Manual of Microsurgical Training

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INTRODUCTION TO MICROSURGERY AND MICROSURGICAL TRAINING

‘Microsurgery’ implies performing surgical procedures on small structures with the aid of operating microscope.

Historically the operating microscope was first used in 1929 by Carl Nylen for middle ear surgery, since then the use of the operating microscope and microsurgery in general, has extended into various fields.

One of the most impactful developments in microsurgery has been the development of microvascular surgery, which opened the entire field of replantation of amputated body-parts, and free-tissue transfer for critical tissue loss arising from trauma or ablative surgery. Microvascular techniques have found their place extracranial vascularisation for stroke and transplantation surgeries.

There are specific considerations that make microvascular surgery particularly challenging.

The blood vessels are ‘soft’, luminal structures ranging from 0.5-2mm in diameter whose walls are easily damaged by small forces and movements, the damage leads to the activation of coagulation pathways resulting in thrombosis. Poor suturing technique resulting in inversion of vessel edges or torsion of the vessels also results in thrombosis and failure of the procedure. Thus success in microvascular surgery depends on a high degree of technical skill, dexterity and consistency in technique.

The microscope provides magnification and visualisation of structures, whereas the specialised microsurgical instruments allow manipulation of small structures, but it requires high degree of training to successfully execute the procedures.

In summary the essential skills that need to be acquired in microsurgical training are,

1. Stereoscopic visualisation under the microscope
3. Visual estimation of dimensions of structures and manual dexterity for accurate execution
4. Minimising tissue trauma throughout the entire process i.e. being able to predict the mechanical effects of individual manipulation.

The courses designed for microsurgical training should be designed to include tasks of gradually increasing complexity, ultimately culminating in anastomosis in a live animal model, usually the rat.

There are also considerable ethical issues when live animals are used for training, and all centres must strive to minimise the use of live animals while maintaining effective training through the use of appropriate simulation techniques.
The Operating Microscope

The microscope is the cornerstone for microsurgery, and a complete familiarity with the use of microscope is essential to achieving successful procedure. The modern microscopes are designed to provide optimum visualisation of small structures for accurate dissection and suture placement.

Parts of a microscope

Boom
Eye pieces
Optical stack
Objective lens
Light source

The key features of a microscope are

1. Stereoscopic vision (depth perception)
2. Optimum illumination
3. Focus
4. Zoom function

Stereoscopic vision or depth perception is an extremely important feature for microsurgery. Without an accurate depth perception it is impossible to perform surgical manoeuvres with precision.

In order to achieve stereoscopic vision the surgeon must align the eye-pieces to ones inter-pupillary distance so that both the eyes see a single field.

Most of the microscopes have light sources that can be adjusted manually to provide appropriate illumination. High intensity illumination can produce glare whereas low intensity may make visualisation of details difficult. Both of these lead to early fatigue. The surgeon should adjust the illumination till he or she feels comfortable and is able to visualise the details of the tissues without strain.

Focus again is essential for proper visualisation of tissues. The lack of precise focus may also result in eyestrain and fatigue. The microscope can focus on objects within a certain vertical distance, and this is known as the depth of focus. Objects that lie outside this zone (closer or further from the lens) will be blurred. When suturing structures at different depths repeated adjustments may be needed.

Zoom refers to the magnification attained. With increasing zoom the field of vision becomes smaller and vice versa. There are no fixed rules as to what magnification needs to be used for each microsurgical procedure. As a general guideline, exploratory
procedures are carried out in lower magnification whereas dissection and suturing on individual structures is carried out under higher magnification.

Clinical microscope being used in an operating room

A table top microscope: commonly used in lab based training
MICROSURGICAL INSTRUMENTS

The Microsurgeon relies in specialised instruments that are designed to handle small vessels and nerves as well as the micro-needles and sutures. Unlike the conventional surgical instruments these instruments are handled using the pen-holding.

These instruments include, the micro-needle holder, micro-scissors, the jeweler’s forceps, and the vessel dialator.

• **Needle holder** with curved or straight tapered jaws with cylindrical handles: needle holders are used for suturing. The tips are designed to grasp the needle without allowing slippage or axial rotation. Needle holders can be curved or straight tipped.

![Needle Holders](image1)

**Micro-scissors** with curved tips with cylindrical handles: These scissors are used for vessel preparation. The design allows for precise dissection and excision of the adventitia around the vessels. It can be used for precisely trimming the vessel ends

**Micro-scissors** with straight tips with cylindrical handles: these are generally used for cutting sutures, and for making straight cuts across vessels or nerves.

![Micro-scissors](image2)

**Jeweller’s forceps**: The Jewellers forceps are fine tipped forceps that allow precise grasp on the tissues. The forceps should be used to manipulate blood vessels by grasping only the adventitia. They should not be used to hold the walls of the vessel as that would cause injury the intima or the wall which may promote thrombosis.

![Jeweller's Forceps](image3)
The tips are also designed to grasp the suture. Similar to the tissues, the forceps may crush and damage the suture. The forceps are also essential in providing controlled counter-pressure to the walls of the vessel when passing the needle. Most of the sets include two forceps of slightly different sizes (the sizes are indicated as #5 and #3).

**Vessel dilator:** the dilators are designed to help dilate the lumen with minimal trauma to the intima. The dilator can be a forceps type dilator or a rod type dilator.

**Micro vessel approximating clamp** Clamps. Sliding clamps are preferable to screw approximating ones, since a more precise and jerk-free approximation of vessel ends is possible. Disposable clamps are currently available from a number of manufacturers.

**Sutures:** Most commonly Nylon (Ethilon) sutures of size 8/0 (800/inch) to 11/0 (1100/inch) are used, with 3/8 circle, swaged, taper-cut tip needles. As a general guide, 10-0 and 9-0 are the most commonly used sizes in microsurgical repair.

