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ORIGINAL PAPERS

Optimizing Non-living Models for Effective Microsurgical Training

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Abstract

Microsurgery, a pivotal surgical field that changed medical perspectives in the 20th century, presents numerous technical challenges due to the precision it requires from the surgeon. To acquire the requisite skills, comprehensive training is imperative. Initiation into microsurgical training on experimental models is a prerequisite before translating these skills to clinical applications. The employment of non-living models in medical training offers a myriad of advantages, notably characterized by their accessibility and cost-effectiveness. Non-living models, such as latex gloves, leaves, flower petals, silicon tubes and chicken legs, provide aspiring microsurgeons an opportunity to train the essential technical skills required in microsurgical practice. Such models significantly alleviate ethical concerns associated with the use of live specimens and human cadaveric models. Furthermore, they exhibit a satisfactory emulation of human vascular properties, providing a realistic context for medical practice. Although the primary focus of this paper is on non-living models, it is important to highlight the transition to living models, specifically small animal models, as a mandatory and advanced phase in microsurgical training, before translating to clinical practice.

Keywords: microsurgery, training, non-living models, latex glove, chicken thigh

Rezumat

Microchirurgia, un domeniu chirurgical de bază ce a schimbat perspectivele medicale în secolul al XX-lea, prezintă numeroase provocări tehnice datorate preciziei necesare chirurgului. Pentru a achiziționa abilitățile necesare, un training cuprinzător este imperativ. Inițierea în trainingul microchirurgical pe modele experimentale este o cerință prealabilă înainte de a le transpune în aplicații clinice. Folosirea modelelor non-living în trainingul chirurgical oferă o varietate de avantaje, în particular caracterizate de accesibilitatea și cost-eficiența acestora. Modelele non-living, precum mănușile de latex, frunzele, petalele de flori, tuburile de silicon și membrul inferior de pui, oferă microchirurgilor în devenire o oportunitate de a își exersa abilitățile tehnice esențiale necesare în microchirurgie. Astfel de modele ameliorează semnificativ problemele etice associate cu folosirea modelelor vii sau a modelelor cadaverice umane. Mai mult, ele expun o asemănare satisfăcătoare a proprietăților vasculare umane, oferind un context realist pentru trainingul abilităților chirurgicale. Deși subiectul principal al acestei lucrări este reprezentat de modelele non-living, este important de subliniat tranziția către modele vii, în special modele animale mici, ca o fază obligatorie și avansată în trainingul microchirurgical, înainte de tranziția către practica clinică.

Cuvinte cheie: microchirurgie, training, modele non-living, manusa de latex, pulpa de pui

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INTRODUCTION

Microsurgery is proof of the rapid advancements of modern medicine. It is a specialized surgical field in which the surgeon performs advanced techniques involving the use of a surgical microscope and delicate instruments, working on structures with a diameter even smaller than 1 millimeter. The emergence of microsurgery as a revolutionizing technique back in the 20th century was made possible when technological advancements led to the development of the surgical microscope, thus allowing surgeons all over the world to perform incredibly precise surgeries that had never been attempted thus far. Advantages for both the patient and the surgeon quickly became obvious to the medical field: the patient benefited from minimized tissue damage and the surgeon could work with enhanced accuracy on very fine structures. To the present day, the armamentarium of more surgical subspecialties includes microsurgery to some extent, including but not limited to plastic surgery, neurosurgery, ophthalmology, ENT and even urology. Supermicrosurgery, a specialized field of microsurgery, requires exceptional precision and skill to manipulate vessels and structures less than 0.8 mm in diameter.[1-3]

