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Towards a standardized initial training program in experimental microsurgery for pediatric surgeons

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ABSTRACT

Objective. To describe a basic training program in microsurgery and to analyze the learning curve through the process, including improvement in operating times and functional outcome.

Materials and methods. Our learning program included basic, transitional, and experimental models. The experimental model included tail vein cannulation, intestinal resection and anastomosis, dissection, division and anastomosis of the cava and aorta. Wistar rats (66.7% male; 406.9 ± 38.9 grams) were used. The program adhered to the 3R principle and obtained animal welfare committee approval.

Results. Mean tail vein cannulation time was 2.4 ± 1.2 minutes. Mean intestinal resection and jejunocolic anastomosis time was 14.8 ± 2.7 minutes and 10.4 ± 3 minutes, respectively. All anastomoses were functionally valid. Mean vessel dissection time was 22.9 ± 7.7 minutes, aortic artery anastomosis was 17.2 ± 7.1 minutes, and vena cava anastomosis was 25.9 ± 7.3 minutes. 66.7% of vena cava anastomoses were functionally valid vs. 88.9% for the aorta. The time required for all procedures decreased after the third attempt, except for vena cava anastomoses, which remained similar in all 9 procedures.

Conclusions. Our model demonstrated that the procedures were suitable for trainer progression in terms of surgical time and functional outcome. Microsurgical training would benefit from standardized programs to optimize results.

KEY WORDS: Simulation training; Microsurgery; Microdissection; Rats; Wistar.

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HACIA UN PROGRAMA INICIAL DE FORMACIÓN ESTANDARIZADO EN MICROCIRUGÍA EXPERIMENTAL PARA CIRUJANOS PEDIÁTRICOS

RESUMEN

Objetivo. Describimos un programa de formación básica en microcirugía y analizamos la curva de aprendizaje a través del proceso, incluyendo la mejora en los tiempos operatorios y en el resultado funcional del procedimiento.

Material y métodos. Nuestro programa de aprendizaje incluye modelos básicos, de transición y experimentales. Dentro del modelo experimental se incluyeron: canulación de la vena de la cola, resección y anastomosis intestinal, disección, sección y anastomosis de la cava y la aorta. Se emplearon ratas Wistar (66,7% machos; 406,9 ± 38,9 gramos), el programa se adhirió al principio de las 3R y obtuvo la aprobación del comité de bienestar animal.

Resultados. l tiempo medio de canulación de la vena de la cola fue de 2.4 ± 1,2 minutos. El tiempo medio de resección intestinal y anastomosis yeyunocólica de 14.8 ± 2,7 minutos y 10.4 ± 3 minutos, respectivamente. Todas las anastomosis fueron funcionalmente válidas. El tiempo medio de la disección de vasos fue de 22,9 ± 7,7 minutos, la anastomosis de la arteria aorta de 17,2 ± 7,1 minutos, mientras que la anastomosis de la vena cava fue de 25,9 ± 7,3 minutos. El 66,7% de las anastomosis de la vena cava fueron funcionalmente válidas en comparación con el 88,9% de la aorta. El tiempo requerido para todos los procedimientos disminuyó después del tercer intento, excepto para las anastomosis de vena cava, que se mantuvo similar en los 9 procedimientos.

Conclusiones. Nuestro modelo demostró que los procedimientos eran adecuados para la progresión del entrenador en términos de tiempo quirúrgico y resultado funcional. La formación microquirúrgica se beneficiaría de programas estandarizados para optimizar los resultados.

PALABRAS CLAVE: Entrenamiento de simulación; Microcirugía; Microdisección; Rata Wistar.

INTRODUCTION

The continuous development and improvement in the understanding of the healthy and diseased human being, the diagnostic methods, and the application of treatments is a success shared between initial study and performance in the experimental setting, and subsequent implementation in humans(1-3). Furthermore, experimental training models in inert matter and in live animals are essential in the training of future surgeons.