In the clinical setting the following guidelines can be followed:

<table>
<thead>
<tr>
<th>Suture size</th>
<th>Vessel diameter</th>
<th>Example (in adults)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-0</td>
<td>2-3mm</td>
<td>Radial artery</td>
</tr>
<tr>
<td>9-0</td>
<td>1.5mm</td>
<td>Common digital artery</td>
</tr>
<tr>
<td>10-0</td>
<td>1mm</td>
<td>Digital artery</td>
</tr>
<tr>
<td>11-0</td>
<td>0.5 to 0.8mm</td>
<td>Digital artery at distal interphalangeal joint</td>
</tr>
<tr>
<td>12-0</td>
<td>Less than 0.5mm</td>
<td>Lympho venous anasromoses, digital arteries at mid-pulp level</td>
</tr>
</tbody>
</table>
**General care of instruments**

The microsurgical instruments are very delicate. They are quite expensive, thus the proper instrument care cannot be overemphasized. Serum or blood, which is quite corrosive, must not be allowed to dry on these instruments. For storage the instrument tips should be protected in rubber or silicone tubing and the instruments must be stored in special cases with silicone padding in order to protect them from impact. Sterilization is best achieved using EtO gas.

Demagnetization: Instruments should be tested and demagnetised before storage using special de-magnetizers.
TRAINING MODELS IN MICROSURGERY

Introduction:

Acquiring expertise in microsurgical suturing has a distinct set of challenges when compared to standard surgical skills.

At the outset, the trainee has to acquire basic hand eye coordination and has to learn to adapt manual skills for handling the tissue, the needle and the suture at a scale of approximately one tenth of a millimetre, under magnification, where small movements and tremor become amplified.

Since minute errors in suturing almost invariably lead to microvascular thrombosis, and result in major complications, generally skill acquisition is conducted in a simulation lab before the individual performs microsurgery of patients.

There has been a considerable research and debate on best forms of training and accreditation, although no universal consensus has been reached.

In general the trainee needs to acquire the skills for dissection and tissue handling under magnification, the technique for suture placement and finally demonstrating the ability to perform a complete and patent anastomosis, usually on rat vessels.

The acquisition of psychomotor skills follows the Fitts-Posner three stage learning model. The first stage being the cognitive phase where the trainee understands the steps involved in the task usually through instruction manuals or demonstrations.

The second stage being the phase of integration, which involves several cycles of deliberate practice and should end with a high degree of consistency in surgical performance or the phase of automation, when the skill becomes ‘automatic’ i.e. the suturing is performed smoothly and accurately without conscious effort.

The phase of integration is the most important phase for the acquisition of psychomotor skills. In this phase should include several cycles of practice for the given task, and should be coupled with feedback on the surgical technique and the end-product by an instructor. The feedback at the end of each cycle allows the trainee to rectify the technique in each cycle. Detailed and specific feedback enables the trainee to address the errors, leading to progressive improvement in performance.

This phase of training should take place on cost effective prosthetic, low -fidelity to ‘near-fidelity’ models. It is only when the trainee has acquired sufficient skill in tissue handling and suture placement, live animal model should be used.
The Fittz-Posner model of learning, emphasising cycles of deliberate practice and feedback leading to acquisition of psychomotor skills

Stages of skill acquisition in microsurgery

Microsurgical skill acquisition can be subdivided into the following progressive stages of learning

Stage 1: Stereoscopic visualisation of objects under the microscope, hand-eye coordination, and basic dexterity under the microscope

Stage 2: Basic steps of suture placement and knotting

Stage 3: Uniform suture placement and bimanual control

Stage 4: Uniform Suture placement on a tubular structure (anastomosis)

Stage 5: Tissue handling, dissection, control of haemorrhage and anastomosis with successful demonstration of blood flow and patency

Stage 6: Tissue handling, dissection, control of haemorrhage and anastomosis with successful demonstration of blood flow and patency

Stage 1: Models for development of general dexterity under the microscope

The training starts with developing dexterity under the microscope. Various innovative methods have evolved to allow the trainee to acquire basic manipulative skills in a relatively stress-free and simple environment. A number of low-fidelity and low-cost models have been described, for example Yenidunya et al (1998) described
an exercise of threading round fenestrated beads of 1-2mm external diameter into a 5cm long microsuture under x10 magnification and knotting it to form micronecklaces under x6 magnification. The glass beads had the tendency to jump outside the field if handled roughly. They recommended using multiple colours to reduce eye strain for beginners. Demirseren et al (2003) described using pieces of gauze stabilized on an empty box with a rubber band and passing a 10/0 nylon suture over and under a gauze fibre to improve manipulation skills under the operating microscope.

Stage 2: Models for learning basic microsurgical suture placement on a stable substrate (Crude bimanual dexterity)

This is the basic skill which forms the foundation of microsurgical anastomosis. Basic suture placement can be considered a bimanual activity that requires the stabilisation and eversion of the tissue edge by the non-dominant hand using a pair jeweller’s forceps and perpendicular insertion of the needle by the dominant hand using the micro-needle holder. Following which the non-dominant hand stabilises and provides counter-pressure the opposite edge to allow the exit of the needle perpendicular to the surface of the tissue. This process is followed by passing an adequate length of the suture and making a square knot to approximate the edges.

Concept of stable and unstable edges

There is one very important characteristic that differentiates skills necessary for suturing skin from the skills necessary for suturing vessels. In a skin incision the edges are well supported and adherent to the tissues below and the role of the non-dominant hand is to evert the edge to allow for the needle to pierce the edge vertically.

In a vessel, the edges are floating, and the non-dominant hand has to be trained not only to evert the edge but also to provide a support and stabilise the vessel in space, to facilitate the passage of the needle. The task is made even more challenging by the small size of the vessel and the effect of tremor. Hence the acquisition of bimanual skills is a crucial part of microsurgical training.

