Review Article

Anaesthetic considerations for microsurgical repair of limbs

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With the advent of surgery under the operating microscope microvascular surgical techniques requiring prolonged anaesthesia have greatly increased in number.

Local anaesthetic techniques, whilst often producing excellent surgical conditions, are limited by the duration of action of the anaesthetic agents and by the ability of the patient to remain still, often in uncomfortable positions, for periods of up to twenty hours. The use of indwelling catheters as a means of prolonging the duration of nerve blocks is discussed along with methods of sedation or general anaesthesia to enable the patient to tolerate lengthy surgical intervention. Present general anaesthetic techniques may not be ideally suited to long surgical procedures. The problems and possible alternatives are discussed.

Sympathetic ganglion blockade, intravenous regional blockade and systemic vasodilator therapy are discussed as a means of improving the success rate of these procedures.

The general principles of patient management such as fluid balance, temperature control, patient positioning and control of the operating room environment assume a much greater significance when related to the provision of prolonged general anaesthesia, whilst the effect of extended periods of work on operating personnel must also be considered.

Key words

ANAESTHETIC TECHNIQUES; regional, general, inhalation, intravenous.

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History is scattered with reports of tissue replantation, the nose and fingers being common candidates.¹ However, it is now recognised that successful, functional reattachment of limbs and digits requires accurate neurovascular anastomoses. Since the introduction of the operating microscope in 1960,² replantation has become an established procedure with acceptable results in 70–90 per cent of well-selected cases;³ similar techniques are used for free-skin grafting.⁴ Cooling in plastic bags surrounded by ice increases the permissible ischaemic time of digits to 24 hours, and of the forearm to 12 hours.⁵ Local anaesthetic techniques are indicated in microvascular surgery because of their specific advantages in the control of vascular spasm perioperatively.^{6,7} However, local anaesthetic techniques are not always applicable and the problems associated with the provision of prolonged general anaesthesia must also be considered.

The anaesthetist aims to provide good, long-lasting surgical anaesthesia with optimum operating and postoperative conditions, as in all procedures. Therefore, one must be aware of all the anaesthetic techniques available and how to either avoid or ameliorate their problems.

Local anaesthesia

Details of the standard techniques and their complications are available in text-books and will not be discussed. Recently there has been increased reporting on methods of prolonging the blocks produced, usually by the insertion of in-dwelling catheters at the site of the block.

Brachial plexus blocks

These are the recommended techniques in the litera-

ture for upper limb microsurgery.^{3,8} They produce good anaesthesia, with suitable sensory, motor and sympathetic block. Prolonged block for surgical procedures and postoperative control of pain and vasospasm is possible with all the standard approaches.

The supraclavicular approach has been used for both the placement of an in-dwelling needle of unmentioned calibre⁹ and for polyethylene catheter placement through a 16G cannula for prolonged anaesthesia.⁸ Neither method is reported to have had any neurological sequelae although these may be expected to occur in up to six per cent of patients having standard supraclavicular blocks.¹⁰

Prolonged anaesthesia by catheterisation of the interscalene or subclavian perivascular space has also been reported,^{11,12} again with no neurological sequelae despite the use of 15-18G needles. These were both very small series however.

Catheterisation of the axillary perivascular space has been reported in large series^{8,13} with very few complications using 19G and 23G teflon catheters as used for intravenous cannulation. In standard single-dose axillary blocks, up to three per cent of patients may develop neurological sequelae.^{13,14} Although usually transient, permanent damage has been reported following both axillary and interscalene approaches.^{14,15} Selander emphasizes that paraesthesiae should not be sought during axillary block,¹⁴ whilst the use of short-bevelled (45°) needles may reduce the chances of axonal trauma.¹⁶

Epinephrine has been widely used to prolong the action of local anaesthetics. However, vascular insufficiency of the arm has been described following axillary perivascular block with epinephrine containing agents.^{8,17} Epinephrine may also increase any axonal damage caused by needle trauma¹⁸ and for these reasons the use of vasoconstrictors, even in low doses, is not recommended.