As microsurgery started to be performed on a larger scale throughout the years, the need and demand for training in this field were recognized. To acquire microsurgical skills is a challenge for surgeons in training, since the process requires attention to detail, dedication and desire for improvement.[4] With a steep learning curve, the trainees must practice thoroughly in simulated environments, often facing feelings of frustration and impatience before getting to live surgeries. Moreover, one must learn to operate the special instruments and the surgical microscope, all while maintaining the mental endurance to sustain a precise level of focus and attention throughout a lengthy procedure. Traditional training methods often face limitations, particularly in providing ethically and economically feasible practice, keeping in mind the high cost of microsurgical equipment, restricted access to regular practice or the absence of real-life surgical conditions. In modern education, students should begin with lab exercises and progress to clinical practice when their skills are optimal, focusing on realistic simulations to enhance skill transfer. This is essential due to time limitations and the goal of mastering specific skills. Animal models are crucial for integrating various skills, making them a vital component of any microsurgery program. Such programs must adhere to the 3 Rs principle: replacing animals with models where possible, reducing animal usage as much as possible, and refining experimental designs to minimize the potential distress to the animals.[4-8]

The article highlights the importance of creating and implementing proper training models for microsurgery. The emphasis is on creating a realistic surgical environment that mimics the complexities and nuances of actual surgical procedures, all while keeping in mind that the models should be affordable, accessible and easy to perform for the trainees. The goal of microsurgical training organized in a step-by-step fashion is the rational use of animal models when the trainees have already been accustomed to the basics.

Microsurgery training should initially use simple, non-living models to build fundamental skills like eye-hand coordination, microscope operation, instrument handling, and surgical techniques. It is of utmost importance to understand the specific skills these models aim to simulate.[9,10] We have reviewed and summarized the prevalent non-living training models that ensure an appropriate start for microsurgery training, as well as current innovations in microsurgery training courses.

CORE SKILLS DEVELOPMENT IN MICROSURGERY TRAINING

In the field of microsurgery, both in clinical and training contexts, there are specific recommendations regarding the operative setup. Paramount is the ergonomic positioning of the surgeon to ensure comfort, which is crucial for the precision required in microsurgical procedures. This includes a quiet and undisturbed working environment, along with proficient use of microscopic techniques, where the appropriate handling of the microscope is of utmost significance.

The focus on the surgeon's physical and mental well-being is critical. The surgeon should be adequately rested and should avoid excessive caffeine intake and strenuous physical activities, such as heavy weightlifting or intense physical training, before undertaking microsurgical tasks. This precaution extends to avoiding surgical techniques that exert significant physical strain, like osteosynthesis. In live surgery scenarios, although challenging, it is beneficial to have alternate microsurgeons available to replace the primary surgical team members at signs of physical or psychological fatigue.

The ideal posture for a surgeon during microsurgery involves being seated with an upright spine, knees flexed at 90°, calves oriented vertically to the ground, and the soles maintaining contact with the floor. Additionally, providing adequate support for the elbows, forearms, and wrists is essential.[11-13]

However, there are instances when this cannot be achieved due to more challenging operating fields, such as those where the surgical field is moving (i.e. respiratory movements, cardiac pulsations). In these scenarios, the setup must be tailored to maximize the comfort and efficacy of the surgeon performing the technique. Adjustments to accommodate other team members should be made subsequently, ensuring they can assist effectively.[13] After the surgeon gets familiarized with the proper environment and set-up, they can proceed to training on the models described below.

When it comes to the actual models of training in microsurgery, two main categories are available: non-living and living models. Several non-living models are described in the literature, ranging from basic training models (latex gloves, silicone tubes) to finer training models (leaves and flower petals). A useful model is the chicken leg, providing for a variety of training needs, from simpler vessel anastomoses and nerve repairs to dissection and repair of very small caliber vessels (such as those encountered in supermicrosurgery).[6-10,13-23]

This paper focuses on the systematic progression of training in microsurgery, emphasizing the necessity of trainees adhering to a sequenced approach in their learning process. Each stage in the training model is designed to build distinct skills essential to the discipline. The primary subject of this discussion is the use of non-living models, which will be explored in greater detail.