Substrates with stable edges

Latex Sheets:

The most basic and widely used is the latex or a vinyl sheet fixed over cardboards (suture cards). The trainee practices basic suture placement & knot tying over a horizontal incision, paying attention to alignment of edges horizontally, avoidance of overlap or inversion, symmetry of suture from edge and distance between individual sutures.

This model mechanically resembles a skin incision with stable edges that tolerate uncontrolled non dominant hand movements during needle insertion and allows for suture placement by the beginner.
DS Microtrainer system: The DS Microtrainer system has latex strips that are specifically designed for the beginner. These strips are wide and contain a latex strip which is backed by a plastic strip. The plastic strip allows the trainee to rest their instruments and reducing tremor in the non-dominant hand while learning to place sutures in the latex strip.

Exercises performed on both the above models improve one's familiarity with the task, without replicating the actual challenges of suturing a vessel where the edges are unsupported and mobile and the high degree of bimanual control is needed for suture placement.

Stage 3: Uniform suture placement on unstable edges (Advanced Bimanual dexterity):

Once the trainee has acquired the basic suturing technique the trainee should proceed to acquire skills for handling models where, unlike the previous models, the edges are unstable and require high degree of bimanual control.

The skills that are acquired through these tasks are:

1. Supporting the edge of the vessel with the non-dominant hand while piercing the wall with the needle
2. Symmetry of entry and exit points on either side of the suture line
3. Accurate approximation of edges without inversion
4. Uniform spacing between the knots
5. Appropriate suture density for a given length of suture line.

The following models are designed for this stage of training:

The I model: Lahiri et al (2005) described the I model, a 1cm long incision on a vinyl sheet with two horizontal cuts on either end of the line. The horizontal cuts remove the inherent stability of the edges and the degree of instability is increased by the length of the horizontal cut. An initial 4mm (2mm on each side) is recommended, progressing to a 10mm cut for increasing level of difficulty. The horizontal cuts also help the trainee a definite landmarks for estimating the length free edge for placement of evenly spaced sutures. This model can be compared to suturing a large 3mm diameter vessel.

Double Triangle Model: This model can be further modified to the double triangle model also described by Lahiri et al. (2005) where the edge is reduced to 3mm corresponding to the circumference of a 1mm diameter vessel. It trains bimanual coordination and equidistant suture placement. It also allows enough visualization and access behind the edges to practice back-wall stitching.
Microtrainer Model:

The DS Microtrainer® system was developed by National University Hospital (Singapore) and Digital Surgicals Singapore

It consists of a standardised latex strip held between a set of clamps that can be positioned in three dimensional space. Placement of sutures in the strip (though non tubular) has significant similarities to a vessel ends held in a clamp, as evidenced by hand motion analysis. The main advantage of this system is that it allows standardisation of positions for suturing in three dimensions. This makes this an excellent model for skill acquisition through repeated practice before proceeding to vessels.

Another unique feature of this system is the computer based analysis of the quality of suturing that uses the uniformity of suture spacing and deviation from optimal suture density as evaluation criteria. This feature allows for immediate and objective feedback on the quality of suturing.
Stage 4 circumferential suturing in absence of bleeding and thrombosis: Tubular models

Allow a closer simulation for circumferential suturing before proceeding to a live anastomosis. Various forms of synthetic tubes with standardised diameters are available for microsurgical training. These allow the trainee to place sutures on a tubular structure comparative to the blood vessel without the additional difficulty of tissue dissection and bleeding.

Silicone tubes

Peled et al (1983) described using medical grade silicone tubes for lacrimal system reconstruction. They come in 0.94, 1.19, 1.65mm external diameter. Injecting a dye solution after anastomosis with 10/0 nylon allows checking for distal flow and leakage. This also allows practice in approximator clamp placement. The tubes are however, thick and inflexible. Another material that can be used is polytetrafluoroethylene (Gore-tex) tube of 0.5 or 1.5mm diameter. These tubes are flexible and thin so trainees can practice atraumatic needle insertion, counter-pressure manoeuvres with nondominant hand and atraumatic pulling through of suture and knot placement.

The patency and leakage can be tested by injection of various dyes through the tubes.

Stage 5: Tissue dissection and vessel anastomosis without bleeding and thrombosis (Ex-vivo model)

After completing a 360 degree anastomosis on synthetic tubes, the trainee can move to biologic tissue materials to learn peri-vascular microdissection, vessel end preparation, and anastomosis in a safe environment without active bleeding. This is an interim step before proceeding to live anastomosis. ex-vivo models are cheap and easily available and provide an ideal platform to experience tissue handling and dissection without the problems of bleeding without using live animals for training.

Various ex-vivo models described for training include, pig coronary-arteries, chicken wing (brachial artery), chicken thigh (femoral artery), arteries harvested from rats or rabbits sacrificed in the laboratories for scientific studies have been described.

Chicken thigh (femoral vessels and sciatic nerve):
This is the easiest, and possibly the cheapest ex-vivo model available for microsurgical training. Chicken thigh can be easily acquired from the super-market and in most cases approved for human consumption with low risk of disease transmission. The neurovascular bundle can be conveniently exposed immediately posterior to the femur.
The trainee is required to perform atraumatic dissection and separation of the artery, vein and the nerve under the microscope. The thigh artery is 1.5mm to 2mm diameter, the vein is approximately 2mm in diameter and the sciatic nerve is approximately 3mm. The large structures are ideal for the beginner to develop suturing skills. When traced distally, the secondary branches have intermediate and terminal branches with a mean diameter of 0.55+/- 0.18 mm. These branches can be used to practice super-microsurgery. (Chen et al. 2014)

Non-living models, apart from training, are useful for skill maintenance at a low cost without animal sacrifice.