Most local anaesthetic agents have been used but bupivacaine, without epinephrine, would seem to be the agent of choice because of its duration of action.¹⁹ Surgical anaesthesia can be expected for three to six hours with a single dose of plain 0.5 per cent bupivacaine. When used with locally implanted catheters, top-ups at approximately three-hour intervals have maintained surgical anaesthesia for up to seventeen hours.⁸

Local nerve blocks

Ulnar and median nerve blocks at the wrist provide good anaesthesia and sympathetic block for digital surgery. Bupivacaine, injected through locally implanted catheters, may be used to prolong the block for days if necessary.⁷ Distal sympathetic block should reduce the amount of shunting of blood in the limb which may accompany proximal plexus blocks. Lack of proximal motor block to prevent gross limb movements or of analgesia for the tourniquet site would suggest this procedure as being suitable only in conjunction with general anaesthesia per-operatively, or as a technique for postoperative relief of pain and vascular spasm.

Prolonged blockade of the radial, median, ulnar and musculo-cutaneous nerves at the elbow using catheters has not been reported and this is probably not a serious alternative to the brachial plexus techniques.

Lower limb nerve blocks

The perivascular concept has been applied to the inguinal approach to the femoral, obturator and lateral cutaneous nerves giving effective blockade with much reduced doses in comparison to standard approaches.²⁰ By combining this with a sciatic nerve block, complete surgical anaesthesia of the leg can be produced. The use of in-dwelling catheters for prolonged blockade of these nerves has not been reported, although the inguinal perivascular approach should make this technique possible. However, the anatomy of the sciatic nerve would make a catheter technique very difficult. Winnie has described a combined lumbo-sacral plexus block using a paravertebral approach at L4 with 30-40 ml of local anaesthetic solution.²¹ This may be an alternative to the use of epidural anaesthesia, which, whilst providing ideal conditions, most physicians would be reluctant to perform on a patient who will be heparinised during surgery.

Intra-venous regional block (IVRB)

Bupivacaine in low doses (40 ml of 0.25 per cent) produces effective anaesthesia with minimum morbidity²² but the necessity for an arterial/venous tourniquet limits surgery to approximately one hour.

Magora has shown that high-dose techniques

(40 ml of 0.5 per cent bupivacaine) will produce surgical anaesthesia for up to five hours after release of the tourniquet, and has used this technique for digital replantation.²³

Intravenous regional anaesthesia may be used in the leg after appropriate adjustment of the dose is made for the increased volume of the limb. The risk of systemic toxicity will necessarily be higher when using these doses (60–70 ml), whilst the disadvantages of this technique, already mentioned when considering its use for producing anaesthesia of the arm, are still relevant.

Medullary depression, leading to respiratory arrest and cardiovascular collapse, is the major complication of IVRB with bupivacaine. Several deaths have been reported,²⁴ leading to suggestions that prilocaine may be a safer agent to use than bupivacaine.²⁵ Problems with systemic toxicity are usually due to leakage of anaesthetic under the tourniquet.²⁶ The high-dose techniques must carry considerable risk as some patients are known to have a low threshold of toxicity to the agents used.²⁶ A more promising use for IVRB may be in the prevention or relief of perioperative vasospasm by long-lasting sympathetic blockade using 15–30 mg of guanethidine with or without local anaesthesia. This may give relief for up to 10 days.²⁷

Long surgical procedures make sedation desirable and as local anaesthetic blocks may not satisfactorily overcome discomfort due to either the positioning necessary for the operation or the presence of an arterial tourniquet, systemic analgesia may also be required. In some cases, particularly children, general anaesthesia will be necessary. Diazepam is the agent of choice for sedation. It has been shown to be useful in the prophylaxis of local anaesthetic-induced seizures²⁸ and may therefore help prevent problems due to either overdosage or systemic leakage of the agents. Up to 40 mg of intravenous diazepam have been given over the course of a seventeen-hour operation with no notable complications.¹³ Tomlin and Gjessing have developed the concept of balanced regional anaesthesia.²⁹ In addition to the local anaesthesia for surgical pain and benzodiazepines for anxiolysis, they stress the need for central analgesia (opiates) to control the discomfort due to disturbed proprioception. Only four per cent of their patients could not be managed in this way. Combinations of fentanyl and

droperidol have been popular but respiratory depression or distressing dissociative phenomena may be a problem. The use of continuous intravenous infusions of hypnotic agents to provide sedation in conjunction with regional anaesthesia is discussed below.