The training of surgical specialists is challenging and increasingly difficult due to changes in the learning model, changes in the distribution of the caseload, the emergence of new technologies, and changes in the shifts of residents. One of the consequences of this is that they graduate feeling unprepared to carry out their daily work in clinical practice with confidence and autonomy(4-7). Since the mid-20th century, experimental microsurgery has developed rapidly and has been a valuable tool for the acquisition of technical skills, which results in a more delicate handling of tissues and greater dexterity in the operating room, while increasing the safety of the surgeon in training(8-10). Finally, this will not only benefit the trainees, but also the research institutions, and most importantly, the patients. With these considerations in mind, many centers have introduced experimental microsurgery training programs to optimize the training of their residents, with good results. However, one of the main problems is the lack of standardization in the learning process.

The main objective of this study was to present our training program in basic microsurgery for pediatric surgery residents and for this to become integrated and serve as an example for others and in other specialties. As a secondary objective, we analyzed the learning curve throughout the process, including operating times and the functional outcome of the procedures.

MATERIALS AND METHODS

In cooperation with the Research Institute of our Center, the approval of the Animal Ethics Committee and under the European directive EU 63/2010, we developed a training program consisting of an initial theoretical part and several practical modules divided into three levels (Fig. 1):

- **Basic module:** this included surgical skill activities (correct handling of instruments and microscope, basic manipulation, etc.) performed on synthetic material (gauze, latex gloves, etc.).
- **Transition module:** this included surgical skill activities (knot tying, knotting principle, position of edges, anastomosis, dissection, etc.) on cryopreserved rat aortas.
- **Experimental module in live animals:** this included basic surgical skill activities in rats.

For the purposes of this study, we decided to focus on describing and analyzing the experimental model in albino Wistar rats. After a thorough assessment, we included a series of basic procedures suitable for initial training. The activity was performed during the month of December 2021 by a single pediatric surgery resident (5-6 hours per day from Monday to Friday, with a total of 9 sessions) in a room of the experimental laboratory. The room was equipped with several general anesthesia sevofluorane breathing systems, polyurethane for intraperitoneal injection as an alternative to breathing anesthesia, microscope, macrosurgical and microsurgical material, and record sheets (Fig. 2). The animals were kept in cages, with water and food *ad libitum*, air, light and temperature control, and materials for environmental enrichment.

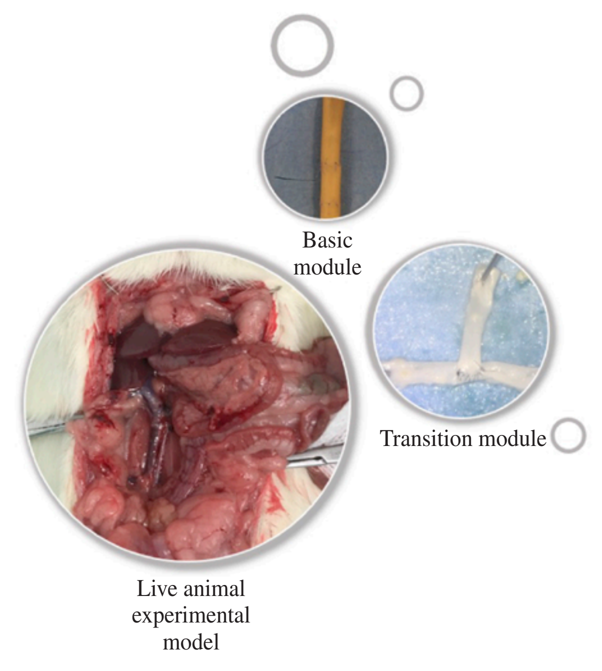

Figure 1. Images of the practical modules of different levels that make up the experimental microsurgery training program. The surgeons in training will first perform the basic module on non-living material (gauze, latex gloves, silicone probes, etc.), then on the transition module on cryopreserved aortas, and finally on the transition module on a live animal (Wistar albino rats).

The sessions began with the preparation of the field and surgical material, followed by anesthetization of the rat, removal of hair from the abdomen and placement in the supine position. After verifying that the animal was adequately anesthetized, the procedures were carried out in the following order:

- **Tail vein cannulation:** after locating and choosing the puncture site, antiseptic was applied and, with a 24G Abbocath® catheter and at an angle of 30-45º, the puncture was performed. Punctures in which the extraction and infusion of 1.5 ml of blood was achieved were considered successful.
- **Intestinal resection (jejunum and ileum):** a median laparotomy of about 5 cm in length was performed followed by exteriorization of the intestinal package.