STEP-BY-STEP GUIDE TO NON-LIVING MODELS IN MICROSURGERY TRAINING

The surgical glove training models

Surgical gloves made of latex are appropriate for beginners in training, providing a feasible initial model for learning. Latex is an elastic and resistant material, mimicking the properties of skin and soft tissues. The glove model provides tactile feedback and focuses on sensitivity and fine motor control. It can be adapted with various training exercises, each having a higher level of difficulty. The sutures are monofilament material with a starting size of 8/0. Training is then continued with 9/0 and 10/0 after skills improvement. Trainees must set up the ergonomics of the body, hand, and arm, as well as adjust the position under the microscope, with progressive refinement of movement.[9,13,15]

The training starts with 4 suture lines with different directions, progressing from the simplest (1) to the most difficult (4), displayed on a practice card, as seen in **Fig. 1A**. Training involves correct suture placement, various methods of knot tying, as well as forehand and backhand methods: lines (1) and (2) must be approached with the forehand technique, line (3) is suitable for both the forehand and the backhand techniques, while line (4), the most difficult one, is sutured using the backhand method. All four directions must be completed before attempting the next exercise.[9,10]

Moreover, the latex glove can be used as a dynamic training model, improving eye-hand coordination by transforming it into a conduit. The process involves making two parallel incisions in the glove that can be sutured together, creating a tube (**Fig. 1C**) with the consequent possibility of simulating a larger-caliber vessel for anastomosis in various techniques, including end-to-end anastomosis, end-to-side anastomosis, side-to-side anastomosis and practice of diameter mismatch situations.[9,22]

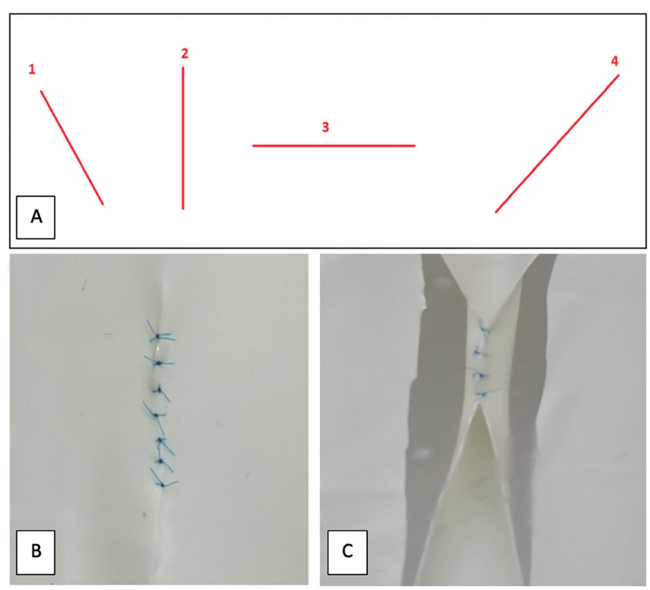

Figure 1. The surgical glove training model. A. Different directions of suturing (1-4), each with a higher difficulty level than the previous one. B. The glove is cut with a blade, then the edges are sutured together. C. The dynamic glove model: after two parallel incisions are made in the glove, they are sutured together to create a conduit.

The leaf and flower petal models

The subsequent phase in microsurgical training involves refining precision and delicacy in operative techniques, essential attributes in microsurgery. Exercises utilizing leaves and petals serve as an effective training medium. These natural materials, with their delicate and thin structures, closely emulate the fine and subtle textures encountered in human tissues.[13, 24-25]

The floral petal model, described by Volovici et al., offers a superior level of difficulty compared to the leaf model in microsurgical training, primarily due to the inherent fineness of the petals. The petals, characterized by their smooth and soft texture, present an elevated challenge in mastering knot-tying techniques. Although the structural composition of flower petals differs from human tissue, their fragility and sensitivity provide an analogous experience in handling delicate biological materials. A notable distinction, however, is the absence of elasticity in flower petals, unlike in living tissues. In microsurgery, a common error involves exerting excessive tension. The petal model serves as an exceptional environment for cultivating the skill of applying appropriate tension.[23]

Excessive force in this context leads to either the tearing of the petal or the enlargement of puncture holes created by the needle. This direct feedback allows trainees to self-assess and adjust their techniques based on the observable condition of the petals. Such a hands-on approach facilitates a gradual and perceptible improvement in handling delicate surgical maneuvers.

Trainees can use these two models to practice delicate procedures such as knot-tying and suturing, helping to improve dexterity and precision (**Fig. 2**). The leaf or the petal can be cut with a blade and sutures ranging from 9/0 to 11/0 should be used to suture the incision. Moreover, they both have the obvious advantages of cost-effectiveness and accessibility, whilst providing an opportunity to practice fine motor skills.

