra care not to compress, "or even touch" the wall with instruments (forceps, coagulator, clamps), so as not to traumatize it. If the vein is traumatized initially, prior to performing the anastomosis, the chances of success/patency are significantly diminished. Dissecting the vein in the clinical setting is less demanding than the vein in the rat; however, anastomosing the vein is typically more challenging. The same thin and delicate wall of the vein, that makes it difficult to suture, however, makes it ideal for applying an anastomotic coupling device (especially when the vein is 2 mm and larger), which is common practice in the clinical setting, and significantly reduces the time and level of difficulty [31].

Interestingly, while several trainees found it more difficult to perform the *vein* than the *arterial* end-to-end anastomosis, some were able to go on to perform seemingly more challenging techniques, such as interpositional vein grafts, end-to-side, one-way-up, and end-to-end anastomoses using continuous suturing. For example, 288 of 495 (58.1%) trainees were able to successfully perform vein grafts, even considering the fact that the epigastric vein, used for these grafts, is half the size of the femoral vein. Furthermore, trainees who performed more challenging anastomosis techniques such as "end-to-side", and end-to-end using the "one-way-up" and "continuous suturing" techniques were able to achieve 82.7, 89.5 and 72.6% patency rates, respectively. It must be noted that the above mentioned, relatively high success rates in the "more difficult" techniques were performed at the end of the course, by a select few trainees, who had already successfully performed 2–3 arterial and/or venous end-to-end anastomoses.

From its beginning, microvascular surgery has had international roots. While the clinical applications of microvascular surgery have evolved and expanded a great deal since the 1960s, the delicate fine motor skills required to successfully repair very small blood vessels and nerves have remained largely the same. The ever-expanding clinical applications of microvascular procedures has led to an increase in the number of cases and consequently an increase in the demand for training opportunities. By teaching the time-tested basic motor skills that form the foundation of microsurgical technique this international microsurgery-teaching course is helping to meet this demand.

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Author contributions GPA: instructor of the course, contributed to conceptualizing the study, collecting data and reviewing the manuscript, LP and JHB: conceptualized the study, collected, organized, analyzed, and interpreted data, and wrote, revised and reviewed the manuscript; ZNO: collected data and reviewed the manuscript, MSP: provided background information and reviewed the manuscript, and JF, IM, MSA, SMC, LS, MM, SS, PW, XL, OB, JPD, MEM, CME and IJ: reviewed the manuscript. All authors had full access to all data contained in the article, reviewed the paper prior to submission and take responsibility for its integrity and accuracy.

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Declarations

Conflict of interest Markus Spingler is the President and CEO in the company S&T AG—Microsurgical Instruments. Gustavo Perez-Abadia is the President of Maximum, LLC and the Director and Instructor of the International microcourse described in this paper and charges a fee for attending the course. Lukas Pindur has no commercial associations or financial interests to declare. Johannes Frank has no commercial associations or financial interests to declare. Ingo Marzi has no commercial associations or financial interests to declare. Michael Sauerbier has no commercial associations or financial interests to declare. Sean M. Carroll has no commercial associations or financial interests to declare. Luis Schnapp has no commercial associations or financial interests to declare. Manuel Mendez has no commercial associations or financial interests to declare. Sergio Sepulveda has no commercial associations or financial interests to declare. Paul Werker has no commercial associations or financial interests to declare. Xavier Libouton has no commercial associations or financial interests to declare. Oliver Barbier has no commercial associations or financial interests to declare. Jean-Paul Dehoux has no commercial associations or financial interests to declare. Marcelo E. Maquieira has no commercial associations or financial interests to declare. Cuahutemoc Marques E. has no commercial associations or financial interests to declare. Irving Joshua has no commercial associations or financial interests to declare. Zachri N. Ovadja has no commercial associations or financial interests to declare. John H. Barker has no commercial associations or financial interests to declare.

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Authors and Affiliations

Gustavo Perez-Abadia[1,15] · Lukas Pindur[2,4] · Johannes Frank[3] · Ingo Marzi[3] · Michael Sauerbier[4] · Sean M. Carroll[5] · Luis Schnapp[6,7] · Manuel Mendez[7] · Sergio Sepulveda[8] · Paul Werker[9] · Xavier Libouton[10] · Oliver Barbier[10] · Jean-Paul Dehoux[10] · Marcelo E. Maquieira[11] · Cuahutemoc Marques Espriella[12] · Irving Joshua[1] · Zachri N. Ovadja[2,13] · Markus Spingler[14] · John H. Barker[2]

[1] Department of Physiology, University of Louisville, Louisville, KY, USA

[2] Frankfurt Initiative for Regenerative Medicine, JW Goethe-University, Frankfurt am Main, Germany

[3] Department of Trauma, Hand and Reconstructive Surgery, JW Goethe-University, Frankfurt am Main, Germany

[4] Department of Plastic, Hand and Reconstructive Surgery, BG Trauma Center, Frankfurt am Main, Germany

[5] Plastic Surgical Training to the Royal College of Surgeons in Ireland, Dublin, Ireland

[6] School of Medicine, University of Chile, Santiago, Chile

[7] Traumatologia and Orthopedica, Clinica Las Condes, Santiago, Chile

[8] Cirugia Plastica, Clinica Alemana, Santiago, Chile

[9] Department of Plastic and Reconstructive Surgery, University Medical Center Groningen, Groningen, The Netherlands

[10] Orthopedic and Traumatology, Cliniques Universitaires Saint-Luc, Brussels, Belgium

[11] Traumatology and Hand Surgery, Buenos Aires, Argentina

[12] Department Plastic and Reconstructive PEMEX, Mexico City, Mexico

[13] Department of Plastic, Reconstructive and Hand Surgery, AMC, Amsterdam, The Netherlands

[14] Microsurgical Instruments, S&T AG, Neuhausen am Rheinfall, Switzerland

[15] Department of Orthopedic Surgery, Director, Louisville MicroSurgery Teaching Course, University of Louisville, 511 S Floyd Street, 328F, MDR, Louisville, KY 40292, USA