First and last name:				*Session/Rat number:*		
Procedure	Tail vein cannulation	Intestinal resection	Intestinal anastomosis	Cava and aorta dissection	Cava anastomosis	Aorta anastomosis
Time (minutes)						
Functional result (Yes/No)						

Figure 2. Record sheet for each session.

The meso was controlled, the jejunum was divided 1 cm away from the duodenojejunal angle, and the ileum, 1 cm away from the cecum. The ends were ligated with 6/0 absorbable monofilament.

- **Dissection of the aorta and cava:** the region of the cava and the aorta was delimited between the exit of the renal vessels and the division into the iliac vessels. Dissection was considered complete when a proximal and a distal microsurgical clamp could be placed with a separation of at least one cm between the two.
- **Division and anastomosis of the aorta:** two microsurgical vascular clamps were placed in the aorta, one proximal under the exit of the renal vessels, and the other distal just before the division in the iliac vessels. After securing them, the vessel was divided medially and the termino-terminal anastomosis was started with 9/0 nonabsorbable interrupted monofilament suture on two sides (posterior followed by anterior). When the suture was completed, the clamps were removed and it was checked for patency and tightness.
- **Division and anastomosis of the cava:** two microsurgical vascular clamps were placed in the cava, one proximal under the exit of the renal vessels, and the other distal just before the division in the iliac vessels. After securing them, the vessel was divided medially and the termino-terminal anastomosis was started with 10/0 nonabsorbable interrupted monofilament suture on two sides (posterior followed by anterior). When the suture was completed, the clamps were removed and checked for patency and tightness.
- The patency and tightness of the anastomoses was checked for using the technique proposed by Acland. For this purpose, two clamps were placed distally to the anastomoses, and a maneuver was performed to empty the central region. The proximal clamps were subsequently released, and we checked whether the empty intravascular space was refilled proximally to distally. When this occurred, they were considered successful. If functionality was not achieved, we attempted to repeat the entire anastomosis. If not valid after a second attempt, the process was considered unsuccessful.

  Tightness was considered successful when no blood leakage was observed in the region of the anastomosis. If blood leakage was observed, we attempted to reinforce with stitches using the same thread as the anastomosis and, if this was not possible, the anastomosis was repeated.
- **Jejunocolic anastomosis:** after removal of the intestinal end ligatures, a jejunocolic end-to-end anastomosis was performed with 6/0 absorbable interrupted monofilament suture. Patency and tightness were checked for with the passage of intestinal contents through the anastomosis. Non-tight areas were reinforced with 6/0 absorbable interrupted monofilament stitches when possible, and the anastomosis was repeated in those cases in which it was not patent.

Sex and weight of the animal, total time spent for each process, and functional outcome (patency and tightness) were collected.

All participants were trained in the handling of live experimental animals, the 3 basic principles – 3R (replacement, reduction, refinement), GLP (good laboratory practice), and 3C (curriculum, competency, clinical performance) – were applied. The absence of animal suffering was ensured by checking the anesthetic status every 15 minutes, vital signs, and ending with the euthanasia of the animal.

RESULTS

9 sessions were performed in Wistar rats (66.7% male) with a mean weight of 406.9 ± 38.9 grams. Mean times for each procedure and functional outcome (patency and tightness) are shown in Table 1. Within the great vessel anastomoses, we experienced patency and/or tightness failures in the first three anastomoses in the vena cava, and in the first and third anastomoses in the aorta. A 100% success rate was achieved in the last six anastomoses of both vessels.

The variation in the times of each procedure is shown in figure 3. It was observed that the greater the number

Table 1. **Mean times for each procedure (mean ± standard deviation) and its functional result (tightness and patency) in percentage of success.**

Procedure / Measurements	*Tail vein cannulation*	*Jejunoileal resection*	*Jejunocolic anastomosis*	*Great vessel dissection*	*Vena cava anastomosis*	*Aorta anastomosis*
Mean time (minutes)	2.4 ± 1.2	14.8 ± 2.7	10.4 ± 3	22.9 ± 7.7	25.9 ± 7.3	17.2 ± 7.1
Functional outcome	100	-	100	-	66.7	88.9

