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Guidelines

Ergonomics in the anaesthetic workplace

Guideline from the Association of Anaesthetists

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Summary

Ergonomics in relation to anaesthesia is the scientific study of the interaction between anaesthetists and their workspace environment in order to promote safety, performance and well-being. The foundation for avoiding pain or discomfort at work is to adopt and maintain a good posture, whether sitting or standing. Anaesthetists should aim to keep their posture as natural and neutral as possible. The successful practice of anaesthesia relies on optimisation of ergonomics and lack of attention to detail in this area is associated with impaired performance. The anaesthetic team should wear comfortable clothing, including appropriately-sized personal protective equipment where necessary. Temperature, humidity and light should be adequate at all times. The team should comply with infection prevention and control guidelines and monitoring as recommended by the Association of Anaesthetists. Any equipment or machinery that is mobile should be positioned where it is easy to view or reach without having to change the body or head position significantly when interacting with it. Patients who are supine should, whenever possible, be raised upwards to limit the need to lean towards them. Any item required during a procedure should be positioned on trays or trolleys that are close to the dominant hand. Pregnancy affects the requirements for standing, manually handling, applying force when operating equipment or moving machines and the period over which the individual might have to work without a break. Employers have a duty to make reasonable adjustments to accommodate disability in the workplace. Any member of staff with a physical impairment needs to be accommodated and this includes making provision for a wheelchair user who needs to enter the operating theatre and perform their work.

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[Correction added on 24 August 2021, after first online publication: In the originally published article, affiliation 2 was incorrect. This updated version has been corrected.]
This is a consensus document produced by members of a Working Party established by the Association of Anaesthetists of Great Britain and Ireland. It has been seen and approved by the Board of Directors of the Association of Anaesthetists of Great Britain and Ireland and has been endorsed by the Difficult Airway Society and RA-UK.
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What other guideline statements are available on this topic?

There is no published guidance on ergonomics specifically aimed at anaesthetists.

Why was this guideline developed?

This guidance was developed to provide advice specifically for the anaesthetist to promote a safe and healthy workplace environment.

How and why does this statement differ from existing guidelines?

There are currently no guidelines on ergonomics in the anaesthetic workplace. This guideline summarises existing advice developed from other industries to promote health and safety in the anaesthetic workplace.

Recommendations

1. Musculoskeletal injuries are common in anaesthetists and they should aim to make their posture as natural and neutral as possible at all times
2. Wherever possible, patients should position themselves on the operating trolley or table and remain there for their procedure and first-stage recovery
3. All purchased equipment should be assessed using ergonomic principles to ensure it is acceptable for its intended use and that it is adjustable to maintain comfort for the anaesthetist, including those who are pregnant or have disabilities
4. All staff should receive regular teaching in manual handling as part of their mandatory training
5. Room temperature should be at least 21 °C, the relative humidity should be in the range of 40–70%, there should be adequate and adjustable lighting and noise should be no louder than 80 dB and for short periods only
6. Good ergonomic practice is one where the patient is at a height that approximates to the level of the umbilicus, T10 dermatome or waist of the anaesthetist
7. If the anaesthetised patient is lying on an operating table or trolley for tracheal intubation, the table height should be adjusted until the patient's forehead is at the level of the anaesthetist's xiphoid process or nipple
8. Tasks such as regional anaesthetic nerve blocks, central venous cannulation and siting of arterial lines should be performed with the preparation trolley on the side of the dominant hand, the ultrasound machine directly opposite the operator's view and the monitor at eye level.

Introduction

For the purposes of this guideline, we define ergonomics as the scientific study of the interaction between anaesthetists and their workspace environment to promote safety, performance and well-being. Musculoskeletal problems, such as back pain, account for 40% of sickness absence among NHS staff and cost approximately £400 million per year [1]. Legally, employers are obliged to provide a safe working environment for their staff. Under the Manual Handling Operations Regulations 1992 (as amended) [2], employers are required to avoid the need for hazardous manual handling, so far as is reasonably practicable; assess the risk of injury from any hazardous manual handling that cannot be avoided; and reduce the risk of injury from hazardous manual handling, so far as is reasonably practicable. It requires employees to follow appropriate systems of work laid down for their safety; make proper use of equipment provided for their safety; co-operate with their employer on health and safety matters; inform the employer if they identify hazardous handling activities; and take care to ensure their activities do not put others at risk.

The foundation for avoiding pain or discomfort at work is to adopt and maintain a good posture. What is considered a 'good' posture does not change significantly whether the anaesthetist is sitting or standing. The basic principles remain the same; everyone should aim to keep their posture as natural and neutral as possible. A neutral posture is one where the individual remains upright and forward facing with their arms close to their body. The arrangement of the patient, equipment and monitoring should not result in the anaesthetist reaching or looking behind their sitting or standing position. The anaesthetic team should wear comfortable clothing and temperature,

humidity and light should be adequate at all times. They should comply with infection prevention and control guidelines [3] and monitoring as recommended by the Association [4].