Whilst many units achieve satisfactory operating conditions with combinations of local anaesthesia and sedation, there is always the potential hazard of the restless patient whose movements will be greatly amplified under the operating microscope and some surgeons will prefer the ensured immobility of the patient under general anaesthesia.

General anaesthesia

There are many theoretical and practical problems associated with the provision of prolonged general anaesthesia. A few of these will be reviewed together with their implications for microsurgical procedures.

Inhalational anaesthetic agents

Nitrous oxide (N_2O). This gas is known to cause bone-marrow depression,³⁰ resulting in megaloblastic changes,^{31,32} and possibly gross neuropathology.^{33,34} Methionine synthetase is a vitamin B_{12} dependent enzyme, and is essential for the synthesis of methionine, tetrahydrofolate and hence DNA. Active methyl cob(I)alamin is oxidised to the inactive cob(II) and cob(III) forms in the presence of N_2O ,³⁵ and thus DNA synthesis is impaired. It used to be believed³⁰ that prolonged exposure to nitrous oxide, of the order of the days, was necessary to cause bone marrow depression. More recently, the deoxyuridine (dU) suppression test on bone marrow aspirates has demonstrated abnormalities in ill patients admitted to an intensive care unit following as little as two to six hours of nitrous oxide exposure;³² such acute megaloblastic bone marrow failure is associated with a high mortality. However, changes in healthy patients, although occurring in the same time period of exposure to nitrous oxide, are less severe and there is usually rapid recovery of bone marrow function after exposure.^{31,36} Prophylactic use of vitamin B_{12} or folic acid supplements has not yet been reported. This potential hazard of nitrous oxide toxicity may be avoided by the use of oxygen-enriched air as a carrier gas in place of N_2O/O_2 mixtures.

Halothane, enflurane and isoflurane. Their varied pharmacological properties are described elsewhere. However, exposure to these agents for as much as twenty MAC-hours has now been well documented in clinical practice. All these agents undergo biotransformation. Of an inhaled dose of the agent, some 25 per cent of halothane,³⁷ 2.4 per cent of enflurane³⁸ and 0.2 per cent of isoflurane³⁹ may be recovered as metabolites. Many theories on the organ toxicity, particularly to the liver and kidney, of these agents are based on metabolite production. Great care must be taken in trying to interpret studies in this field. Whilst centrilobular necrosis is demonstrable in rats with all the inhalational anaesthetics,⁴⁰ the significance of these changes in relation to clinically serious hepatic damage in man is less clear.

Nephrotoxicity is not regarded as being a problem with halothane, enflurane or isoflurane anaesthesia. Fluoride is only released in quantity from halothane during reductive metabolism⁴¹ but is a product of normal oxidative metabolism of enflurane and isoflurane. A plasma concentration of $50 \mu\text{mol}\cdot\text{L}^{-1}$ is accepted as that, above which renal dysfunction may be expected.⁴² Mean peak fluoride concentrations with enflurane are about $20 \mu\text{mol}\cdot\text{L}^{-1}$, but morbid obesity may increase these significantly.⁴³ The mean peak fluoride concentrations seen with isoflurane anaesthesia, at $4 \mu\text{mol}\cdot\text{L}^{-1}$, are probably insignificant.^{39,44}

Isoflurane would appear to be the preferred agent for prolonged anaesthesia in view of the minimal biotransformation it undergoes, thus reducing the likelihood of organ toxicity. It also possesses the desirable properties of being rapidly eliminated from the body and causing less cardiac depression than other volatile agents.⁴⁵ Although arterial blood pressure may fall, this, in the absence of hypovolemia, will be due to a fall in peripheral resistance, and hence may be beneficial to perfusion of microvascular anastomoses.

Intravenous anaesthetic agents

It is possible to avoid the potential problems of administering inhalational agents over a prolonged period by using intravenous agents for hypnosis and analgesia, whilst the patient breathes oxygen-enriched air.

The use of an Alfathesin infusion for both

surgical anaesthesia in conjunction with opiates and sedation in conjunction with regional anaesthesia has been extensively reviewed⁴⁶ with the conclusion that it is an effective and versatile technique with a wide safety margin. Anaphylactoid reactions have not yet been reported during continuous infusions of the drug. Changes in serum bilirubin and liver isoenzymes were noted but their significance is uncertain.