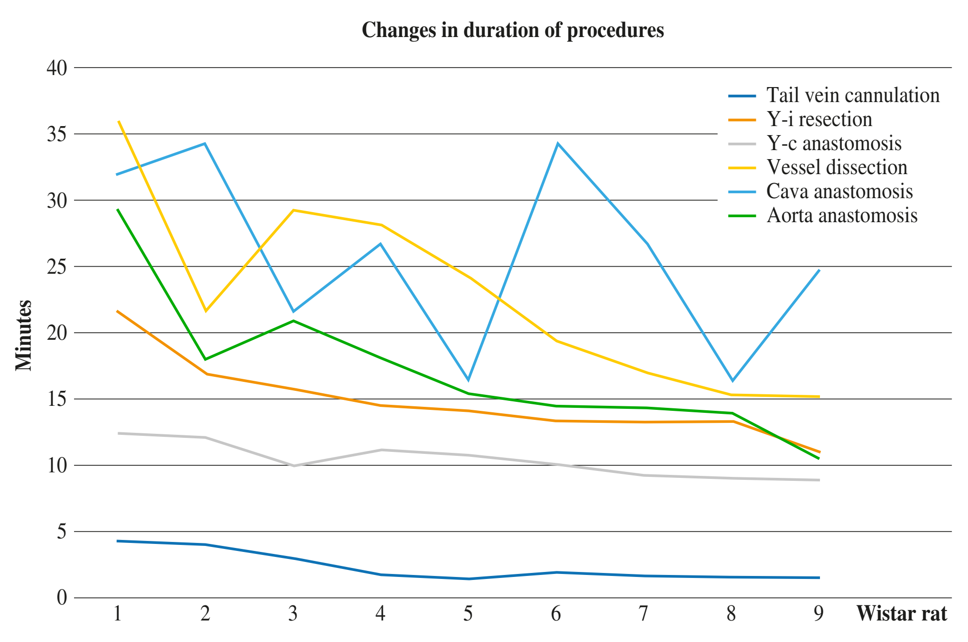

Figure 3. Time-session curve. The image demonstrates the changes in the time spent for each procedure throughout the different sessions. The X axis shows the session number (or Wistar rat used), and the Y axis shows the time in minutes.

of procedures, the shorter the time, except for vena cava anastomosis, which maintained a similar pattern in the 9 procedures. Therefore, it was considered as the procedure with the most difficult learning curve. Figure 4 features some images of these procedures.

DISCUSSION

Surgeries carried out in newborns, surgeries performed in pediatric patients on weak and fragile tissues, and vascular anastomoses pose a great challenge at a theoretical and practical level. Because of their relative infrequency, surgeons in training have little or no opportunity to deal with them before becoming specialists, which results in a lack of confidence in conducting these procedures safely and autonomously. Experimental practice helps to create a sound and secure foundation by simulating the aforementioned infrequent scenarios as closely as possible(11). With this goal in mind, we designed an experimental microsurgery program with small live animals for pediatric surgical residents. Initially, we chose a small number of procedures aimed at the initial acquisition of skills such as finesse, precision, and dexterity in various basic techniques. Based on the results obtained, we would subsequently design and introduce new, more complex, and more demanding procedures. In line with the dynamism of this idea, we collected the data obtained by a pediatric surgery resident in order to record and compare the data obtained by other residents and even specialists in the future, like Schimpke et al.(4) and Lascar et al.(12). The initial results revealed a model that appeared adequate for the progression of the resident in terms of operating time and functional outcome, consistent with those obtained by other authors such as Feijoo et al., Juratli et al., and Rodriguez et al., among others, who obtained satisfactory results when applying microsurgical experimentation programs in their most junior professionals(10,13-16). Even authors such as Kim et al. show the improvement in technique, confidence, and even the willingness of specialists to grant a higher level of participation and autonomy to residents after an experimentation program(17).