Temperature, humidity, noise, lighting and electrical safety

Temperature and humidity are controlled by the ventilation system, while noise, lighting and electrical safety are separate aspects. Ergonomists can provide specialist help with the effects of the physical environment on anaesthetists [5]. Guidelines on the provision of anaesthetic services have been published by the Royal College of Anaesthetists; this includes guidelines for the environment [6]. Building regulations require that all enclosed workspaces be ventilated by either natural or mechanical means [7].

Temperature

Employers are required to make a suitable assessment of the risks to the health and safety of their employees and take action where necessary and where reasonably practicable [8]. While there is no absolute legal requirement for a specific temperature in the workplace [9], the minimum temperature in the operating theatre should be at least 21 °C [10]. A meaningful figure cannot be given for a maximum temperature due to the high temperatures found in some workplaces [8]. Vertical air temperature difference between head and ankle levels should be < 3 °C [11].

Thermal comfort

The temperature of the ambient air alone is not a valid or accurate indicator of an individual person's thermal comfort. It should always be considered in relation to other factors [12, 13]. These comprise environmental factors (air temperature, radiant temperature, air velocity and humidity) and personal factors (clothing insulation, including personal protective equipment, work rate and metabolic heat). In particular, thermal radiation is the heat that radiates from warm objects. Radiant heat may be present if there are sources of heat in the operating theatre such as some types of equipment. For air velocity, as the design of operating theatres should incorporate appropriate ventilation systems for the control of infection, this will affect the flow of air within the room and hence the thermal comfort of personnel.

Clothing can be used to control thermal comfort but can also be a cause of thermal discomfort. A person's physical characteristics should always be taken into account when considering their thermal comfort, as factors such as their size and weight, age, fitness level and sex can all have an impact on how they feel, even if all other factors such as air temperature, humidity and air velocity are constant. There are differences between men and women in terms of thermal comfort and temperature preference [14].

The stability of the temperature (and humidity) in the operating theatre can be disrupted by opening doors and movement of people and equipment [15].

Humidity

There are two aspects to humidity: absolute humidity – the amount of water vapour present in a particular volume of air, usually expressed in units of $g.m^{-3}$; and relative humidity – the amount of water vapour in the air relative to the maximum amount that can be contained in the air at a particular temperature, expressed as a proportion. Generally, relative humidity rather than absolute humidity is important when discussing thermal comfort. In the UK, levels of relative humidity in the range of 40–70% are recommended for the workplace environment [7, 16, 17].

Clothing, including personal protective equipment

Three properties of clothing material to consider are thermal resistance, water-vapour resistance and air permeability [18]. Results from tests carried out according to standards [19] can help a purchaser make an informed choice of appropriate clothing (including personal protective equipment) for use in the operating theatre.

Noise

Any unwanted sound is a noise and this may disturb patients and staff. Noise in the operating room arises from various sources, including staff activities; conversations and communications; ventilation; surgical equipment; and alarms and music [20]. Surgical procedures may need to be undertaken in a noise-free environment. It is, therefore, important that there is no transfer of noise between adjacent theatres [21].

Three parameters are important in assessing the level of noise in operating theatres. Two are in relation to external noise; that is, noise emanating from outside the operating theatre. The third is related to the noise level from mechanical and electrical services within the operating theatre itself. There are noise rating curves, a set of curves based on the sensitivity of the human ear and used to give a single figure for noise levels at a range of frequencies. Typically, noise rating curves are determined between 63 Hz and 4 kHz. In operating theatres, noise rating should be 40 dB, or 50 dB for ultra-clean laminar-flow operating theatres.

Music

Music is commonly played in operating theatres [22]. The appropriate use of music in the operating theatre can reduce stress and improve the performance of some staff [23]. However, music can impair communication [22]. Music that is pleasing and helpful to one practitioner might be distracting to other operating theatre personnel.

Conversation and communication

Non-essential conversation and communication can be distracting, leading to errors. The sterile cockpit concept was introduced into aviation to reduce the effect of distractions during the critical phases of flight, normally below 10,000 feet, effectively take-off and landing. This requires pilots to refrain from all non-essential conversation and activity during these critical phases. In anaesthesia, induction and emergence can be considered analogous to take-off and landing. During these phases, it has been suggested that the concept of a 'sterile cockpit' should apply [24]. However, each team in the operating theatre has a different cognitive work-load at different times during a case [25]. This potentially leads to a casual conversation just when another team member needs absolute quiet. Anaesthetists should politely and firmly make clear that they are not going to discuss any non-emergency matters during drug preparation, with the aim of reducing medication errors [26].