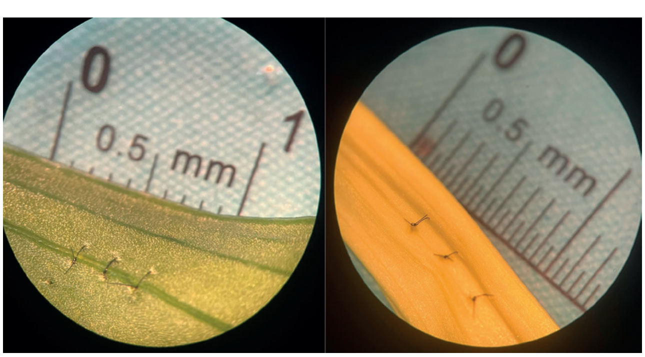

Figure 2. The leaf (left) and flower petal (right) training models.

Silicon tubes

One of the most frequent procedures in microsurgery is the anastomosis of vascular structures. The closest non-biological training model for vascular anastomoses is the silicone tube, designed to replicate blood vessels closely. Silicone replicates the texture and elasticity of the vessel, allowing microsurgeons in training to develop the delicate skills required for vessel manipulation. They come in different sizes, some with infra-millimetric calibers for supermicrosurgery training. A key advantage of silicone tubes is their transparency, which allows trainees to observe needle passage and suture depth, facilitating skill development in suture placement.[6,13,26]. While this visibility is not representative of real surgical environments, it provides a valuable self-assessment tool in a training context (**Fig. 3**).

The tubes accommodate a range of suture sizes, from 8/0 to 11/0, depending on their caliber, thus preparing trainees for the diverse requirements of actual microsurgical operations.

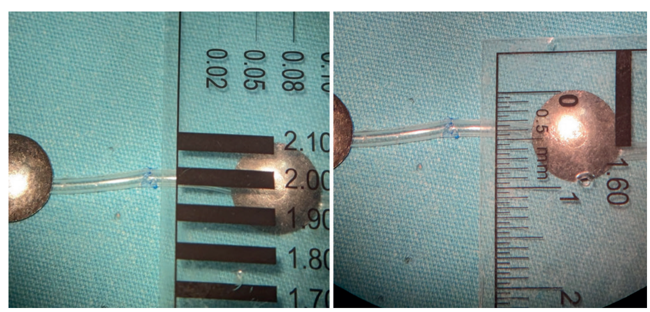

Figure 3. Silicon tube, after anastomosis.

Chicken pelvic limb models

In medical training scenarios, chicken models represent a viable substitute for live animal models. Significantly, the texture of chicken structures closely resembles that of live tissues, providing an authentic platform for gaining delicate microsurgical skills.[16-18]

Chicken thigh represents a feasible microsurgical model presenting arterial and venous vascular networks with various diameters. The anatomical sites of practice involve the proximal thigh, where the ischiatic artery and the ischiatic vein can be dissected and used for practice. The average diameter of the vein is 2.7 mm and for the artery 1.7 mm. The next site, with narrower structures, is at the popliteal level, where the ischiatic artery is continued by the popliteal artery, from which smaller branches emerge (such as the suralis artery, tibialis medialis artery, and tibialis lateralis artery), accompanied by the popliteal vein. The calf presents the tibials cranialis artery as the main vessel, accompanied by the tibialis veins, with diameters averaging 0.9 mm. The branches of the main vessels can be utilized as training models for supermicrosurgery training, having under 0.8 mm in diameter.[16,19,27]

Nerve repair of the sciatic nerve in the chicken thigh is another skill that can be practiced on this model. The nerve presents an average diameter of 2 mm, with two main branches distally and subsequent branching. The main trunk itself can be used for training in basic microneural repairs, using conventional epineural, perineural and epi-perineural microsurgical techniques. The branches of the ischiatic nerve can be used by the surgeon to train for nerve transfer, nerve dissection, but also for end-to-side, end-to-end and even synthetic or vein conduit repair techniques.[28] **Fig. 4** displays the chicken limb model and its different sites where the surgeon can progressively practice their skills.