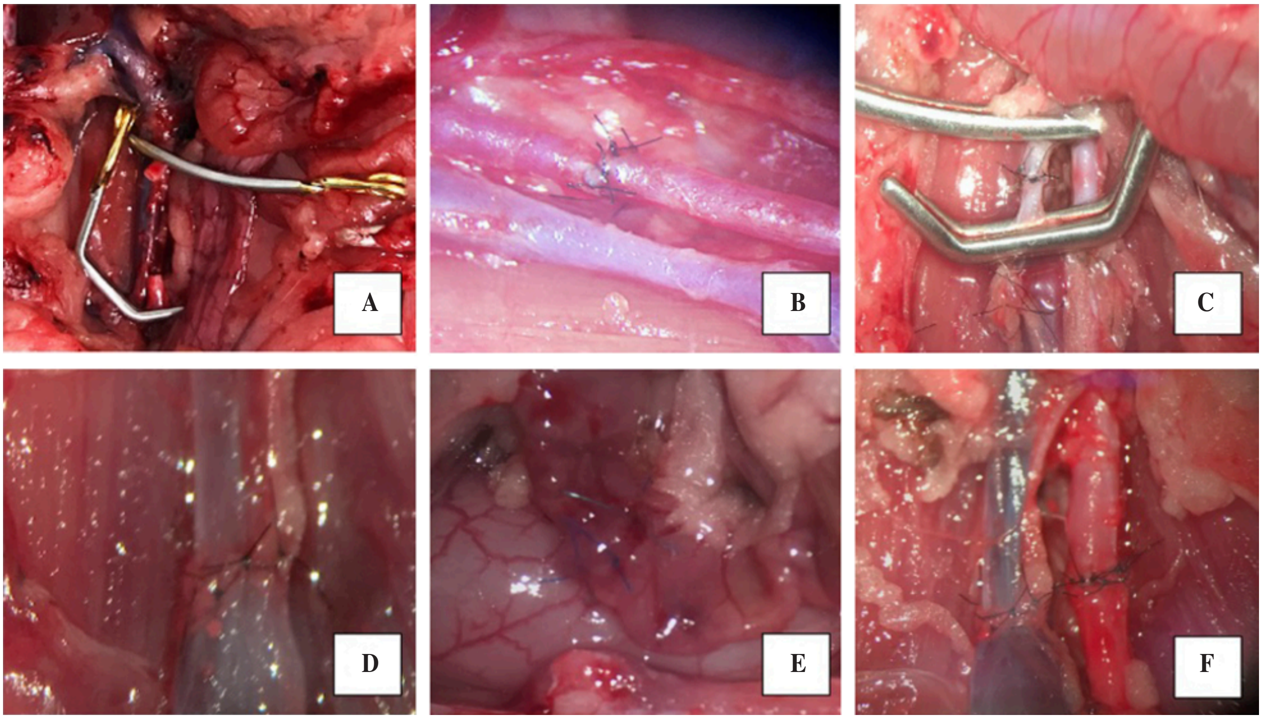

Figure 4. Images of some of the procedures. A) Division of the aorta with vascular clamps in the proximal and distal part of the vessel. B) End-to-end anastomosis of the aorta with 9/0 non-absorbable interrupted monofilament suture. C) Clamped vena cava before checking its patency and tightness. D) End-to-end anastomosis of the cava with 10/0 non-absorbable interrupted monofilament suture. E) End-to-end jejunoileocolic intestinal anastomosis with 6/0 resorbable interrupted monofilament suture. F) End-to-end cava and aorta anastomosis. Both vessels are patent but the anastomosis of the cava causes stenosis of the latter.

Furthermore, experimental microsurgery offers new psychomotor, perceptual, and visuospatial skills by practicing different techniques in the small field delimited by the view of an optical microscope. This results in advantages in hand-eye and hand-hand coordination, a key part of the minimally invasive surgery that is so prevalent today(18–20). Furthermore, the implementation of these programs is included as part of the research activity which, in many cases, is pushed into the background or even ignored.

Consequently, experimental models allow surgeons to make and recognize errors and then try to correct them by repeatedly practicing each procedure, in a process known as feedback. Issemberg et al. mention in their work this feedback as an essential feature of any surgical training and even claim it could have the most significant impact on learning (21). For example, insufficient dissection of the great vessels would result in a more complicated or even impossible anastomosis, and therefore, the resident would receive this feedback inherent to the task and try to improve the procedure on the following occasion. Meanwhile, Ericsson et al. and Gómez et al. advocate repeated practice in order to achieve mastery of the procedure(22,23). As can be seen in the table and in the graph, from the third attempt onwards, the times and functional outcome of the procedures improved, which can be put down to greater experience based on the correction of the errors previously made. However, this progression was not clear in vena cava anastomosis, which we consider to be a technique with a higher degree of difficulty that requires more time for control and automatism. With longer assessment periods in the practice time, the learning curve can probably be better delineated, and an optimal and complete program with different degrees of complexity can be developed. The establishment of surgical tactics and techniques that allow the procedure to be carried out with greater ease will increase motivation, stimulate continuity, and improve the surgeon's overall quality during training(11).