Audible alarms

Alarms generated by anaesthetic equipment can be grouped into three types: high, medium and low priority [27]. Priority levels are determined by the combination of the potential results of failure to respond to the cause of the alarm condition (death or irreversible injury, reversible injury or minor injury or discomfort) and the onset of potential harm (immediate, prompt or delayed). Alarm systems can be an issue for patient safety if they fail to warn of hazards effectively or adversely affect the performance of the operator [28]. A high false alarm rate may lead to desensitisation and neglect [29]. This can lead to inappropriate muting of audible alarms and cause anaesthetists to ignore those alarms that are indicating an urgent response. Appropriate setting of alarm trigger levels is therefore important.

Lighting

Lighting should be sufficient to enable people to work and use facilities without experiencing eyestrain. Minimum values for illumination are 200 lx for work requiring perception of detail [30]. Greater levels of illumination are required in particular healthcare settings. In the anaesthetic room this is 1000 lx at the head of the trolley 1 m from the light source [31]. However, in the operating theatre itself, the luminaire should provide between 15,000 and 30,000 lx at the operating table 1 m from the light source.

Lighting related to anaesthetic equipment

Brightness and contrast controls on the screen of the anaesthetic workstation should be adjusted to suit lighting conditions in the operating theatre.

When selecting laryngoscopes, the brightness, direction and quality of light are important factors to consider. Illumination provided by laryngoscopes should be at least 500 lx [32]. This level of illumination should be maintained when a force of 65 N is applied to the laryngoscope blade. For reusable laryngoscopes, this level of illumination should be maintained after the maximum number of uses (including cleaning, disinfection and sterilisation cycles) recommended by the manufacturer.

Electrical safety

Electrical supplies in the workplace are regulated by the Electricity at Work Regulations 1989 [33]. The electrical supply should automatically switch to an emergency generator in the event of mains supply failure. There is usually a short delay between failure of mains supply and the emergency generator starting operation. Uninterruptible power supplies should be provided to the power equipment that cannot function in the event of any delay in power supply. Emergency lighting should be provided for escape routes in the event of evacuation during power failure. Ergonomic principles should be considered for any electrical power on/off switches on medical devices. An example for an infusion pump is given in IEC 62366 [34].

General anaesthesia

During general anaesthesia, the anaesthetist interacts with their patient and equipment, and this can be represented by a triangle. Trained assistants should hand the laryngoscope, tracheal tube or suction equipment without the anaesthetist having to reach for them. However, the anaesthetist should position themselves conveniently to easily reach the reservoir bag, the controls of the anaesthesia workstation and monitoring, all while staying within comfortable reach of the patient. Ergonomic principles during the COVID-19 pandemic are summarised in the online Supporting Information (Appendix S1).

Anaesthetic workstations

The anaesthetist, or a trained nominated person, is responsible for ensuring that the anaesthetic machine

is plugged in, switched on and that the battery back-up is charged as part of the Association checklist for anaesthetic equipment [35]. Anaesthetic workstations typically include an internal power source to power the unit in the event of failure of the mains supply. If mains supply failure occurs, the internal source should provide power for at least 30 min. Changeover to an internal power source should be indicated by a low priority alarm. When the internal power source nears depletion, this should be indicated by a medium priority alarm. A means should be provided to indicate the state of the internal power source, for example, proportion capacity or time remaining. Anaesthetic workstations should continue to provide a supply of oxygen in the event of complete power failure (failure of both the mains supply and internal power source).

Machines should be light, compact and easy to manoeuvre. Manufacturers are regularly consulted to determine whether changes can be introduced in order that future models are more ergonomically friendly. They are required to conform to existing medical device regulations which cover health and safety, manual handling, the weight of machine and appropriate testing such as the 'tilt test'. All companies offer adjustable arms and add-ons as a user-benefit but each company is restricted by patent protection on specific design features.

Anaesthetic machines have two different configurations depending on the location of the reservoir bag. These may be described as 'left-handed' (the most common) or 'right-handed' depending on whether the machine is designed to be positioned to the left or right of the anaesthetist. The left-handed machine, when placed to the left, would require the anaesthetist to hold the facemask with the right hand and control the reservoir bag with the left, whereas the right-handed machine would be on the right of the anaesthetist enabling them to control the reservoir bag with their right hand and hold the facemask with the left. If a left-handed machine is on the right of the anaesthetist, the anaesthetist must lean forward to reach the reservoir bag or move the machine. Such repositioning would place the monitor behind the anaesthetist requiring them to repeatedly turn their head. It is the same problem if a right-handed machine is positioned on the left. It is therefore important that the two different configurations are recognised and placed appropriately to the right or left of the anaesthetist.