**Stage 6: Tissue dissection and Vessel anastomosis with tissue bleeding, and vessel thrombosis (Living models (in-vivo models))**

Rats are commonly used in microsurgical training and research. The ability to successfully dissect and anastomose rat vessels in an anaesthetised rat provides a close simulation of the challenges in clinical anastomosis. The skills acquired include

1. Atraumatic dissection and manipulation of vessels
2. Vessel preparation and excision of adventitia
3. Atraumatic suture placement
4. Handling leaks and thrombosis at the anastomosis.

The commonly used exercises are the rat femoral vessels, the rat tail artery and carotid artery. Other modifications such as free tissue transfer and renal transplant have been described.

The technical details of the exercise are described in later chapters

**Virtual Reality models**

There are virtual reality microsurgical simulators that provide high fidelity training without use of live animals. It uses a computer that provides 3D graphic image, a display module and an electromagnetic or haptic device attached to the microsurgical instruments for visual or tactile feedback.

An example would be the Brown et al (2001) virtual microsurgery trainer that is composed of a 3D graphic workstation and stereoscopic displays that run custom software that create elastic, deformable vessels that obey gravity. Their software system includes a deformable object simulator, a tool simulator, and a collision-detection module. The participant views the simulation through special 3D glasses for true binocular depth perception and uses real microsurgical instruments attached to electromagnetic trackers to perform microsurgical anastomoses. There is no haptic feedback in this system.

However these systems are costly and not readily available.
REFERENCES


ASSESSMENT OF MICROSURGICAL SKILL

Hands-on training in actual surgical setting is becoming more and more impractical and has led to an increasing demand for better and cost effective simulators that provide realistic experience and prepare the trainee for the operating room. In microsurgery, a high level of technical competence in suturing under the microscope is a basic but crucial skill that is necessary before embarking on a clinical procedure, with no room for trial and error. Microsurgical suturing has its distinct set of challenges, the degree of accuracy required is at sub-millimetre scale, that results in a steep learning curve. One of the key elements in training is the evaluation of skills. Evaluation of skills by the instructor plays a crucial role in learning as well as final certification of skills. The Fitts-Posner three stage model for skill acquisition can be applied to microsurgical training. This requires cycles of deliberate practice and feedback before the skill becomes ‘autonomous’ i.e. the task is performed smoothly and accurately without conscious effort. This underscores the importance of accurate feedback in enhancing learning. The more accurate the feedback during the practice stage, the better the trainee would be able to address and eliminate the errors and achieve competence in the task reducing the number of learning cycles. Evaluation of microsurgical skills can be considered in three separate but interrelated domains:

1. Evaluation of surgical technique
2. Patency of anastomosed vessel
3. Quality of suturing

Numerous methods have been devised to assess microsurgical competence.

Objective Structured Assessment of technical skills (OSATS), and global rating scores (GRS) have been validated for their application in various surgical training models. The evaluation system relies on observation of a surgical task being performed with emphasis on familiarity to the procedure and ability to carry out a surgical procedure.

Imperial College Surgical Assessment Device (ICSAD): Objective measurements of hand motion using the can measure the economy of hand motion and indirectly reflects microsurgical competence. Both the above methods do not address the evaluation of the anastomosis.

A number of studies have addressed the issue of ‘objective evaluation’ of the ‘end-product’ which is the anastomosis.
UWOMSA (University of Western Ontario Microsurgical skills acquisition Instrument) uses expert evaluation of Knot tying and anastomosis in which the preparation, suturing and final product. Although specific criteria are given to the evaluators, the evaluation is still subjective depending on the evaluators perception, moreover observation of a completed anastomosis on a tubular vessel may be erroneous and the posterior wall may not be assessed properly for the uniformity suturing.

Patency of anastomosis is an important criterion as evaluated in Structured Assessment of Microsurgery. Patency reflects the ability to avoid the back wall and to create a leak proof anastomosis but patency alone may not reflect the consistency of uniformity in suture placement.

Quality of suturing

One of the practical and difficult issues involved in micro-surgical training is that currently there is no objective method for expressing the ‘quality’ of suturing as the trainee progresses through the course. In other words, how does the instructor compare the quality of suturing between two sequential exercises performed by a trainee, which may appear nearly similar, and provide an objective feedback on specific errors. One of the key features that differentiate a ‘good’ anastomosis from a poor anastomosis is the uniformity of suture placement. Uniform suture placement indicates the ability to judge the circumference of the vessel, the ability to pre-empt and visually estimate points of suture placement (visual skill) and the ability to accurately place the suture through the intended points (motor skill). Once the trainee demonstrates a reproducible level of uniform suture placement, it should be considered a key criterion for certifying microsurgical competence.

(In clinical microsurgery there may be numerous occasions where intentional non-uniform suturing may be required, but the fundamental skill is the ability to visually estimate the intended point of suture placement and the motor skill to pass the suture through the intended point)

This component of suture uniformity is subconsciously assessed by the instructor, but is difficult to express objectively. Even under the microscope, it is not possible to compare the subtle differences between the uniformity of suture placement on a tubular vessel on day to day basis, unless there are gross differences, and hence, a system of analysis that bypasses human perception is needed.
Computer assisted Assessment of microsurgical skills

This concept was first described by Lahiri et al in 2016. It allows for an objective assessment of the quality of suturing. The concept is based on the optimal suture density that can be achieved on a standardised substrate. The objective scoring system removes the observer bias and allows for performance tracking over time.


ORGANIZING A MICROSURGICAL TRAINING LAB

The Microsurgical simulation and training lab:
A microsurgical training lab is invaluable for any that is involved in training surgeons for microsurgery. These labs provide a place for the residents to acquire and maintain their dextrous skills and prepare them for into clinical practice.

The training set-up may range from a simple dry lab to an elaborate training lab that has facilities for live animal surgery. A point to be emphasised is that all labs should actively try to minimise the use of animals for training.