Etomidate infusions have been used to produce both surgical anaesthesia⁴⁷ and sedation in the intensive care unit.⁴⁸ Again this appears to be a versatile technique. No reports of anaphylactoid responses to these infusions have been published. As an anaesthetic induction agent, etomidate may cause involuntary muscle movements and also pain and thrombophlebitis at the site of injection.⁴⁹ However, it has little effect on total peripheral resistance or other cardiovascular parameters.⁵⁰

Ketamine provides hypnosis and analgesia and can be used as the sole anaesthetic agent by infusion.⁵¹ Major problems are muscular hypertonicity with involuntary movements and psychotomimetic effects which may occur in up to 40 per cent of patients.⁵² These latter effects can be overcome by adding intravenous lorazepam or flunitrazepam.⁵³ Changes in the serum concentrations of hepatic enzymes which may indicate hepatotoxicity have been reported following ketamine anaesthesia,⁵⁴ but again their significance is uncertain. Hypertension and tachycardia are common problems and difficult to suppress.⁵¹ The mechanism of this apparent sympathomimetic response is not clearly understood.

There has been much discussion concerning possible toxic effects of long-term infusions of both Alfathesin and etomidate.^{55,56} These reports have been from intensive care units running drug infusions over several days in seriously ill patients. Care must be taken when considering these reports as drug effects are very difficult to isolate from the multiplicity of factors associated with morbidity in such units. It is doubtful whether such reports are relevant in the context of surgical anaesthesia or sedation. However, continuous infusion techniques are not common practice because of either lack of experience with the technique itself or lack of the appropriate equipment for accurate infusion administration.⁵⁷

Vasodilator therapy

It may be expected that the vasculature of reimplanted or revascularised tissues will be maximally vasodilated due to the combination of denervation, hypoxia and accumulation of metabolites.⁵⁸ However, this may not be the case with the vessels proximal to the surgical site. Sympathetic ganglion blockade may increase blood flow in a normal limb as much as ten-fold⁵⁹ and stellate ganglion and lumbar sympathetic blocks are commonly used for the treatment of arterial insufficiency and reflex sympathetic dystrophies.⁶⁰ The main disadvantage are the brief duration of a local anaesthetic block,⁶¹ requiring many repeat procedures over several days, and the inherent risk of complications.⁶⁰ Phenol and alcohol blocks or surgical sympathectomy will produce the opposite extreme of prolonged or permanent sympathetic block of the limb.

IVRB with guanethidine has been shown experimentally to enhance the survival of skin flaps, with increased neovascularisation. Pre- and post-capillary sphincter relaxation is thought to decrease intraluminal capillary pressures, increase capillary blood flow and improve tissue oxygenation. Together with improved lymphaticovenous communication this also helps to reduce the formation of oedema.⁵⁸ Clinically, guanethidine IVRB produces vasodilatation for at least three days and has been used for a variety of problems related to either arterial insufficiency or sympathetic dystrophy.⁶² Great advantages are the anaesthetist's familiarity with the technique and the relative lack of serious complications.

Systemic vasodilators may effectively enhance survival of the revascularised tissues. The alpha-adrenergic blocking agents phentolamine, phenoxybenzamine and thymoxamine have been used experimentally but the side-effects of profound systemic vasodilatation with hypotension and tachycardia make these difficult agents to use clinically.⁵⁸ Recently the successful use of the beta-adrenergic agonist isoxuprine has been reported,⁶³ again with the inherent problem of the systemic effects, namely tremor, tachycardia and hypotension.

Of all the methods of vasodilatation available to the anaesthetist, IVRB with 15–30 mg guanethidine appears to be the most effective, the easiest to perform and the least troubled by complications.

The evidence dictates that some form of vasodilator therapy should be considered in all patients undergoing microvascular surgery.