Most medical equipment is designed for right-handed people. In a study that looked at 2437 Korean men and women, 6% were left-handed, 8% were ambidextrous and the rest, right-handed. The right-handed and ambidextrous used their right hands for tasks that required accuracy rather than force. The left-handed used the left hand for tasks that required a certain amount of force rather than accuracy. This implies that, in all participants, the right hand was used for tasks that required accuracy [36].

It has been shown that the performance of the non-dominant hand is detrimental and may affect outcome in critical task performance [37]. Anaesthetists must make workplace adjustments to optimise their performance with their dominant hands. Ideally equipment should be designed that is essentially neutral and may serve both groups effectively, for example, by placing the reservoir bag and common gas outlets at the centre of the machine.

Patient monitors

Monitoring, as recommended by the Association, is displayed electronically. The monitor screen is often on movable arms allowing for adjustment to the required position. The monitor should be at eye level and in front of the anaesthetist.

The position of the anaesthetist relative to the patient

The position of the patient on the trolley, bed or operating table places ergonomic demands on the anaesthetist [38]. Anaesthetists vary in height and good practice is one where the patient is at a height whereby the anaesthetist can hold a facemask above the patient without having to bend their knees or back. This approximates to the level of the umbilicus, T10 dermatome or waist of the anaesthetist because the spine bends around this point. The adopted position should also facilitate drug administration by the anaesthetist without having to lean or bend. This is best achieved by bringing the injection port close to the anaesthetist by gently flexing the arm of the patient or by attaching an infusion with a three-way tap or injection port sited close to the anaesthetist.

The shoulder joint

The ball and socket joint at the shoulder allows for flexion, extension, adduction, abduction and rotation. It sacrifices stability for mobility and therefore is more vulnerable to injury. When a weight is held in the hand away from the body, the length of the arm increases the effective load on the shoulder by the lever principle. Therefore, inappropriate movement of the arm with excessive load can easily strain or damage the shoulder. The arm, when flexed at the shoulder with the elbow extended, can be moved approximately 45° in an arc away from the midline. Beyond this the movement begins to strain the shoulder and the relevant muscles. For optimum results it is recommended that the patient is

positioned to allow the anaesthetist to hold the facemask above the patient with a partly flexed elbow and no strain on the shoulder. The other shoulder should allow movement of the hand towards the reservoir bag at an approximately 45° angle from the sagittal plane. Here the arm will again be partly flexed at the elbow with the arm in three-quarter pronation. This would allow for optimum use of both shoulder joints and arms for bag/valve/mask ventilation with least strain to the joints involved.

The controls of the anaesthetic workstation should ideally be within this arc. With one hand holding the facemask, the other hand can close the adjustable pressure-limiting valve, adjust gas flows, turn on the vaporiser if required and control the reservoir bag. The machine must be positioned in order that these controls are all within comfortable reach of the anaesthetist.

Tracheal intubation

Tracheal intubation, whether performed using a traditional laryngoscope, a videolaryngoscope or a fibreoptic bronchoscope (asleep or awake) poses ergonomic challenges [39]. The anaesthetist should have a direct line of sight of the patient, the monitor and the video monitor if appropriate. There should be immediate access to infusion pumps, the anaesthetic machine, oxygen delivery device and suction. The anaesthetic assistant's primary position should be with immediate access to the airway trolley, and close to the anaesthetist. If the anaesthetised patient is lying on an operating table or trolley for tracheal intubation, the table height should be adjusted until the patient's forehead is at the level of the anaesthetist's xiphoid process or nipple [40]. There is some evidence that the use of videolaryngoscopes result in body postures less likely to induce musculoskeletal injuries compared with traditional laryngoscopy [41]. For awake tracheal intubation the patient may be placed in different positions as shown in the online Supporting Information (Figure S1) [42].

Manual handling and patient positioning

Manual handling is a common feature of the activities performed by anaesthetists, even with the availability of aids such as slide sheets. The fact that a patient must be transferred between trolleys and beds, or their head needs to be supported as a pillow is removed, results in manual handling issues for all members of the team dealing with a patient. The increase in the number of bariatric patients presents additional challenges that must be met. Legally, employers are obliged to provide a safe working environment for their staff. Under the Manual Handling Operations Regulations 1992 [2], employers are required to avoid the need for hazardous manual handling, so far as is reasonably practicable, assess the risk of injury from any hazardous manual handling that cannot be avoided and reduce the risk of injury from hazardous manual handling, so far as is reasonably practicable. It requires employees to follow appropriate systems of work laid down for their safety; make proper use of equipment provided for their safety; co-operate with their employer on health and safety matters; inform the employer if they identify hazardous handling activities; and take care to ensure their activities do not put others at risk. The understanding of ergonomic principles in the reduction of manual handling injuries has been included within the Scottish Manual Handling Passport Scheme [43]. Employers should carry out formal risk assessments of the manual handling activities associated with an anaesthetist's work. In addition, there should be less formal, on-the-spot assessments before any lifting or moving activity commences. One of the biggest issues facing a handler is the weight of the patient, although many other factors can increase the risk of injury, such as the frequency with which something is moved; how far it is carried or pushed; the height at which it is picked up or put down; and whether it is handled at a distance from the body. Added to these considerations must be a review of whether any twisting, bending or stretching occurs at the same time.