The Dry lab
A dry lab is the most convenient and inexpensive way to acquire basic microsurgical techniques. Dry labs use non biologic models such as latex sheets, latex strips, silicone tubes etc or specifically designed simulators such as the DS Microtrainer® system.

Material required for establishing a dry lab
1. Space: It is preferable to have an isolated room free from disturbance. The room should be isolated and free from wind or draft, which may result in loss of the sutures and needles
2. Microscope: an operating or table top microscope with magnifications from 5x to 22 times is preferable.
3. Microsurgical instruments: A jewelers forceps, a micro-needle holder and a pair of micro-scissors is needed
4. Table and an adjustable stool
5. The table should be covered with a plastic or foam sheet to prevent damage to the instruments
6. Sharps box: for disposal of needles
7. Simulators: Latex sheets/silicone tubes/ DS Microtrainer system.
Material needed for a dry lab: Microsurgical needle holder, scissors and jeweller’s forceps, simulator, suture.

The Wet Lab

Wet labs use biological tissue for training. This includes training ex-vivo training models such as chicken thigh or chicken wings, or live animal models such as rats. The training centres that use live animals should seek the requisite approvals from local authorities. The organizers should also be cognizant of the ethical aspects of animal use and should design programmes that provide the desired level of training with minimal use of animals.

The three Rs of animal usage, are Reduce, Replace and Refine, so as to minimise dependence on animal models.

Material required for establishment of a wet lab

1. Space: It is preferable to have an isolated room free from disturbance. The room should be isolated and free from wind or draft, which may result in loss of the sutures and needles.
2. The lab should be certified for use of animals and biological tissue.
3. It should be in the vicinity of animal holding facility.
4. The lab and personnel should have the requisite training and certification for handling animals.
5. Microscope: an operating or table top microscope with magnifications from 5x to 22 times is preferable.
6. Microsurgical instruments: A jewelers forceps, a micro-needle holder and a pair of micro-scissors is needed.
7. Table and an adjustable stool.
8. The table should be covered with a plastic or foam sheet to prevent damage to the instruments.
MONITORING AND FEEDBACK

The presence of an instructor is an essential part of microsurgery training. The instructor facilitates the training process, monitors progress and provides feedback on technique and quality. The lay-out of the lab should provide space for the instructor to move from table to table. The use of split screen monitors or monitors connected to individual microscopes allows the instructor to conveniently observe each trainee without having to peer through each microscope. An objective evaluation system should be in place in order to evaluate the progress of each trainee during the course. The labs may choose structured systems or computer aided systems for evaluation.

Layout of a microsurgical training lab for 4 participants. Each participant has his own workstation and table top microscope. The microscopes are connected to a split-screen TV. The instructor (standing) can monitor all the participants at once. The workstations are spaced so that the instructor can move around and assist each participant. Please note in a wet lab participants and instructors must wear protective gowns gloves and masks.
STRUCTURING A MICROSURGICAL COURSE

A training program in microsurgery should have specific aims.

In our unit we have divided the courses into

1. **Introductory course** aimed to provide an exposure to microsurgery for trainees considering a future in microsurgery,
2. **Basic course** aimed to provide a complete skill set to perform end-to end anastomosis on a live animal model.
3. **Advanced course**: aimed at trainees who have already attained basic competence to learn advanced techniques such as ‘back-wall first’ technique and end-to side anastomosis and supra-microsurgical techniques.

The training should take place in a staged and step-wise manner. The skills that the course aims to impart determines the duration of training.

The table below shows the stages of incremental training and the approximate duration of time required to attain each skill set.
BASIC MICROSURGICAL SKILLS AND THE APPROXIMATE DURATION REQUIRED TO ACQUIRE EACH SKILL SET

<table>
<thead>
<tr>
<th>BASIC DEXTERITY &amp; SUTURE PLACEMENT TECHNIQUE</th>
<th>Introductory Practice on latex sheets or simulators (DS Microtrainer):</th>
<th>1 Hour</th>
<th>Introductory course 1-2 days</th>
<th>Basic course 5 days</th>
<th>Advanced skills course</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADAPTING TECHNIQUE TO UNSTABLE EDGES:</td>
<td>simulators (DS Microtrainer):</td>
<td>2 Hours</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APPLICATION OF SUTURES ON TUBULAR MODELS</td>
<td></td>
<td>2 Hours</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TISSUE HANDLING AND DISSECTION: EX VIVO MODEL</td>
<td>Chicken Thigh</td>
<td>2 Hours</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LIVE MODELS: BASIC END TO END ANASTOMOSIS :</td>
<td>Rat femoral artery and vein</td>
<td>6 hours</td>
<td>Repeated over 3 days</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LIVE MODEL ADVANCED TECHNIQUE: BACK WALL/ END TO SIDE:</td>
<td>Rat/mouse model</td>
<td>6 hours</td>
<td>per technique repeated over 3 days</td>
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MICROSURGICAL TECHNIQUES

GENERAL TECHNIQUES AND PRINCIPLES OF MICRO-VASCULAR ANASTOMOSIS

Vessel and tissue handling:
Small blood vessels need to be handled with extreme care. Small, undetected trauma to the wall or the intima may initiate vasospasm or thrombosis resulting in failure of the entire procedure.

As a general rule, vessels are never grasped with any instrument. The vessels are always handled by grasping the adventitia alone. As an exception to the rule, prior to the anastomosis, the injured end that needs to be excised can be held with forceps but it must be ensured that, the part that was grasped has been excised.

Preparation of vessels for anastomosis:

Excision of adventitia: the adventitia surrounding the vessel should be excised to prevent its entrapment into the lumen during the anastomosis. Small segments of adventitia should be held with jewelers’ forceps and excised without damaging the underlying media. If the media is inadvertently injured, that segment should be excised.