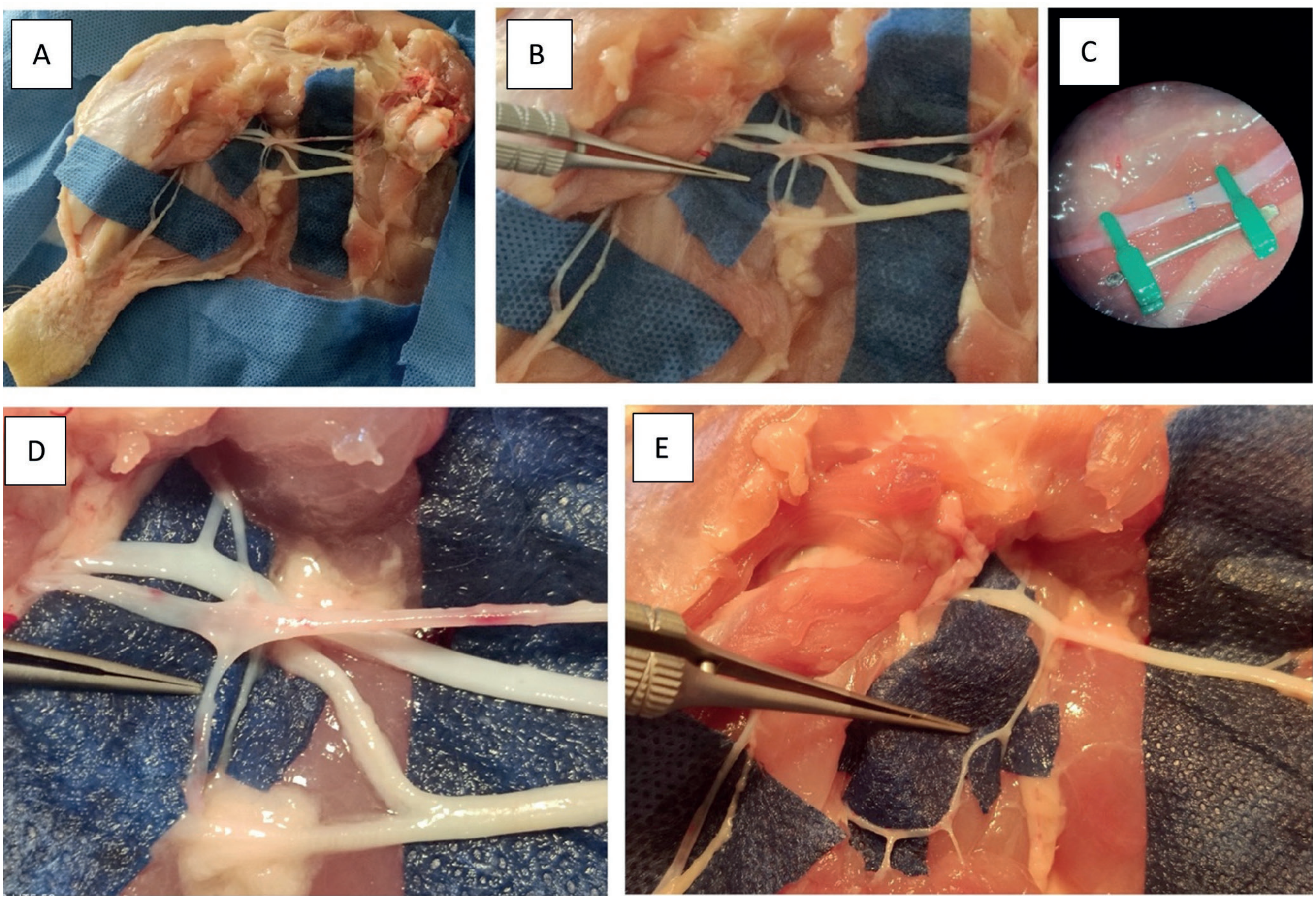

Figure 4. The chicken pelvic limb model. A. Display of the 3 levels of training difficulty, including the ischiatic vessels in the chicken thigh, the popliteal vessels and the vessels of the calf. B. Detailed view of the neurovascular bundle in the thigh. C. Arterial anastomosis in chicken thigh. D-E. Detailed anatomy of the vascular branches in the thigh and popliteal region, including the infra-millimetric caliber vessels that can be used for supermicrosurgical training.