Although the environment in which an anaesthetist works may impose certain limits on how objects can be handled, there are steps they can take to offer better protection to themselves. It is generally accepted that the risk of injury will be reduced if the handler follows a number of simple rules (Box 1).

In order to reduce the number of patient transfers, it is recommended that, where possible, the patient positions themselves on a trolley, is anaesthetised on the trolley and the procedure is performed while on the trolley and the patient is then transferred to the recovery area [44]. However, there are a number of different positions that patients are required to be moved into in order to facilitate different surgical interventions. These pose different challenges to staff and may require different numbers of staff members or equipment to be utilised. In addition, differing patient sizes, other patient factors (such as the presence of unstable spinal fractures) and physical capabilities of staff members will further alter the requirements for safe patient positioning.

Lateral transfer

This occurs when the patient needs to be moved from a trolley or bed to the operating table (and back again) and can finish with the patient in the supine or prone position.

Box 1 Rules of manual handling

- Do not lift or handle unnecessarily. If there is a means to execute the movement without manually handling the patient, or another load, then it should be used.
- If a load is being moved across a distance, avoid carrying it and use a trolley.
- Co-ordinate a lift with team members who will be involved in the movement of a patient. If the patient's weight is a concern, take further action such as having additional handlers or hoists on stand-by.
- If the load, such as a patient, is on a height-adjustable surface, raise it upwards before the movement in order that all handlers remain upright during the move.
- Stand as close to the object being moved as possible as this will limit any reaching. Handling the load at arm's length results in five times the amount of stress than is the case if the load remains very close to the trunk when it is handled.
- Stand with feet apart and with one foot in front of the other when moving a load. This stance will offer stability to the handler. The floor area around or under the object being moved should be kept clear of cables, hoses or other pieces of equipment.
- Lower the upper body by flexing the knees. This is less stressful for the lower back than simply bending forward at the waist, which results in the weight of the upper body being added to the overall lift.
- Raise the head before lifting commences. This will assist in reducing any forward bending.
- Use the feet to move with the load, where possible, rather than reaching forward when putting the load down.
- Avoid placing anything at low levels that might encourage bending.

Supine to supine lateral transfer

If the patient is conscious and able to mobilise themselves then this should be encouraged, with staff available to ensure safety throughout the transfer. If the patient is anaesthetised, the number of staff required to safely position the patient will depend on the patient's size. For a patient who weighs 70 kg, this is the anaesthetist and three staff members, using a lateral transfer device. There is a range of each of the different types of lateral transfer devices on the market and staff should be familiar with the equipment used in their place of work (Table 1). It is important to ensure the bed is at a suitable height for the transferring staff with a pull point (i.e. the starting position of the staff member's hands) between their waist and nipple line.

Supine to prone lateral transfer

The patient is likely to be anaesthetised when positioning the patient in the prone position, therefore the anaesthetist controls the head, neck and airway. An additional four members of staff are required to facilitate the transfer. If a mechanical assist device is available, this should be utilised.

Positioning the patient on the operating table

Once the patient has been transferred on to the operating table, they may need to be moved into another position to facilitate the planned procedure.

Lateral position

In order to safely position the patient in this position, a minimum of three members of staff plus the anaesthetist is required for patients weighing > 50 kg.

Lithotomy position

Putting the patient safely into this position depends on the patient's weight. If the patient is not excessively overweight this can usually be done with one person per leg. It is important to move both legs simultaneously to prevent damage to the patient's pelvis [45].

Positions achievable using mechanical theatre tables

There are a number of other positions that can be achieved using modern mechanical theatre tables (e.g. the beach chair and Trendelenburg positions). This protects operating theatre staff from musculoskeletal injury, but puts patients at risk, therefore knowledge and training in how to operate the theatre table is essential.

Special circumstances

Certain patients, such as those with proven or suspected unstable vertebral fractures, require extra precautions in order to position them safely. This will often involve specialist pieces of equipment and staff members trained in their use [46].

Intra-operative phase

The operating theatre should be 55 m^2 [7, 47] and have a recommended 20 air changes per hour.

Anaesthetists often remain seated during maintenance of anaesthesia and should follow the same advice that is advocated for staff that spend time at a desk working at a

Table 1 Examples of lateral transfer devices.