General patient management and monitoring

Humidification of inspired gases

Dry anaesthetic gases arrest mucociliary flow and damage the respiratory mucosa, particularly if atropine is used.^{64–66} This may be prevented by humidification of the inspired gases.^{67,68} Whether this has a direct influence on the incidence of postoperative chest infections is disputed.^{69,70} Atelectasis appears rather to be related to the site of operation and the incidence is usually low following surgery away from the thorax and abdomen.⁷¹ Other important factors in the production of atelectasis are age, obesity, nutritional status, smoking and pre-existing acute or chronic lung disease. However, warmed, humidified inspired gases will also tend to maintain normal body temperature.⁷² Patients on the intensive care unit invariably breathe warmed, humidified gases and for all the above reasons the authors recommend the technique for prolonged surgery. In the absence of active humidifying apparatus, there are advantages to be gained by the use of low-flow semi-closed or closed breathing circuits.

Temperature control

Air-conditioned operating rooms, cold cleansing solutions, vasodilatation, the use of muscle relaxants and cold dry anaesthetic gases may all contribute to the development of hypothermia in both adults and children and this may be prevented by warming and humidifying the inspired gases.^{72–74} Patients undergoing long microvascular repairs are particularly at risk from hypothermia because the 200–500 per cent increase in metabolic rate associated with postoperative shivering⁷⁵ may cause hypoxia and vasoconstriction and thus severely compromise the potency of the new vascular anastomoses. Use of warmed, humidified gases markedly reduces the incidence of hypothermia and postoperative shivering.⁷² Other methods which may be used in an attempt to maintain body temperature include:

- i *High ambient temperatures.* An operating environment temperature of 24–26°C has been rec-

ommended to prevent hypothermia, although this may not be adequate during open-cavity operations.⁷⁶ Such temperatures are not readily tolerated by operating room personnel.

ii *The metallised plastic sheet.* This has been found relatively ineffective in long neurosurgical procedures.⁷⁷

iii *Warming of all intravenous fluids.* This is recommended particularly for blood transfusions or where large volumes of other fluids are given.⁷⁸

iv *Warming mattresses.* The benefits of these are disputed,^{74,79} and they bring the additional hazard of possible thermal burns if they are faulty or improperly used.

Fluid balance

Long procedures, particularly involving extensive soft tissue dissection, intra-peritoneal or intra-thoracic surgery will cause large shifts of fluid between the intravascular, extracellular and intracellular compartments. Calculations of these shifts applied over many hours can only approximate to the truth, making close monitoring essential. We regard a urinary catheter as mandatory both for monitoring urine output as an indicator of intravascular volume status and renal perfusion and, during long regional anaesthesia, for the comfort of the patient. Heart rate and blood pressure should be monitored routinely. Intra-arterial monitoring may be necessary for measurement of both blood pressure and arterial blood gases in some cases. Seriously ill patients may warrant the use of a pulmonary artery catheter to monitor volume status. EKG monitoring will give guidance both to cardiac and electrolyte status. The biochemical status of the patient should be monitored with regard to electrolytes and blood sugar whilst regular checks of packed cell volume may guide blood replacement therapy. Coagulation screening may be necessary in the event of large losses and replacement of blood.

Pressure areas

This area is largely ignored beyond the well known problems of preventing nerve palsies due to poor padding on the operating table, or the prevention of diathermy apparatus earthing through patient short circuits. Pressure necrosis during prolonged immobilisation on the operating table poses a significant threat to the patient. Predisposing factors to the

development of pressure necrosis are believed to be friction, repeated trauma, infection and malnutrition.⁸⁰ Operating tables although padded are not sprung and probably bear a closer relationship to the floor than a bed. Muscle is very sensitive to ischaemia, degeneration being seen within four hours.⁸¹ Studies have been performed on healthy, anaesthetised pigs using a computer-controlled compressed air apparatus applied to the skin over the greater femoral trochanter.⁸² A pressure of 100 torr for ten hours will damage muscle, 200 torr for 15 hours will produce muscle and deep dermis damage, and for 16 hours will give full thickness damage. Local pressures may be of this order at the occiput, shoulder, buttocks, calves, and heels.⁸³ Pressure studies are difficult to interpret because of technical problems, but they suggest that necrosis could occur during long anaesthesia particularly if cardiac output or peripheral perfusion falls. Danger may be lessened by maintaining an adequate circulating volume. Turning patients is routine on the intensive care units and most general medical and surgical wards but is usually impractical in the operating room, although patients may protect themselves if only lightly sedated. Thought should be given to the provision of ripple mattresses in theatre or to operating on a suitable bed rather than an operating table.