Despite all these advantages, there are limiting factors such as the 3R principle, ethics, or the association with legal problems in some countries, which results in microsurgical models in synthetic material being offered to replace the above(24-26). Far from opposing this idea, we consider that any experimental program should start with synthetic models and end with live animal models, since they are the ones that most closely resemble human surgery and represent an essential step that gives the surgeon confidence and technical skill(4,10,27). An added drawback is their high cost. For this reason, in the first phase we used gauze, latex, and silicone gloves, since these materials are readily available and suitable for initiation. Subsequently, we used cryopreserved rat aorta, which we obtained from other courses where large vessels were not necessary(28). And finally, we chose rats as they are easy to maintain, less expensive, and allow a large number of procedures to be performed on the same specimen.

In conclusion, we propose this easy, simple, and reproducible training model, in which the procedures seem suitable for the progression of the resident in terms of operating time and functional outcome. We should continue to strive in order to maximize the effectiveness of surgical education by improving the technical skills, autonomy, and confidence of residents so that they can carry out their professional activity with assurance. This will ultimately maximize patient safety. Microsurgical training of pediatric surgeons would benefit from standardized programs to optimize outcomes and adherence to the 3R principle.

The main limitation of our study was that the data obtained pertained to a single pediatric surgical resident. In the future, we will expand the collection and analysis of data to include other residents and specialists, which will help us to perfect the model, integrate more complex procedures, and adapt them to the level of each professional in order to reach more reliable conclusions. Another limitation was the small number of procedures reported in our series, which could make them insufficient to interpret the effect of the learning curve.