Friction-reducing sheet	Inserted under the patient to reduce the frictional force required to be overcome when transferring the patient. Often used in combination with a slider board.
Slider board	Used to bridge the gap between two surfaces, for example, trolley and operating table. Various designs available such as boards with vinyl coverings and rollers, or simple boards that are used in combination with a friction reducing sheet. It is important that the patient's weight does not exceed the manufacturer's safe working load.
Air-assisted transfer device	These devices float patients on a layer of air from one surface to another, reducing the frictional forces required for transfer. Use of this type of device should be considered for heavier patients.

Box 2 Arrangement of desk and seat

- The ideal work posture is one where the back is straight or slightly reclined (95–110°)
- The shoulders are abducted < 20°
- The elbows are flexed at 90–100°
- The forearm is pronated with the wrist, hand and forearm in a straight line with the work item
- Wrist extension or deviation of more than 15° should be avoided
- The lower leg should be perpendicular to the floor
- The thighs should be parallel to the floor
- The hip joint should be slightly higher than the knee joint
- The feet should rest flat on the floor or on a footrest

computer screen. The anaesthetist must monitor the patient, administer medications and perform other interventions that require frequent changes in posture. The anaesthetist should remain outside the immediate surgical area for purposes of infection prevention and control. There should be ergonomic seating and a desk for documentation (Box 2).

Tracheal extubation

During tracheal extubation, the anaesthetist should be positioned correctly in order to manage the airway, administer drugs and monitor the patient. This presents more ergonomic challenges than during anaesthetic induction, which is usually performed in a calmer, more predictable scenario than tracheal extubation. The machine, patient and anaesthetist should be in the triangle, with each of them within 45° from the sagittal plane within the arc of movement. The assistant plays an important role by providing equipment, such as suction, and should be positioned appropriately in order to aid the anaesthetist.

Postoperative phase

Once the patient is stable and ready for transfer to the post-anaesthesia care unit, the same principles of safe patient transfer should be employed.

Regional anaesthesia

The practice of regional anaesthesia has increased in recent years, mainly due to the widespread availability of ultrasound equipment. The provision of regional anaesthesia is not limited to anaesthetists alone, and colleagues in pre-hospital medicine, emergency medicine and intensive care are also providing some of these techniques [48]. The successful practice of regional anaesthesia relies heavily on optimisation of ergonomics, and lack of attention to detail in this area is associated with block failure or suboptimal performance [49]. Additionally, lack of attention to ergonomics can result in the development of musculoskeletal disorders in the practitioner [50]. The interaction between the anaesthetist, the patient, the equipment used and the environment where the procedure is performed are all important factors in the successful deployment of regional anaesthesia (Table 2, see also Supporting Information, Figure S2). The anaesthetist should be able to perform the procedure while maintaining asepsis without leaning on, or over, the patient and without exerting excessive thoracolumbar flexion [51].

Central neuraxial blockade – epidural, spinal and combined spinal epidural techniques

The third National Audit Project (NAP3) of the Royal College of Anaesthetists estimated that the annual provision of central neuraxial blockade within the NHS was >700,000 [52]. The NAP3 project took place in 2009 and it is reasonable to expect that this number has increased >10 y later. This represents a significant number of procedures undertaken annually in which ergonomics can be assessed and improved but there is a lack of research in this particular area. In one

Table 2 Ergonomic principles for performing procedures.

Environment
There should be sufficient space to perform the procedure
The area should be quiet and free from distraction
The ambient temperature should be at least 21°C
Lighting should be adjustable, preferably with a dimmer switch
Patient
The patient should be comfortable on a trolley, bed or operating table
The patient should be positioned in a stable and secure manner, with attention to pressure areas.
Access to the patient should be unobstructed and there should be no objects impeding access to the patient (e.g. table attachments)
The level of the patient relative to the anaesthetist should be adjusted in order that the neck of the anaesthetist is not flexed > 60°
Equipment
All equipment should be checked before use
The trolley, bed or operating table should be adjustable in height
The stool or chair should be adjustable in height
The equipment trolley containing the procedure pack should be placed on the operator's dominant side in order to minimise torsion of the torso or overreaching for equipment
Monitoring should be clearly visible and follow the Association recommendations
If using Ultrasound, the machine should be fully adjustable, opposite the operator with the screen at eye level
Assistant
A trained assistant should be available
The assistant should be appropriately dressed
The assistant acts as a patient advocate, providing physical and psychological support
The assistant should support the patient in the optimal position and help prevent movement during the procedure
Operator
The anaesthetist should be appropriately dressed
An aseptic technique should be followed
Whether sitting or standing, the height of the table/stool should be adjusted to minimise flexion of the anaesthetist's neck, lower back and knees
If in the standing position, optimal heights recommended are within 5 cm above to 10 cm below the elbow

study assessing spinal anaesthesia, performed while the anaesthetist was in the standing position, the optimal needle entry angle and anaesthetist comfort level was when the spinal table was raised to the level of the nipple or xiphoid process of the anaesthetist (see also Supporting Information, Figure S3) [53].