Freshening of vessel ends: the vessel ends should be cut to a point when healthy vessel wall and a clear lumen is visible. Contused edges tears should be excised and any branches close to the edge should be ligated or preferably eliminated by further excision.

Irrigation: the lumen should be irrigated with a heparin-saline solution to wash away any clots and to prevent the formation of new clots.

Approximation: Approximation of vessel edges is achieved by using approximator clamps. It should be noted that the vessel ends can be approximated without any tension. If undue force is needed to approximate the edges, also indicated by cutting-out of sutures or suture breakage, the tension should be relieved by further mobilization of the vessel or a vein or an arterial graft should be used. An anastomosis under tension is likely to fail.
The vessel is held with the adventitia using jeweller’s forceps.

The adventitia is excised using the curved micro-scissors.

The prepared vessel is irrigated with heparinised saline to flush out blood or thrombi from the lumen.
The commonly used techniques are, the 180° technique and the back-wall-first technique.

The 180° technique:
This is the most commonly used technique for end-to-end anastomosis
After the approximation of the vessel ends using an approximator-clamp, the first two sutures are placed at the top and the bottom of the edges (representing two points on the circumference 180° apart. Following these sutures, equidistant sutures are placed to suture the top half of the circumference.
The approximator-clamps are then flipped to expose bring the bottom half of the circumference into view, which is sutured as described earlier.
The clamps are then removed to check for blood flow across the anastomosis and for leaks. Leaks can be closed using additional sutures.

The main precaution is to prevent inadvertently suturing the opposite wall.

Back-wall-first technique:
This technique involves suturing the bottom-half of the circumference using inverted suturing technique first followed by suturing the top half of the vessel. The advantage of this technique is that it does not require the step of flipping the approximator clamp, particularly in areas where space is constrained. This technique can also be performed without approximator clamps. It also requires a higher level of skill for accurate placement of inverted sutures.

Triangulation technique: This technique involves initial placement of three sutures 120° apart on the circumference of the vessel, followed by sequential suturing of each of the three segments. This technique is rarely used in microvascular surgery. It is a more common technique in vascular surgery involving large vessels.
PREPARATION OF TRAINING MODELS (see video)
Preparation of Chicken thigh for microvascular anastomosis on the femoral neurovascular bundle.

The chicken thigh is placed with the medial aspect facing up.

Note the triangular muscle immediately posterior to the femur.
The femoral vessels and the sciatic nerve are located deep to this triangular muscle.

The triangular muscle flap is elevated to expose the femoral vessels and the sciatic nerve.
Completed specimen showing the femoral vein artery and the nerve.
The specimen is placed under the microscope. The vessels are then divided and anastomosed using 9-0 or 10-0 sutures.
Preparation of the Live Rat for microvascular anastomosis

Anaesthesia for the rat: All procedures must be verified by local institutional bodies for animal handling and animal care

Rats weighing 350 to 500 grams are suitable for training. They should be handled carefully to avoid inadvertent injury to self or to the animal. One should wear appropriate protective gowns /aprons /gloves /masks and observe hand hygiene. The rat is anaesthetized first with isoflurane. It is placed in an induction chamber and oxygenated. Isoflurane is administered at 4-5% for a few minutes until the rat is asleep but breathing. Once the rat is sleeping, intraperitoneal ketamine (75mg /kg) and xylazine (10mg/kg) is administered. This will provide surgical anesthesia for 30 minutes.

Once adequately anesthesized, the rat is secured supine onto the board with tapes and monitored regularly.

Rat tail artery: The median caudal artery runs through the ventral midline of the rat tail. Its diameter is 0.8mm at the origin and decreases in size to 0.6 to 0.4mm distally. There is a collateral vein accompanying the artery but it is only 0.3mm in diameter. There are two lateral veins running on either side of the dorsum of the tail. They have thin walls but the external diameter is 0.8 to 1.0mm. The median caudal artery is also a common model for practicing end to end arterial anastomosis. The rat tail model had also been described for training in critical revascularization (Sakrak et al 2011).

With the anesthesized rat secured supine onto the board, the entire length of the median caudal artery is exposed by removing the ventral skin of the rat tail with 2 mid-axial longitudinal incisions.

Once exposed, end to end suturing practice can be started from distal to proximal.

Another practice model is to devascularize the rat tail by clamping & cutting the 2 lateral veins and median caudal artery and cauterizing all other smaller vessels in the tail. Then one can proceed with end to end repair of the artery & 2 veins to simulate a

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Preparation of ketamine xylazine

In a 30ml sterile vial, mix 7.5ml Ketamine (100mg/ml) and 5 ml of xylazine (20mg/ml) in 7.5ml 0.9% saline for injection. Injected 0.2ml of this solution per 100g body weight of the rat intraperitoneally. Repeat if the animal is not adequately anesthetized or prolonged anaesthesia is required. Give one-third to half dose at a time every 30 minutes.
critical revascularization. The rat observed for viability of its tail post-operatively. If the tail is viable, one can re-explore the anastomoses on post operative day 7 to assess patency and presence of thrombosis.

**Rat femoral artery** is a common model for end to end arterial anastomosis and vein grafting. It is 1mm in diameter and 1.5cm long from the inguinal ligament to where it branches into superficial and deep. The common femoral artery lies lateral to the vein in the perivascular sheath with the femoral nerve lateral to it. Just before it divides, it gives off the epigastric artery. The epigastric artery has an accompanying epigastric vein that is used for end to side anastomosis training with the femoral artery.

**Detailed Procedure:**

With the anesthesized rat supine on the board, make an oblique incision between the abdomen and the hind leg. Take care to incise just the skin, exposing the inguinal fat pad underneath. Apply wire hook retractors to keep the wound open.