Thrombo-embolism

This should not pose a problem as the patients will be anti-coagulated during surgery. Anti-coagulation itself may pose a threat to local anaesthetic procedures, however, and will probably dictate against the use of spinal or epidural anaesthesia. Haematoma formation is not commonly a problem with other regional procedures but it may impair the quality of the block.

Immune status

The immune status of patients undergoing prolonged anaesthesia is compromised. Both B- and T-cell functions are depressed after nitrous oxide and halothane,⁸⁴ but this may be common to all agents and is possibly a result of the stress of anaesthesia and surgery *per se* rather than any specific technique.⁸⁵ Phagocytic function is also depressed following surgical as well as non-surgical stress.⁸⁶ Certainly care should be taken to maintain

asepsis during all anaesthetic manoeuvres and prophylactic antibiotics should be considered if not already indicated by the surgery.

Personnel

Anaesthetists regularly perform an eight- to ten-hour day. A twenty-hour operation adds a great strain. Factors which may detract from the ability to perform safely have been extensively reviewed by Paget *et al.*:⁸⁷

i *Loss of sleep*: even during the early hours of the first night reaction times are prolonged and accuracy of observation diminished. Permanent night shift workers do not suffer this problem and it has been suggested that anaesthetists might work similar shift patterns.

ii *Length and complexity of a task* may not of itself be deleterious but multiple sensory input, provided by the vast array of modern monitoring equipment that can surround a patient, may indeed prejudice the anaesthetist's performance.

iii *Noise*. Piped music can prevent a deterioration in performance by masking unfamiliar and unwanted sounds, but not alarm systems.

iv *Anaesthetic gas pollution*. Whilst Kortilla claims that operating theatre personnel become habituated to gas pollution,⁸⁸ Bruce maintains that all cognitive functions and motor responses are impaired.^{89,90} Modern theatres equipped with anti-pollution circuitry should reduce this potential hazard whilst total intravenous anaesthesia may eliminate the problem altogether.

Conclusions

Prolonged anaesthesia is demanding on personnel, equipment and techniques. It should only be undertaken by staff well versed in anaesthetic techniques, local and general, and their problems. To maximise patient safety they should work as a team with no single person bearing the brunt of the procedure.

Regional techniques are of great value, particularly for surgery to the upper limb. They should be supplemented by adequate sedation and analgesia with general anaesthesia when necessary. The potential hazards of inhalational gases and vapours might be avoided by the use of total intravenous anaesthesia and oxygen-enriched air although such techniques may have hazards of their own. Sym-

pathetic blockade should be considered for all cases and IVRB with guanethidine will often be the most practical method.

Special attention should be given to the often unconsidered problems of humidification, temperature control, patient's pressure areas, control of environmental noise and careful selection of only essential monitoring equipment. Fluid balance must be monitored and a urinary catheter should be used routinely along with other monitoring when indicated.

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Résumé

Avec la venue de la microchirurgie pour la réparation des vaisseaux, des anesthésies prolongées sont de plus en plus fréquentes.

Les techniques d'anesthésie loco-régionale, bien que produisant d'excellentes conditions chirurgicales, sont limitées à cause de la durée d'action des agents employés et par l'impossibilité pour le patient de rester calme, sans bouger dans des positions souvent inconfortables, pour des périodes pouvant aller jusqu'à vingt heures. On discute de l'utilisation de cathéters pour prolonger le bloc nerveux et de méthodes de sédation ou d'anesthésie générale qui permettent au patient de tolérer ces longues interventions chirurgicales. Les techniques anesthésiques habituelles ne sont pas conçues pour de longues opérations; les problèmes posés et les solutions possibles sont discutés.

On discute de l'intérêt du bloc sympathique, du bloc intraveineux et des vasodilatateurs systémiques comme moyen d'améliorer le taux de succès de ces interventions.

Des facteurs comme l'équilibre hydrique, le contrôle thermique, la position du patient et le contrôle de l'environnement de la salle d'opération acquièrent une importance accrue lors de ces anesthésies prolongées. On doit également tenir compte de l'effet de fatigue sur le personnel de ces longues heures de travail.