Box 3 Phases for performing regional blocks [51]

- Positioning the ultrasound machine relative to the anaesthetist and patient
- Hand grip positioning and handling of the ultrasound probe
- Acquisition of adequate nerve/target image
- Manipulation and alignment of the needle with the ultrasound beam
- Identifying the advancement of the needle in real time
- Placing the tip of the needle by the target
- Identifying acceptable distribution of local anaesthetic around the nerve/target

Ultrasound-guided regional anaesthesia for peripheral nerve blocks

Modern regional anaesthesia utilises ultrasound imaging technology. This introduces further ergonomic considerations in addition to general principles. There are well-described industry standards for prevention of musculoskeletal disorders for sonographers. While these do not specifically relate to ultrasound for regional anaesthesia, many principles are relevant.

Ultrasound machine

The machine should be fully adjustable and suitable for use in the sitting or standing position. The power cable should be of adequate length to allow access to the power outlets without providing a trip hazard. The monitor display should have adjustable height and tilt in order to maintain a direct line of sight. The screen should be of high resolution with antiglare properties that allows viewing from standing or sitting postures.

Ultrasound probe handling

Transducers and cables should be lightweight and balanced to minimise torque on the wrist. Transducer probe designs that facilitate a palmar grip and neutral wrist position are recommended. The transducer should be held towards its base, and the 'pinch' grip should be avoided.

The act of performing an ultrasound-guided regional nerve block consists of a number of phases, each with potential ergonomic challenges [49] (Box 3). If any of these steps are not successfully adopted, the likelihood of achieving a successful nerve block is reduced. Turning the trunk, turning the head 45° or more and non-dominant hand

needling are associated with fatigue and suboptimal block performance [54].

Needle insertion

The needle can be advanced towards the target structure either perpendicular to the ultrasound beam – out-of-plane, or parallel to the ultrasound beam – in-plane. The out-of-plane technique is familiar to many anaesthetists as it is similar to siting central venous access. However, the insertion technique for regional anaesthesia can be complex as needle tip identification may be a challenge and the aim is to place the needle in close proximity to the target without piercing it. The in-plane technique is often the first technique to be taught and, when employed appropriately, allows tracking of the whole length of the needle on its trajectory towards the target. Caution must be employed to ensure the needle is steered within the narrow ultrasound beam without losing view of the needle tip. Phantom-based in-plane nerve block simulations have demonstrated that ultrasound machine placement in front of the operator, as opposed to perpendicular to the operator, improves accuracy of in-plane needling.

In-plane needling can be achieved by placing the hands and long axis of the ultrasound probe in two orientations (see also Supporting Information, Figure S4): ACROSS the visual axis – with the needle insertion perpendicular to the visual axis or ALONG the visual axis – with the needle insertion parallel to the visual axis.

Speed and accuracy of in-plane needling is improved when the in-plane needling ALONG the visual axis is employed [55]. Although these studies were performed in phantoms, the principles hold true for ultrasound-guided regional anaesthesia in actual patients and are recommended for novice practitioners.

Hand dominance

There is a range of opinions regarding dominant-hand needling vs learning to be ambidextrous to achieve ergonomic advantage. Although bench top studies have shown that visual-spatial aptitude is more relevant than hand dominance in learning ultrasound skills [56], there are significant differences in the way that novices will perform a nerve block compared with an expert [57]. Therefore dominant-hand needling is recommended for novices.

Procedures

When performing procedures, such as arterial cannulation or central venous access [58], similar principles to performing regional nerve blocks apply (Table 2).

Intensive Care Unit

The Department of Health, in its Health Buildings Note on critical care [59], specifies standards that define space, bed arrangement and equipment in each bed area. It recommends that each bed space should be 25.5 m^2 to allow room for an ICU bed, a patient recliner chair, wash basin and enough space for five staff to attend to the patient when needed. Equipment such as ventilators, syringe drivers and monitors should be ceiling mounted. The mount moves on a swivel and allows for these to be located around an arc on either side of the patient. This configuration allows for ergonomic positioning of these devices. The note also specifies that each space must be 3 m in height.

An ICU patient has critical health needs and may have several attachments such as infusions, breathing circuits and monitors that make this area particularly challenging to optimise for ergonomic tasks. These patients also need to be frequently moved or placed in a prone position as part of their routine care. The ICU currently is well rehearsed in these areas of patient care due to the COVID-19 pandemic.