Reflect the inguinal fat pad laterally by cutting through the fat in the upper, medial and lower margins of the wound with micro-scissors. Use bipolar cautery for hemostasis. Visualize the vessel end before cauterizing. Make sure that bleeding is stopped by the grip of the bipolar forceps before applying the current. Lift up the medial edge of the fat pad and pull it laterally. Incise the adherent thin film of tissue underneath, keeping most of it on the fat pad. Dissecting from medial to lateral, the epigastric vessels would be seen entering the fat pad. These vessels should be preserved. The common femoral vessels are seen in the limb once the fat pad is adequately mobilized.

The entire length of the common femoral artery is exposed by blunt dissection. Use moist gauze pieces to push the abdominal wall away from the leg, until the shiny inguinal ligament comes into view. Apply wire hooks to the abdominal wall just above the vessels and secure it with elastic bands across the body of the rat. Achieve a bloodless field at this point before proceeding with vessel dissection.

Use Ringer’s solution to keep the wound moist.

Using jeweller’s forceps and micro-scissors, excise any loose connective tissue overlying the perivascular sheath. The perivascular sheath is that layer which is not easy to pick up with forceps. Incise the perivascular sheath to expose the artery and vein. The perivascular sheath is then dissected off the artery from proximal to distal, until where the epigastric artery branches. Use jeweller’s forceps to pick up the sheath laterally and use the curved micro-scissors with its blade flat on the artery to separate the sheath from the artery. Keep scissor blades parallel to the artery and do not cut what you cannot see. There is a vasa vasorum around the artery and any bleeding should be controlled with a bipolar prior to continuing with the dissection. Remember to keep the wound moist by irrigating it with Ringer’s solution periodically.
Check your jeweller’s forceps to make sure it is clean and the jaws are closing properly. Pick up the artery by its adventitia only with your non-dominant hand. This is the loose white fibrous tissue around the vessel. Take care not to pinch the entire thickness of the vessel wall. Clear the vascular sheath from the entire circumference of the artery using round-tipped micro-scissors. Remember to keep your scissor blades flat on the vessel while working. There is at least one large deep branch arising from the common femoral artery going into the muscles midway between the inguinal ligament and the epigastric artery branch. Lift the common femoral artery to one side and dissect around the deep branch for adequate length away from the common femoral artery. This will allow ample space to ligate & divide or cauterize and divide the branch without damaging the common femoral artery. Dissect the common femoral artery free from the inguinal ligament until the epigastric artery branch. Apply 1% lignocaine and wait three minutes to reverse vasospasm before clamping the vessel.

Use a blue or green-coloured material for background as the artery is almost translucent once cleared of blood. Apply a maximally spread double clamp approximator one end at a time with the clamp applicator. Pick up the vessel in between the clamps, loosen one end then pull a length of the vessel in between the clamps to allow redundancy. If the ligated branch falls near the centre of the clamps, the segment of artery from which it branches can be excised for end-to-end anastomosis. If not, a transverse cut can be made at the centre for ease of anastomosis. Prepare each cut end of the vessel of anastomosis by washing out the blood, removing the adventitia, and dilating it. The adventitia hangs loosely around the vessel end like a shirt sleeve. Pick up the adventitia of one end and irrigate the vessel end with a fine jet of Ringer’s solution. It is not necessary to cannulate the vessel end to clear the blood from it. Then carefully excise the fluffy white fibers around the vessel ends by picking them up with jeweller’s and cutting them off with micro-scissors. Trim all adventitia hanging over both vessel ends and those that can be easily pulled over the vessel end in its longitudinal axis. Take your time and be patient in this process. Keep the field moist by irrigating intermittently with Ringer’s solution. It is important to remove all adventitia from the vessel end in order to see the media clearly when sutureing and to prevent the adventitia from falling in the anastomotic line. Once the media is well delineated, dilate the vessel end by picking the end up with jeweller’s and gently inserting the closed tips of the dilator straight center into the vessel till it is halfway between the end & the clamp. Then slowly open the dilator ends till the vessel is one and a half times its diameter. Maintain the stretch for a second then slowly close the tips before sliding it out smoothly. Do this for both ends then position the clamps such that you have one vessel’s width distance between the two ends.

Put the first suture where there is good visibility near the lateral or medial wall. There is no need to put it at the farthest edge of the available vessel width. Keeping the needle tip parallel to the vessel wall, pick up the adventitia with the needle tip and lift
it up such that the lumen is visible. Insert the tip of your left hand forceps gently into the lumen and use this to support the vessel wall while you push the needle downward through the wall into the lumen. Once in the lumen, take care to manoeuvre the needle tip out towards the other vessel end rather than toward the back wall. Take the whole length of the needle out completely from the lumen and prepare to take the exit bite in the other vessel end. Use the left hand forceps to lift the adventitia of the opposite vessel end to expose the lumen. Position the needle tip in the lumen and aim for the vessel wall directly across the entry bite taken at the first end. Let go of the adventitia and use the forceps to support the vessel wall near where you want the needle tip to exit and push the needle through. Make sure to secure the suture with a square knot and cut one end long to serve as a stay suture. Repeat the same steps for the entry bite of the next suture. Space the first two sutures at one-third of the circumference apart from each other. Accurate placement of the second suture in this distance at both vessel ends determines the quality of the anastomosis. This ensures that when these 2 sutures are pulled and the intervening vessel wall is made taut, the back wall will be longer and will fall away from the side being sutured. The placement of the exit bite of the second suture is most crucial. Assess if this bite can be taken without changing the grip on the needle. Most of the time, this is possible. Doing so and keeping your needle pointing straight across will ensure that your exit point is equidistant from the first suture. If bites taken from each end are not equidistant from the first suture, the vessel wall will become distorted and affect the quality of the succeeding sutures. Once placed, tie a square knot and cut one end long to use as a stay suture. The long ends can be secured to cleats on the vessel approximator (if available) or held taut by an assistant. Remember to keep the field moist in the entire process of suturing.