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REFERENCES

1. Di Cataldo A, La Greca G, Rodolico M, Candiano C, Li Destri G, Puleo S. Experimental models in microsurgery. Microsurgery. 1998; 18(8): 454-9.
2. Di Cataldo A, Li Destri G, Trombatore G, Papillo B, Racalbuto A, Puleo S. Usefulness of microsurgery in the training of the general surgeon. Microsurgery. 1998; 18(8): 446-8.
3. Zhang F, Dorsett-Martin W, Fischer K, Angel M, Buncke HJ, Lineaweaver WC. Role of medical students in microsurgery research. J Reconstr Microsurg. 2001; 17(2): 89-93.
4. Schimpke SW, Larson BM, Veenstra BR, Myers JA, Wojtowicz A, Velasco JM. Do one, do one, teach one: Altering the dogma using simulation-based training to maximize efficiency of surgical resident education. J Am Coll Surg. 2020; 231(1): 140-8.
5. Malangoni MA, Biester TW, Jones AT, Klingensmith ME, Lewis FR. Operative experience of surgery residents: Trends and challenges. J Surg Educ. 2013; 70(6): 783-8.
6. Mattar SG, Alseidi AA, Jones DB, Jeyarajah DR, Swanstrom LL, Aye RW, et al. General surgery residency inadequately prepares trainees for fellowship: Results of a survey of fellowship program directors. Ann Surg. 2013; 258(3): 440-7.
7. George BC, Bohnen JD, Williams RG, Meyerson SL, Schuller MC, Clark MJ, et al. Readiness of US general surgery residents for independent practice. Ann Surg. 2017; 266(4): 582-94.
8. Moglia A, Ferrari V, Morelli L, Melfi F, Ferrari M, Mosca F, et al. Distribution of innate ability for surgery amongst medical students assessed by an advanced virtual reality surgical simulator. Surg Endosc. 2014; 28(6): 1830-7.
9. Moglia A, Morelli L, Ferrari V, Ferrari M, Mosca F, Cuschieri A. Distribution of innate psychomotor skills recognized as important for surgical specialization in unconditioned medical undergraduates. Surg Endosc. 2018; 32(10): 4087-95.
10. Feijoo PG, Benito FEC, Kalra N, Cárdenas GP, Alegre MS, Sánchez CV, et al. Seven microaneurysms: Description of an experimental rodent model for neurovascular training. Turk Neurosurg. 2021; 31(2): 217-22.
11. Neto BF de M, Neto FV de O, Secanho MS, Carvalho LB, Moragas WR, Fernandes MS. Submerged vascular anastomosis. A technique for vascular suturing in experimental microsurgery. Acta Cir Bras. 2021; 36(8): e360807.
12. Lascar I, Tortir D, Cinca A, Cortan S, Stefanescu A, Bratianu R,et al. Traininf program and learning curve in experimental microsurgery during the resindency in plastic surgery. Microsurgery. 2009; 504-6.
13. Juratli MA, Becker F, Palmes D, Stöppeler S, Bahde R, Kebschull L, et al. Microsurgical training course for clinicians and scientists: a 10-year experience at the Münster University Hospital. BMC Med Educ. 2021; 21(1): 1-10.
14. Rodriguez JR, Yañez R, Cifuentes I, Varas J, Dagnino B. Microsurgery workout: A novel simulation training curriculum based on nonliving models. Plast Reconstr Surg. 2016; 138(4): 739e-747e.
15. Onoda S, Kimata Y, Matsumoto K. Iliolumbar vein as a training model for microsurgical end-to-side anastomosis. J Craniofac Surg. 2016; 27(3): 767-8.
16. Zhou SJ, Li EC, Jun H, Weng G Bin, Yuan HX, Hou JQ. Staged microvascular anastomosis training program for novices: Transplantation of both kidneys from one rat donor. Chin Med J (Engl). 2014; 127(4): 712-7.
17. Kim SC, Fisher JG, Delman KA, Hinman JM, Srinivasan JK. Cadaver-based simulation increases resident confidence, initial exposure to fundamental techniques, and may augment operative autonomy. J Surg Educ. 2016; 73(6): e33-41.
18. Di Cataldo A, Latino R, Perrotti S, Di Franco G, Gianardi D, Morelli L. Use of experimental microsurgery to improve resident autonomy and training. J Am Coll Surg. 2020; 231(5): 606-7.
19. Koskinen J, Torkamani-Azar M, Hussein A, Huotarinen A, Bednarik R. Automated tool detection with deep learning for monitoring kinematics and eye-hand coordination in microsurgery. Comput Biol Med. 2022; 141: 105121.
20. Chainey J, Elomaa AP, O'Kelly CJ, Kim MJ, Bednarik R, Zheng B. Eye-hand coordination of neurosurgeons: Evidence of action-related fixation in microsuturing. World Neurosurg. 2021; 155: e196-202.
21. Issenberg SB, McGaghie WC, Petrusa ER, Gordon DL, Scalese RJ. Features and uses of high-fidelity medical simulations that lead to effective learning: A BEME systematic review. Med Teach. 2005; 27(1): 10-28.

22. Ericsson KA. Acquisition and maintenance of medical expertise: A perspective from the expert-performance approach with deliberate practice. Acad Med. 2015; 90(11): 1471-86.
23. Gomez M, Nicot C, Verdier J, Baldini N, Blancheton A, Bourry M, et al. Does the repetition over a short time of a microsurgical suture improve its reliability? Hand Surg Rehabil. 2019; 38(6): 348-52.
24. Camargo CP, e Silva DI de SB de C, Maluf FC, Morais-Besteiro J, Gemperli R. A non-living, effective model for microvascular training. Acta Cir Bras. 2017; 32(12): 1087-92.
25. Safi AF, Safi S, Tayeh M, Timmer M, Goldbrunner R, Kauke M. A novel microsurgical anastomosis training model using gradually thawed cryopreserved microvessels of rat cadavers. J Cranio-Maxillofacial Surg. 2018; 46(7): 1126-31.
26. Capkin S, Cavit A, Kaleli T. Microsurgery training with smartphone. Handchirurgie Mikrochirurgie Plast Chir. 2018; 50(6): 443-5.
27. Tolba RH, Czigány Z, Osorio Lujan S, Oltean M, Axelsson M, Akelina Y, et al. Defining standards in experimental microsurgical training: Recommendations of the European Society for Surgical Research (ESSR) and the International Society for Experimental Microsurgery (ISEM). Eur Surg Res. 2017; 58(5-6): 246-62.
28. Kinshoku MR, Rodriguez CAL, Fidalgo R de S, Duran CCG, Leme PLS, Duarte I da S. Uso racional de modelos animais para pesquisa e ensino de microcirurgia. Rev Col Bras Cir. 2012; 39(5): 414-7.