DISCUSSIONS

Meeting the increasing need for microsurgical expertise requires efficient training methodologies. Starting with non-living models enables novices to develop fundamental skills in a low-risk setting. This step-by-step strategy not only aids skill enhancement but also aligns with ethical guidelines by delaying the use of animal models until the trainee is adequately equipped to handle such a task.

Training on live animals or cadavers raises ethical concerns, and in some cases, legal restrictions. Thus, non-living models provide an ethical alternative, addressing these concerns by eliminating or postponing the use of live specimens or human cadaveric models. These ethical considerations reflect a conscientious approach to training, whilst ensuring compliance with regulations and guidelines, reinforcing the importance of responsible and humane practices in the pursuit of medical education.[29]

Among the non-living training models, a trainee may attempt to enhance microsurgical skills on either synthetic or biological models.[6,19] Non-living models, such as latex gloves, leaves, flower petals, silicon tubes and chicken legs, provide aspiring microsurgeons with a controlled and standardized environment. The lack of physiological variability enables focused skill development, allowing for precise refinement of techniques. Trainees can repetitively practice on these models to enhance their movements and eye-hand coordination, all without the challenges posed by the variable nature of living tissues. As a result, these models offer consistent conditions, ensuring reproducibility and standardization, facilitating a systematic progression in training programs where each trainee faces comparable requirements.

In the beginning, suturing simple lines on a static model as a starting point prepares the trainees for the technically difficult live models that are to follow. Since the trainee is faced with challenging and progressively complex problems, a noticeable improvement is seen in their skills. Training on fragile substrates such as leaves and petals demands and enhances fine motor skills and meticulous handling, qualities that are imperative for successful microsurgical interventions. This approach not only fosters precision but also accustoms the practitioner to the gentle manipulation required when dealing with sensitive and fragile biological tissues.

Chicken models offer an alternative to live animal models in medical training contexts. This approach not only addresses ethical considerations inherent in the use of sentient beings for educational purposes but also presents a cost-effective solution compared to synthetic models. Crucially, chicken legs mimic the realistic texture necessary for practicing fine microsurgical skills.[16-19,29,30]

Evidence from recent studies indicates that microsurgical training using non-living chicken thigh models demonstrates a non-inferior efficacy when compared to the conventional approach employing live rat models. This alternative method has not only shown comparable outcomes in skill acquisition and proficiency but has also emerged as an effective substitute. This finding underscores the viability of using chicken thigh models in microsurgical training, offering a promising pathway that balances ethical considerations with educational effectiveness.[18,21,30]

However, this approach is not without limitations, a primary drawback being the absence of perfused vasculature, which is crucial for simulating dynamic blood flow conditions inherent in living organisms. One feasible solution would be to introduce a ”blood-flow” system, such as the one described by Zeng et al. to simulate natural hemodynamics when training microvascular skills.[31]

The aforementioned models play a pivotal role in microsurgery training due to their high accessibility and cost-effectiveness, making microsurgery training available to a broader spectrum of trainees. This approach is crucial in fostering broader participation in the field, ensuring that surgeons with varied resources and backgrounds can benefit from valuable training.

Although the primary focus of this paper is on non-living models, it is important to highlight the transition to living models, specifically small animal models, as a mandatory and advanced phase in microsurgical training. This progression is essential for trainees to bridge the gap between simulated practice and real clinical surgical situations, emphasizing the indispensable role of living models in comprehensive surgical education.

CONCLUSION

This paper provides a step-by-step guide for microsurgery aspirants who wish to undergo training to develop their technical skills using non-living models. It offers beginner microsurgeons a diverse and ethical training program that equips them with essential skills before they advance to higher fidelity models, such as animal models and further transition to clinical practice. This comprehensive approach is instrumental in shaping the future of microsurgical expertise, paving the way for more proficient and skilled surgeons in the field.

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