Once the first two sutures are placed and the intervening vessel wall held taut, the back wall will hang down from the front anastomotic line. Gentle separation of the vessel clamps will allow the back wall to also hang proximal to the anastomotic line. Sutures can be placed in between these two with ease. It will be easy to make both entry and exit bites at this point without changing the grip on the needle. Be careful to support the vessel wall as the needle is passed through as this helps in keeping the vessel ends everted. Remember not to tie the knot on the second-to-the-last suture but to use the space to visualize the lumen and your needle tip while passing the last suture. Tie the knot after the last suture is passed with the needle still in the wall. Other measures to remember to avoid a through-stitch are 1. To point the needle tip horizontally and support /lift up the vessel wall perpendicular to it to pass it through, 2. To keep the vessel wall being sutured lifted off the back wall with forceps supporting the wall inside the lumen, picking up the adjacent knotted suture, or picking up the adventitia near where the suture is being placed.

Turn over the vessel clamp when the front wall sutures are completed. The next suture should be placed midway between the first two stay sutures and cut long as the third
stay suture. This stay suture can be secured on the far cleat or held taut by an assist away from the surgeon to allow suturing of the intervening stretched vessel wall. Remember to use the untied second to last suture manoeuvre to avoid suturing the back-wall for the last suture. Then repeat the same steps for the last one-third of the vessel wall after repositioning the third stay suture to the nearer cleat or asking the assistant to hold it towards the surgeon.

Remember to turn over the vessel clamp to the original position once back wall suturing is completed. Release the clamp distally first then proximally and the leg can be released from the board and allowed to flex. There will be brisk bleeding but this is expected. Place the fat pad over the anastomotic site and a moist gauze pad over it for two minutes to achieve haemostasis.

Alternative Models for anastomosis in the rat

Aside from the rat femoral vein, its dorsal penile vein has been described as a model for venous anastomosis. (Akyurek et al 2002) The dorsal penile vein is 1.2 to 1.6mm in diameter and had thicker vessel walls than femoral vein, with prominent tunica media & adventitia. It has a length of up to 25mm without branching.

Rat superficial inferior epigastric artery: end to end anastomosis
Yamashita et al. (2008) dissected the superficial inferior epigastric (SIE) vessels of 270 to 300 gram male Wistar rats. They designed 3x3cm superficial inferior epigastric artery (SIEA) flap based on this pedicle. It was designed similar to a groin flap. The pedicle has an external diameter of <0.5mm and arises from the common femoral artery, close to the popliteal and saphenous branches. The authors clamped the pedicle and performed distal anastomosis with varying ischemia time before reperfusion and had one group wherein no anastomosis was performed. All the flaps with no vascular anastomosis died and highest flap survival rate was seen in the group with the shortest ischemia time.

Free tissue transfer
Ozkan et al.(2006) described successful free tissue transfer of an abdominal perforator flap based on short segment deep epigastric vessels in 400 to 500gram Sprague -Dawley rats. These perforators found at approximately equidistant intervals extending along a vertical lines on each side of the midline from the xiphoid to the pubis. There are three to five major perforators on each side of the midline. The upper second and third perforators above where an umbilicus is expected are the largest with diameters of 0.1 to 0.2mm. The skin flap is bordered superiorly by a line slightly inferior to the twelfth rib, inferiorly by a transverse line passing through the distal one-third of the abdomen, laterally by the anterior axillary line, and medially by the
anterior abdominal midline. The deep epigastric artery and vein were anastomosed to the superficial inferior epigastric artery and vein in the groin. The long thoracic vein was anastomosed to femoral vein in some specimens where the perforator vein was not clearly identified.

De la Pena et al. (1998) investigated the use of free latissimus dorsi (LD) and serratus anterior (SA) muscle flap in rats in their search for a small animal model of free tissue transfer to study flap physiology, biochemistry and histology. Both the LD and SA were supplied by the thoracodorsal artery. The artery and vein averaged 0.57 and 0.71mm in diameter at their origin and had a pedicle length of 19mm to the LD and 27mm to the SA. They successfully transferred both muscles to groin vessels and deemed the SA easier to transfer because of longer pedicle length.

Karamursel et al (2005) performed detailed study of rat penis vascular anatomy and described both replantation and free tissue transfer of the rat penis based on 0.6mm internal pudendal artery and the branch connecting inferior external pudendal vein to internal pudendal vein. Free tissue transfer was performed with femoral artery and vein as recipient vessels.

There are many variations in the method of rat renal transplantation since it was first described by Fisher and Lee in 1965. A review of these surgical techniques by Schumacher et al (2003) showed that using rats with body weight >200 grams, keeping warm ischemia time to <30 minutes, using end-to-end or end-to-side anastomosis instead of a sleeve technique for vessel anastomosis were associated with graft survival. Rats weighing 200-400 grams made microvascular anastomosis easier. The ability to perform a quick and reliable anastomosis was crucial for graft survival. The left donor kidney is generally used because the liver prevents adequate access to the right kidney. The left renal artery and vein are mobilized after ligating the adrenal branches. Both donor vessels harvested as close to the aorta and vena cava as possible to ensure adequate length for anastomosis. The renal vessels are cut close to the kidney hilus in the recipient rat. The donor ureter is cut at middle length and the recipient ureter is cut as proximally as possible. End-to-end anastomosis is performed with interrupted sutures for the artery and ureter. Wider-spaced running sutures were used for the venous anastomosis. For end-to-side vessel anastomosis, part of the aorta and vena cava are excised with the donor vessels. The short segment of aorta or vena cava is anastomosed end-to-side with the recipient aorta and vena cava with running sutures. The ureter may also be reinserted by bladder-patch technique. The ureter is harvested with a cuff of bladder dome and this cuff is repaired onto the recipient bladder in two layers with running sutures.
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