Bag/valve/mask ventilation of the patient's airway may require two people to achieve adequate oxygenation and the confined space may be challenging. Tracheal intubation of a patient in critical care poses a greater degree of difficulty [60] when compared with routine elective tracheal intubation in a theatre setting. This is due to a variety of reasons, including the increased oxygen demands of the patient; oedema of the airway; and the underlying illness itself. Optimisation of a patient's position for tracheal intubation may be hampered by the degree of urgency and the anaesthetist may have to lean and bend unnaturally to access the patient's airway. Tracheostomy procedures require two performers, one positioned at the head end and one to the side of the bed with nursing assistance. This procedure is usually undertaken electively and therefore allows for adequate planning and positioning. The width of the bed requires the person performing the tracheostomy to bend and lean excessively in order to gain access to the surgical airway. Insertion of central lines, arterial lines and feeding tubes should be undertaken while minimising musculoskeletal strain. Ultrasound machines are recommended aides and must be positioned according to good ergonomic principles. Intensive care personnel carrying out these tasks are advised to include ergonomics as a discussion point in team briefings. Such discussions help develop a culture of ergonomics in the ICU set up and can influence future equipment design. Transfer of ICU patients to other areas

of the hospital, such as the operating theatre and radiology suite, are potentially difficult. Patients are attached to monitors and ventilators, additional staff are required and these journeys should be carefully planned. Ideally equipment should be securely mounted on the bed and not placed on the patient's body. Handling and moving of patients from their bed requires careful planning and adequate staff who have been trained in handling and moving.

Special circumstances

Paediatrics

The physically smaller sizes of patients, and those with congenital diseases or learning difficulties, present a challenging environment for paediatric anaesthetists and associated healthcare workers. Working surfaces, cots, beds and operating tables should be sufficiently manoeuvrable and height-adjustable in order to allow sufficient access for the anaesthetist.

Paediatric airway management is often challenging and limited by time. Preparation before rendering a child unconscious should include positioning the patient at an appropriate height. As anaesthetists vary in height, it is important to adjust the height of the table to obtain the best position in which they feel comfortable.

They should perform tasks such as central venous cannulation at a comfortable height with the preparation trolley on the side of the user's dominant hand, the ultrasound machine directly opposite the anaesthetist and the monitor at eye level.

Resuscitation demands the performance of cognitive and technical tasks while working under the pressure of time so that effective and efficient care is provided. Working within a team, the application of human factors and limited physical space all provide a challenge [61]. The physical demands of cardiopulmonary resuscitation itself can lead to fatigue and rescuers should switch after every second cycle of heart rate assessment [62].

Pregnancy

Pregnancy changes the needs of an anaesthetist and additional thought needs to be given to requirements for standing, manually handling, applying force when operating equipment or moving machines and the period over which the individual might have to work without a break. Although there are regulations that offer protection to pregnant workers, there are some basic steps that should be taken to accommodate them when at work [63]. There should be suitable, adjustable seating with sufficient unobstructed space for the chair to be moved, as well as adjustable equipment, beds, trolleys and screens.

Disabilities

The World Health Organization defines disability as "*any condition of the body or mind that makes it more difficult for the person with the condition to do certain activities and interact with the world around them*". Employers have a duty to make reasonable adjustments to accommodate disability in the workplace. Any member of staff with a physical impairment needs to be accommodated and this includes making provision for a wheelchair user who needs to enter the operating theatre and perform their work. There should be sufficient clearance under a work surface, such as an operating table, to allow them to get close enough to the patient. Armrests should be removed on a temporary basis to provide greater access to equipment and staff. An unobstructed space behind the wheelchair of one metre is required and they should have an unobstructed floor space of 1.5 m x 1.5 m in which to turn. Shelves should be set no higher than 1.15 m above the floor to allow access. The way in which doors are opened, for example, by pushing or automatically, should be reviewed to accommodate a wheelchair user. Viewing windows may need to be incorporated into some theatre doors. Wheelchair users should have access to one regular operating theatre where facilities have been arranged specifically for them.

The future

Wireless monitoring units reduce the number of cables attached to patients and improve ergonomics, as well as patient management. Bluetooth technology can now be reliably used in the operating room [64], for example, to continuously monitor the patient's electrocardiograph. Head mounted devices provide real-time continuous imaging and improved ergonomics. Previously they were bulky and unfeasible but modern devices, such as Google Glass™, are lightweight and have shown promise by superimposing displays over the anaesthetist's field of view. They have been investigated for monitoring patients' vital signs as well as while performing ultrasound-guided regional anaesthesia. Preliminary studies have shown potential advantages of reduced head-turning, arching and eye movements when the devices are employed.

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Supporting Information

Additional supporting information may be found online via the journal website.

Figure S1. Tracheal intubation performed with the operator positioned facing the patient and behind the supine or semi-recumbent patient.

Figure S2. Equipment trolley placed on the dominant side for left- and right-handed operators, respectively.

Figure S3. Operating table at two different heights during insertion of spinal anaesthesia.

Figure S4. In-plane needling variations.

Appendix S1. Ergonomics during the COVID-19 pandemic.

